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Cost function estimation in the Norwegian pelagic fisheries

A study of coastal vessels, purse seiners and pelagic trawlers through a cost minimisation approach

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Contents

Abstract

This thesis contains a study of cost structures through a cost minimisation approach. Estimations reveal predicted u-shaped unit cost functions for three types of vessels participating in the Norwegian pelagic fisheries: coastal vessels, purse seiners and pelagic trawlers. Interaction terms on defined vessel groups identify relative advantages in the unit cost of the most important species. Through a cost minimisation problem, we assess the potential for reductions in variable costs. The data origins from the profitability surveys conducted by the Norwegian Directorate of Fisheries in the period 2000-2014.

The estimated cost functions take a polynomial form. Such a functional form is sufficiently flexible to estimate/fit a u-shaped unit cost function. OLS analyses reveal the predicted long-run cost curve for several of the species included in the estimation. For the coastal vessels, these are herring, capelin and cod and pollock. In the combined fleet of purse seiners and pelagic trawlers, we find the predicted non-linear specification of costs for blue whiting and capelin. For both fleets, a linear relationship describes the underlying structure between variable costs and output of mackerel in the final specification. This specification applies also to the output of herring in the case of purse seiners and pelagic trawlers. These differences in the predicted relationships seem consistent with the structure of the data.

We find a potential reduction of variable costs of NOK 10.5 billion in the optimal solution to the cost minimisation problem. This amount serves as an indication of the costs of certain regulations within the management system in the period. Our optimal solution disregards policy constraints such as redistribution of catches between vessel groups.

1. Introduction

> *In the most improved societies [...] there are always a few commodities of which the price resolves itself into two parts only, the wages of labour, and the profits of stock [...]. In the price of sea-fish, for example, one part pays the labour of the fishermen, and the other the profits of the capital employed in the fishery. Rent very seldom makes any part of it, though it does sometimes [...].*

Adam Smith (1776), *The Wealth of Nations (p. 42)*

Creating an optimal fishery management system in the capture fisheries is a daunting task for the regulator. The fish, in particular pelagic species, follows changing migration patterns and cross several international borders. As is true for many natural resources, it is hard to assess optimal volumes of extraction. Variations in the levels of the stock make it difficult to plan according to the expected future setting of quotas.

To further complicate the picture, policies are supposed to fulfil numerous and often conflicting objectives. In addition to environmental sustainability, an optimal management system should preserve the economic and social sustainability. Recent policies have focused on improving the economic outcome. Some have argued that the introduction of these policies have been at the expense of employment in the coastal communities and thus a breach of the social contract.

It is interesting to read the above quotation from Adam Smith's famous work *The Wealth of Nations*. Smith lived and worked in a time of technological improvement and changing social structures. Thus, it is no wonder he concluded that the rent dissipation in the fisheries were a feature of progress. Today, this curve has turned. Due to the natural production process of the fish, we know that rent generation is a feature only possible in the properly managed fisheries. The costs of acquiring this knowledge have been immense, with stock depletion and economic waste as outcomes in earlier management regimes. Thus, understanding the historical development is crucial to grasp the functioning of modern regimes establishing pre-catch property rights to the fish.

Norwegian management of fisheries has improved in the last decades. Stocks are better preserved and the continuous focus on management of capacity has improved the economic foundation. Nevertheless, the overall economic state is still unclear given a complicated landscape of laws, regulations and objectives. Cost efficiency plays a crucial role in any economic assessment of an industry. The aim of this thesis is to assess the cost structure of vessels participating in the Norwegian pelagic fisheries. We run an optimisation using estimated cost functions for two fleets: coastal vessels and the combined fleet of purse seiners and pelagic trawlers. The estimation work takes a cost minimisation approach, and allows for within fleet differences using interaction terms on different vessel groups. We use data from the profitability surveys of the Norwegian Directorate of Fisheries from 2000-2014. Natural variations and conflicting policy goals could make a diversified fleet best suited to catch the seasonal quotas. We conduct optimisations both restricting and not restricting reductions of vessels within a fleet to highlight this.

The thesis constitutes of five main chapters (2-6). In chapter 2, we introduce the Norwegian management of fisheries. This includes a presentation of central developments with respect to the three sustainability criteria: environmental, economic and social sustainability. Due to the similarities in trends and regulations, the discussion is not limited to regulations only on pelagic species. For a broader introduction to Norwegian fishery management, we recommend e.g. Iversen et al. (2016).

Chapter 3 introduces the theoretical approaches to fishery management. We begin with the open-access fishery introduced by Gordon (1954), and describe the predicted outcome in such a fishery. Second, we discuss a regulated open-access fishery by presenting a paper by Homans & Wilen (1997). Finally, we describe a management system with individual vessel quotas (IVQs). In this discussion, we modify an idealised system of individual transferable quotas (ITQs) by Arnason (1990), though we also build on other papers.

In chapter 4, we present descriptive statistics and explain the division of fleets and groups. We include the distribution of catch, the cost structure of the fleets, description of variables, selected trends and the structure of the data. To connect theory and the chosen estimation approach, chapter 5 begins with a discussion of seasonal and long run behaviour in an IVQ fishery. We present the functional form specification and the estimated cost functions. Papers by Sandberg (2005) and Nøstbakken (2006) serve as a point of departure for the work towards the chosen approach. Chapter 6 contains a cost minimisation problem. We optimise based on the estimated cost functions from chapter 5, and discuss the feasibility of the results. We use results and discussions from Steinshamn (2005) and Grimsrud, Lindholt & Greaker (2015) as background material. Chapter 7 includes concluding remarks.

2. A brief introduction to Norwegian management of fisheries

Norway has long traditions within the management of and extraction from fisheries. In this chapter, we discuss developments and policy goals within this management. This yields an important introduction to the analyses conducted in the modelling chapters. We do not limit ourselves to look only at regulations directed towards the conservation and optimal extraction of pelagic species.

The discussion primarily centres on important developments within the three pillars of current fishery policies: environmental, economic and social sustainability. Thus, there are many important aspects of Norwegian fishery management that we have not found room for in this short chapter. The processing industry has an important relation to the fishing fleet, and, historically, the regulation of landings has been important. Liberalisation and the growth of market solutions have been present in the sales process. Improving prices abroad have made export an important factor, and fish today totals 9% of Norway's total export revenues (though this includes aquaculture).[1] Other trends include developments with respect to legislation such as the participation law of 1999.

Fishery management cannot rely solely on national legislation. Extraction on stocks that migrate between different countries is a challenge in need of international solutions. Around 90% of the fishing conducted in Norway is on stocks shared with other states.[2] This helps explain the growing focus on the spatial dimension in fishery management. We are not primarily concerned with spatial or biological matters in this thesis. However, it is important also for the economist to understand how single fishery models may fail to represent the challenge of optimal extraction. We assume that an exogenous TAC determines revenues in chapter 5. This thesis thus gives the spatial and biological dimensions less consideration than they deserve. We do however mention a few selected international developments in this chapter.

1 Iversen et al. (2016), p. 92.

2 Årland & Bjørndal (2002), p. 308. Together with Norwegian Directorate of Fisheries (2016), Grimsrud et al. (2015) and NOU 2006:16 (2006), this paper introduce trends and developments discussed in this chapter.

Management policies have developed as a response to technological developments and political goals. A century ago, open-access systems persisted in fishery management. The current regime is a complex mixture of regulated open-access and IVQ policies. Several conflicting objectives are the basis for the Norwegian regulations of fisheries. This further complicates the picture, as the regulator faces trade-offs in the selection of appropriate regulations. Such trade-offs help explain deviations in outcome as compared to the economic models we discuss in chapter 3.

Fish has always been one of Norway's primary commodities. Stockfish became an important export product already in the 12th century. From around 1350 to the 18th century, the Hanseatic League kept a strong presence in Bergen to gain control over the revenue streams generated by this export. Coastal cities like Stavanger and Bodø experienced sudden and explosive growth in inhabitants due to the repercussions from the fishing industry.

In earlier periods, the need for extensive regulations remained low. Natural variations undoubtedly created seasonal differences, but the open-access fishery persisted.[3] However, technological progress and population growth created growing pressure on the stocks from the 19th century and onwards. While some continued to explain the collapse in several fishing stocks as natural variations, a growing number of researchers acknowledged man's effect as a predator with respect to reduced biomass levels.[4]

The developments led to the establishment of a directorate of fisheries and an institute of marine research in 1900. Internationally, the establishment of the International Council for the Exploration of the Sea in 1902 was important to promote cooperation between coastal nations. A 1906 law closed all Norwegian fisheries to foreigners, and a temporary law from 1938 introduced minimum length with respect to catchability for the saltwater species.[5] In 1946, Norway became the first country in the world to establish a ministry of fisheries.

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[3] This statement is not equal to saying that there existed no regulations in the fisheries. As stated by e.g. Norwegian Directorate of Fisheries (1951), one can trace the introduction of gear restrictions back to the administration of Magnus 6. of Norway (1238-1280). The legal right for everyone to fish meant, however, that fish remained an open-access resource.

[4] See section 3.1 for a further discussion.

[5] Norwegian Directorate of Fisheries (1951), p. 4.

Figure 2.1 illustrates the number of fishermen and vessels in Norway from 1930-2015. Fishermen are defined as the number of workers with fishing as a primary or secondary source of income. For later years, we have included active vessels. These are vessels with a registered catch income during the year. People with fishing as a primary or secondary source of income totalled around 125 000 in 1940. This rapidly decreased to 50 000 in 1970. Some might interpret this as a sign of a reduction in the overall effort in the fisheries.[6] There are good reasons why we should not accept such a storytelling. It is for example doubtful that the number of fishermen is an accurate measure of the total capacity in the fisheries. The introduction of larger vessels, stronger engines and improved gear and fish finding equipment is likely better explanations of the falling employment in the fisheries. This corresponds well to the overall growth expectation of productivity in the Norwegian economy after World War 2.

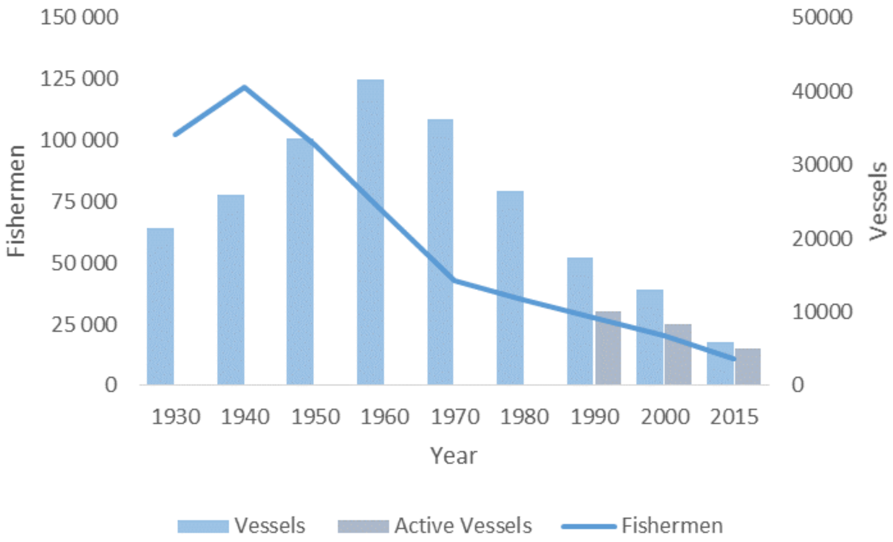

Figure 2.1 – The development in the number of fishermen and vessels in the period 1930-2015, including active vessels from 1990. Source: Norwegian Directorate of Fisheries (2015).

It is however interesting to discuss whether the productivity growth in the fishing fleet has been as high as in other sectors. Such a discussion implies a need to measure both effort and capacity in a fishery. We can define capacity in a fishery in a number of different ways. This definition is of importance, as we will see in chapter 3, because a feature of the open-access

[6] Effort is a measure of the utilisation of the capacity in a fishery. There are different ways to measure this. Steinshamn (2005) uses capacity utilisation, defined as operating days/330. The number 330 is an assumed maximum of operating days.

equilibrium is that actors commit capacity until all rents are dissipated. Thus, regulators wanting to improve the economic outcome should introduce accurate measures to limit capacity. As this thesis regards economic efficiency, one relevant definition is the following: "*Economic capacity is reflected through the capital invested in vessels and gear. Optimal [capacity] is achieved when the economic result is maximized.*"[7]

A strong growth in capacity would potentially hint towards overcapitalisation and inefficient use of economic resources. Vessel development in Figure 2.1 shows such transitional dynamics towards the 1970s. If the development is accurate, persistent rents led to a continuous introduction of new capacity. The decrease in vessels from 1960 to 1970 would be equivalent to a correction due to (very high) overcapacity, leading some actors to leave the industry. In unregulated fisheries, we expect overcapacity to lead to overfishing. Thus, there exists a likely relation between the correction and lower levels of biomass. Continuous overfishing in an open-access fishery could, as discussed in chapter 3, lead to a collapse in the fishery and depletion of stocks.

To what extent can the theoretical framework help explain the developments in the timeframe considered? As stated in NOU 2006:16 (2006), capacity reductions did not become an important governmental priority before the 1970s (NOU 2006:16, 2006, p. 22). With the benefit of hindsight, we know that several herring stocks collapsed between the 1950s and the 1970s (Lorentzen & Hannesson, 2004). This led to a closing of fisheries, and capacity reductions receiving an increased amount of attention from regulators. Even though the number of active fishermen decreased in the period 1930-1970, we can conclude that overcapacity and overfishing resulted in substantial biological and economic challenges for the Norwegian regulators.

The above discussion implies that management of Norwegian fisheries was based on far from optimal policies in the years before 1970. Falling employment made it harder to preserve the many coastal communities dependent on the fisheries. However, Norway was not alone in experiencing these problems.

[7] Translated from (NOU 2006:16, 2006), p. 25. Chapter 3 of this government white paper introduce difficulties related to capacity estimation in a fishery.

As a response, the international cooperation saw further developments in this period. An example of such a development was the establishment of the Norwegian-Russian fisheries commission in 1974 (Joint Russian-Norwegian Fisheries Commission, 2016). This establishment formalised negotiations on a TAC and the setting of minimum sustainable biomass levels. In 1977 and 1980 respectively, a protection zone around Svalbard and a fishery zone around Jan Mayen were established. Even more important was the conclusion of the United Nations Convention on the Law of the Sea (UNCLOS) in 1982. The law established the exclusive economic zone of 200 nautical miles as an international standard.[8] These developments were important prerequisites for current management regimes, as they gave states control over fishing activities in national waters.

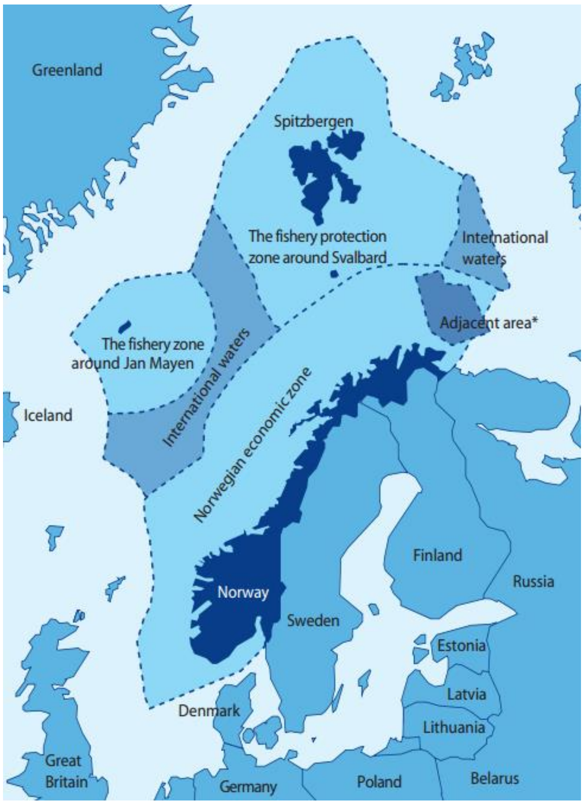

*Figure 2.2 - Zones under Norwegian fisheries jurisdiction. * An agreement between Norway and Russia cover the adjacent area in the Barents Sea. Source: Ministry of Fisheries and Coastal Affairs (2007).*

Figure 2.2 shows the current fishing zones under Norwegian jurisdiction and surveillance. These are, in essence, the zones established through the mentioned agreements. The area of

[8] It is however important to note that the convention first came into force when Guyana in 1994 became the 60th country to ratify it. The limitation of the UNCLOS framework in the high seas, where vessels are subject only to the jurisdiction of their flag state, has led some to criticise the economic zones.

the zones is more than six times larger than the Norwegian mainland, creating challenges with respect to maintaining control over fishing activities. To deal with this, Norway in 1994 adopted a black list of vessels known to engage in illegal fishing, and banned such vessels from fishing in Norwegian waters. It is important to emphasise that countries periodically fished more than the agreed upon quotas during the period. Thus, one could question to what extent the establishment of fishing commissions and the UNCLOS framework actually helped protect stocks.

While measures such as the above mentioned were developed to secure biologically sound levels of stocks, the focus on economic efficiency was still low. Rögnvaldur Hannesson wrote in a 1985 paper

> *[Norway's fishery policy] objectives put a low priority on economic efficiency, while various objectives based on equity are put in the foreground. The result is that the contribution of Norway's fisheries to the national income is slight. Norway's fishery policy consists of two largely uncoordinated parts, one concerned with maintaining fishermen's incomes and the other with managing fish stocks.*[9]

Since the 1950s, the government had subsidised the Norwegian fisheries. In 1964, an agreement between the state and the fishermen's association secured yearly transfers. Thus, the state contributed to high employment and overcapitalisation. Though the agreement lasted until 2004, actual abolishment of subsidies happened in the early 1990s. The European Free Trade Association's conclusion of the free trade agreement for fish abolished distortive measures, and thus central parts of the subsidy regime (Flaaten & Isaksen, 1998).

At this point, it is appropriate to make a divide between the demersal and pelagic parts of the fleet. Due to the volatility of the migration of pelagic species, the pelagic part of the fleet has not maintained the same regional affiliation as e.g. the vessels primarily fishing cod over time. These differences have increased the possibility for productivity improvements in the pelagic parts of the fleet, because the target of preserving coastal settlements has been less important. Thus, already in the 1950s and 1960s there was a rapid efficiency increase in the pelagic fisheries, with introduction of larger vessels and capital intensive equipment like the sonar and power block (Lorentzen & Hannesson, 2004). However, this discussion does not

[9] Hannesson (1985), p. 115.

imply that the pelagic fleet did not have potential for restructuration in the 1990s. Higher efficiency could correspond to even higher levels of capacity, in line with the definition of economic capacity earlier in this chapter.

In 1990, the government closed the cod fisheries. This was the first utilisation of such a measure of pre-catch ownership rights in a Norwegian coastal fishery (NOU 2006:16, 2006, p. 23). During the 1990s, implementation in other fisheries followed. Today, only a small portion of the catch remains in an open group, available to everyone that wants to participate. The development towards a system of IVQs, giving the vessel a right to catch a portion of the TAC, has led some to argue that we have moved towards a “privatisation of the oceans”, see for example Røed (2016). We discuss the theoretical predictions of different management systems in chapter 3.

The latter part of the 1990s also saw the introduction of another efficiency improving measure. The Norwegian government introduced a structural system to reduce overcapacity in the fleet. Such systems enable the transfer of a pre-determined part of the vessel quota from one vessel to another. A condition for this transfer is the scrapping of the vessel losing its quota. Thus, the government stimulates the less efficient actors to sell their vessels and leave the industry. This reduces overcapacity and potentially realises rent generation.

Initially, the system operated with an 18-year duration on the structured part of the quota. A coalition government of centre-right parties decided to change this to indefinite. The change sparked a lengthy discussion on the ownership of the rights to fish. This discussion culminated in the reversal of the perpetuity by a centre-left coalition that came to power in 2005. Owners of structural quotas tested the reversal in court, but the appeal fell through. A modified version of the structural quota system thus still exists.

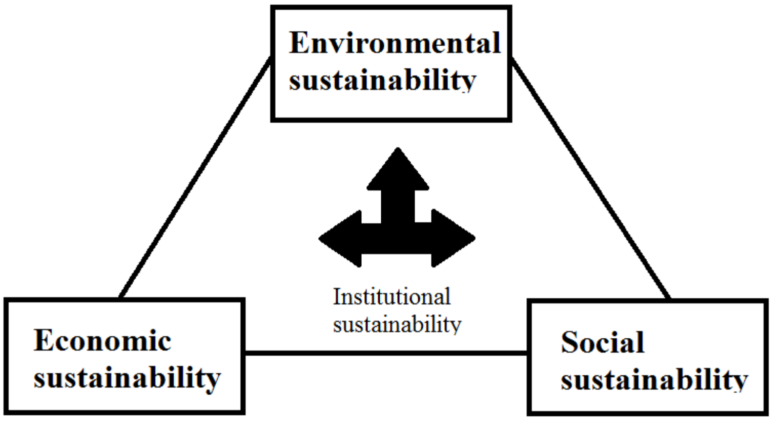

Figure 2.3 – The triangle of sustainability. Replicated from Iversen et al. (2016).

