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Individual Transferable Quotas and Market Power

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Preface

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All remaining errors are my own.

Trondheim, 01.06.2016
Irmelin Slettemoen Helgesen

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1. Introduction

There is a longstanding tradition for fishing in Norway, and as of 2014 Norway was the world's second largest exporter of fish products (FAO, 2014). Despite this, fishery and aquaculture production only contributes to 0.9% of total GDP (Statistics Norway, 2016)[1], a fact which might explain why Ola and Kari Nordmann has paid relatively little attention to the 'war' on the Norwegian commons.

In January 2015 the European Court of Human Rights denied ship owner Eivind Volstad's appeal concerning perpetual quotas, and the decision of the Norwegian Supreme Court prevailed. The Norwegian marine resources belonged to the Norwegian people (Øyehaug, 2015; Stige, 2015; Grytås, 2014). The appeal was the result of a series of amendments in Norwegian fishery management, and while the Supreme Court halted the process of privatising, the Norwegian quota regime is once again up for evaluation (Regjeringen.no, 2016). Hersoug (2005) argue that Norway may already be on a path towards individual transferable quotas (ITQs). Will ITQ be the result of this new evaluation?

The proponents of individual transferable quotas argue the instrument, which is based on tradable rights to a share of the total harvest, is an economically efficient regime for the management of fisheries. This result however, depends on a number of assumptions, including perfect competition. Simultaneously, the regime's ability to reduce excess capacity in the fishing fleet relies on the concentration of rights (Grafton, 1996; Tietenberg, 2001). At some point the concentration of rights may facilitate the emergence of market power. Within the Norwegian trawl industry the existing licenses are already highly concentrated. With 29 cod licenses the company Havfisk controls about 78% of the trawler's rights to the Northeast Atlantic cod (Grytås, 2014; Havfisk, 2016). My aim with this thesis is to analyse how the efficiency of ITQ is affected by market power.

Most of the literature on tradable rights regimes and market power stems from the area of tradable pollution permits and was pioneered by Hahn's paper 'Market Power and Transferable Property Rights' from 1984 (Hahn, 1984). He looked at the case of one market leader with the

[1]Statistics collected in April 2016

ability to manipulate the quota price, and a fringe of competitive price takers. Hahn's model was extended by Westskog (1994) who included more dominant agents and found similar results, namely that with the existence of market power, ITQ leads to an inefficient outcome. Within fisheries Anderson (2008) studied a fishing firm with dual market power, a situation in which an agent has market power in both the quota and corresponding product market. Hatcher (2012) examines the compliance behaviour of a dominant firm with market power only in the quota market as well as dual market power. The results of Hatcher (2012) are comparable to the previous studies of Hahn (1984) and Westskog (1994).

In this thesis I will be studying how market power affect the efficiency of individual transferable quotas. With the use of a Cournot game I will examine an ITQ fishery with market power only in the product market, a scenario which to my knowledge has not yet been studied. Based on the model developed by Hahn (1984) I thereafter look at an ITQ fishery with market power only in the market for quotas. Although both Hahn (1984) and Westskog (1994) use estimated cost functions to conduct numerical illustrations I extend upon Hahn's work by introducing a specific convex cost function which enable me to solve for explicit harvesting and quota price expressions. Finally I will attempt to conduct some illustrative numerical examples.

The rest of the thesis is structured as follows. In chapter 2 I will give a brief overview of the current status of worldwide fisheries and ITQ as a method of regulation. There will be a closer look at the situation in Norway, and a review of the existing literature on market power within the market for tradable permits. Chapter 3 discuss ITQ in relation to private property rights, whereas chapter 4 will introduce the benchmark model and examine the analytical features of ITQ. Market power in the product and quota market will be studied respectively in chapter 5 and 6. Chapter 7 provides the numerical illustrations while chapter 8 concludes the thesis.

2. Overfishing and Regulation

2.1. A History of Overexploitation

Throughout much of history the myopic[1] behaviour of the global fishing fleet could be justified on the basis of a smaller world population coupled with crude and primitive fishing gear. The 'freedom of the seas' was supported by Grotius's opinion of an inexhaustible fish stock.Without evidence of a diminishing stock there were no arguments for prudent management or property rights (Clark, 2006; FAO, 2014). The biologist Thomas Huxley advocated Grouitus's claim as late as in 1883, yet recent evidence suggest that reports of severely depleted fish stocks were prevalent by the beginning of the 19th century. This indicate that scientific inquiry have consistently lagged behind the realities of overexploitation, and some research suggests the worldwide marine resources have been subject to overfishing for many centuries, even before industrialised fishing methods were introduced (Jackson et al., 2001; Røed, 2013). As much as 80% of the extinctions in marine species are assumed to be attributable to overfishing (Jackson et al., 2001; Dulvy et al., 2003).

During the 19th and 20th century much of the industry was heavily intensified with the introduction of the beam trawl, large steam- and diesel-powered vessels, and the otter trawl. Studies find that biomass of industrialised fisheries were reduced by 80% within 15 years of industrialisation (Jackson et al., 2001; Dulvy et al., 2003). Regulation had not been a topic as it was often believed that fisheries would become unprofitable and thus left alone before biological sustainability was a problem. A comparison of the theoretical open access and maximum sustainable yield (MSY)[2] solutions within the Gordon-Schaefer model[3] display that this may not be the case. In 2011 29% of marine stocks were categorised as biologically unsustainable and estimates indicate that rebuilding these stocks could increase the global harvest by 16.5 million tonnes (Jackson et al., 2001; Dulvy et al., 2003; Pauly et al., 1998; FAO, 2014).