In this chapter, we have briefly discussed three important developments in the Norwegian fisheries: the fall in employment, stock management and economic profitability. The foundation of current management of fisheries rests upon three pillars of sustainability. We illustrate these in Figure 2.3. Structural quota systems help maintain economic sustainability through the incentive to reduce overcapacity. Vessel quotas serve the same purpose because of the removal of the need to overcapitalise, as we will explain in section 3.3. Thus, later years' developments have increased the profitability of the sector.

The closing of previously open-access fisheries and the international cooperation sustain the environmental foundation of the industry. Management of stocks has improved and species such as herring have become economically profitable again. Social sustainability typically relates to the target of maintaining smaller coastal communities. As illustrated in Figure 2.1, the total number of fishermen has decreased every decade since the 1940s. Given innovation and the general economic development, this is an unsurprising trend. Nevertheless, one could argue that social sustainability has lost ground to the other two policy foundations.

3. Theories on the management of fisheries

This chapter contains a broad introduction to the development of theories on the management of fisheries. We start by introducing the "classical" theory of a fishery, the open-access model. In an open-access fishery, entry is open to and free for all, leading profit-maximising actors to deplete the stock. Next, we extend the analysis to a regulated open-access fishery, where the introduction of regulatory measures such as a closing of the fishing season and various forms of gear restrictions ensure conservation of fish stocks. While such systems have positive biological effects, they fail to eliminate the "race for fish", creating economic waste and overcapacity. Finally, we discuss systems introducing private property rights to the fish stocks. Shifting individuals' perspective from one of profit maximisation to cost minimisation, systems utilising ITQs or IVQs can, entirely or partially, eliminate economic waste and attain a socially desirable equilibrium. Understanding the IVQ system outcome is crucial when modelling the current and optimal cost structure for the Norwegian fisheries, and for the development of a theory on the cost minimising behaviour in section 5.1.

When participation is free and open, as in the open-access fishery, one say that the resource is common property. From a legal standpoint, this entails that no one exerts a property right with respect to the fish stock. This is not the same as saying that no one exerts property rights over the fish. As soon as the fish is caught, it is under the fisherman's ownership, exerting the liberty to either sell or consume it. Comparing fishery management systems, a crucial point is whether establishment of the property right happens before or after the catch. We come back to this discussion in section 3.3.

Optimal management of a natural resource can lead to the generation of a resource rent. This rent represents a return above the normal returns on capital and labour inputs. Such a rent may exist because nature does part of the production process, leading the unit cost faced by a single actor to be lower than social unit cost of production. As we will see, the resource rent may therefore only be realised when private actors take a long-term stake in the fishery. A natural theoretical outcome is to give private actors ownership of the fish prior to the catch. In systems where such an ownership is lacking, rents are always dissipated and economic resources wasted.

Whenever we are discussing elimination of economic waste, we are therefore referring to the maximisation of such a resource rent. The resource rent is not a primary focus in this thesis per se. Mathematical discussions on stock dynamics are not a central theme of this thesis, and therefore not included in the following chapter.

We are concerned with the pelagic fisheries in this thesis. Gordon (1954) emphasises that the analytical framework only holds true for demersal fisheries, but that the main conclusions nevertheless should be true for all species (Gordon, 1954, p. 129). We assume this claim to hold true for the other models as well. Chapters 5 and 6 include all relevant formulas and mathematical expressions in an attempt to make this chapter more accessible.

Constructing an optimal management regime for a fishery is a difficult task. The size of the fish stock is an unobserved entity, as is true for many natural resources. Further complicating the task of a social planner, the stock is also subject to large changes due to variations. The economist, eager to maximise the sum of current and future profits, thus finds it necessary to accept a large degree of uncertainty when modelling an equilibrium. A focal point of our later analyses will be to bind together the following theories with estimations on real world data.

3.1 The open-access fishery and the bionomic model

An open-access fishery is a system of resource extraction where participation is open to and free for all. In this section, we introduce the open-access fishery and the bionomic model presented by Gordon (1954).[10] Through the model illustrated in Figure 3.1, we explain the equilibrium under such a management regime and discuss why such an outcome is socially undesirable. The predicted outcome of such a fishery is important to include, explaining the development towards output regulations validating the usage of duality theory in the estimation.

Historically, no universal agreement existed on the importance of economic theory in fishery management. One factor can in particular help explain the initial limited role of economics when designing fishery management systems. The extraction of fish from fisheries was, by

[10] However, we undoubtedly also include much of the analysis from Scott (1955).

many, not viewed upon as extraction of a limited resource. Doctor Harden F. Taylor (1951), biologist and president of the Atlantic Coast Fisheries Company, argued: "*no single species so far as we know has ever become extinct, and no regional fishery in the world has ever been exhausted.*"[11]

With such a point of departure, it is easy to take the stand that an open-access system leads to the socially desirable outcome. This is the standard microeconomic competitive equilibrium where marginal costs (MC) equal marginal revenues (MR) (which also corresponds to the constant, exogenous unit price).[12] Assuming unlimited resources, such an equilibrium yields neither biological degradation nor economic waste.

Economist H. Scott Gordon's famous 1954 paper *The theory of a common property resource: The fishery* challenges this view. Gordon is critical of using standard microeconomic theory as a predictor of the realised outcome in a fishery. While the assumption of MC = MR holds on an individual level, the presence of negative externalities lead to social marginal costs being higher than those faced by an individual firm (Smith, 1968, p. 413). He introduces an open-access fishery in a model combining biology and economy, also referred to as a "bionomic" or "bioeconomic" model of fisheries. A crucial element of this model is possible stock depletion, justified e.g. by substantial technological improvements.

If stock depletion is possible, what is the optimal level of extraction over time? Gordon discusses potential equilibria. An obvious candidate for equilibrium extraction is to extract at the maximum sustainable yield (MSY).[13] MSY is where the net growth of the stock is at its highest. This enables the maximum possible sustained catch levels. Gordon denies this approach as an optimal one. The management of fisheries is interesting because it is beneficial for man, e.g. as food or as a commodity, not because it is beneficial for the fish.

With such a mind-set, one should choose the production that gives the maximum economic yield (MEY). This leads to optimal utilisation of the limited capital, labour and natural

[11] Taylor (1951), p. 314.

[12] Pindyck & Rubinfeld (2013).

[13] Gordon (1954) discuss this, though never actually utilising the term maximum sustainable yield. Instead, he terms it the largest sustainable catch.

resources. When one assumes that the cost per unit of fishing effort is constant, Figure 3.1 illustrates how the economic optimum is typically located to the left of the MSY point. The MEY point is the point where the total cost curve is tangent to the total revenue curve.

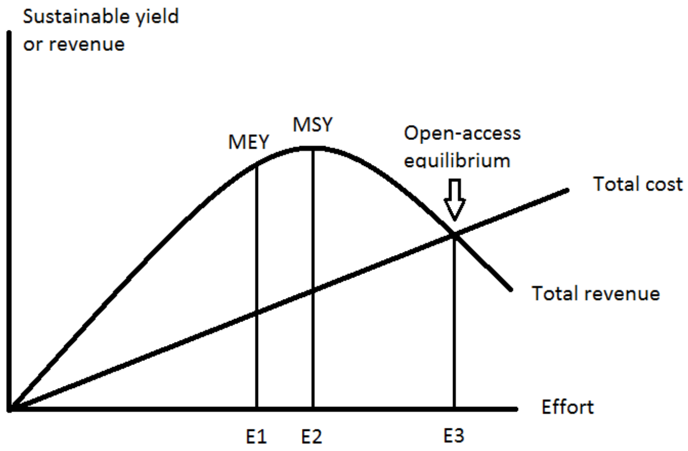

Figure 3.1 - The maximum economic yield (MEY), maximum sustainable yield (MSY) and open-access equilibrium as described through Gordon`s model.[14]

The crucial takeaway from Gordon's model is that we cannot realise the MEY allocation with an open-access management system. Private actors commit too much fishing effort due to differences in the individual and social unit costs. The open-access equilibrium leads to an excess build-up of capital and overfishing, often referred to as "*too many vessels chasing too few fish*" (Conrad, 2010, p. 84). These effects are self-reinforcing.

This analysis shows that we cannot achieve the optimal market allocation in a pure open-access fishery. The presence of negative externalities leads profit maximising actors to overexploit and deplete the resource. Gordon acknowledges this, though at the same time questioning the effectiveness of regulations. He argues that such systems are no better at obtaining the maximum economic yield than the open-access fishery. As we will see in the next section, the main elements of Gordon's framework describe well economic failures also with regulatory measures.

[14] Note, however, that Gordon utilise a different diagram when describing his theory. We base our illustration on *Figure 3.4 open-access equilibrium of effort* presented in Conrad (2010).

3.2 Regulated open-access fisheries

This section extends the analysis from section 3.1 through the introduction of regulatory measures. We show how the regulated open-access fishery yields biological protection, but fails to achieve an economically desirable outcome. We include a discussion on the setting of a quota rule and other regulatory measures. The section is important to understand the introduction of catch limits, prior to the establishment of pre-catch rights to the fish in section 3.3. A regulated open-access fishery treats the fish as a common property, like the open-access system, but sets a TAC for the fishery. To ensure achievement of the target TAC, the system entails a closing of the fishing season, gear restrictions or other regulatory measures.

Figure 3.2 illustrates a regulated open-access system. Developed in Homans & Wilen (1997), it is today a standard framework for the evaluation of the regulated open-access fishery.[15] Officials determine a biologically safe long-term boundary for the fish stock. Whenever the actual stock is below this boundary, lower total quotas are set allowing the stock to recover. Conversely, higher total quotas are set when the level of the stock is above this regulatory equilibrium level. This prediction is also important for an IVQ system, because the TAC determines the size of the individual quotas.

There are still no pre-catch property rights in a regulated open-access fishery. Thus, individual actors have an incentive to fish as much as possible before the season closes. The industry therefore commits capacity each season until all rents are dissipated. Vessels fish until the individual marginal costs reach the marginal price in the market. The individual unit cost is still different from the actual social unit cost, explaining the persistent economic waste.

[15] We have also included much of the analysis from Conrad (2010).

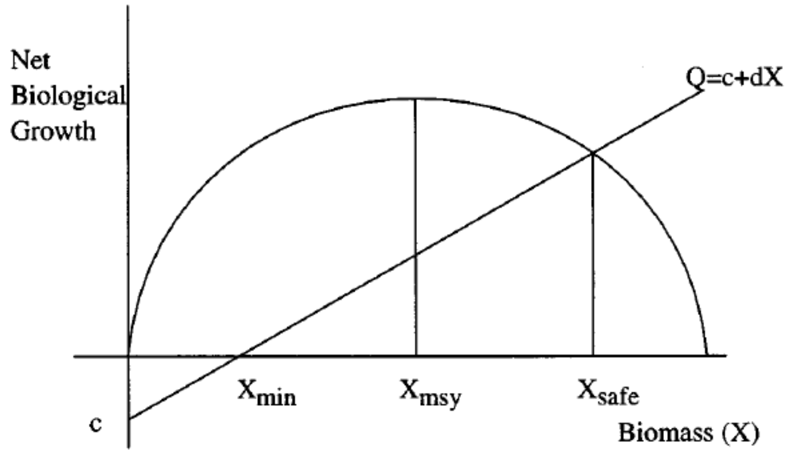

Figure 3.2 - The regulator quota rule, as presented at page 6 of Homans & Wilen (1997).

The entire transitional path is part of the dynamic equilibrium. Starting from an arbitrary biomass level, this evolves according to the between season growth and total catch quota. Note that the rent dissipating capacity is not part of this transitional path. It is easy to see this from Figure 3.2. The determinant of the steady state equilibrium biomass is the intersection of the growth and regulator quota. Capacity is a determinant of the optimal season length. One could therefore say that the outcome of the entire fishery is a result of the joint "*behaviour of both the industry and regulatory agency, coupled with biological dynamics*" (Homans & Wilen, 1997, p. 10).

Understanding the differences between the frameworks of Gordon (1954) and Homans & Wilen (1997) is crucial to understand the importance of the models described in this section. We have already established that the biomass should be higher in the regulated case, as the official quota protects the stock from overfishing when set according to biological measures. Furthermore, an aggregate TAC limit introduces an incentive for each individual fisher to maximise his share of the catch. This is the same as the competitive race for fish described by Gordon, but with a persistently higher biomass, capacity remains at higher levels. Thus, the persistent economic waste is in fact larger in the case of a regulated open-access management system.

3.3 Individual vessel quotas

The models presented in the previous two sections treated the right to fish as common property. In this section, we consider management systems where establishment of property rights happens prior to the catch. With correct implementation, these models can lead to economically efficient outcomes and biological protection. The methodology follows the approach of Arnason (1990), modelling an idealised ITQ system. We modify the approach to resemble the IVQ system in e.g. Eggert & Tveterås (2007).[16] As suggested by the names, the primary difference between these two management systems is the lack of direct transferability of quotas in the latter. The reader should however also note that in the case of IVQs the quota holder is the vessel, while in the case of ITQs it is the firm.

Describing the equilibrium of an IVQ system has been difficult. With transferability considered a good for both seller and buyer, much of the theoretical literature focuses on ITQs. Initial recipients of transferable quotas have in some cases profited significantly on the selling of quotas. Regulators in e.g. Norway have deemed this outcome unacceptable (see chapter 2). IVQ systems have therefore often been preferred in system implementation to limit a "*privatisation of the oceans*". While there is an indirect transferability of quotas through structural policies and transferability of vessel ownership, most of the relevant Norwegian fisheries correspond to a model of IVQs. Understanding such a system theoretically is therefore of crucial importance in the modelling chapters. Note however that Norwegian quota systems operate with both vessel quotas and (vessel) maximum quotas. The difference between a vessel quota and a maximum quota is that the first is reliable in the period and guaranteed by the authorities, while the second is not.[17]

In the following, we consider cost minimisation through output restriction and non-transferability sufficient modifications to the model in Arnason (1990). If these modifications induce the least efficient actors to leave the industry at the point of rotation of capital (i.e., at the point where the old vessel is scrapped), our expected equilibrium capacity is the same as in an ITQ system. This holds true when vessels may be bought and sold and if

[16] In addition, Conrad (2010), Grafton (1996), and Buck (1995) also provide important background material to this section.

[17] Maximum quotas are introduced e.g. when IVQs do not result in the full TAC being caught. We discuss when this might happen in section 5.1.

there exists an opportunity cost of capital, corresponding e.g. to the rent capitalists can obtain by investing in bonds of similar risk. Without transferability of quotas, less efficient actors might lack incentives to leave the industry in the short run. Thus, our system of IVQs has a longer transitional path than one including transferability.

Our approach yields five fundamental factors characterising an idealised IVQ system. Factors 1 and 3-5 are from Arnason (1990), with the exception that we refer to individual vessels rather than firms.

1) *The individual catch quotas are shares in the total allowable rate of catch. These quotas are referred to as share quotas.*
2) *The regulation of output yields an (absolute) upper boundary for the vessel, i.e. no quota trading is possible between vessels, equivalent to the utilisation of a cost minimising approach.*
3) *The share quotas impose an upper limit on the vessel's permitted rate of catch.*
4) *The share quotas are permanent in the sense that they allow the holder the stated share in the total quota in perpetuity.*
5) *The quota authority issues the initial shares and subsequently decides on the total quota at each point in time.*

Systems establishing pre-catch property rights have an important feature dealing with the inefficiency of the regulated open-access system. They break down the TAC into individually held rights of landing a specified portion of the catch of fish. With guaranteed landings, there is no need for overcapitalisation. Where a rush to the fishing grounds, catching as much as possible before the closure of the season, was important in the open-access systems, IVQ systems eliminate the race for fish. Thus, rent generation is possible in such fisheries. One effect of guaranteed quotas is attempted improvements in the quality of fish extracted, typically leading to higher prices, longer fishing seasons and more fresh fish sold (Homans & Wilen, 2005). This is a potential challenge when using duality theory to minimise costs (see section 5.1).

With many outstanding quotas, the individual vessel cannot affect the market price for fish and revenues are exogenously given. Fishermen then alter their perspective from varying output given a production function to a cost minimising approach holding output constant. For this to be true in equilibrium, ownership of vessels must not be too concentrated as this could lead to monopolistic behaviour. The alteration of perspective is a crucial assumption in our thesis, as we use the cost minimisation approach to estimate non-linear cost functions in chapter 5 (see section 5.1 for a discussion on the cost minimising vessel's behaviour). Note that such an approach would be incorrect in an ITQ system, as output remains unconstrained (at least up to the species' TAC) through the possibility of buying additional quotas (Bjørndal & Gordon, 2000). At the owner level, the possibility of buying and selling vessels make output variating behaviour possible to some extent also in an IVQ system. As we are estimating using predicted seasonal behaviour, this should not induce a problem.

The assumption of the individual quota being an upper limit for the permitted rate of catch is crucial if the aggregate catch is to equal the TAC. Fulfilment of this assumption is costly, as it requires the implementation of monitoring and penalties set by the regulator. Otherwise, the lack of incentive to hold the quota would lead to overfishing, resulting in the open-access equilibrium. Quotas awarded indefinitely is, as we discussed in chapter 2, one of the most controversial parts of these systems. Indefinite quotas have led some to argue that regulators "forever" have privatised the profits from a common resource (Røed, 2016). Using the discussion from Arnason, we can show how a finite (or discrete) quota system leads to a lack of efficiency. In an infinite quota system, the transitional path always takes the most rapid approach. Thus, excluding natural stock variations, quotas are set according to the first path resulting in the long-term optimal stock level. With finite periods, several exploration paths satisfy the constraint that fish caught cannot exceed the quota. Not all these paths are optimal. Therefore, implementation of infinite lasting quotas is the only way to ensure achievement of the social equilibrium.[18]

Discussions on how quota authorities set and distribute initial shares have been important. One of the main reasons is that firms normally obtain these initial quotas gratis. Arnason (1990) highlights the possibility of allocating initial shares through a quota market. Thus, with a perfectly functioning market there is nothing wrong with the public profiting on the setting up of an ITQ system. In fact, this should lead to an optimal set of actors entering the industry from the beginning. The IVQ nature of our model make such a quota market allocation impossible. However, an auction based initial allocation should yield a similar result. Other political goals, e.g. the protection of fishermen at the time of implementation, often make these approaches difficult. This explains the rare utilisation of such initial actions. For the purpose of this thesis, the important takeaway is that the initial distribution

[18] Our approach, omitting structural quota systems in the optimisation problem, is equivalent to fishing permits lasting indefinitely. While the law states that granting of permits happens on a year-to-year basis, history tells us that vessels fulfilling requirements get a permit to fish also in the following year.

of quotas is inefficient, yielding incentives for regulators to reduce economic waste. Furthermore, redistribution of catches might be hard to achieve due to conflicting policy goals.

Systems also introducing transferability have a second feature reducing economic waste. Transferability limits inefficiency as the most efficient quota owners can buy out less efficient actors, minimising the economic cost of catching a fish. In the very long run, the effect of such transfers vanishes as our assumptions ensure that only the most efficient actors reinvest the capital necessary to remain in the IVQ fishery.

Another feature of an ITQ fishery may nevertheless give an improvement over IVQ systems. When quotas fall, some actors might want to leave the fishery because their discounted future stream of revenues is lower than what they could achieve by selling the quota today. Transferability ensures that these can quit the fishery, leaving only the economically efficient actors. This is an improvement over IVQ systems, where information known at the time of reinvestment is the primary determinant of fishery capacity. Thus, an optimal fleet in an IVQ system might need a higher degree of diversity to be able to respond to the natural variations in biomass affecting the size of the seasonal quotas.

4. Data and descriptive statistics

In this chapter, we describe our dataset and show important descriptive statistics. The intention of the chapter is to give the reader a better initial understanding of the work conducted and the methods applied in our analysis. We comment on the collection of data, distribution of catch, variables, classification of cost items, distribution of costs, selected trends and structure of the data.

4.1 Collection of data and the population

The Norwegian Directorate of Fisheries (NDF) has collected information from profitability surveys conducted on the Norwegian fishing fleet since 1950 (Norwegian Directorate of Fisheries, 2015). These data enable researchers, bureaucrats, and other stakeholders to evaluate e.g. fishery regulations, strategies on profitable and sustainable fisheries, and the structure of the fishing fleet. Our dataset stems from such surveys. We look at annual cost and catch data at an individual vessel level for the 15-year period 2000-2014. The dataset consists of data from coastal vessels, purse seiners and pelagic trawlers. Due to similarities in technology and cost structures, we combine the latter two. Utilisation of vessel groups allows for within fleet differences. We come back to this grouping later in this chapter.

Several different species are included in the dataset we possess. These include Norwegian spring spawning herring (NSSH), North Sea herring (NSH), mackerel, blue whiting, capelin, sandeel, cod, haddock, pollock, Greenland halibut, shrimp and other species. Out of these, the first six are included as pelagic species. Note that this excludes certain pelagic catches from our later analysis, such as that of Norway pout, as these are included in the other species categories. The inclusion of two groups divides catches from several species. One group includes fish caught south of the 62nd latitude, the other catches north of the 62nd latitude.

Over time, the population included in the surveys has changed. Until the 2009 survey, there were criteria regarding operating days and length of the vessel that had to be satisfied to be included as part of the population. However, from 2009 the population consists of vessels with catch revenue above a minimum level. The consequence of this selection process is that the survey consists of the vessels that are responsible for the dominant share of the catch revenue in the Norwegian fishing fleet (Norwegian Directorate of Fisheries, 2016). In addition to information about the vessel revenue, costs and balance sheet, key figures such as the operating days and man years are collected.[19]

The division of vessels into vessel groups and the calculations of variables have also been subject to changes during the relevant period. In 2008, the profitability survey changed from an economic to an accounting perspective. In conjunction with the change of perspective, NDF created new time series based on the perspective of accounting. The change of perspective is not concern to us, as the dataset we use contains these new time series.

The scheme of statistical sampling consists of three steps: stratification, methods for determining the number of vessels included in the population, and the actual drawing of the sample. It ensures a representative sample (Norwegian Directorate of Fisheries, 2016). The prevailing method for statistical sampling in the period of our dataset has not been subject to change. The reader should also note that from the 2009 survey and onwards, NDF decided to reduce the statistical sample. This is worrisome, because we want to estimate cost functions on the entire period. In chapter 5, we include year dummies to limit potential effects of for example the unequal distribution of the time series.

Only a few vessels have their total catch caught in either pelagic or demersal species. To separate pelagic from demersal fisheries, we apply the same criterion as in the profitability survey: the fishery where the vessel has generated the largest share of catch revenue determines to which fishery the vessel belongs.

Vessel grouping corresponds to the prevailing method as presented in the profitability survey. As we are concerned only with the Norwegian pelagic fisheries, our groups correspond roughly to groups 9-13 in the profitability surveys. The grouping of the vessels is not straightforward, as we do not have information on the corresponding vessel group of the vessels in the dataset. However, vessels have a corresponding operation code. An overview of the operation codes and their respective names also follows the dataset. The names are typically describing characteristics of the vessel. To exemplify, the corresponding name for operation code 12 in 2009 is “Purse seine”, while the corresponding name for operation code 19 in 2007 is “Coastal vessels using seine. Vessels 11-21.35 meters quota length”. We use

[19] Man year is a variable expressing average employment of a vessel during a year.

this overview to divide vessels into vessel groups. This division is important in the estimation process, because it allows us to correct for the utilisation of different gear within a fleet. In Table 4.1, we present an overview of the utilised operation codes from the profitability survey. The table also includes the number of observations in each vessel group.

For the coastal vessels, there are 37 observations dropped due to not fulfilling the criteria of belonging to the pelagic fishery, and having an operation code and a respective name, that, to a reasonable degree, coincides with the vessel descriptions we use. We drop no observations from the data on the purse seiners, and 5 observations from the data on the pelagic trawlers. In total, we have 434 unique vessels in the dataset for the coastal vessels, 177 unique vessels in the fleet of purse seiners and 96 unique vessels in the fleet of pelagic trawlers.

Table 4.1 – Vessel groups

Vessel group	Vessel description	Operation code in profitability survey	No. Observations		
			Coastal vessels	Purse seiners	Pelagic trawlers
9	Coastal vessels using seine. Vessels below 11 meters quota length	9, 18, 41	56		
10	Coastal vessels using seine. Vessels 11-21.35 meters quota length	10, 19, 20, 21, 22, 23[a], 25	639		
11	Coastal vessels using seine included purse seine vessels without license (SUK-group)	11, 23[a], 26	310		
12	Purse seiners	12, 24, 27, 28, 29		1 013	
13	Pelagic trawlers	13, 23			266
Total number of observations			1005	1013	266

[a] *Operation code 23 in 2000 is included in vessel group 13, in 2003 in vessel group 10, and in vessel group 11 in 2004. For all other years: vessel group 10.*

Table 4.2 provides basic descriptive statistics on the distribution of quantity caught for the vessel groups in the fleet of coastal vessels. We see that several species have only small catch volumes. In chapter 5, we set as a criterion that a species should constitute at least 5% of the total catch to be included in the estimation. This applies to both of the fleets we look at. NSSH counts for the largest share of quantity caught for each vessel group as well as for the fleet of coastal vessels as a whole. Total catch volume is largest for vessel group 10, followed by vessel group 11. Vessel group 9 has the lowest total catch volume. This is what we would expect considering the number of observations from each group (see Table 5.1).

Table 4.2 – Catch in tonnes for vessel groups and species for the coastal vessel fleet

Species/vessel group	9	10	11	Total	Share
NSSH	4 593	721 220	562 640	1 288 453	59 %
NSH	497	48 648	38 225	87 371	4 %
Mackerel	2 752	103 127	97 649	203 528	9 %
Blue whiting	0	1915	2 615	4 530	0 %
Capelin	0	20 097	91 222	111 319	5 %
Sandeel	0	520	3 731	4 251	0 %
Cod N62	540	60 019	52 646	113 205	5 %
Haddock N62	34	8 408	8 642	17 084	1 %
Pollock N62	398	162 406	117 898	280 702	13 %
Greenland halibut N62	10	779	315	1 103	0 %
Shrimp N62	0	183	650	833	0 %
Pollock S62	600	15 313	8 936	24 849	1 %
Shrimp S62	2	156	0	157	0 %
Other	851	24 046	10 547	35 445	2 %
Total	10 277	1 166 838	995 716	2 172 832	

Table 4.3 provides basic descriptive statistics on the distribution of quantity caught for the purse seiners and pelagic trawlers. Blue whiting have low catch volumes in the coastal vessel fleet. As a comparison, the species constitutes the largest catch share for both purse seiners and pelagic trawlers. NSSH again constitutes a relatively large share of total quantity caught. The other important species in terms of quantity caught for the purse seiners are mackerel and capelin. For the pelagic trawlers, sandeel is the most important species in addition to blue whiting and NSSH herring. However, for the combined fleet sandeel constitutes only 4% of the total catch.

Table 4.3 – Catch in tonnes for each vessel group and species for the purse seiners and pelagic trawlers

Species/vessel group	12	13	Total	Share
NSSH	3 788 558	453 780	4 242 338	26 %
NSH	961 205	54 211	1 015 415	6 %
Mackerel	1 454 139	45 274	1 499 413	9 %
Blue whiting	4 928 819	698 687	5 627 507	35 %
Capelin	2 168 180	125 970	2 294 150	14 %
Sandeel	192 614	479 648	672 262	4 %
Cod N62	4 740	137	4 877	0 %
Haddock N62	940	615	1 555	0 %
Pollock N62	28 717	4 246	32 964	0 %
Greenland Halibut N62	0	0	0	0 %
Shrimp N62	1 111	0	1 112	0 %
Pollock S62	927	34 695	35 622	0 %
Shrimp S62	0	1 362	1 362	0 %
Other	410 443	186 996	597 440	4 %
Total	13 940 394	2 085 622	16 026 016	

4.2 Variables

The dataset contains information concerning costs and revenues as well as information about vessel size, age, man years and catch quantities and values of the fish species included in the survey. All costs and revenues are in Norwegian kroners (NOK), and catch quantities in kilogrammes. We have inflated all monetary values to 2014 NOK utilising the consumer price index (CPI). While the price increases may have been lower or higher in the sector than for the generalised consumer, we consider this the best possible approximation. Collected CPI values stems from national statistics (Statistics Norway, 2016).

Operational revenues are the total revenues from fishing and all other activities. Incidental revenues and minor compensations are also included in operational revenues. Operational costs are costs generated through operational activities. Depreciation on vessels and fishing licenses and permits, items such as fuel, miscellaneous fees, labour remunerations of crew, maintenance on vessels and gear as well as other operating and administrative expenses, are also included in operational costs.[20] The operating profit is the difference between operating revenues and operating expenses.

4.3 Classification of cost items and distribution of costs

To investigate the relationship between output and variable unit costs, we first need to define variable costs. The table below shows a classification of the different cost items in our dataset. We also provide a brief description of the different cost items. Our division between operating costs, quasi-fixed costs and fixed costs is similar to Sandberg (2005).

The definition of operating cost items includes items necessary to operate the vessel in the short term. Quasi-fixed cost items include items necessary within a year. The fixed cost items relate to long-term vessel costs. When output from vessels is constrained by seasonal IVQs, it seems reasonable to assume that firms will minimise operating costs and costs of quasi-fixed input factors. These two types of cost items are therefore included as variable costs when estimating cost functions for the pelagic fisheries.

Table 4.4 – Cost items and classification

Item	Classification	Comment
Product fee	Variable	
Structural fee	Variable	Came into force in July 2003, ceased in July 2008
Control fee	Variable	Came into force January 2005
Labour remuneration	Variable	
Food	Variable	
Social costs	Variable	
Pension costs	Variable	
Depreciation on vessel	Fixed	
Depreciation on fishing licenses and permits	Fixed	Various depreciation methods

[20] Note that total value of the catch determines wages paid to workers in the fisheries.

Fuel	Variable	Extra fee on NOx emission came into force in 2007
Bait, ice, salt and packing	Variable	
Maintenance vessel	Quasi-fixed	
Maintenance gear	Quasi-fixed	
Insurance of vessel	Quasi-fixed	
Other insurances	Quasi-fixed	
Unspecified expenses	Quasi-fixed	

The product fee is a fee intended to cover part of the fishermen’s obligations to the National Insurance Scheme. This fee is in essence a tax collected on sales revenue. The structural fee goes into a fund, intended for capacity adjustment in the fleet. Another tax on sales revenues is the control fee. This fee covers costs regarding control activities. The cost items food, fuel and bait, ice, salt and packing are self-explaining.

Total labour remuneration to crew on board the vessel, or “*lott*”, is also a share of the total value of the catch. Social security and other personnel costs are included in social costs. Collection of the variable pension costs uses a tax on sales revenue. This intends to finance expenditure on pension insurance for fishermen. Depreciation on vessel is depreciations collected from the vessel’s accounting. Depreciations on permits, unit quotas and structural quotas are included in depreciation on fishing licenses and permits.

The quasi-fixed cost items maintenance vessel and maintenance gear are self-explaining. Hull insurance of the vessel is included in the cost item insurance of vessel. Other insurances consist of all other types of insurances related to the vessel. The cost item unspecified expenses includes, amongst other things, costs regarding contract labour, port charge, other administration fees and costs related to the purchase of quotas. As we do not know the relative size of the purchases of quotas as compared to the others unspecified costs, we decided to include these as quasi-fixed. This should not have large effects on the estimated results given the share of unspecified costs to total variable and quasi-fixed costs (see the cost distribution in Table 4.5).

Table 4.5 – Distribution of costs amongst coastal vessels, purse seiners and pelagic trawlers. NOK in 1000.

	Coastal vessels		Purse Seiners		Pelagic Trawlers	
Cost item	**Total costs**	**Share of total costs**	**Total costs**	**Share of total costs**	**Total costs**	**Share of total costs**
Variable costs	4 961 400	56 %	19 602 307	55 %	2 318 181	59 %
Fixed costs	1 324 594	15 %	5 801 974	16 %	537 534	14 %
Quasi-fixed costs	2 565 461	29 %	10 138 671	29 %	1 060 068	27 %
Parameter	**Total costs**	**Share of total costs**	**Total costs**	**Share of total costs**	**Total costs**	**Share of total costs**
Variable cost items						
Product fee	295 804	6 %	1 390 240	7 %	135 447	6 %
Structural fee	8 895	0 %	31 490	0 %	3 453	0 %
Control fee	13 161	0 %	50 330	0 %	4 807	0 %
Labour remuneration	3 766 358	76 %	12 489 177	64 %	1 296 247	56 %
Food	102 325	2 %	384 911	2 %	44 219	2 %
Social costs	42 568	1 %	261 399	1 %	20 181	1 %
Pension costs	24 517	0 %	112 166	1 %	10 822	0 %
Fuel	692 726	14 %	4 729 953	24 %	772 369	33 %
Bait, ice, salt and packing	15 046	0 %	152 641	1 %	30 636	1 %
Fixed cost items						
Depreciation on vessel	1 100 157	83 %	4 931 948	85 %	436 962	81 %
Depreciation on fishing licenses and permits	224 437	17 %	870 026	15 %	100 572	19 %
Quasi-fixed cost items						
Maintenance vessel	854 674	33 %	3 659 920	36 %	454 331	43 %
Maintenance gear	480 939	19 %	2 100 625	21 %	224 828	21 %
Insurance of vessel	219 796	9 %	632 170	6 %	101 811	10 %
Other insurances	107 154	4 %	374 996	4 %	41 856	4 %
Unspecified expenses	902 898	35 %	3 370 960	33 %	237 242	22 %

Table 4.5 presents the distribution of costs for the coastal vessels, purse seiners and pelagic trawlers. We have separated purse seiners and pelagic trawlers to highlight similarities and differences in the cost structure. In addition, the cost distributions are summarised for each

fleet in the same table for illustrative purposes, while reminding the reader that we estimate cost functions for coastal vessels and the combined group of purse seiners and pelagic trawlers independently from one another. The upper segment of the table summarises the total variable costs, fixed costs and quasi-fixed costs. Percentage values presented are associated with these total costs numbers. The lower segment of the table looks isolated at cost items classified as variable, fixed and quasi-fixed. Shares of total costs calculated are the shares the different cost items constitute of the total cost within each of the three cost categories.

When summing over all coastal vessels, costs defined as variable total almost NOK 5 billion. With a share of total costs of 56%, it is clearly the most important cost category. Quasi-fixed costs account for 29% of total costs, while the fixed costs accounts for 15%. Variable costs and quasi-fixed costs combined accounts for 85% of total costs for the coastal vessels. This share is more or less the same for purse seiners and pelagic trawlers.

Within the group of variable costs, labour remuneration accounts for the largest share. Costs regarding fuel and the product fee also accounts for high shares. The other cost items constitute the last 4% of the total variable costs. The picture is similar for all vessels, though the share to labour remuneration is higher for the coastal vessels. This indicates a higher labour intensity in the production function.

For the quasi-fixed cost items, there do not exist large differences in which cost items that accounts for the largest share of total quasi-fixed costs: maintenance vessel, maintenance gear and unspecified expenses constitute almost 90% of total quasi-fixed. Including e.g. unspecified expenses in variable costs when regressing is in particular important in years where the use of contract labour has been high.

4.4 Selected trends in the dataset

In this section, we focus on the time series dimension of the dataset. The intention is to identify whether clear trends exist in the data that need special treatment when conducting econometric analysis. We comment also on the possible complications related to estimating on time series data. Again, we separate purse seiners and pelagic trawlers to highlight different developments between these.

Figures 4.1-4.3 illustrate the average of man years and the average length of vessels amongst coastal vessels, purse seiners and pelagic trawlers included in the profitability surveys. Sampling methods implicate that trends in these variables not necessarily yield good proxies for the total employment and cost structure of the Norwegian fishing industry as a whole.

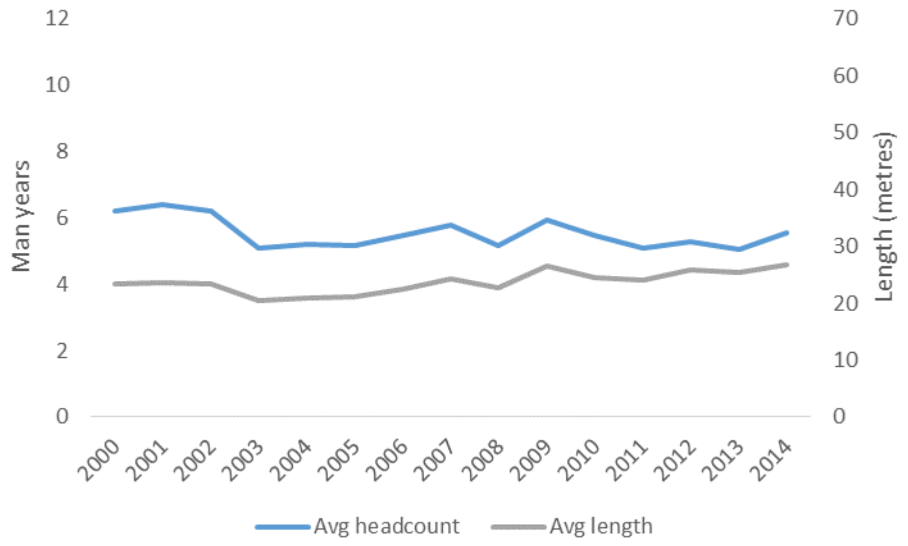

Figure 4.1 – The average of man years and length for the coastal vessels (2000-2014).

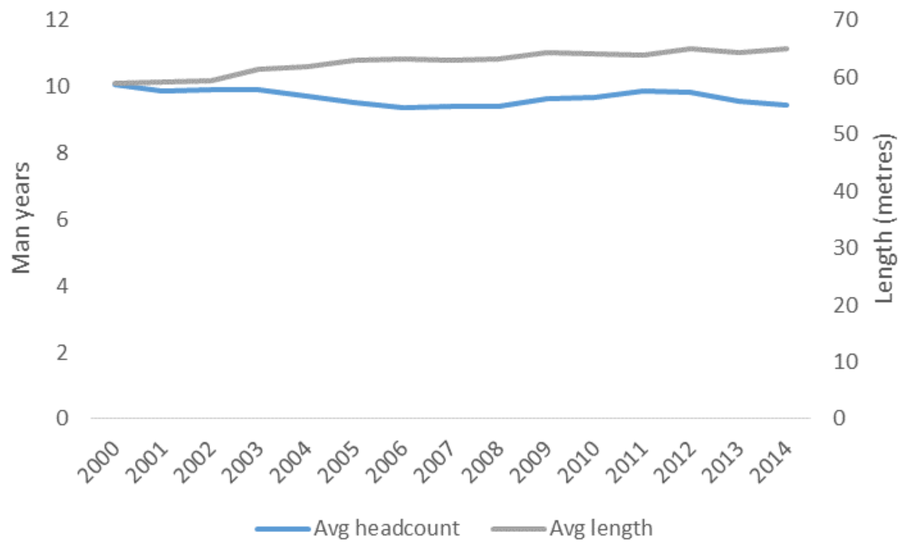

Figure 4.2 – The average of man years and length for the purse seiners (2000-2014).

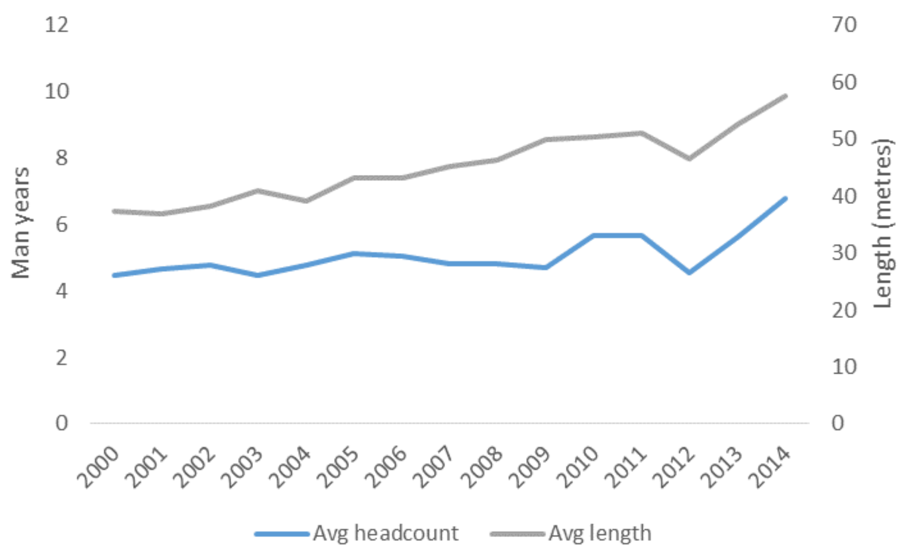

Figure 4.3 – The average of man years and length for the pelagic trawlers (2000-2014).

We study the time series of these variables to get an indication of whether there is reason to believe that major technological shifts have occurred in the period. A technological shift in the fishery industry could result in reduced demand for workers, and thus a reduction in the number of people employed over time. As is clearly illustrated in the next section, where we look in more detail at the structure of the data, there is great variation in the number of observations from year to year. Hence, we use the average of the variables when studying the time series.

Looking at the time series for average man years isolated does not yield information on whether technological shifts have taken place. The number of people employed at a vessel relates also to the size of the vessel – larger vessels would typically employ more people. A reduction in the number of small vessels and an increase in the number of large vessels would then result in an increase in the number of people employed at the average vessel. As Figure 4.3 illustrates, there is clear evidence of covariance in the time series of pelagic trawlers. For the coastal vessels, there is also evidence of a high degree of covariance between average man year and average length. We note that the relative variations in the two variables throughout the time series is smaller for this fleet. It is however difficult to conclude whether these plots indicate changes in technology. While we could examine the production per man years, quota variations might explain more of the variations of this measure than improving technology.