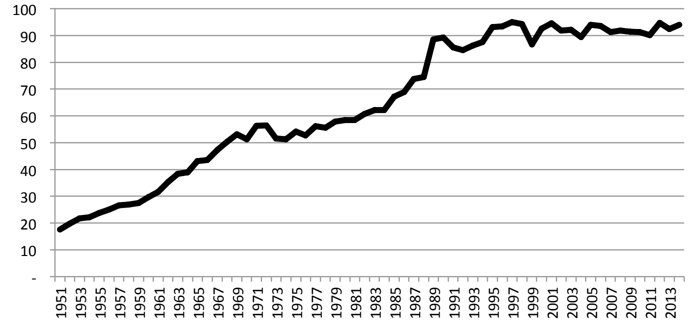
Global capture production reached a peak at about 94 million tonnes in 1997 (figure 2.1). With

[1]The myopic agent take stock size as given (Inarra and Skonhoft, 2008).

[2]The maximum sustainable yield is the largest harvest that can be caught each year without depleting the stock. x^{MSY} is the stock corresponding to this harvest and it is used as the general notion for biological sustainability. Any stock below the MSY stock level is categorised as overfished (FAO, 2014).

[3]The Gordon-Schaefer model is discussed in appendix A.

Figure 2.1.: Total global capture production in million tonnes

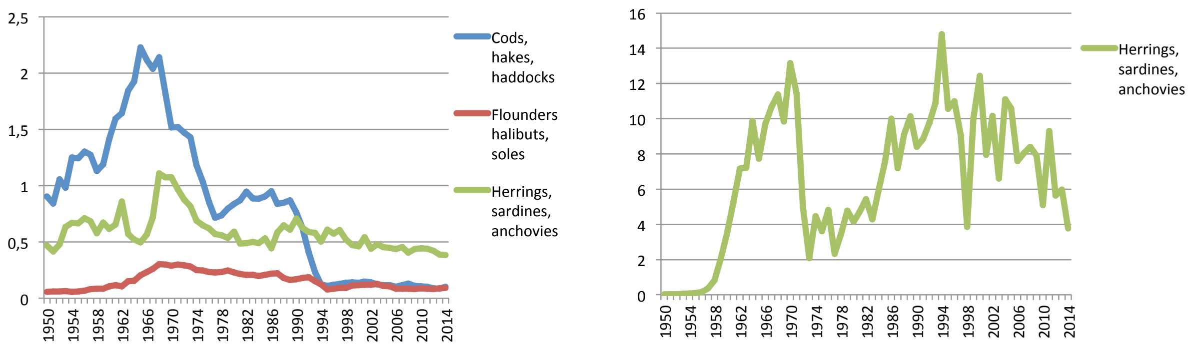


Data collected from FAO's online Fishery Statistical Collection: Global Capture Production (http://www.fao.org/fishery/statistics/global-capture-production/en) in April 2016. The chosen data was exported to excel where the graphs were created.

most stocks either overexploited or at MSY there is little scope for increasing the catch before overfished stocks have been rebuilt (FAO, 2014). Among the areas that display the most critical declines in catch levels are the Northwest, Southwest, Southeast and the Western Central Atlantic, as well as the Southeast and Southwest Pacific ocean areas. As seen in figure 2.2 the Northwest Atlantic and Southeast Pacific oceans especially, display a decline in the harvest of cod and herring.

Figure 2.2.: Capture production in million tonnes.

(a) Northwest Atlantic (b) Southeast Pacific



FAO's online Fishery Statistical Collection: Global Capture Production.

2.2. Regulation

Although some countries such as Norway attempted to regulate fishing within the 4 and 12 nautical mile area as early as the 1930s, 'the freedom of the seas' reigned for most marine areas. The introduction of the 200 nautical mile exclusive economic zones (EEZs) in the 1970s politically defined the management responsibilities and restricted foreigners' access to fisheries

(Symes and Crean, 1995; Hersoug, 2005). Many fisheries began with 'total allowable catch' (TAC) management, which limited the amount of fish that could be caught within a period. To achieve this a series of input regulations were introduced; including gear and effort restrictions, but most importantly the fishing season was regulated. The regulated open access approach may be effective in averting biological overexploitation, but it also led to increased competition, a race for fish and overcapitalization (Grafton, 1996).

2.2.1. Total Allowable Catch (TAC)

As in the following, many fishery models are static and do not consider the change in TAC over time. Because TAC regimes often aim to restore an overexploited fishery the TAC evolvement should reflect some path towards the target stock size. The optimal path will differ depending on the model used, though unless a most rapid approach path (MRAP) including a fishery moratorium is chosen, the TAC will typically follow an increasing trend (Conrad and Clark, 1987, Clark, 2006). In most fisheries the TAC is set either annually or every second year (European Comission, 2016, Sandberg et al., 1998).

Historically biologists have recommended the MSY level as the target in many renewable resources such as fisheries, wildlife and forestry. This objective has been criticised on the basis of economic inefficiency and biological considerations. Some of the criticism is taken into account by adjusting the TAC for natural fluctuations, as harvesting the MSY of a population in a meager year could severely hurt the population. Similarly MSY is thought of as an unstable target as the slightest overestimation could deplete the resource over time (Conrad and Clark, 1987, Sandberg et al., 1998). Quite generalised, the TAC is determined by adjusting last years TAC with data from catch per unit of effort (CPUE) analysis. With CPUE proportional to stock, stock size can be estimated on the basis of time series data on harvesting and effort levels (Flåten and Skonhoft, 2014).