For the purse seiners, the degree of covariance is less clear. During the period 2000-2014, the average man years has decreased while the average length has increased. However, the relative changes are small. Hence, we cannot conclude from these plots that a major technological shift has occurred.

Comparing the time series of average man years and length across the fleets, one could argue that the pelagic trawlers are more technological advanced than the coastal vessels. The pelagic trawlers have consistently higher average length throughout the period as compared to the coastal vessels. Average man years amongst the pelagic trawlers are also lower than for the coastal vessels. In such an analysis, one should also look at possible underlying causes such as differences in the species targeted by different vessels etc.

Figures 4.4-4.6 show the development in average variable costs and average quantity caught. Note that all species are included in the measurement of average catch, and both variable costs and quasi-fixed costs are included in the measurement of average variable costs. Appendix A also contains a breakdown of catches of the species included in the estimation in different years to illustrate quota variations.

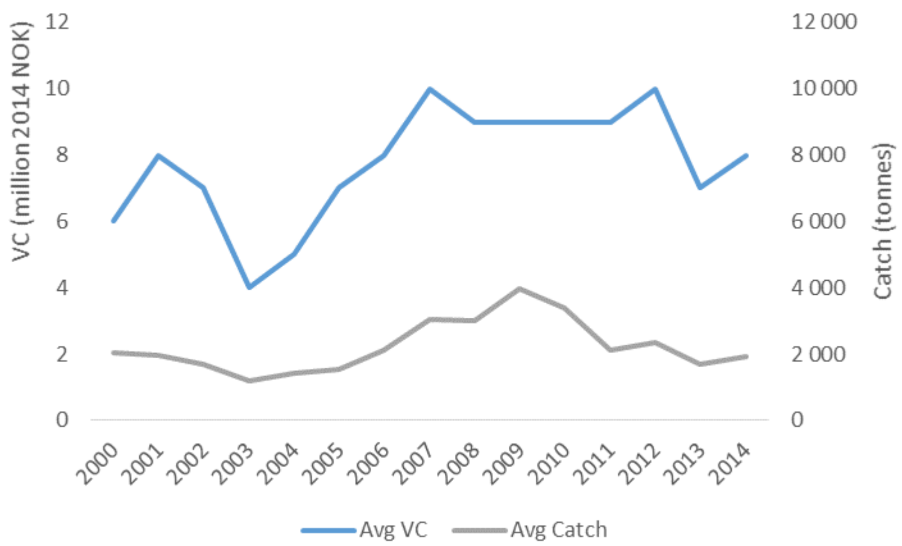

Figure 4.4 – Average variable cost (VC) and catch for coastal vessels (2000-2014).

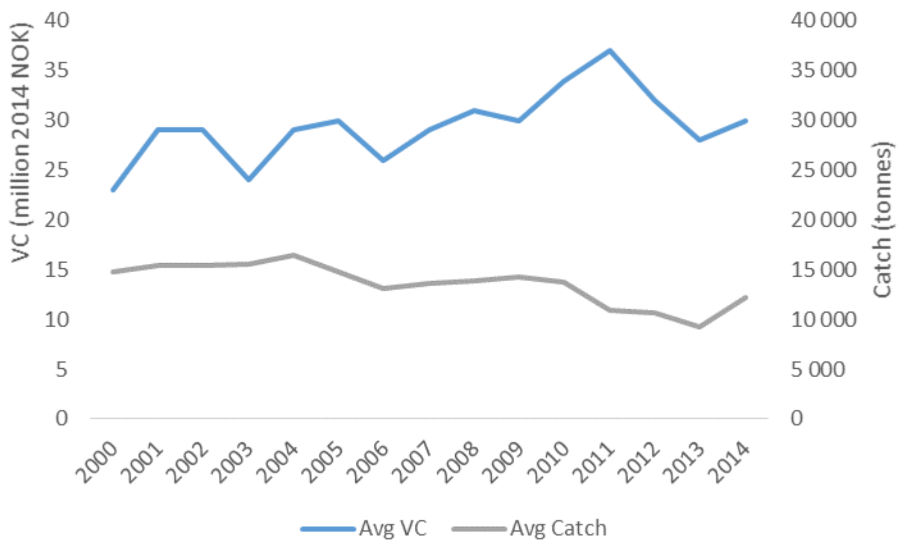

Figure 4.5 – Average variable cost (VC) and catch for purse seiners (2000-2014).

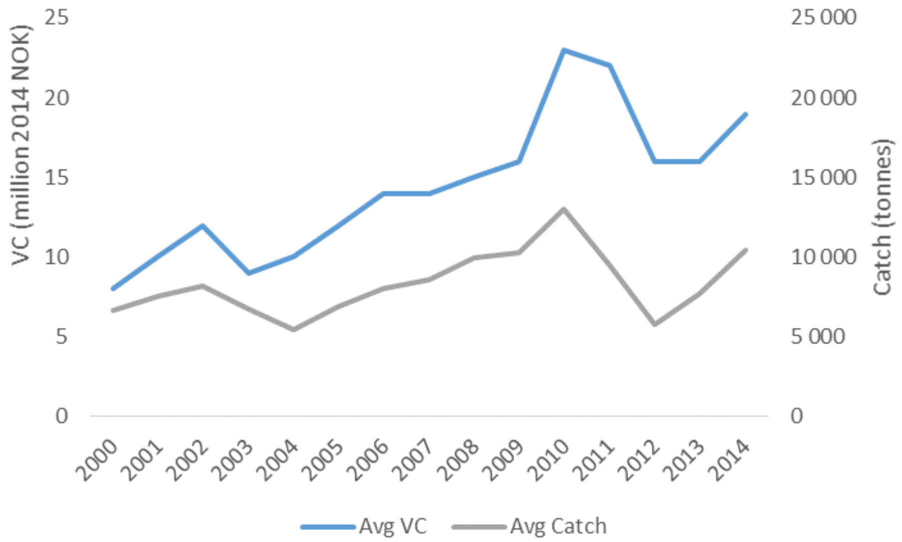

Figure 4.6 – Average variable cost (VC) and catch for pelagic trawlers (2000-2014).

Average catch is a proxy for the scope of the operation of the vessels included in the profitability survey from year to year. The development of average catch and average variable costs is a proxy for the development in the degree of cost efficiency. This development is of interest to us as cost efficiency relates to technological change. An overall decrease in variable costs and an increase in catch could imply technological improvement. As variable and quasi-fixed costs constitute the clear majority of total costs for all fleets and vessel groups (see section 5.3.1), it is reasonable to draw a conclusion based on the study of this proxy for the development in the degree of cost efficiency.

In Figure 4.4, we observe that there is great variation in both time series for the coastal vessels. Except for the periods 2000-2002 and 2008-2010, the fluctuations in average variable costs seem to coincide with fluctuations in average quantity caught. In the first period mentioned above, we observe an increase in average variable costs and a slight decrease in average quantity caught. We observe the opposite for the latter period. Thus, we ascribe changes in biomass conditions and total quotas to these findings. The rationale for this is that it is unlikely that technological shifts have appeared only in these two periods isolated. For both time series, there is an overall slightly increasing trend, implying no increasing degree of cost efficiency, and thus no technological change.

For the purse seiners, the relative fluctuations in the two time series are smaller as compared to the coastal vessels. With smaller relative fluctuations, it is harder to conclude that fluctuations in average catch explain fluctuations in the average variable costs. While the slope of the trend line of average catch is slightly negative, the slope of the trend line of average variable costs is positive. This would indicate that the purse seiners have efficiency decreasing in time.

Figure 4.5 illustrates the time series for average variable costs and average catch for the pelagic trawlers. Clearly, there is positive correlation between the two time series. Following the discussion so far, we find it reasonable to explain changes in the average variable cost with changes in the average quantity caught. The slope of the trend line for the average variable costs is steeper than the slope of the trend line for the average catch. This leads to the same indication as for the purse seiners –less cost efficiency over time.

These trends seem strange. A potential explanation could be the inclusion of investments in quotas as a quasi-fixed cost. Another possibility is a change in the catch of species that has led to disproportionate changes in costs. Quotas of different species are to a varying degree volatile between years.

As a final trend relationship, we have graphed the development in operating days in Figures 4.7 and 4.8. Operating days include includes the time spent on preparation, at quay, days at sea, and finalising the fishing (Norwegian Directorate of Fisheries, 2016, p. 94). It is also an indicator of capacity utilization (Steinshamn, 2005). For the three largest vessel groups in terms of catch (10, 12 and 13) the measure has decreased relatively steadily throughout the period. Since we know that catches have not been subject to clear downward trends, this could indicate that these groups are able to catch the same volumes at a shorter time as compared to earlier. If the variable operating days is a proxy for effort, these findings indicate higher efficiency in these groups because we can interpret effort as a driver of variable costs (see section 5.1). These findings seem to be more consistent with the high levels of investments in several vessel groups in later years, see for example Larsen & Dreyer (2013). This implies utilisation of year dummies in the cost estimations to correct for time trends such as investments in more advanced gear. Year dummies correct also for biomass variations, policy changes and differences in the number of observations between years.

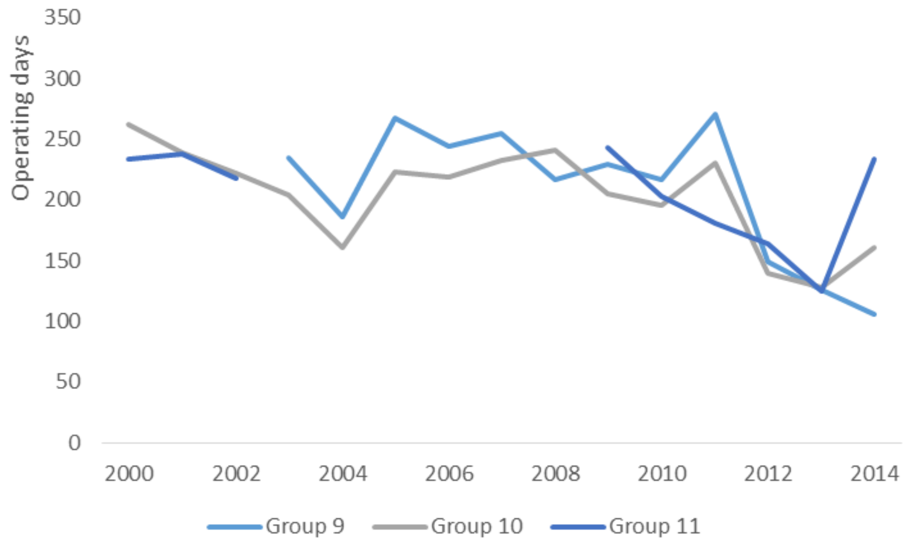

Figure 4.7 – Average of operating days, coastal vessels (2000-2014). Groups 9 and 11 do not report landings in all years.

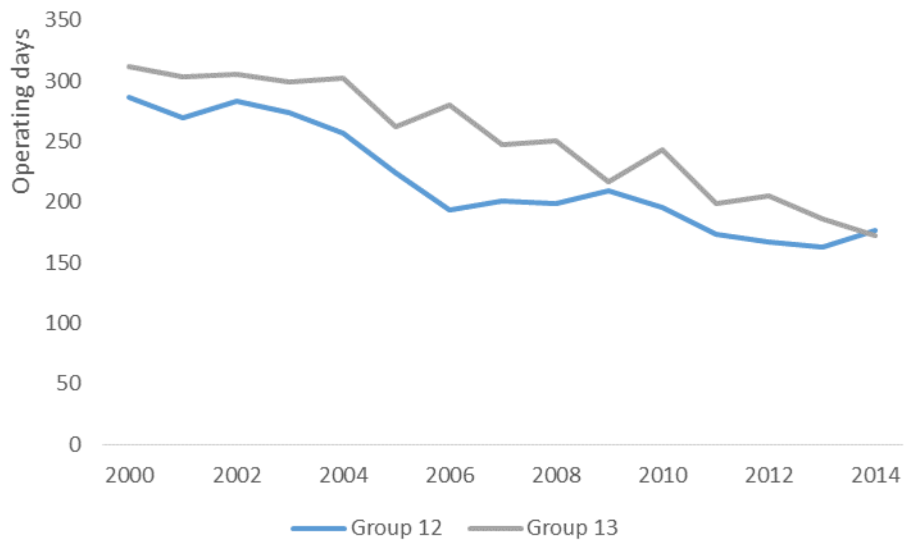

Figure 4.8 – Average of operating days, purse seiners and pelagic trawlers (2000-2014).

4.5 Structure of the data

In Table 4.6, we show the frequency of reports and the number of unique vessels that appear in the profitability survey in the relevant period. As can be seen from the table, the data takes a heavily unbalanced form. Ideally, we would have a set where the same vessels participated in the profitability survey every year. We could then have applied panel data techniques, giving superior estimations with respect to the time dimension. In fact, data close to being panel data could through various techniques enable this type of analysis. None of these situations hold true for our data. We have therefore corrected for the time dimension and applied ordinary least squares (OLS) methods in our estimations.

The structure of the data imposes challenges in finding suitable econometric techniques for our cost function analysis. We need to take into account that we have a time dimension as well as, to a varying degree, two or more observations from the same vessel. In Table 4.7, we describe the distribution of observations over time for the different vessel groups.

Table 4.6 - Unbalanced panel dataset for vessels in the Norwegian pelagic fishery

Frequency	Coastal vessels	Purse seiners	Pelagic trawlers
1	202	42	37
2	87	17	25
3	49	22	8
4	32	14	6
5	20	11	5
6	12	5	3
7	6	6	4
8	5	6	1
9	5	6	1
10	3	7	3
11	2	14	0
12	0	8	0
13	0	5	0
14	0	9	0
15	0	5	0
Number of vessels	434	177	96

Table 4.7 - Unbalanced panel dataset for vessels in the Norwegian pelagic fishery

Year	Coastal vessels	Purse seiners	Pelagic trawlers
2000	46	79	29
2001	56	76	28
2002	64	81	28
2003	71	74	26
2004	102	66	27
2005	125	72	21
2006	99	63	23
2007	70	61	21
2008	77	70	16
2009	57	65	9
2010	51	66	9
2011	52	65	8
2012	59	58	5
2013	45	57	8
2014	31	60	8

Looking at the distribution of observations over time in conjunction with the frequency report in Table 4.6, one can clearly see that the data is not suitable for panel data analysis. Ignoring the time dimension, and treating every observation as individual from one another, the data would take the form of cross sectional. This would allow for utilisation of econometric techniques thereafter.

One suitable approach is to treat the data as pooled cross section. Woolridge (2014) defines pooled cross section as “*data configuration where independent cross sections, usually collected at different points in time, are combined to produce a single data set*” (p. 578). With the right techniques, one can then analyse data that have both cross-sectional and time series features. The cross-sectional and time series features are both clearly present in our data, hence pooled cross-sectional analysis seems to be the most suitable.

For the data to be suitable for analysis with such a technique, we must also have independently pooled cross sections. Sampling randomly from a large population at different points in time ensures this. The independency is a key feature. It yields no correlation in the error terms across different observations. As NDF gathers data on a random sample of vessels annually, we pool annual data and treat the data as independent cross sections.

Our motivation behind using independently pooled cross sections is to increase the sample size to achieve more precise estimators and test statistics with higher power. To reflect that the population may have different distributions in different years we allow the intercept to differ. As mentioned in the last section, the introduction of dummy variables for all but one year accounts for possible differences in the distribution. With a pooled cross sectional model, OLS is the leading method of estimation (Wooldridge, 2014). We describe the OLS approach in section 5.2.

5. Estimating cost functions in the pelagic fisheries

This chapter contains the estimation of cost functions for vessels in the pelagic fisheries. The first section of the chapter contains microeconomic fundamentals of the cost minimising vessel. We discuss both the seasonal and long run adaptions as we attempt to model vessel specific behaviour. The initial discussion in section 5.1 is thus an extension of the framework presented in section 3.3.

In section 5.2, we discuss the choice of functional form and earlier work. We discuss advantages and limitations related to different approaches, including ours. The section also contains a discussion on when we expect a linear relationship between variable costs and output in the OLS estimation. In section 5.3, we estimate cost functions for the coastal vessels and the combined fleet of purse seiners and pelagic trawlers. We discuss findings and graph the predicted underlying relationships. Due to potential error of extrapolation, we only plot the estimated costs against the observed range of output. The chapter includes various discussions on the robustness of the chosen approach.

5.1 The cost minimising vessel – microeconomic fundamentals

In this section of the chapter, we discuss the microeconomic fundamentals of the cost minimising vessel. These fundamentals predict the shape of the variable cost function, and relate directly to the time perspective of the economic actors. With fishing seasons lasting one year, variable profits determine seasonal decisions. The rational seasonal behaviour of a vessel is therefore to optimise variable profits

$$\pi = pY - VC$$

where output, Y, is fixed and the output price, p, is exogenously given.[21] Any vessel minimising variable costs, VC, also maximises seasonal variable profits. This suggests utilisation of duality theory to find realised profits during a season.[22] The intertemporal

[21] In reality, vessels obtain different prices based e.g. on the quality of the output delivered. These quality differences result also in differences in the variable unit costs, because maintaining high quality of the output is costly. With an exogenous price, we do not control for such effects from differences in quality.

[22] See e.g. Cowell (2005) for a general introduction to duality theory.

investment decision maximises profits over several seasons. Rational actors therefore only remain in the fishery over time if also fixed costs are covered.[23]

The time perspective has different implications for the short and long-term decisions of the economic actors. It is a standard assumption in economic theory that capital is fixed in the short run. The vessel therefore has fixed capacity levels during a season. We control for between season effects in the estimation in section 5.3. This implies a need for predictions on the seasonal behaviour of a vessel. We also correct for vessel specific differences such as gear through a grouping within the fleets (see Table 4.1). The predicted unit cost curves should therefore resemble the long-run cost curve of a stylised vessel within a group when capital is variable.

Fixed capacity poses a restriction on the maximum output a vessel could technically produce during a season.[24] We may therefore have seasonal scale effects as vessels can gain by adjusting effort to the given capacity. To exemplify, vessels might have a high vessel quota combined with low levels of effort. With abundant capacity, an increase in effort could then give better utilisation of the vessel's economic capacity. The average variable unit costs then decrease when the capacity restriction is non-binding. When a vessel pushes the capacity constraint, i.e., effort relative to the quota is high, average variable unit costs increase. This implies a u-shaped unit cost curve with respect to effort. If output correlates with effort, u-shaped unit costs are expected. We illustrate such a relationship in Figure 5.1.

[23] Reference to intertemporal investment perspective. See chapter 2 for a brief discussion on economic capacity.

[24] The IVQ on the other hand functions as a legal boundary for output.

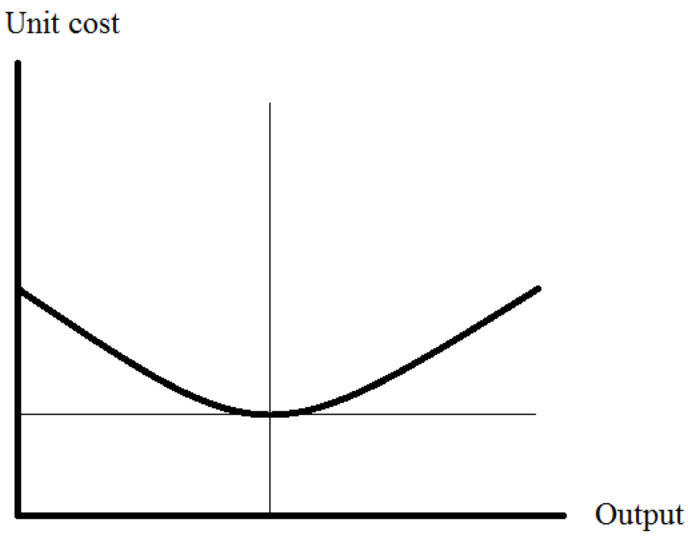

Figure 5.1 – The expected shape of the unit cost curve with respect to output of a species.

The effort on a species is unknown in our dataset. This complicates the estimation. We would thus prefer predictions explaining vessel behaviour on all species. A prediction on total effort and output of all species is included in Figure 5.2. This is a stylised example of the relationship between a vessel's effort and variable profit with an IVQ system. Understanding this predicted relationship is important, because it excludes the need for allocating effort pre-estimation. Both vessels in this example have quotas of the same size for species A, B and C. We note that species A yields the highest variable profit, and species C the lowest. Initially, we assume no differences in vessel or crew characteristics.

When output and prices are exogenous, the u-shaped unit cost curve explains the shape of the variable profit function. This shape relates to the variable set-up costs necessary to prepare the actual harvest process when fishing a species. Resource economics tells us that the fishing of a species is equivalent to an optimal rotation problem (Gordon, 2010). With output regulation, optimisation of this rotation occurs when costs are at a minimum. Holding biomass constant, an increase in the IVQ should increase the number of trips to and from the fishing grounds. If this increase is proportional to the quota increase, functional form linearity is a good approximation of fishing costs. An increase in the quota could however also lead to vessels staying longer on the fishing grounds. This is equivalent to an increase in the length of each trip. Such an adaption is possible if the vessel has available capacity in e.g. gross tonnage in the current optimal rotation, and leads to non-linearity in the cost curve.

The only variation in the stylised example is that the vessels differ in their cut-off point. Vessel 2 will thus participate in the fishery at a lower marginal variable profit than vessel 1. Two vessels only differing in the cut-off point supply different levels of effort. In the stylised example, vessel 1 expects a higher marginal return on the capital invested in the fishery. Thus, the vessel does not catch any part of the quota on species C. Willingness to take on risk may be one explanation for investors' differences in compensation expectancy. Differences in ownership might also have an effect. To exemplify, when the processing industry owns a vessel optimal seasonal effort is the result of a maximisation of variable profits from both the vessel and the industry's operations. This level of effort does not need to correspond with the optimisation of vessel profits alone. The presence of individual vessel effects, resulting in catches below the vessel quota, is well known and the main reason for overregulation through maximum quotas (see section 3.3). Our discussion implies that we should prefer methods of estimation not aggregating away vessel specific behaviour and preferences. The long-run cost curve fitted on the seasonal adaptations would then reveal the sum of individual decisions within a group. Note that the cut-off points could be non-horizontal if investors' expected marginal compensation increase/decrease with effort.

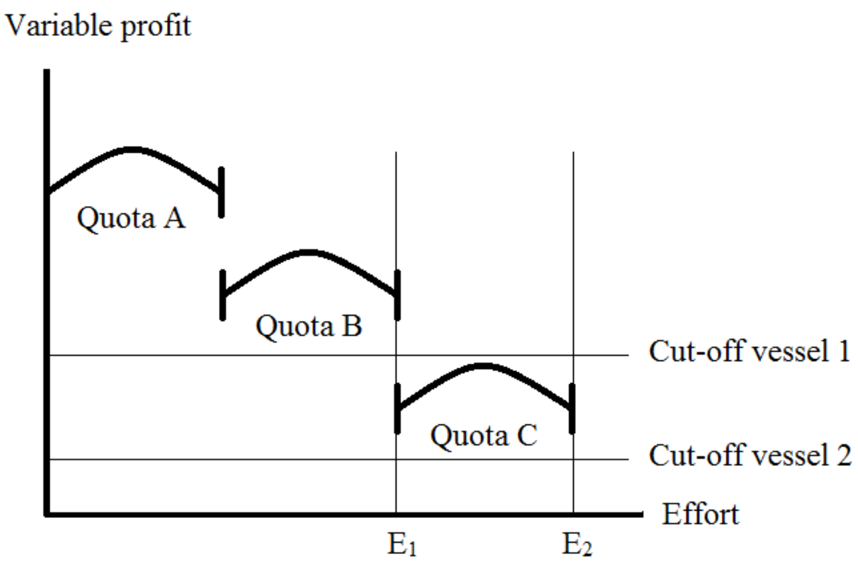

Figure 5.2 – Optimal effort given quotas and the variable profit cut-off point.

In the case of intertemporal profit maximisation, economic capacity varies along the transitional path. Yearly investment is a prerequisite to maintain this capacity if depreciation is present. When investment exceeds depreciation, the economic capacity increases. Utilising the stylised example in Figure 5.2, such a development indicates that the effort needed to catch the quota of a species decreases. If the two vessels install gear increasing the efficiency with respect to output of species A, quota A's total effect on effort shifts to the left. When effort drives costs, this implies that the unit cost of catching A falls. Such a trend was indicated using the development of operating days in section 4.4.

In Figure 5.3, we illustrate a stylised example of the theory on short and long run average cost curves in a fishery. Curves A, B and C represent the seasonal cost curves of an individual vessel at different levels of capacity. During a season, a vessel utilising capacity inefficiently can increase profits by taking advantage of the seasonal scale effects. As we explained above, the only way to take advantage of these effects is to adjust the level of effort to the exogenous output and fixed capacity. To exemplify, when the short run cost curve equals A, the vessel minimises average unit costs when effort equals E_A. Between seasons, the underlying cost structure follows curve D because capital is no longer fixed. Optimal investment in economic capacity implies short-term curve B. The optimal short-run level of effort E_B thus corresponds to the intersection between the optimal short-run average cost curve and the long-run average cost curve.

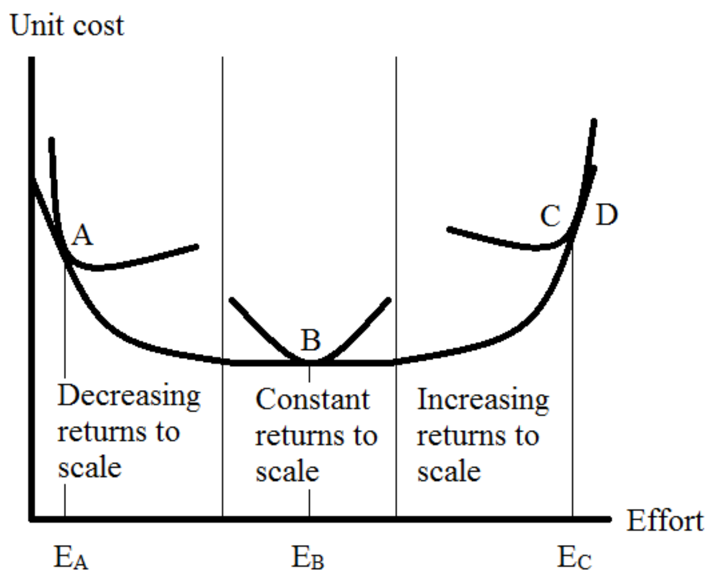

Figure 5.3 - The shape of the unit cost curve with respect to effort.

To what degree will the transitional path of investments lead to the short-run cost curve illustrated in curve B in Figure 5.3? This depends on the degree of information. With perfect information, economic actors know the size of all future quotas and thus also the required level of investments in each period. However, the implemented management system is likely one of the most important determinants of deviations from the transitional path. A regulator sets yearly quotas and vessels cannot freely adjust output to demand as in other industries. This further emphasises that vessels likely invest to minimise the quota-restricted effort. If quotas are of similar size each year, vessels might be able to solve this investment problem. However, quotas often vary substantially from year to year (see the distribution of seasonal catches for vessel groups in Appendix A). Situations of perfect information are thus far from applicable for actual outcomes in the fishery described in section 3.3. Predicted long-run cost curves would then be highly sensitive to the quotas distributed in the period utilised in the estimation. The above theories nevertheless give us a framework for the estimation of cost functions conducted in the next section.

5.2 Pre-estimation: Choice of functional form and earlier work

In this section, we estimate non-linear cost functions for the fleets of coastal vessels and purse seiners and pelagic trawlers. We incorporate the microeconomic fundamentals discussed in section 5.1. In the second half of the chapter, we discuss earlier work. This discussion takes Sandberg (2005) and Steinshamn (2005) as a point of departure. We again emphasise that we inflate all costs to 2014 NOK and regress on variable costs defined as the sum of variable and quasi-fixed costs.

5.2.1 Estimating a polynomial equation incorporating effort in output

Duality theory is applicable when output in a fishery is constrained. This implies that the profit maximising firm takes a cost minimisation approach (see sections 3.3 and 5.1). Generally, we are therefore looking for the total variable fishing costs of a firm

$$VC = f(W, Y, X, S)$$

where

$VC =$ Variable costs

$W =$ Prices of input factors

$Y =$ Output

$X =$ Biomass

$S =$ Skill of owner/skipper/crew and physical characteristics of vessel

Selection of an appropriate functional form depends on the predictions we want to estimate. In section 4.5, we find that the structure of the data is best suited for pooled cross sectional analysis. Treating the data as pooled cross sectional implies disregarding the intertemporal investment perspective of an individual vessel, and looking only at predictions of individual seasonal behaviour. It also suggests utilisation of OLS techniques. Taking into account the optimal rotation problem with respect to a species, a feasible approach could then be to estimate the polynomial form

$$VC_i = \alpha + \sum_{j=1}^{J}(\beta_{1,j} + \sum_{gr=1}^{GR} i_{j,gr})Y_{i,j} + \sum_{j=1}^{J}\beta_{2,j}Y_{i,j}^2 + \sum_{j=1}^{J}\beta_{3,j}Y_{i,j}^3 + \sum_{yr=2001}^{2014}\gamma_{yr}d_{yr}$$

where

$VC_i =$ Variable costs for vessel i = 1, 2, 3, …, N

$Y_{i,j} =$ Output of species j for vessel i = 1, 2, 3, …, N

$i_{j,gr} =$ Interaction term of species j and group gr = 9 and 11 or 13

$d_{yr} =$ Dummy for year yr = 2001, 2002, …, 2014

Output of a species is included with a first, second and third order term in the regression as we utilise total variable costs as the dependent variable. Such a functional form is sufficiently flexible to estimate/fit a u-shaped unit cost function. This specification therefore models the prediction of non-linearity with respect to the optimal rotation problem of each species as explained through Figure 5.2.

First-order interaction terms are included to allow for relative advantages between the vessel groups. As will become evident in section 5.3, this leads to a scaling of the groups' predicted cost functions. The shape of the underlying function remains the same for groups within a fleet. Including interaction terms for the higher order terms of output would allow for also a changing shape. Regressions including such terms do however become highly complex to solve. The main goal of this chapter is to estimate non-linear cost functions to reveal relative advantages between vessel groups. We also need an approach that we can use in an optimisation. A simplified approach with only first-order interaction terms should therefore be sufficient to highlight relative differences in the unit costs of different groups.

It is important to note the indirect link made between output and effort of a species. The above equation treats costs of species as additively separable. Output of each species therefore affects effort independently. This is not necessarily a good approximation. The seasons of different species overlap (Iversen et al., 2016, p. 146). Higher effort on one species therefore often results in a corresponding lower effort on another species. We do not know when a vessel targets different species. Furthermore, the optimal rotation problem differs according to the level of effort. Thus, the marginal effect on the overall effort remains unknown with our cost function specification.

As illustrated in section 4.4, the number of average operating days has fallen throughout the period 2000-2014. This indicates that the optimal rotation within a season occurs at relatively low level of efforts. Thus, it is likely that the fleet could increase average catches substantially before the costs increase at a faster rate than modelled through the third order terms on output. We should thus be able to utilise the framework of short and long run cost functions in Figure 5.3 on each of the included species. This implies that vessels adjust effort to a fixed capacity of a species within a season. Thus, the estimated variable cost function is the result of the optimal rotation problem with respect to each species for all vessels in a fleet. Note however that at sufficiently higher catches the trade-off between species would become increasingly important. We fail to model these effects with our specification.

Nøstbakken (2006) uses the generalised translog functional form in an examination of the cost structures amongst vessels participating in the Norwegian pelagic fisheries. This function enables estimation of the cross-price elasticities between species. Catches of different species are then included with a non-linear relationship in the total cost function. Choosing this function would yield a higher flexibility in the estimation process. While lack of cross-price elasticities is a limitation with the chosen functional form, we choose to accept it to simplify the estimation and optimisation processes.

In the practical estimation, we make two important simplifications. First, only species constituting at least 5% of the fleet's total catch are included. This eases the estimation process. From robustness analyses including species of small catch volumes, we find that these have little effect on the estimated results. These findings are consistent with the predictions in section 5.1. We believe changes in output of a species to correlate with changes in overall effort. Small volumes of catch should therefore not be significant drivers of effort and costs. Second, we pool catches of NSSH and NSH into a species group termed herring. These species likely have very similar cost structures and require similar levels of effort. Earlier work has utilised the same pooling (Nøstbakken, 2006). We also group cod and pollock caught north of the 62nd parallel. Catches of these two species happen in the same areas, and again likely have similar cost structures.

Modelling on a fleet with many vessels catching different levels of output of a species, the chosen OLS approach should be able to identify the predicted underlying cost structure. However, there are at least a few cases where the OLS approach might be unable to identify the possible u-shaped unit cost function. When the interval of the observations of catch volumes is small, predicted costs are likely to resemble a linear cost specification. This could for example be the case if most vessels have low or high overall effort. The steep slope of the u-shaped curve over these intervals would then lead OLS to fit a linear cost function.

Similarly, if the vast majority of observations centres around the bottom point of the unit cost function, OLS fits a horizontal line through this point. This second case is of particular interest. When quotas are relatively stable between seasons, vessels are likely able to adjust capacity to output. If most vessels choose this adjustment to a species, observations in the fleet likely centres around the part of the u-shaped unit cost function where costs are lowest. Oppositely, volatile quotas complicate adjustment of capacity over time. This case increases the chance of finding a u-shaped predicted unit cost curve due to inefficient levels of capacity measured against the long-run cost curve.

In a case where we only have a few unevenly distributed observations, the least squares could result in a linear cost specification. This should not be a particular issue in our estimation, as we have a high number of observations for all included species. Finally, if most observations are zero for a given species, we likely fail to estimate the cost structure of vessels catching the species. Including interaction terms for vessels with positive catch of the species could solve this problem. Robustness analyses utilising this approach did however add little insight to the modelling. None of the above cases imply that the actual cost function of a vessel could not be u-shaped, but rather that the structure of the data combined with the chosen econometric technique fail to identify such a relationship.

As we want to utilise pooled cross sectional analysis, we need to correct for possible time effects in the dataset. In the above equation, we have included year dummies to exclude effects related to time trends such as variations in biomass, real input prices, policy changes and technology. In addition, these dummies correct for pure differences in the number of observations between years. This correction is important as we regress on total variable costs.

We also correct for other differences within a fleet through the correction of group effects. For the coastal vessels, we include group 10 as the base case, and interaction terms for group 9 and 10. Group 12 is the base case in the estimation on purse seiners and pelagic trawlers. We include interactions terms for group 13. Vessels within a group e.g. utilise similar gear. Group corrections are therefore important if we are to graph the relative differences in the long-run underlying cost curve when capital is flexible.

5.2.2 Earlier work

Earlier work has taken different approaches to the selection of functional form. The simplest, using a linear relationship, defines the variable unit costs

$$C_{i,j} = f_{i,j} VC_{i,j}$$

where $f_{i,j}$ is a time/catch relation for species *i* and group *j*, and $VC_{i,j}$ the variable costs for species *i* and group *j*.[25] The time/catch relation corresponds to the vessel specific effort on a species discussed in section 5.1. This measure is unknown in our dataset. Thus, utilising this approach necessitates allocating variable cost to the output of different species pre-estimation. There are several techniques for doing this. One approach would e.g. be to utilise the share of catch quantity of a species to total quantity (Steinshamn, 2005). This reduces the

[25] See e.g. Steinshamn (2005) and Grimsrud et al. (2015).

flexibility of the estimation technique. Furthermore, the above equation does not allow for non-linearity with respect to output of a species.

We argued in the last part of the previous section that the translog function yields a flexible functional form. However, to simplify the estimation and optimisation processes we would like to explore other possible candidates for a non-linear cost function. Sandberg (2005) approximates the unit costs in a pelagic fishery using a multiplicative non-linear cost function. This function allows for non-linear effects in output and biomass. As we want to allow for non-linearity in accordance with the discussion in section 5.1, this makes such a functional form more appealing than the above linear specification. Sandberg assumes that fishermen are price takers in the input market and that real prices in these input markets are constant. The specification yields the variable cost function

$$C_{i,y} = \alpha Y_{i,y}^{\beta_1} X_y^{\beta_2} S_i^{\beta_3} \varepsilon_{i,y}$$

where

$C_{i,y}$ = Variable costs for vessel *i* in year *y*.

$Y_{i,y}$ = Catch for vessel *i* in year *y*.

X_y = Biomass in year *y*.

S_i = Skill of owner/skipper/crew and physical characteristics of the vessel.

$\varepsilon_{i,y}$ = Lognormally distributed error term

Sandberg divides the function by $Y_{i,y}$ to find the unit cost of a fishery, yielding

$$C_{i,y}/Y_{i,y} = \alpha Y_{i,y}^{\beta_1 - 1} X_y^{\beta_2} S_i^{\beta_3} \varepsilon_{i,y}$$

Which we can rewrite

$$\widehat{C_{i,y}} = \alpha Y_{i,y}^{\widetilde{\beta_1}} X_y^{\beta_2} S_i^{\beta_3} \varepsilon_{i,y}$$

The coefficients $\widehat{\beta_1}, \beta_2$ and β_3 yield the elasticity of cost with respect to output, biomass and skill respectively. The use of a dummy technique removes the unobserved (fixed) effect of the S parameter.

Compared to the approach described in section 5.2.1, this functional form specification has at least two advantages. First, the above approach models the effects of biomass explicitly. Sandberg (2005) utilises the results in Bjørndal (1987, 1988) that there is no, or only a weak, relationship between stock size and catch per unit effort (CPUE). When a species concentrates in schools, it is not uniformly distributed over the fishing grounds. Thus, the total stock size need not affect vessel costs when targeting a school of fish, as long as the vessel is able to locate the school. This is important when modelling pelagic species, as we might have a biomass effect if stock size affects the target time.

Year dummies remove all biomass effects in our estimation. These dummies do however also correct for other between season effects. Thus, we are unable to correct explicitly for possible biomass effects. However, there are two reasons why we should be able to accept this limitation. If the findings in Bjørndal (1987, 1988) hold true for our dataset, changes in stock size should not affect catch per unit effort much. Thus, correcting for stock level variations between seasons using a dummy technique should be a sufficient approach.

The second advantage relates to the utilisation of a (fixed) effect approach to remove the unobserved S parameter. Through this approach, Sandberg removes vessel specific characteristics and effects such as skill of the owner/skipper/crew. As argued in section 4.5, we do not deem our dataset fit for panel data techniques. While we include corrective measures with respect to the physical characteristics of a vessel, our approach leaves the unobserved skill effect in the residual.

When attempting to estimate the above function, we discovered one drawback making us discard this approach as feasible for our study. Sandberg (2005) estimates cost functions of a single species. As we have data of total variable costs per vessel, and all vessels catch several species, we would have to allocate variable costs pre-estimation to be able to conduct single species estimations. This necessitates techniques such as a time/catch parameter, described in relation to the linear modelling approach above. Such an initial allocation would be an important determinant of any underlying relationship.

In the discussion in section 5.2.1, we highlighted that we would like to analyse a cost function including different species as additively separable to incorporate effects of overall effort. An advantage of this approach is therefore that we do not need to allocate variable costs to the output of a species pre-estimation. In addition, we can explicitly examine the structure of the underlying relationship between variable costs and output. We do not impose non-linearity, which could happen with a multiplicative approach. The discussion in this section indicates that our approach fits well to the predictions of seasonal behaviour that we want to study, while at the same time simplifying the estimation as compared to the utilisation of a translog function.

5.3 Estimation of cost functions

In this section, we present the results of the cost function estimation for the two fleets. We conduct estimations based on the functional form specification presented in section 5.2.1. This is a polynomial form, allowing us to explore the relationship of variable costs and output. For each of the two fleet, we provide tables of regression outputs and graphs of underlying relationships.

5.3.1 Cost function and structures: Coastal vessels

The fleet of coastal vessels consists of 1 005 observations, and has vessels from vessel groups 9-11. Our selection criteria results in the inclusion of four species in the regression. These species are herring (NSSH and NSH, 63% of the fleet's catch), cod and pollock caught north of the 62nd parallel (N62, 18% of the catch), mackerel (9% of the catch) and capelin (5% of the catch). These four species total 95% of the fleet's catches. Group 10 constitutes the base case as the majority of vessels belongs to this group. Year 2000 is the omitted year dummy. We present in Table 5.1 the regression output on the equation.

Table 5.1 – Parameter estimates of output (in kilos), dummies and interaction terms for the coastal vessels. Variable costs defined as operating and quasi-fixed costs (NOK).