In Norway the collapse of the Barents Sea capelin in 1986/87 gave rise to stock management and TAC determination which took account of even more variables, including the economic consequences of various TACs (Sandberg et al., 1998). An insufficient TAC could have severe economic and social consequences, including the loss of jobs, in a fishery dependent coastal community. In the end it is the politicians, which often prioritise social considerations, that determine the TAC (Péreau et al., 2012; Røed, 2013).

2.2.2. Individual Transferable Quotas (ITQ)

According to the Coase theorem the clear establishment of property rights will, conditioned upon zero transaction costs and no wealth effect, result in an efficient resource allocation regardless of the initial distribution of the rights (Coase, 1960). It follows that the cost-efficiency of a regime based on this theorem, would be independent of the authority's information concerning individual agents' cost. Inspired by this, the use of tradable permits have become common in pollution control and their application to fisheries was first suggested by Christy in 1973 (cited in Grafton, 1996). Individual transferable quotas (ITQs) is a cap-and-trade program for fisheries, implying the fishermen must hold quotas for all their landings (Tietenberg, 2001). With the TAC as the upper aggregate constraint, ITQ allocates the TAC among agents by granting exclusive rights to a share of the total harvest. While the total number of fishermen is now given, they continue to behave as myopic profit maximising agents (Grafton, 1996). Though, without the race to fish the agents will have better incentives to only use the most economical combination of labour and capital, and ITQ is argued to be more equipped to deal with the problem of excess capacity. Theory predicts the rights will be transferred to the more efficient agents and that ITQ will yield a cost-efficient outcome (Copes, 1986; Libecap, 2007). Specific input controls become unnecessary and the removal of limited harvesting seasons have increased work safety and enabled a year round supply of fresh fish, thus smoothing volatile prices (Grafton, 1996).

In 1983 New Zealand became the first country to decide upon ITQ as a fisheries management regime. Australia followed in 1984 where ITQ was introduced as a response the Southern Bluefin Tuna crisis (Symes and Crean, 1995). Somewhat simultaneously Iceland pursued a path that in 1990 would lead to a uniform ITQ regime for all of Iceland's fisheries. The system that eventually emerged in Iceland is closely related to the theoretical ideal, in which perpetual quotas, relatively free of restrictions were traded as financial assets and used as collateral for mortgages (Clark, 2006; Grytås, 2014; Durrenberger and Palsson, 2015). Other countries that practice some variation of an individual fishing quota (IFQ)[4] include Canada, USA, South-Africa, the Netherlands, Namibia, Sweden, Denmark, the UK and Norway (Eythórsson, 1996; Asche et al., 2008; Hersoug, 2005).

Although most of the quotas are distributed free of charge many fisheries in Australia, Canada,

[4]IFQ here refer to all variations of individual quota management, including non tradable individual quotas (IQ), ITQs and individual vessel quotas (IVQs), in which the quota is locked to the vessel.

Iceland and New Zealand attach a small fee to the quota. This fee is supposed to ensure that the industry itself covers the cost of administration and enforcement, albeit most of the time the fee only cover about fifty percent of total administration cost (Tietenberg, 2003; Clark, 2006).

The Market for Quotas

Quite naturally transferability is key to the efficiency of ITQ. It enables the attractive feature of final distribution being independent of initial allocation (Schlager and Ostrom, 1992; Grafton, 1996; Coase, 1960). The quota market in which the ITQs are traded can be separated into a short- and a long-term market, or as they are sometimes referred to, the quota leasing /quantity quota market and the quota share market, respectively (Arnason, 1993; Eythórsson, 1996). In the short-term market agents may lease part of their quota for some period within the time frame of the relevant TAC. The short-term market facilitates the agents' ability to adjust according to a variable need, a requirement for efficiency and in ensuring the entire TAC is caught. The long-term market is where the quota property rights are traded in perpetuity. Today most IFQ regimes have some restrictions on trade, especially concerning how many quota rights one agent can control (Grafton, 1996). Unless otherwise specified all mentions of the quota market refers to the short-term quota market and we will assume this lasts for one year.

A positive quota price arise from the scarcity of the resource and will reflect the resource rent, as well as the economic efficiency of the fishery (Arnason, 2012; Eythórsson, 1996; Hersoug, 2005). The price related to a permanent transfer of the quota right, i.e. the long-term market price should reflect the expected present value of future resource rents, adjusted for any uncertainty related to the TAC and stock development (Arnason, 2012; Eythórsson, 1996). In reality it is difficult to foresee a vessel's quota need at the beginning of the period and trade in the short-term market is conducted throughout the entire period, thus quota price may depend upon the agents' relative bargaining power.

Biological Sustainability

The biological effects of ITQ have been mixed. After implementation the Chilean squat lobster fishery and the Icelandic herring fishery saw about a sixfold increase in biomass (Tietenberg, 2003; Clark, 2006; Arnason, 1993). In a global study of 11135 fisheries from 1950 to 2003 Costello et al. (2008) report that a fishery's probability of collapsing may be reduced by 13.7 percentage points by introducing ITQ. In another study 24 out of 37 fisheries were found to have declining stocks after the implementation of IFQ regimes (Tietenberg, 2003). This does not necessarily contradict Costello et al. (2008) in which ITQ managed fisheries performed better than non-ITQ fisheries, yet some still collapsed. Thus it is important to note that ITQ mainly is an instrument for economic management, not biological conservation and the eventual effect upon the biomass of the fishery is dependent on the TAC and the enforcement of the system (Symes and Crean, 1995).