Variable cost driver	Coefficient	Std. Err.	T-value	P>t	95% Conf. Interval	
Herring	4.256023	.2540059	16.76	0.000	3.75756	4.754485
Herring^2	-5.69e-07	1.11e-07	-5.11	0.000	-7.87e-07	-3.50e-07
Herring^3	2.97e-14	1.30e-14	2.28	0.023	4.11e-15	5.53e-14
Mackerel	3.177423	.3504863	9.07	0.000	2.489627	3.865219
Capelin	.8413203	.7258351	1.16	0.247	-.5830621	2.265703
Capelin^2	-9.88e-07	7.68e-07	-1.29	0.199	-2.49e-06	5.20e-07
Capelin^3	3.13e-13	1.69e-13	1.85	0.065	-1.89e-14	6.45e-13
Cod and pollock N62	3.960232	.3542128	11.18	0.000	3.265123	4.655341
Cod and pollock N62^2	-8.77e-07	2.46e-07	-3.56	0.000	-1.36e-06	-3.94e-07
Cod and pollock N62^3	9.15e-14	3.91e-14	2.34	0.019	1.48e-14	1.68e-13
Group 9 herring	-1.91956	1.889789	-1.02	0.310	-5.628091	1.788971
Group 9 mackerel	4.223031	4.69755	0.90	0.369	-4.995465	13.44153
Group 9 capelin	0	(omitted)				
Group 9 cod and pollock N62	-4.231981	7.030338	-0.60	0.547	-18.02835	9.564389
Group 11 herring	-.2468805	.1109787	-2.22	0.026	-.4646656	-.0290953
Group 11 mackerel	1.875277	.4451545	4.21	0.000	1.001703	2.74885
Group 11 capelin	1.546586	.7607654	2.03	0.042	.0536558	3.039515
Group 11 cod and pollock N62	.1204922	.2258229	0.53	0.594	-.3226637	.5636482
Dummy 2001	2307397	302942.7	7.62	0.000	1712901	2901893
Dummy 2002	2378701	299268	7.95	0.000	1791416	2965986
Dummy 2003	1644389	303612.4	5.42	0.000	1048578	2240199

Dummy 2004	1984395	276837.8	7.17	0.000	1441127	2527663
Dummy 2005	2977448	273994.1	10.87	0.000	2439760	3515135
Dummy 2006	2325923	289785.5	8.03	0.000	1757247	2894600
Dummy 2007	1914125	320906.1	5.96	0.000	1284377	2543873
Dummy 2008	2191220	321328.3	6.82	0.000	1560644	2821797
Dummy 2009	882090.7	342428.2	2.58	0.010	210107.8	1554074
Dummy 2010	836512.7	325304.7	2.57	0.010	198133.1	1474892
Dummy 2011	3780737	313348.5	12.07	0.000	3165820	4395653
Dummy 2012	4497079	305428.5	14.72	0.000	3897704	5096453
Dummy 2013	3437399	324400.7	10.60	0.000	2800794	4074005
Dummy 2014	3181208	369519.1	8.61	0.000	2456061	3906354
Alpha (constant)	-2118181	271395.9	-7.80	0.000	-2650770	-1585593
Number of observations: 1 005			SS model: 6.3447e+14			
Adjusted R-squared: 0.8951			SS residual: 2.2877e+12			

The explanatory power of this estimation, measured as the adjusted R-squared, is 0.8951. Thus, the final estimated equation explains almost 90% of variations in variable costs for the coastal vessels. Plots of predicted variable unit costs with respect to output, illustrated in Figures 5.5-5.8, indicate that we are able to identify the possible u-shaped unit cost structure discussed in section 5.1 for several of the included species.[26] All base case first order terms are significant, with the exception of capelin. Testing a regression with variable costs defined only as operating costs does not give large variations in coefficients or significance, but a slightly higher R-squared. This is not surprising as vessels probably treat a portion of the quasi-fixed costs as fixed during a season. The regression omits the interaction term for group 9 catching capelin, as the group reports no catches for this species in the period.

[26] In Appendix B, we include the predicted structure of the variable cost curve for species where we include higher order terms.

We argued in section 5.1 that plots of the individual vessels' cost curves could resemble the long-run cost curve of the vessel group when capacity is variable. This implies that each vessel minimises the optimal rotation with respect to a species within a season. In the case of herring, Figure 5.5 indicates that we are able to identify the possibly u-shaped long-run unit cost curve. With exogenous prices and a sufficiently increased quota, these results suggest that a vessel maximising variable profit could invest along the transitional path to obtain the lowest possible unit cost within its group.

There are several reasons why this adjustment will not necessarily maximise the profit of the individual vessel. Different vessels land herring used for different purposes. Catches of herring sold to plants producing for the consumer market typically achieve higher prices than herring sold to plants producing fish meal and oil. It is likely that this also results in an expectancy of higher quality in catches going to human consumption. While we do not model price effects, the estimation treats cost effects endogenously because quality is costly to achieve. Thus, the plot of herring does not enable us to determine whether vessels actually want to invest according to the indicated transitional path of the long-run unit cost curves.

We could likely make similar arguments regarding the output of mackerel and cod and pollock (N62). However, there are indications that in the main season the processing industry differentiates little on price with respect to quality (Sogn-Grundvåg & Henriksen, 2011). The processing industry is an important recipient of cod and pollock. With the coastal vessels landing over 80% of all cod between January and April, increasing the quality of the output to increase the obtained price should not be a major determinant of fleet behaviour. Other effects should therefore better explain potential deviations from the transitional path for species such as cod and pollock. We argued in section 5.1 that the implemented IVQ system explains why vessels cannot adjust freely according to the transitional path. A stability requirement disallows the cod quota to vary more than 10% from year to year. This could potentially ease the investment decision.

However, the quotas can be and have changed over time. As illustrated in Appendix A, observations on landings from the groups belonging to the coastal vessels have varied substantially between years. Furthermore, these show no clear trends. In section 5.1, we argued that varying quotas might make it difficult to invest in the capacity minimising the variable costs required to catch the quota. Thus, while the estimated cost functions could be correct for the period of which we are concerned, it is not certain that these provide good guidance going forward. With different quotas during the period, re-estimated long-term cost curves would likely differ. This argument is also important with respect to relative advantages between groups.

Several interaction terms are significant, and give clear differences within the fleet. Group 10 e.g. catch both mackerel and capelin at the lowest unit costs of the three groups. The cost of conducting fishing on herring and cod and pollock is almost identical between groups 10 and 11. Landings of these two species are of similar size as a relative share of the vessel groups catches.

There are in particular differences between group 9 and groups 10 and 11. This is not surprising. We expect unit costs to vary between e.g. small coastal vessels using seine and purse seiners without concession. Group 9 have for example the highest unit costs with respect to mackerel. This seems consistent if there is non-linearity with respect to output. The group only have 1% of the fleet's catches of mackerel, and should therefore use less efficient gear than the other two groups.

Certain results do however indicate that we have effects that are not properly corrected for in the model. If group 9 catch sufficiently high volumes of herring, the unit cost shifts sign and becomes negative. Catches of such volumes are unrealistic, even if the group is given time to invest in additional capacity. The group catch 0.4% of the fleet's total herring catch, and have an average actual length of only 10.4 meters. Thus, it seems unlikely that these vessels should be much more efficient than the other groups of coastal vessels. The optimisation conducted by Grimsrud et al. (2015) did not allocate any herring catches to this group. We thus consider it a sufficient modification to restrict the group's herring catch in the optimisation conducted in chapter 6.

A similar argument can be made with respect to the results of cod and pollock (N62) for group 9. The unit cost is negative for all levels of output, but the group's catch of cod and pollock constitutes only 0.2% of the fleet's total catches. Again, we argue that it is unrealistic to redistribute large catch shares to this group. In the optimisation, we disallow any catches of cod and pollock for group 9.

Output of mackerel is included only with a linear specifiation in the final model. This group only constitutes small volumes of catch for the coastal vessels. Thus, the OLS estimation likely fits this relationship as a result of the interval being small. The small catch levels make us accept this modification, as it should have little effect on the insights of the optimisation.

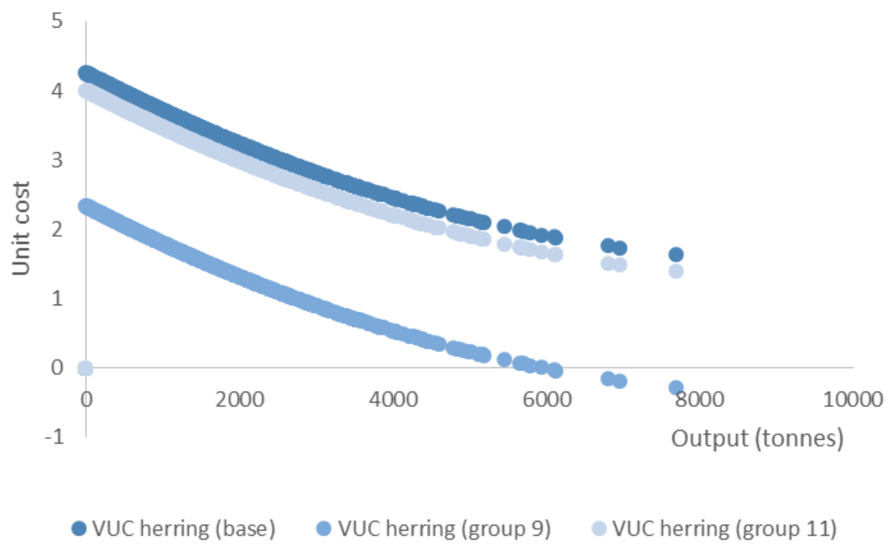

Figure 5.5 – The predicted variable unit cost of herring for the three groups, coastal vessels (2000-2014).

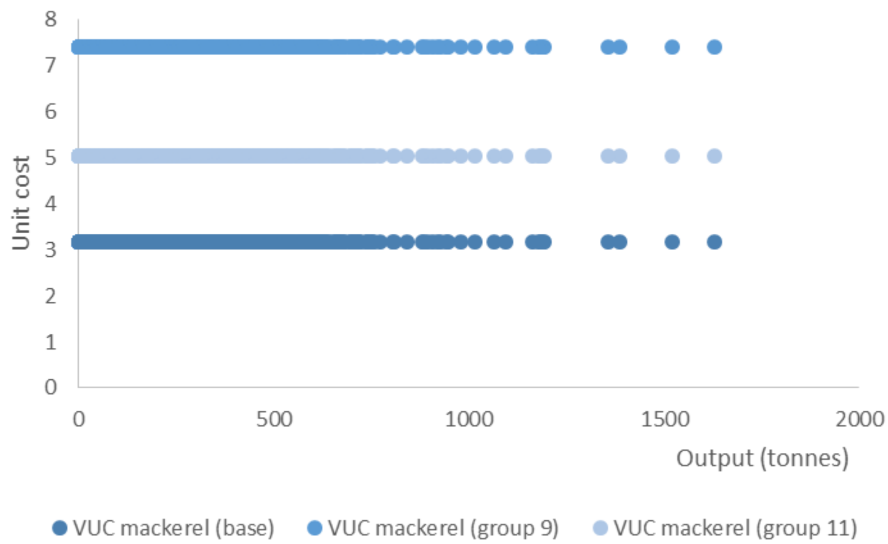

Figure 5.6 – The predicted variable unit cost of mackerel for the three groups, coastal vessels (2000-2014).

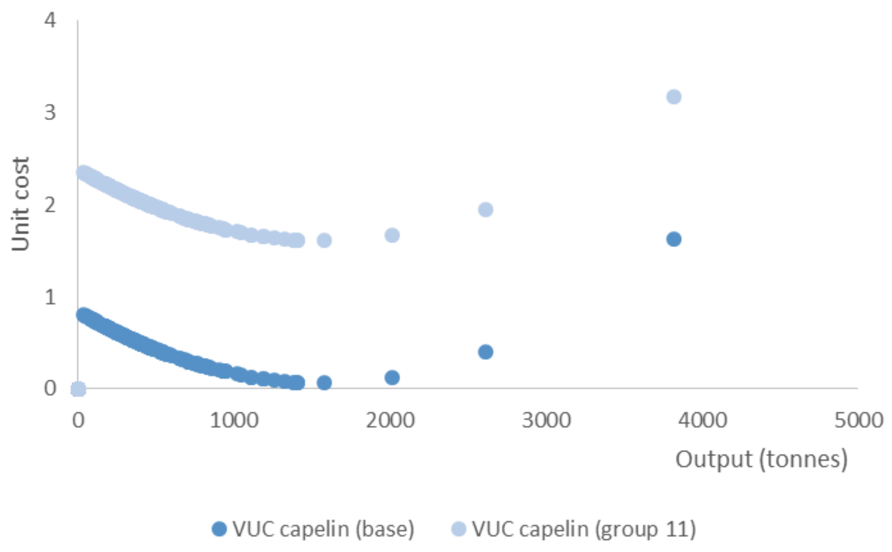

Figure 5.7 – The predicted variable unit cost of capelin for the three groups, coastal vessels (2000-2014).

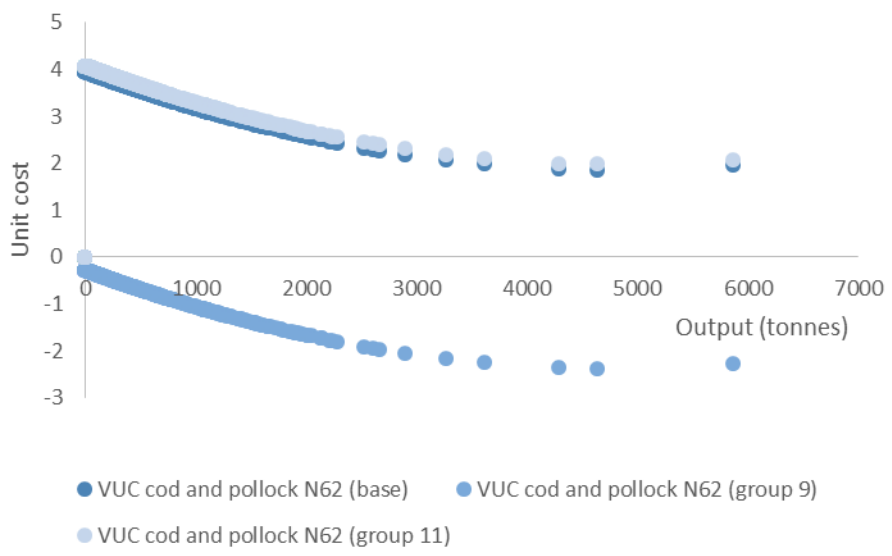

Figure 5.8 – The predicted variable unit cost of cod and pollock (N62) for the three groups, coastal vessels (2000-2014).

5.3.2 Cost function and structures: Purse seiners and pelagic trawlers

The combined fleet of purse seiners and pelagic trawlers consists of 1 279 observations. These correspond to vessel group 12 and 13 respectively. Our selection criteria results in the inclusion of four species in the regression. These species are herring (NSSH and NSH, 33% of the catch), blue whiting (35% of the catch), capelin (14% of the catch) and mackerel (9% of the catch). These four species total 92% of the fleet's catches. A majority of vessels belongs to the purse seiners (1 013). We thus selected a year 2000 purse seine vessel as a base case. Presented in Table 5.2 is the final regression output.

Table 5.2 – Parameter estimates of output (in kilos), dummies and interaction terms for the purse seiners and pelagic trawlers. Variable costs defined as operating and quasi-fixed costs (NOK).

Variable cost driver	Coefficient	Std. Err.	T-value	P>t	95% Conf. Interval	
Herring	2.333356	.1582596	14.74	0.000	2.022873	2.643839
Mackerel	4.271245	.4162642	10.26	0.000	3.454593	5.087898
Blue whiting	1.538926	.1621306	9.49	0.000	1.220848	1.857003
Blue whiting^2	-1.26e-07	2.00e-08	-6.31	0.000	-1.65e-07	-8.69e-08
Blue whiting^3	3.47e-15	6.22e-16	5.58	0.000	2.25e-15	4.69e-15
Capelin	.9242172	.5940761	1.56	0.120	-.2412773	2.089712
Capelin^2	-1.93e-07	1.96e-07	-0.99	0.325	-5.77e-07	1.91e-07
Capelin^3	2.05e-14	1.87e-14	1.09	0.274	-1.63e-14	5.73e-14
Group 13 herring	-.3382932	.2257046	-1.50	0.134	-.7810942	.1045078
Group 13 mackerel	.8985898	2.150403	0.42	0.676	-3.3202	5.11738
Group 13 capelin	.1755783	.6119619	0.29	0.774	-1.025006	1.376162
Group 13 blue whiting	-.1420015	.1428625	-0.99	0.320	-.4222777	.1382748
Dummy 2001	5973666	702832.4	8.50	0.000	4594807	7352525
Dummy 2002	6084311	701691.9	8.67	0.000	4707689	7460933
Dummy 2003	2963194	695989.9	4.26	0.000	1597759	4328629
Dummy 2004	4819190	805711.1	5.98	0.000	3238497	6399883
Dummy 2005	6353647	782180.9	8.12	0.000	4819117	7888177
Dummy 2006	4929808	891275.9	5.53	0.000	3181249	6678367
Dummy 2007	3597611	910370.4	3.95	0.000	1811591	5383631
Dummy 2008	3926333	992636.4	3.96	0.000	1978919	5873747

Dummy 2009	3838896	885763.5	4.33	0.000	2101151	5576640
Dummy 2010	5997542	811831.3	7.39	0.000	4404842	7590241
Dummy 2011	1.60e+07	792442.7	20.21	0.000	1.45e+07	1.76e+07
Dummy 2012	1.16e+07	786806.9	14.80	0.000	1.01e+07	1.32e+07
Dummy 2013	1.06e+07	815645.6	13.01	0.000	9009841	1.22e+07
Dummy 2014	8202994	1146551	7.15	0.000	5953621	1.05e+07
Alpha (constant)	-1611055	682527.6	-2.36	0.018	-2950079	-272031
Number of observations: 1 279			SS model: 4.5057e+15			
Adjusted R-squared: 0.8065			SS residual: 2.1890e+13			

The explanatory power of the estimation, measured as the adjusted R-squared, is 0.8065. Thus, the final estimated equation explains more than 80% of variations in variable costs for the combined fleet of purse seiners and pelagic trawlers. However, our model specification explains about 10% less of the variations in variable costs as compared to the estimated cost function for the coastal vessels. Plots of predicted variable costs with respect to output, illustrated in Figures 5.9-5.12, indicate that we are able to identify the possible u-shaped unit cost structure discussed in section 5.1 for two of the four incldued species. These two are blue whiting and capelin. Of these, only blue whiting has significant ouput terms.

We find no significant interaction terms for pelagic trawlers in the initial regression equation. This is not particularly surprising as we expect the two fleets to utilise the same type of gear and technology. The initial regression gave inconsistent results with respect to the predicted relationship between variable costs and output of herring and mackerel. Regressions with only a linear specification of variable costs in these species yield significant coefficients without large variations in the explanatory power of the model. This indicates that this might be a feasible way to modify the initial equation.

Cases where OLS fails to identify the u-shaped unit cost structure due to small volumes or few observations seem not to explain a linear specification with respect to herring or mackerel. The fleet have well distributed volumes of the herring catch and the species constitutes a large share of the fleet's total catches. While the share of the total catch is lower for mackerel, catches are again well distributed. Theory on the optimal rotation problem during a season indicates that a linear specification could exist when an increase in IVQs only leads to an increased number of trips. A possible explanation for these findings could be that vessels already utilise their maximum catch capacity for such species during a trip. The decline in operating days, discussed in section 4.4, might indicate that vessels have become better at exploiting the full capacity of each trip.

We are modelling over the period 2000-2014. The long-term investment perspective discussed in section 5.1 might help explain the linear variable cost specification if quotas have remained relatively stable throughout the period. We have illustrated landings of all species included in the estimation in Appendix A. These landings vary substantially between years. However, group 12 seems to have relatively stable landings of herring and mackerel. Nofima (2013) confirms this in a plot of purse seiners' landings in the period 2005-2011. Thus, it is possible that investors can easier adjust capacity over time to minimise effort and utilise the full per trip capacity of these species. As a comparison, purse seiners' landings of blue whiting have experienced large seasonal variations in the period. This prediction therefore seems consistent with the expectance of linearity in an OLS estimation, discussed in section 5.2.

The above findings are worrisome with respect to group 13. This group does not show the same stability in landings of any species. Thus, the possibility exists that we have imposed a linear specification on this group even when we should not. Robustness analysis including higher order interaction terms for group 13 does however not give consistent results. This leads us to accept the linear specification for both groups in the fleet.

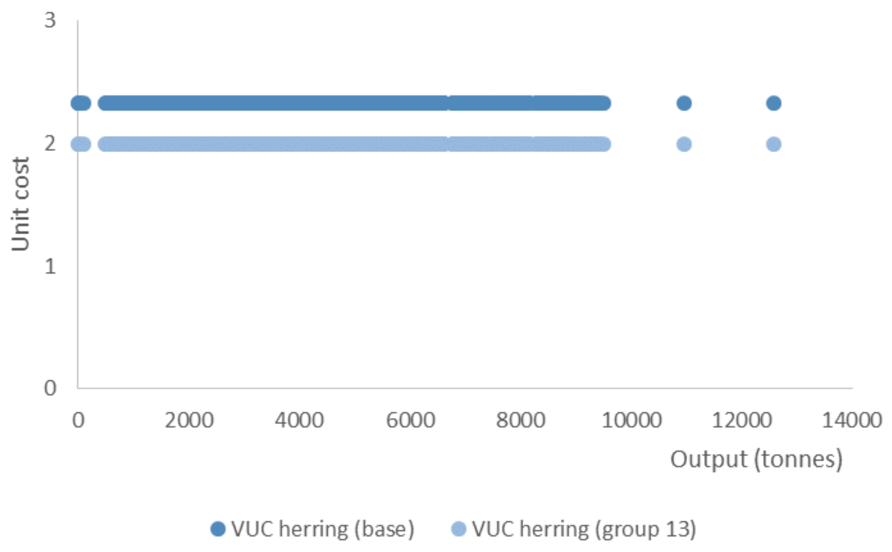

Figure 5.9 – The predicted variable unit cost of herring for the two groups, purse seiners and pelagic trawlers (2000-2014).

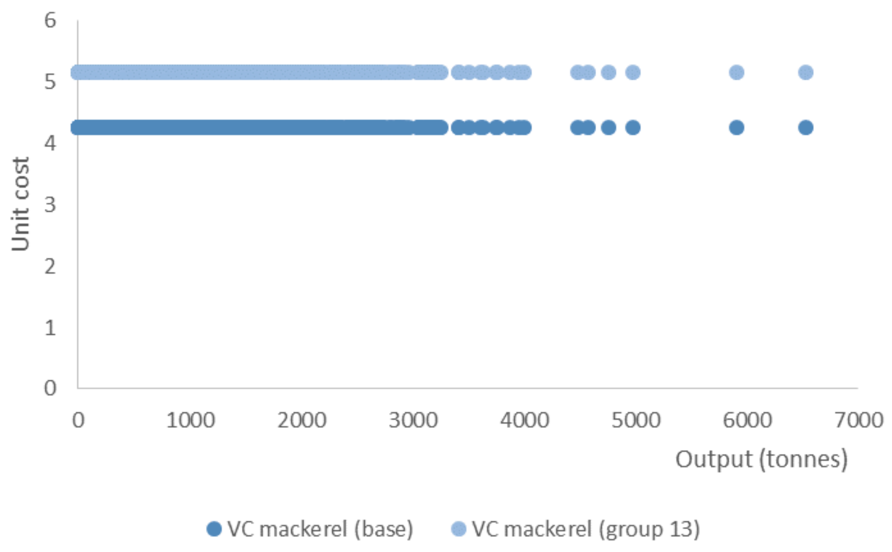

Figure 5.10 – The predicted variable unit cost of mackerel for the two groups, purse seiners and pelagic trawlers (2000-2014).

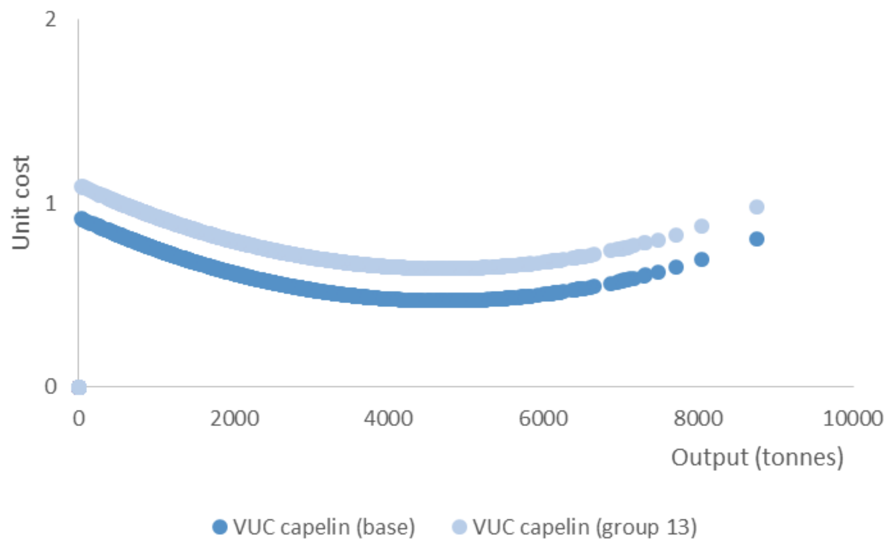

Figure 5.11 – The predicted variable unit cost of capelin for the two groups, purse seiners and pelagic trawlers (2000-2014).

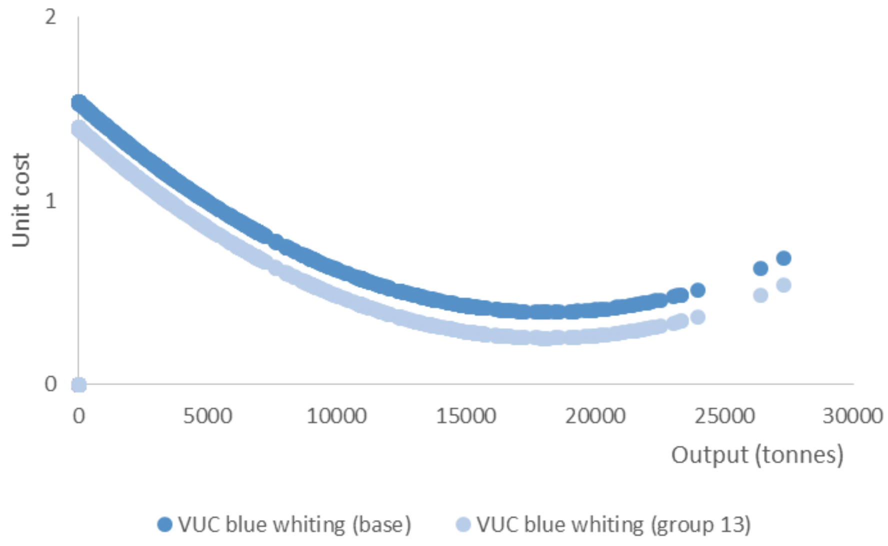

Figure 5.12 – The predicted variable unit cost of blue whiting for the two groups, purse seiners and pelagic trawlers (2000-2014).

5.4 Sub-conclusion: estimation

In this chapter, we estimate cost functions for the coastal vessels and the combined fleet of purse seiners and pelagic trawlers. We estimate on a polynomial function, through the utilisation of OLS techniques. Predicted underlying relationships between output and variable costs are included in Figures 5.5-5.12.

We argue in section 5.1 that the predicted plots of individual vessels form a long-run cost curve, i.e., a description of costs when capital is flexible. During a season, capital is fixed. Rational actors therefore minimise costs by adjusting effort. This is equivalent to an optimal rotation problem. It explains non-linearity in the cost function when an increase in the IVQ leads to a less than proportional increase in the number of trips. Over time, the economic actors adjust capacity to the expected level of the quota. We illustrate this relationship of short and long run cost curves in Figure 5.3.

The econometric approach reveals the predicted long-run cost curve for several of the species included in the estimation. For the coastal vessels, these are herring, mackerel, capelin and cod and pollock (N62). In the combined fleet of purse seiners and pelagic trawlers, we find a non-linear specification of costs for blue whiting and capelin.

The predicted shape of the cost function for mackerel caught by coastal vessels end up being included with a linear specification. This species constitute only small volumes of output for the fleet. OLS could therefore fit this relationship due to the small interval of observations. The case indicates that mackerel is of small importance for the coastal vessels, and thus makes it unlikely that the fleet has any major cost advantages. We should therefore not miss important information in the optimisation when using a linear term.

For purse seiners and pelagic trawlers, we identify a linear specification of the cost function for the species herring and mackerel. In contrast with the coastal vessels, the fleet has well distributed volumes of catch for both of these species. If most vessels have adjusted economic capacity and effort around the bottom of the unit cost curve, OLS could fit a constant relationship of output and variable unit costs. The stability of the quotas over time possibly indicates that the economic actors have been able to adjust effectively the economic capacity along the transitional path. Keeping the linear specification should then not affect the fundamental insights from the optimisation, because unit costs in the fleet should be close to the lowest achievable in the period. As a comparison, blue whiting has experienced substantial variations in landings over time. Subsequently, this species shows the predicted u-shaped unit cost curve.

We have simplified the relative advantages between fleets by only including first order interaction terms. While this scale vessel groups' differences in the unit costs, we are unable to identify possible differences in the location of the bottom point with respect to output. While this approach should be sufficient to enable optimisation of catches between groups, further work could develop the framework through the inclusion of higher order interaction terms.

6. Optimisation

In this chapter, we utilise the estimated cost functions in a non-linear optimisation problem. We try to identify whether redistribution of catches could result in gains in terms of reduced variable costs among the vessels. Section 6.1 presents a variable cost minimising problem using the linear programming model introduced by Steinshamn (2005) as a point of departure. We then present the results from the optimisation. The analyses in this chapter are an extension to the discussion on cost structures in the Norwegian pelagic fisheries.

6.1 The model

The purpose of running the optimisation problem is to identify potential reductions in total variable costs in the pelagic fisheries (2000-2014). We constrain the individual vessel's allowed catch levels of the included species and impose that the aggregate total catch of the species must equal the actual total catch of the species in the period. Not imposing such a constraint would result in the vessels catching as little as possible in a pure cost minimisation problem. In Table 6.1, we show the total quantities caught of the species in the period. We allow for the number of vessels to differ from the true number of vessels in the period, both in aggregate terms and within each vessel group.

We optimise based on the generalised vessel behaviour and characteristics for each of the vessel groups. This implies that we assume that the modelled vessels in a vessel group have the exact same cost structure. The estimation of the variable cost functions in chapter 5 utilise all variation in the data to predict the costs of each of the vessel groups.

The period from 2000-2014 is treated as one season (see section 4.5). The consequence of optimising for the period as a whole is that all numbers reported in this chapter regarding total variable costs accumulates over the entire period. The inclusion of year dummies in the estimated cost equations remove for between season effects such as changes in biomass. In the optimisation problem, we ignore politically determined catch distributions in the period. We introduce the decision variable N in the optimisation problem, defined as the number of vessels. Due to the treatment of the data, this measure coincides with the number of observations.

The model minimises total variable costs, TVC, given the aggregate total catch for each species *i* for the period as a whole, TAC_i . We also include catch capacity per vessel in group *j*, in terms of total allowable catch for each species *i*, $\overline{Y_{i,j}}$. The problem then solves for the optimal number of vessels in each vessel group N_j , and the total catch of species *i* for each vessel in vessel group *j*, $Y_{i,j}$. We specify the model as

$$TVC = \min_{Y_i, N_j} \sum_{j=1}^{J} VC_j * N_j$$

subject to

$Y_{i,j} \leq \overline{Y_{i,j}}$ for all *i* and *j*

$\sum_{j=1}^{J} N_j * Y_{i,j} = TAC_i$ for all *i*.

$N_j \geq 0$, $Y_{i,j} \geq 0$

VC_j is the estimated variable cost function for vessel group *j* when the interaction terms are utilised.[27]

Generally, one should be careful about predicting how total variable costs will behave outside the observed range of quantities caught of the different species. Extrapolation beyond the range of the data might lead to erroneous outcomes and dubious results. This motivates the first constraint in the model above. $\overline{Y_{i,j}}$ equals the maximum quantity caught of species *i* of a vessel in the dataset, unless otherwise specified. In Table 6.1, we show these quantities together with the aggregate total catch of the different species. Our optimisation problems do not allow for the quantity caught of a species *i* by a vessel in vessel group *j* to exceed the values presented here. The aggregate total catch of the different species must also

[27] We ignore the constant term and year dummies from the regression output in chapter 5 as we consider the period as a whole in the optimisation problem.

always equal the values presented in the rightmost column in the table below. N/A in the table means that the vessel group does not catch this species in our model.[28]

Table 6.1 – Maximum quantity caught of a species *i* and aggregate total catch. Catches in tonnes.

Species/Vessel group	9	10	11	12	13	Total catch
Herring	529	7 700	6 955	12 587	6 818	6 633 577
Mackerel	176	1 188	1 630	6 526	1 022	1 702 941
Capelin	0	740	3 821	8 754	2 208	2 405 469
Cod and pollock N62	213	5 871	3 619	N/A	N/A	393 907
Blue whiting	N/A	N/A	N/A	27 311	12 715	5 627 507

The cost structure for vessel group 9 of the species cod and pollock (N62) requires special treatment in the optimisation problem. As discussed in section 5.3, the estimated coefficients indicate that total variable costs are decreasing and negative if the vessels in this group increase catch of the above species within a certain interval. We treat this misspecification of the cost structure of cod and pollock for vessel group 9 by excluding this as a decision variable in the optimisation problem. We constrain the quantity caught to equal zero. The species group constitutes only a small share of these vessels catches. This constraint should therefore not be of any major concern.

6.2 Optimisation Results

In this section, we first establish a base case using predetermined decision variables in the total variable costs model. This is utilised to compare predicted total variable costs and actual total variable costs. We comment on the robustness of the model before we solve the cost minimisation problem as described in the previous section.

6.2.1 Base Case

For the base case, we use predetermined decision variables. $Y_{i,j}$ and N_j . Values of $Y_{i,j}$ are set to the average catch quantities of the species for the different vessel groups, while values

[28] See section 5.2 for a discussion on the selection criterion for species.

of N_j are set to equal the actual number of vessels in the period. We expect a deviation between the actual and predicted total variable costs. Actual total variable costs cover the sum of all variable costs generated by vessels in the dataset, while our model only predicts total variable costs generated by catching the most important species. Thus, the predicted total variable costs from the model should be less than actual total variable costs. Furthermore, approximating vessel's costs through any functional form will lead to deviations. In addition, there is a great degree of variations between vessels in the quantities caught of different species. In the table below, we show the values of the predetermined decision variables utilised to calculate the total variable costs in the base case.

Table 6.2 – Predetermined decision variables in the base case. Catches in tonnes.

Species/Vessel group	**9**	**10**	**11**	**12**	**13**
Herring	91	1 205	1 938	4 689	1 910
Mackerel	49	161	315	1 435	170
Capelin	0	31	294	2 140	474
Cod and pollock N62	17	348	550	N/A	N/A
Blue whiting	N/A	N/A	N/A	4 866	2 627
Actual number of vessels	56	639	310	1013	266

Table 6.3 – Actual and predicted total variable costs for the vessel groups. NOK in millions.

Vessel group	**9**	**10**	**11**	**12**	**13**
Actual total variable costs	56	4 185	3 286	29 741	3 378
Predicted total variable costs	32	3 941	3 119	23 574	2 137

The model predicts total variable costs of NOK 32.8 billion. The actual total variable costs in the period sum up to NOK 40.6 billion. With reference to the discussion above, the negative deviation is not surprising. Table 6.3 presents actual total variable costs and the predicted total variable costs from the base case for the vessel groups.

Predicted total variable costs are lower for each vessel group compared to the actual numbers. For the coastal vessels, we see that the deviations are relatively small for vessel group 10 and 11 as compared to vessel group 9. The species included in the model for the coastal vessels constitute about 96% of total catch for vessel group 10 and 11, and 85% for vessel group 9. Thus, these seem to be logical deviations between the actual and predicted total variable costs. The deviations for the purse seiners and the pelagic trawlers also seem logical. The species included in the model for the purse seiners and pelagic trawlers constitute 95% and 66%, respectively. The deviation between actual and predicted total variable costs in relative terms is higher for pelagic trawlers than for the purse seiners.

We can assess the robustness of the model through a comparison of the explanatory power of the two cost function estimations with the ratio of predicted total variable costs in the base case to the actual total variable costs. The estimated fleet cost function with the highest explanatory power should also result in the highest value of the cost ratio. We expect such a relationship due to this function being able to explain more of the variations in costs. The explanatory power of the estimated cost function for the coastal vessel fleet is about 0.90. The corresponding number for the purse seiners and the pelagic trawlers is 0.81. The ratio of predicted total variable costs to the actual total variable costs is 0.94 for the coastal vessels. For the purse seiners and pelagic trawlers this number is 0.78. The explanatory power and cost ratio in each fleet show only small deviations. These findings indicates a robust model.

6.2.2 Variable cost minimisation

Running the variable cost minimisation problem as specified in section 6.1, yields the following optimal solution[29]

Table 6.4 – Optimal solution to variable cost minimisation problem 1. Catches in tonnes.

Species/Vessel group	9	10	11	12	13
Herring	0	0	6 955	0	0
Mackerel	0	0	0	4 810	0
Capelin	0	0	0	6 795	0
Cod and pollock N62	0	0	413	0	0
Blue whiting	0	0	0	15 896	0
Number of vessels	0	0	954	354	0

[29] We use the GRG Nonlinear Solving method in Excel to solve the optimisation problem.

We find that the total variable costs in the period could have been reduced from NOK 32.8 billion (the base case) to NOK 22.3 billion if catches were redistributed among the vessels. Vessel group 11 catches all herring and cod and pollock, while vessel group 12 catches the remainder of the species included in the model. The number of vessels in vessel group 11 increases from 310 to 954, while the number of vessels in vessel group 12 decreases from 1013 to 354. No vessels from the other vessel groups participate in the fishery in the optimal solution.

In the cost function estimation, we find that vessel group 13 has a constant variable unit cost of NOK 2 per kg. herring. The coefficient of the first order term of herring equals 4 for vessel group 11. However, vessels in vessel group 11 have a u-shaped unit cost function for output of herring. When vessels in vessel group 11 increase the volumes caught, they achieve a lower variable unit cost. Thus, in the optimal solution, the variable unit cost for vessels in vessel group 11 when fishing herring is lower than for vessel group 13.

The total number of vessels in the pelagic fishery is reduced from 2 284 to 1 308. A reduction in the number of vessels of this magnitude would obviously have major repercussions. Even though the result indicates a potential reduction in total variable costs if fewer vessels caught higher volumes, this does not imply that this is the desired structure of the fleet. Regulators must always compare results such as these against other policy considerations and sectors. Furthermore, the considerable variations in landings of species between years might indicate that a diversified fleet is preferable. If economic efficiency implies utilisation of different gear, this would also point in the direction of maintaining a fleet consisting of several types of vessels. See for example (NOU 2016:26, 2016). The modelling results naturally build upon the assumption that all vessels could invest to achieve the unit costs of the most efficient vessel within the group.

We solve two additional cost minimisation problems, where we change the constraints to identify how these alterations affect the solution. In the first problem, we impose constraints on the minimum and maximum allowable number of vessels in each vessel group. The motivation for including such constraints is policy goals of maintaining different vessel types. We allow for a decrease/increase of 20% of the actual number of vessels in the vessel groups, and constrain the total number of vessels to be equal or less than the actual total number of vessels.

In the second problem, we alter the constraint on the decision variable $Y_{i,j}$. Rather than allowing $Y_{i,j}$ to equal the maximum quantity caught of species *i* of a vessel in the dataset, $Y_{i,j}$ cannot exceed two times the average quantity caught of a species. We report the optimal solutions to the problems in Appendix C.

Both optimisation problems yield higher total variable costs than the original cost minimisation problem. The total variable costs are reduced with about NOK 1 billion from the base case. The optimal solutions also find a reduction of vessels. Clearly, altering the constraints in such a manner removes a degree of freedom for the decision variables, resulting in a reduction in potential gains from redistributing catch. This highlights the costs of implementing policy constraints to achieve goals of e.g. social sustainability.

6.3 Sub-conclusion: discussion of methods and results

In this chapter, we optimise based on the estimated cost functions from chapter 5. We ignore both time and geographical dimensions in this analysis. The optimisation conducted is on the period as a whole and impose no constraints on the geographical location of the vessels. The analysis allows us to get an indication of the potential gains of a redistribution of the quantities caught of the most important species. We also find suggested reductions in the number of vessels, assuming that vessels within a group can achieve the unit costs of the group's most cost efficient vessel. Findings in section 6.2.1 indicate that the model is robust.

In the total variable cost minimisation problem, we use only estimated variable cost functions at the vessel group level. This approach disallows for between-vessel variations within vessel groups. Vessels in a vessel group thus have the exact same cost structure. While removing information on individual preferences, we are nevertheless able to utilise these functions to indicate the potential for increased efficiency in the fleet.

Our findings suggest an increase in efficiency with redistribution of catches. In the base case scenario, we find that group 11 (consisting of coastal vessels) should catch the entire quotas of herring and cod and pollock. Group 12, the purse seiners, catch the entire quotas of mackerel and capelin. The inclusion of higher order interaction terms in the estimation, as suggested in chapter 5, would likely nuance this picture.

7. Conclusion

In this thesis, we have studied cost structures in the Norwegian pelagic fisheries. The objective was to estimate non-linear cost functions for different vessel groups participating in an IVQ system, and to utilise these functions in an optimisation problem. This approach revealed the potential for redistributing the catch between fleets to achieve higher economic efficiency. We have used data from the profitability surveys conducted by the Norwegian Directorate of Fisheries in the period 2000-2014.

Vessels have a predicted non-linear shape due to the presence of set-up costs and scale effects. A vessel takes capacity as fixed during a season. The rational actor then minimises the effort required to catch the quota. This is an optimal rotation problem, inducing non-linearity between variable costs and output when an increasing IVQ leads to a less than proportional increase in the number of trips. Between seasons, the transitional path enables alteration of capacity. If there exists scale effects, this could incentivise actors to invest to reach the bottom point of the long-run unit cost curve.