Efficiency

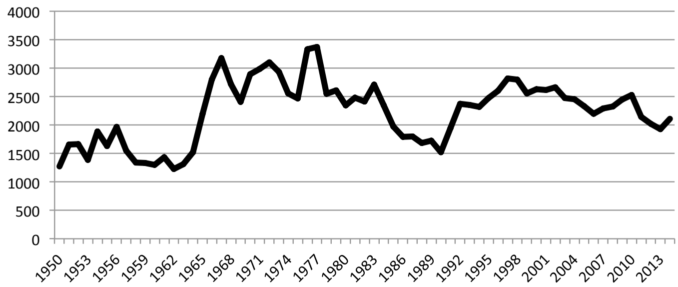
Although the evidence varies between species, the ITQ system of Iceland seem to have been successful in handling the problem of excess capacity, and already in 1993 effort in the herring fisheries was reduced by 20% while the fleet targeting capelin was downsized by 40%. An indicative empirical study suggest that effort in demersal fisheries could be 34% lower relative to the unobserved expected effort of the pre ITQ management system (Arnason, 1993).

The evidence for economic improvement is more speculative. In the 1990s Iceland seemed to have one of the most profitable and efficient fisheries in the world and ITQ appears to have generated positive rents in the Icelandic herring and capelin fishery (Grytås, 2014). It is asserted that increasing quota values in the demersal fisheries strongly suggest the creation of significant rents also here, but in light of the 2007/08 financial crisis much of the rise in quota prices might be attributed to the speculation that occured in Icelandic fishing quotas (Arnason, 1993; Clark, 2006; Røed, 2013). Eythórsson (1996) argues the soaring quota prices cannot be explained by efficiency improvements alone. Some of the stocks were still in decline and prices might have reflected increased scarcity, also the rent might be a temporary effect of the transition from the owners of physical capital to the quota owners. Eythórsson (1996) further explains the immense quota prices for cod as a result of problematic amounts of cod bycatch which spiked the demand for quotas. Lastly, what appears to be resource rents may be a result of cheaper labour as there are indications of a decline in the crew's wages since the introduction of ITQ (Eythórsson, 1996). On the other hand, results from an econometric study covering 15 years and more than 150 quota markets are consistent with improved profitability and reduced capacity (Newell et al., 2005).

2.3. World Champions at Fisheries Management

Over the last 60 years the Norwegian harvest has been highly variable, yet there are indications that Norway, in line with the global trend, is facing a decline in harvest (figure 2.4).

Figure 2.4.: Total Norwegian fisheries capture production in 1 000 tonnes



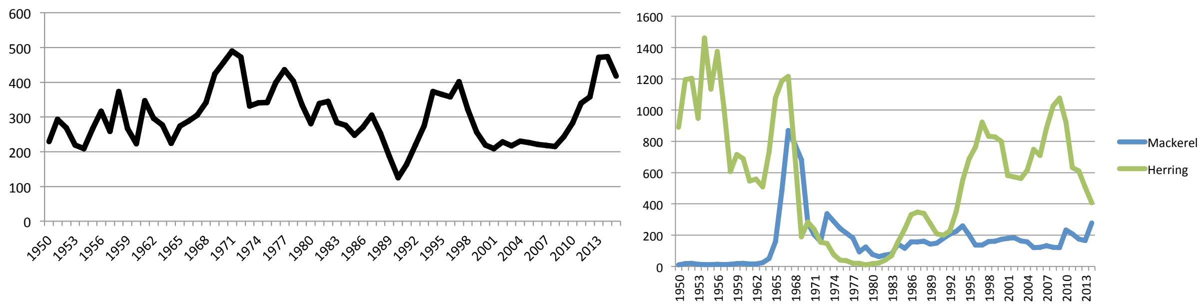
FAO's Fishery Statistical Collection: Global Capture Production.

The cod crisis of 1989/90 hit Norway hard and had major repercussions for Norwegian fisheries management (Hersoug, 2005). After successfully cooperating with Russia in rebuilding the cod population to a sustainable level, and with the world's first ministry of fisheries, Norway held the unofficial position as world champions at fisheries management (Røed, 2013; Hersoug, 2005). Aside from this, the title is mainly a testament to how terrible the rest of the world was. Only one out of ten Northeast atlantic cod become mature enough to spawn and in 2006 the species was characterised as near threat, a fact which is reflected in the harvesting level around this period (figure 2.6a). The reduction in biomass might be attributable to a TAC that has often been above the recommended level (Røed, 2013; Hersoug, 2005). In 2000 and 2002 the TAC for Northeast Atlantic cod was respectively 225% and 70% above recommendation (Røed, 2013).

Figure 2.5.: Norwegian capture production in 1 000 tonnes

(a) Northeast Atlantic cod

(b) Mackerel and herring



FAO's online Fishery Statistical Collection: Global Capture Production.

Other brutal examples of Norwegian overfishing are of course the exessive hunting of whales and the collapse of the herring population in 1969. During the 1970s the herring fry remained inshore, leading some to believe the stock had never been larger. The truth was that overexploitation had lead to the loss of ancient migration patterns, as the older generations no longer were present to lead the way. Thankfully the director of fisheries Knut Vartdal listened to the biologists and placed a 15 year moratorium on the Norwegian spring spawning herring (Røed, 2013). The decline in the population of herring is clearly evident in figure 2.6b, so is the stock's restoration.