Using an OLS approach, we estimated cost functions for the coastal vessels, purse seiners and pelagic trawlers. The inclusion of interaction terms enabled explicit modelling of differences between vessel groups. Plotting the sum of the predicted variable costs with respect to output, revealed the long-run cost curves for different vessel groups. We were able to reveal the predicted u-shaped unit cost function for output of several of the included species. However, the estimation technique lead to output of some species being included with a constant unit cost. Both estimations resulted in a linear specification of costs and output of mackerel. For the purse seiners and pelagic trawlers, this also included herring. We explained these findings using the structure of the data, and argued why acceptance of these should not result in loss of insights from the optimisation.

The conducted cost minimisation problem revealed a potential for reducing the number of vessels and redistributing the catch. We discussed the robustness of the estimated cost functions through establishing a base case, and concluded that the model yielded consistent results. Including additional constraints, such as a limitation on the change in the number of vessel within a group, gave reduced potential gains. The optimal case yielded variable costs of NOK 22.3 billion. This was a reduction of NOK 10.5 billion as compared to the base case.

Cases including additional constraints reduced the potential gains from redistributing catches substantially.

The solutions to the optimisation problem highlight the costs of implemented policies preserving non-economic considerations. As discussed in chapter 2, Norwegian fishery management rests upon three pillars of sustainability: economic, environmental and social. Thus, one must see our findings in conjunction with environmental and social considerations. We have highlighted the improvement of biomass in fisheries through management regimes limiting the access to participate. The current discussion is on the relative priorities between policies emphasizing the social and economic sustainability.

In our opinion, successful policies must enhance both these sustainability criteria if Norwegian fishery management is to succeed in the future. Norway is a high-cost country, and a large net exporter of fish. This implies strong requirements on productivity and efficiency to maintain the position as a leading fishing nation. If the fisheries are to provide attractive opportunities for investors and fishermen also in the future, continuous improvements must be made. A crucial part of this is to adjust the economic capacity of the fleet. At the same time, the chosen approach should emphasise fish as a common property providing benefits to all Norwegians. It will be interesting to follow the possible implementation of measures suggested, such as systems collecting the resource rent, in the latest government white paper, *a provident quota system* (NOU 2016:26, 2016).

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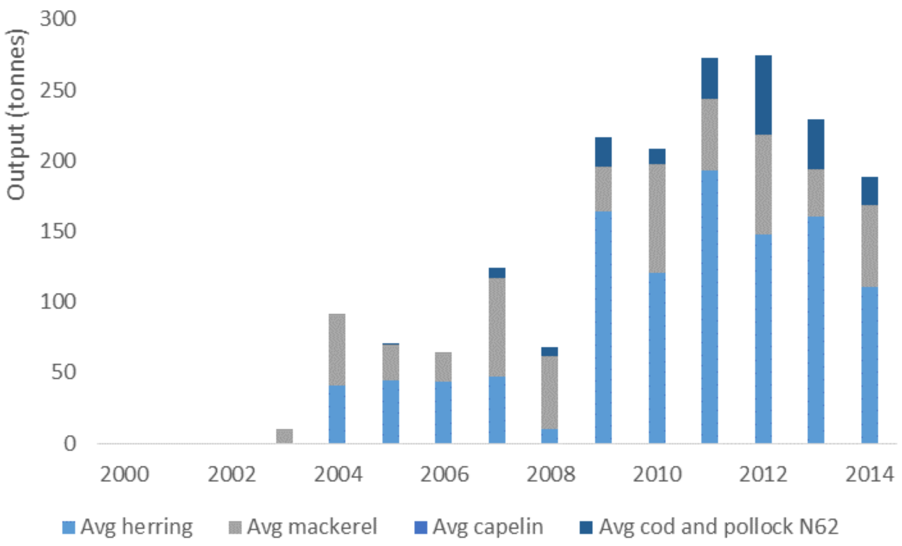
Appendix A - Data

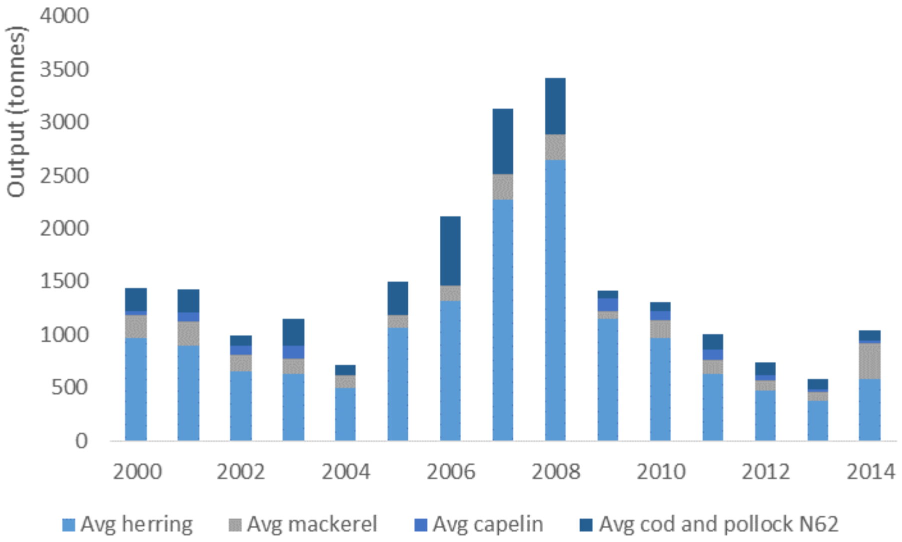
A.1 Distribution of catches (2000-2014)

A.1.1 Coastal vessels

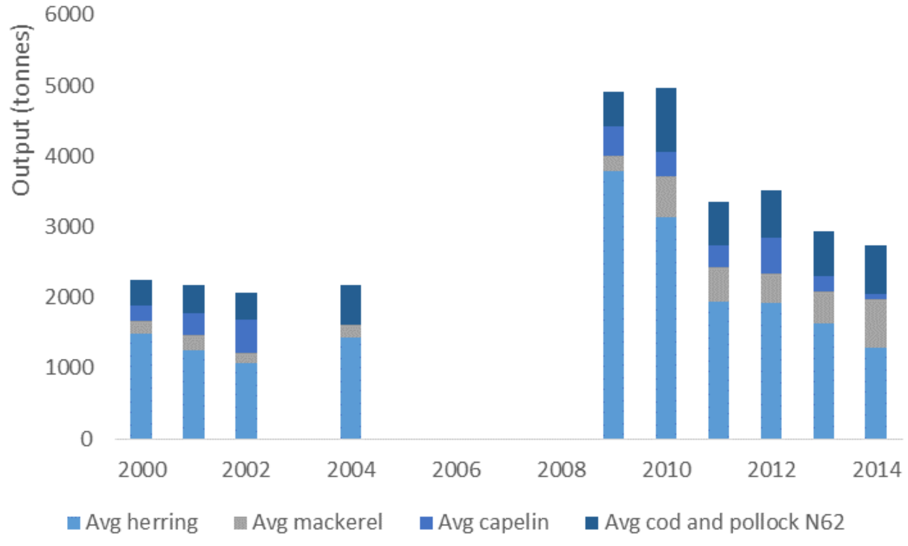
Group 9



Group 10

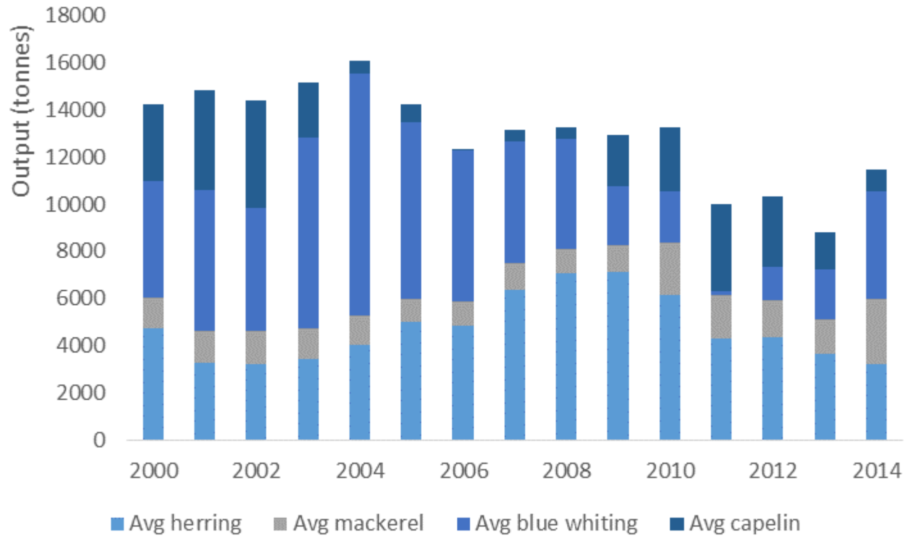


Group 11

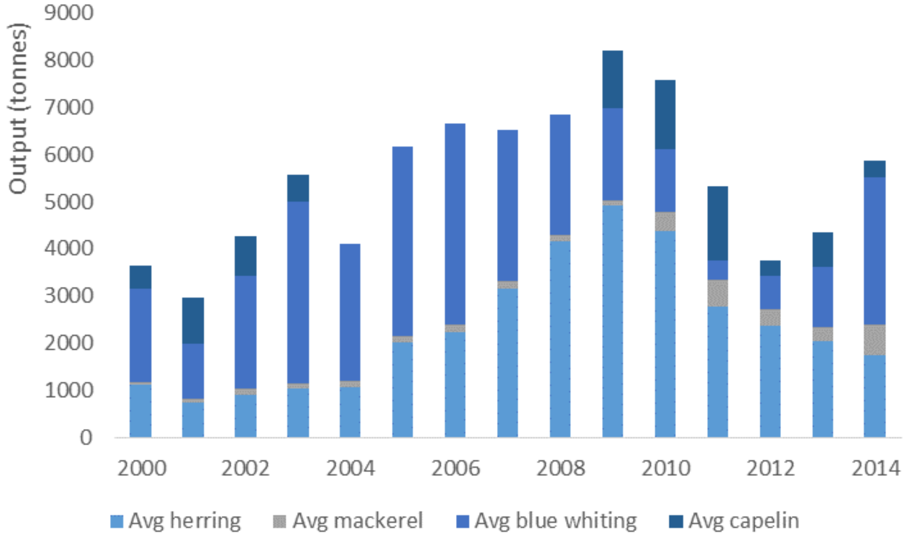


A.1.2 Purse seiners and pelagic trawlers

Group 12



Group 13

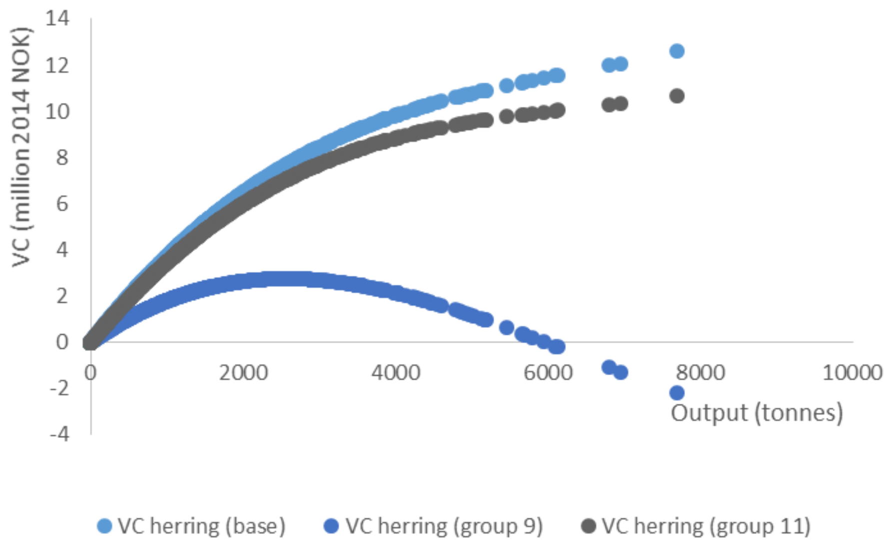

Output (tonnes)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2000
2002
2004
2006
2008
2010
2012
2014
Avg herring
Avg mackerel
Avg blue whiting
Avg capelin

Appendix B - Estimation

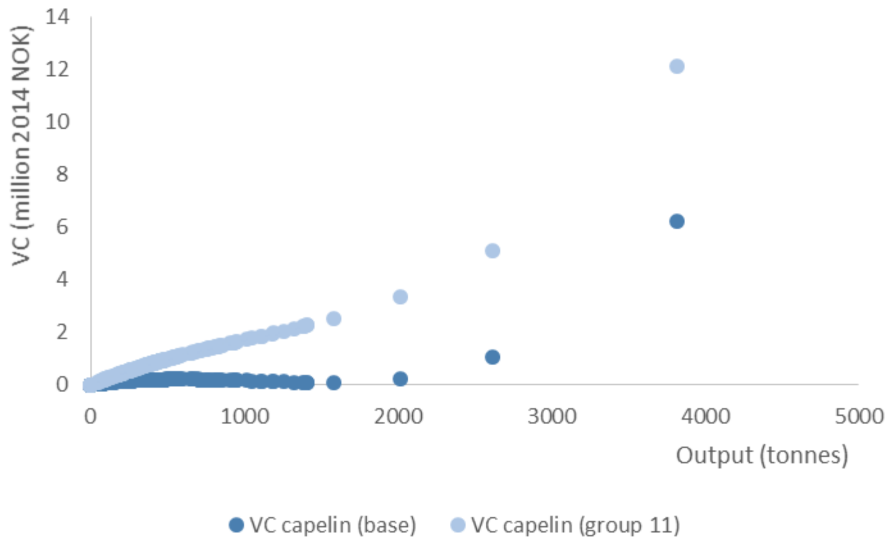
B.1 The estimated variable cost structure

B.1.1 Coastal vessels

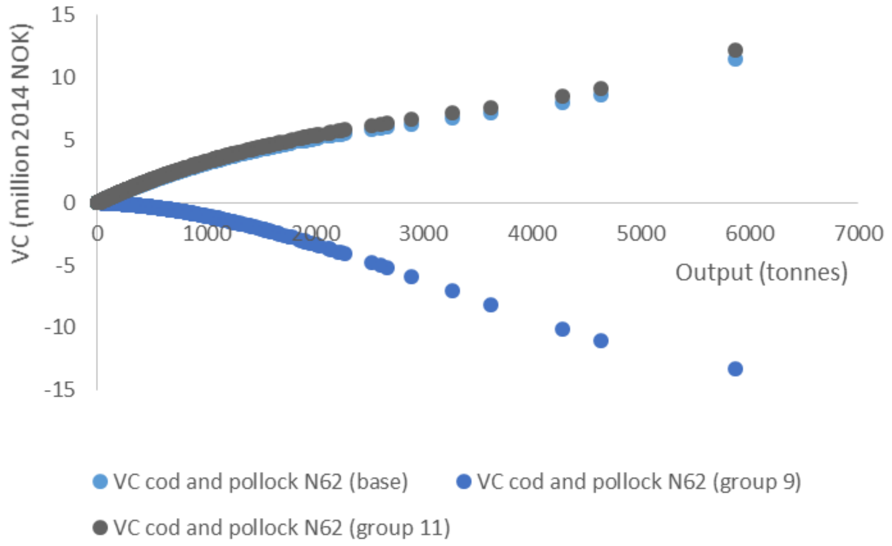
Herring



Capelin

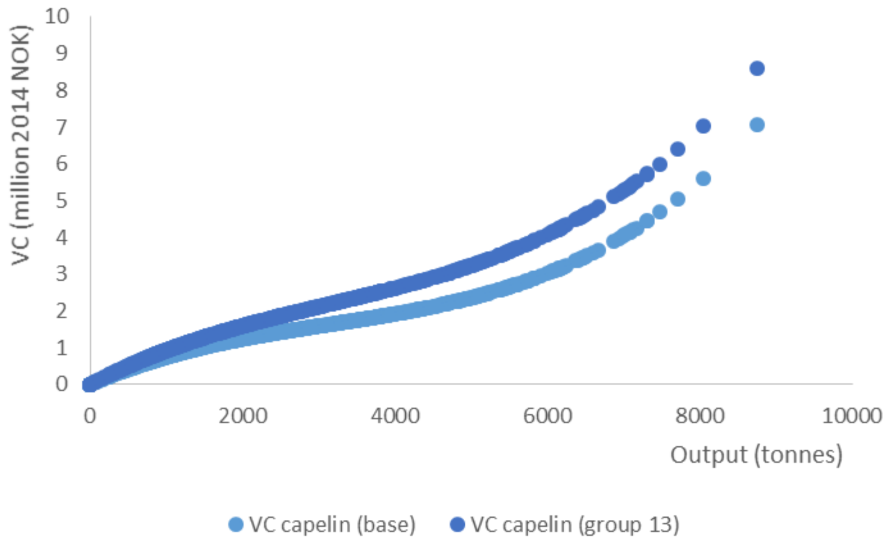


Cod and pollock N62

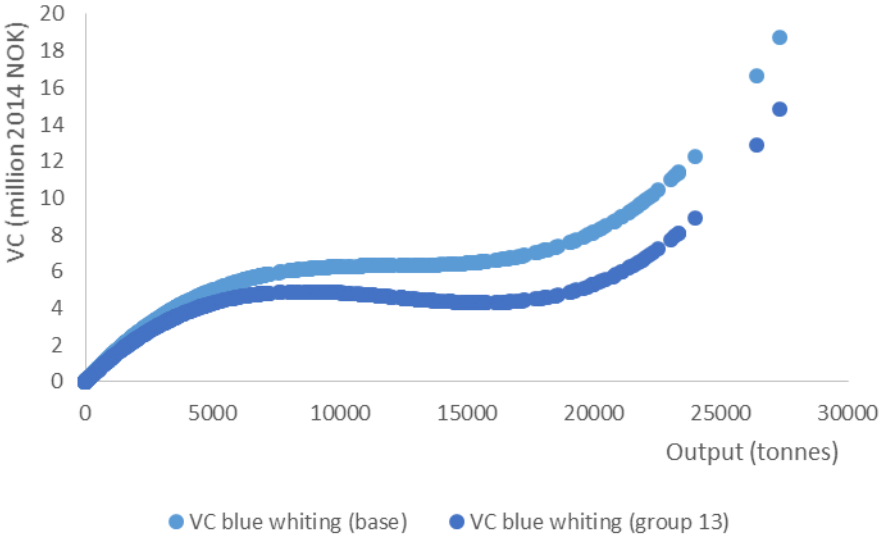


B.1.2 Purse seiners and pelagic trawlers

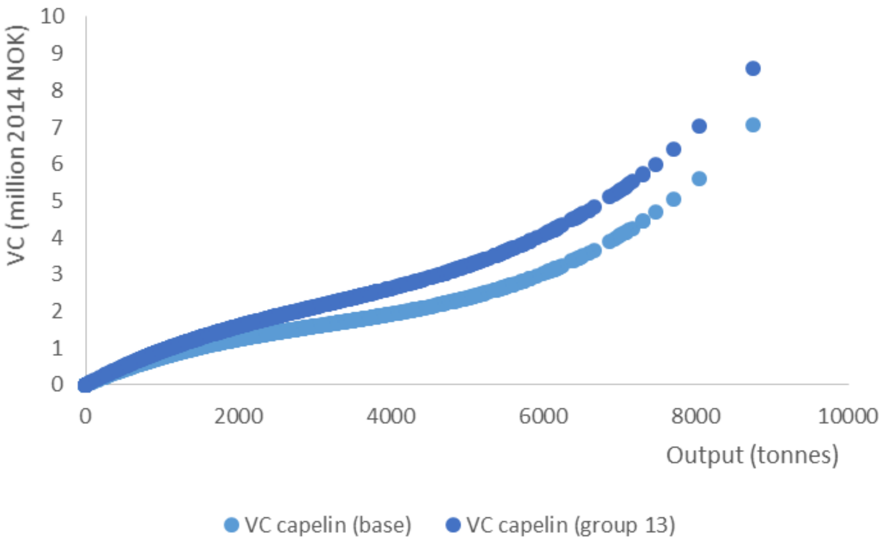
Capelin



Blue whiting



Capelin



Appendix C - Optimisation

C.1 Solutions to the sensitivity analyses

Solution 1

Species/vessel group	**9**	**10**	**11**	**12**	**13**
Herring	91	1 270	2 020	6 242	1 977
Mackerel	49	165	321	1 851	172
Capelin	0	32	298	2 731	481
CodN62 and pollock N62	0	446	669	0	0
Blue whiting	0	0	0	6 227	2 731
Number of vessels	45	511	248	810	213

Total variable costs: 31 761 406 821

Number of vessels: 1827

Solution 2

Species/vessel group	**9**	**10**	**11**	**12**	**13**
Herring	91	1 212	1 973	5 445	1 966
Mackerel	49	162	317	1 605	171
Capelin	0	31	295	2 249	476
CodN62 and pollock N62	0	696	1 100	0	0
Blue whiting	0	0	0	4 866	2 627
Number of vessels	10	151	262	954	376

Total variable: 31 844 586 676

Number of vessels: 1753