An additional problem is the illegal and unreported fishing. In 2007 the amount caught was almost the triple of the TAC, and with the introduction of quotas, discarding based on the incentive to highgrade[5] is a major issue. Discarding is illegal in Norway, yet it has been especially prominent within mackerel fisheries and might be the reason why figure 2.6b do not display any successful restoration for mackerel (Grytås, 2014; Røed, 2013).

2.3.1. Closing the Norwegian Commons

Norwegian fisheries have, to some extent, been regulated ever since 'Magnus Lagabøter's landslov' in 1247. New to the closing process that began in the 19030s was the limitation of access (Hersoug, 2005).

For the trawlers the closing process began with the Trawler Act of 1908, with key amendments in 1936 and 1939. Access was limited by the use of yearly assigned vessel licenses, though overcapitalisation was not tackled as the regime was coupled with heavy state subsidies (Hersoug, 2005). The Participation Act in 1972 introduced licenses for the purse seiner fleet and thus access to most of the offshore fishery was effectively restricted. The objective of restricting the offshore fleet was to preserve the coastal fleet's open access regime and maintain the social structure along the coast. While it might combat biological overexplitation, a license regime is a restricted open access regime and competition within the licensed group will still exhaust any rents (Hersoug, 2005).

In 1984 the trawl industry encountered the first attempt at a unit quota system (UQS), in which a share (determined by vessel capacity) of total catch was allocated with each license. The trawl companies were allowed to merge two licenses and keep the quota of the scrapped vessel for five years. In 1987 a structural committee, established to discuss future management regimes, lay the foundation for the new unit quota system (also known as the structuring system), and the coming individual vessel quota regime (IVQ) (Hersoug, 2005).

With the cod crisis in 1989 the TAC was almost halved with 340 000 tons compared to 630

[5]Highgrading is the discarding of less valuable fish in order to fill the quota with only the best quality (Anderson, 1994; Copes, 1986).

000 tons the year before. According to 'the trawl ladder'[6] the coastal fleet received 116 000 tons and the season was closed on the 18th of April. The crisis spurred the introduction of non-transferable individual vessel quotas (IVQ) (Hersoug, 2005). The 9000 coastal vessels were divided into two groups. The winners, who were deemed too cod dependent as they had the largest harvest throughout the years 1987, 1988 and 1989, were guaranteed vessel quotas free of charge. The losers received no such right and had to race to harvest a small residual quota (Grytås, 2014). The coastal vessels were further divided into five size groups and each vessel within the size group would get the same quota, based on average catch of the group (Hersoug, 2005; Røed, 2013).

During the period of 1994-1996 the offshore fleet implemented the new UQS in which each vessel could acquire two structural quotas in addition to the base quota associated with the license. The structural quotas could be kept for 13 years, 18 if the additional vessels were scrapped. After this they were to be returned to the common (Hersoug, 2005). By 2002 there had emerged a grey market for transferring IVQs. Though the quotas were not transferable it was not illegal to sell the vessels, and there are several examples of vessels with quotas being sold for huge amounts before being sold back to the original owner without the quota for only a fraction of initial price. The accounts from the 1990s indicate that many earned more from selling quotas than from fishing, and many bought quotas in anticipation of a rise in value and favourable changes in the regime (Hersoug, 2005; Grytås, 2014; Røed, 2013). The politicians continued to claim the rights were non-transferable, but it was evident that a change was necessary. In 2004 the concept of structural IVQs was introduced for the coastal fleet, allowing the owners to merge quotas within their size group and keep the structural quotas in perpetuity (Grytås, 2014; Hersoug, 2005). For both fleets the base quota is allocated on a yearly basis, but seeing as no one has lost their right[7] most considered them perpetual (Røed, 2013).

The various systems have been through several amendments and it is once again being evaluated, with an official report expected this autumn (Regjeringen.no, 2016). Today the structuring regime remains. The trawlers may collect up to four quotas in total and although the quotas are allocated on a yearly basis they may be allocated for 20 and 25 consecutive years, for respectively the offshore and the coastal fleet. In addition, quotas may be leased for a certain period of time (Armstrong, 2008; Grytås, 2014; Hersoug, 2005). A brief overview of the statistics display

[6] The trawl ladder is the distributional key that allocates quotas between trawlers and coastal vessels (Hersoug, 2005).

[7] Agents have only lost their right, or specifically their license when they are left unused for some period of time.

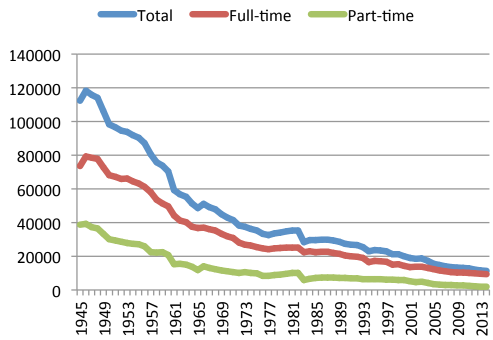
a steady decrease in the number of vessels and fishermen since the limitation of access, this is evident in figure 2.7 and 2.9.

Figure 2.7.: The number of vessels in the Norwegian fishing fleet

(a) The coastal fleet (b) The offshore fleet

Data collected from the Norwegian directorate of fisheries (http://www.fiskeridir.no/English/Fisheries/Statistics) in April 2016.

Figure 2.9.: The number of fishermen with fishing as full- and part- time occupation



Data collected from the Norwegian directorate of fisheries

2.4. Literature Review

Both being cap-and-trade regimes, the basic properties of ITQs mirror those of marketable emission permits (Hatcher, 2012). The theoretical literature that has been developed is considerably more extensive for the latter topic, especially concerning efficiency and the issue of market power

2.4.1. Pollution Permit Literature

Montgomery (1972) formally proved the Coase theorem in his seminal paper 'Markets in licenses and efficient pollution control programs.' This implied that tradable emission permits could be able to reach a given target in a cost-effective manner, independently of initial allocation of the permits. The outcome though, is contingent on a number of strict assumptions: perfect competition, no transaction costs, clearly defined and enforceable property rights, and no wealth effect (Grafton, 1996; Coase, 1960).

Hahn (1984) was the first to examine how the efficiency of transferable property rights is affected by market power. Modeled as a two-stage game he let one dominant firm be able to manipulate price, while the remaining firms were perfectly competitive price takers. All transactions take place at a single price and the price takers minimise abatement cost with quantity of permits as the strategic variable. The market leader use price as strategic variable. The model is static in the sense that the permit market only lasts for one period. Hahn (1984) finds that market inefficiency is related to initial distribution of rights and varies with the market leader's excess demand for, or supply of permits. With excess demand the leader will act similarly to a monopsonist and purchase fewer permits at a lower price than socially optimal. Accordingly the leader will act as a monopolist, selling less at a higher price, when the leader has an excess supply of quota. The efficient outcome is only reached when the leader is allocated permits that equal his demand inherently eliminating his need to participate in the market.

Westskog (1994) extended Hahn's argument by increasing the number of agents with market power. The market leaders act as Cournot players who take the price taking fringe's best response function as given. Also different is the leaders' decision variable, here quantity. Still, given that there are more market leaders, the results are similar to those of Hahn (1984). Both Westskog (1994) and Hahn (1984) find that inefficiency increase the further the number of permits allocated to the dominant firm deviates from its demand for permits. The numerical illustrations conducted by Hahn (1984) and Westskog (1994) however, suggest the efficiency loss in general is of little significance. Hagem and Westskog (1998) develop a two-period model of a tradable permits market with market power, and find a tradeoff between cost-efficiency across agents and periods. Similarly Liski and Montero (2005) examine the banking behaviour of a dominant firm and end up with the intertemporal equivalent of Hahn (1984)'s result.

On the basis of numerical analysis Maeda (2003) reported that, market power in general is not a significant problem within emission trading markets, due to the large amount of emission sources and hence market participants. 10 years earlier such arguments encouraged Von Der Fehr (1993) to analyse how and under what conditions strategic interaction would occur. With a dupooly of two symmetric Cournot firms Von Der Fehr (1993) find that monopolisation is more likely when permits are essential to production and that the number of permits held determines the frims' strategic behaviour. Additionally the ability to rise rivals' costs is identified as an incentive to exercise market power and manipulate quota price (Von Der Fehr, 1993).

Maeda (2003) derive the conditions for emergence of market power within the quota market, which is found to depend entirely upon the initial allocation of permits. In fact Maeda (2003) argue there is a threshold of initial permit allocation above which the firm will exercise market power. Quite similarly, Hintermann (2011) derive a threshold of freely allocated permits above which a dominant firm will find it profitable to engage in monopoly behaviour. Based on a model with two dominant firms and a competitive fringe, Maeda (2003) argues the permit price will never fall below the competitive market price. This result differs slightly from that of Hahn (1984), but is contingent on the specific model setup of one dominant firm acting as a net seller, while the other dominant firm and the fringe are net buyers.

Egteren and Weber (1996) extend Hahn's model to allow for noncompliance, yet their findings regarding the effect of initial permit allocation and monopolistc behaviour essentially agree with those of Hahn (1984). However, the results suggest that studies which ignore noncompliance tend to underestimate the social cost of market power. This is because the firms' compliance choice is affected by initial allocation of permits and the degree of market power in the market.

2.4.2. Quota Managed Fisheries

Anderson (1991)(cited in Hatcher (2012)) was the first to study the problem of market power in a market for fishing quotas. He examined the behaviour of a a profit maximising compliant fishing firm with dual market power[8]. In his revised work Anderson (2008) assumes one dominant firm and derives a formula for the maximum percentage of the TAC the market leader can hold without benefiting from monopoly behaviour. In the event that initial allocation of permits inspire monopsonistic behaviour there is incentive to buy additional permits and restrict output in order to raise both the product price and the value of the quotas. Whether it is beneficial to withhold quotas and engage in fish price manipulation however, will depend on the size of the TAC relative to the firm's profit maximising output (Anderson, 2008).

[8]Dual market power refer to the situation in which an agent has market power in both the quota and corresponding product market.

Hatcher (2012) examine the compliance behaviour of a dominant firm with market power only in the quota market and with market power in both markets. Similarly to Westskog (1994) Hatcher (2012) let quantity be the dominant firm's strategic variable and find results similar to those of both Westskog (1994) and Hahn (1984). In the event that the firm has market power in both markets output price is only increased when the dominant firm holds quotas off the market. Similar to Anderson (2008), the dual market power may motivate a net buyer to hold excess quota. The compliance decision of the dominant firm is for a given quota allocation, dependent on relative capacities, consumer output demand and the fringe's quota demand (Hatcher, 2012).

Whether the choice of allocation mechanism can affect the scope for market power is analysed by Armstrong (2008). With market power only in the quota market, she develops a model similar to the dynamic model of Hagem and Westskog (1998). Armstrong (2008) find that, under specific conditions, it is possible to eliminate market power with an optimal history dependent allocation mechanism. These results will be explored further during the discussion of the initial distribution of quotas.

3. ITQ and Property Rights

There is a general misconception that the tragedy of the commons is inevitable for common pool resources. Such statements do not recognize the distinction between open access and common pool resources nor the difference between local and global common property (Ostrom, 1990). Within economics there seem to be a consensus that such 'tragedies' result from a lack of well defined property rights, and the use of property rights to correct externalities is strongly supported by the Coase Theorem (Copes, 1986; Grafton et al., 2000; Coase, 1960). While this is not technically wrong, it is often misinterpreted as a need for private property. Even Hardin (1968), himself presented the two counterparts socialism and state control or privatisations and free markets as the only solutions to the tragedy (Ostrom, 1990). Both resource management regimes have been applied to 'common property tragedies' and, albeit the results are various, it suggests that neither state nor market is uniformly successful in enabling individuals to act in the long-term interest of society (Ostrom, 1990; Ostrom et al., 1999). There are cases of forests, previously managed by a local community, that have been left unregulated once nationalised and thus succumbed to the tragedy of open access (Ostrom, 1990). Owners of individual private property might find it optimal to exploit the resource to the point of extinction (Clark et al., 2010), for instance on the basis of a private discount rate much higher than what is socially optimal (Schlager and Ostrom, 1992; Bromley, 1991; Copes, 1986).

Bromley (1991) defines a resource management regime as the relationship structure between individuals with respect to a particular resource. Concerning property rights, there are a myriad of definitions. According to Bromley (1991) a property right is the claim to a stream of benefits, that the state will agree to protect. This highlights both that property rights not necessarily refer to tangible objects, and that they are nothing without an authority that ensure compliance. Property rights are social contracts which can only exist when they are socially accepted (Solstad and Skonhoft, 2001).

3.0.1. Common Property

Much of the misconception concerning common property is attributable to the frequent lack of specification. The term is used referring to a variety of concepts including property belonging to the government, a community or no one (Bromley, 1991, Schlager and Ostrom, 1992). To clarify, resources for which no property rights has been recognized, i.e. 'property owned by no one' are resources subject to the open access situation, where no one can be excluded. Property the government has full control over is more correctly specified as state property, but often refers to a state regulated common property in which the rights are collectively exercised by the entire nation's population, such as the Norwegian fisheries (Grytås, 2014; Regjeringen.no, 2007).

Common property entails property rights that are collectively exercised by a group. They are characterised by the right to withdrawal and rivalry e.g. as one fish is harvested that unit of resource is no longer available for the other members (Skonhoft, 1999; Ostrom, 1990). These characteristics are, together with the costly exclusion of others, also found at the origin of 'the tragedy of the commons' (Ostrom, 1990; Schlager and Ostrom, 1992). A common property may be classified as local if the member of collective owners is small, otherwise it is regarded as a global common property resource. The exclusion of non-owners will be more costly with the latter, which is generally more difficult to manage and often relies on the authority for management. Local common property may reach a consensus through cooperation, but still relies on the authority to ensure its rights. Without cooperation or with a lacking authority system the common property resources become, for all practical purposes, a case of restricted[1] open access where the the rational behaviour of individual agents is contrary to the collective optimum (Bromley, 1991; Skonhoft, 1999). This (open access) is the basis for the tragedy of the commons, not that a resources is owned in common (Boyce, 1992; Arnason, 2012).

3.1. ITQ

In light of this ITQ may be regarded as a state controlled individual rights regime applied to a global or local common property, depending on the size and location of the fishery[2]. The advocates of ITQ argue for the efficiency[3] of the system and its ability to reduce overcapitalization. The concentration of quotas that result from trading enable the reduction in overcapacity, given that the initial quota owner's vessel is scrapped, but it is also a source of much controversy (Grafton, 1996). The opponents derive their arguments from a large pool of criticism, but the main focus is whether or not ITQ may be regarded as property rights and the ethical implica-

[1]Unrestricted open access if the group or authority system fail to exclude non-owners.
[2]A small inshore fishery may be regarded as a local common property, whereas the Norwegian ocean fishery enclosed by the EEZ is more suitably described as global (Ostrom, 1990).
[3]The regime's efficiency feature will be proven in Chapter 4, The Benchmark Model.

tions of this. Transferability and duration are key characteristics in determining the property right status of ITQs. An ideal right, over which the owner has full control, is perfectly transferable and perpetual (Scott, 1988; Grafton et al., 2000). How the rights are acquired is also important for ITQ's status as property rights.

3.1.1. Initial Allocation

There are several mechanisms for allocating ITQs, they can either be auctioned off or be allocated free of charge on the basis of first possession- or uniform allocation rules (Libecap, 2007). Studies (e.g. Morgan, 1997, Crampton and Kerr, 2002, Tietenberg, 2001) indicate that auctions are the most economically efficient method of distributing the TAC. Yet, auctions may be viewed as unfair as it not necessarily favour the most efficient agent, but those with a strong financial position (McCay, 1995; Durrenberger and Palsson, 2015). Furthermore, it is common for incumbent agents to oppose systems that require payment for services they feel entitled to for free, such as access to a common property. Most of the literature on auctions originate from the emission permits market, where it may be easier to support on the basis of the polluter pays principle. In fact the initial allocation of the TAC has been identified as the main concern in relation to the implementation of an ITQ system and much of this problem stems from debate on the privatisation of the commons and the issues of equity. Ultimately it would be practically impossible to introduce individual rights in an existing open access fishery without the support of current participants. As a result the TAC is commonly distributed for free, using the first possession method known as 'grandfathering' (e.g. Morgan, 1997,Libecap, 2007, Anderson, 1995).

Auctions

Auctions generate state revenue and has the opportunity to reduce tax distortions in the economy (Crampton and Kerr, 2002, Anderson et al., 2010, Lopomo et al., 2011). Auctions carry the benefit of more transparently stating to whom the resource belongs. When time limited quotas are sold, the state accrues the resource rents, and arguments claiming the resource still belongs to the common is more convincing than when the rents benefit those holding the rights (Crampton and Kerr, 2002). On the other hand, if permanent rights are auctioned off the new holders may claim to have bought private property rights to a resource, note that the rents still should accrue to the state through the initial selling price. Anderson et al. (2010) refer to four cases where auctions have been used as the primary tool in allocating ITQs in fisheries. There seem to be little evidence of other cases.

In the basic scenario, a fixed supply of permits or quotas is offered by the authority. The buyers thus submit their bids expressing their willingness to pay for various quantities of quotas. The most common auction structures are sealed-bid auctions[4] and ascending auctions[5]. Payment can either be based on uniform pricing where each winner pays the market clearing price, or pay-your bid pricing where each winner pays its bid (e.g. Crampton and Kerr, 2002; Lopomo et al., 2011). It is assumed that auctions immediately result in the cost-effective allocation of permits, as all buy according their optimality condition. However, trade is still important and the significance of transferability is increasing in the durability of the rights, seeing as cost and benefit structures may change over time.

It is commonly believed that auctions provide greater incentives for innovation (Crampton and Kerr, 2002). Anderson et al. (2010), who study the allocation methods within fisheries, claim that the argument for auction neglects to consider dynamic efficiency. According to them, the rents from fishing are not only resource rents, but also returns from the agents' investment in discovery, exploration, innovation and capital. Auctions and their transfer of rents to the state would discourage this entrepreneurial activity which contribute to maximising and increasing future rents.

Grandfathering

Grandfathering is the allocation of quotas based on historical catch levels, capital investments or some combination of the two (e.g. Morgan, 1997,Libecap, 2007, Anderson, 1995). The method is often chosen on the basis of the justice argument; those who have made a living in the industry and invested in capital and effort are thought to have a legitimate claim to rights, should the industry become regulated. Another frequent argument in favour of grandfathering suggests that transitioning to a regulated system will be less costly if the agents participating in the industry prior to regulation are allowed to continue after regulation (Bergland et al., 2002, 2004). Similarly, grandfathering may be more efficient than previously thought as the

[4]In sealed-bid auctions the bids are submitted simultaneously and they generate an aggregated demand curve. The market clearing price is determined by standard equilibrium analysis, i.e. at the point where aggregated demand equal the fixed supply.The demands above the clearing price are winners and receive their demanded quotas, those at the clearing price are rationed and the demands below the clearing price are rejected (e.g. Crampton and Kerr, 2002; Lopomo et al., 2011).

[5]Ascending auctions is a game with several stages in which both price and allocation are determined through a process of open competition. In each round the bidders have the opportunity to change their bids from losers to winners. The bidding game continues until total bids equal the fixed supply (e.g. Crampton and Kerr, 2002; Lopomo et al., 2011).

agents with specialised local knowledge and larger historical stakes in the fishery often are the low-cost, efficient agents (Libecap, 2007). This is in line with Anderson et al. (2010) and his argument of dynamic efficiency and grandfathering's ability to increase future rents.

Inherent in the decision to introduce TAC and ITQ management is the issue of overexploitation. As a result aggregated historical catch level will exceed the TAC. Inarra and Skonhoft (2008) models this issue as a game theoretic bankruptcy problem[6] and discuss the possible rules according to which the resource should be allocated. Under the more commonly used 'The Proportional Rule' incumbent agents receive shares of the TAC that are proportional to their claim, i.e. historical harvest. The associated initial quota at time t is formally given by

$$\tilde{Q}_{i,t} = \frac{h_{i,t-1}}{\sum\limits_{i=1}^{n} h_{i,t-1}} TAC_t, \ \forall i = 1, ..., n. \tag{3.1}$$

where $h_{i,t-1}$ is historical catch level (Inarra and Skonhoft, 2008). $h_{i,t-1}$ may among others, be based on average catch over a number of years, catch levels in the best year or during the previous season (Morgan, 1997). Giving away rights to a natural, often common, resource is highly controversial. In addition to creating entry barriers the distribution of TAC according to The Proportional Rule reward agents whom with large historical catches have contributed the most to the overexploitation of the resource (Inarra and Skonhoft, 2008; Libecap, 2007).

Once the 1989/90 cod crisis had spurred the introduction of individual quotas for cod in the Norwegian coastal cod fishery, vessels in the coastal fleet began to sign on in fisheries where they previously had no recorded catch. The mackerel fishery, for instance, saw a doubling from 200 to 400 registered vessels (Hersoug, 2005). The fishermen were 'rent-seeking', changing their behaviour in anticipation of regulation and attempting to increase historical catch levels in order to secure more property rights in the future. Considerable rent-seeking activity will magnify the problem of excess capacity and overexploitation. Yet, agents might find rent-seeking profitable despite the probability of reducing the stock that future quotas will be based upon and (Bergland et al., 2002, 2004).

Bergland et al. (2002) find that, when harvesting an unregulated resource, agents who feel responsible for meeting a future common resource constraint will harvest less than with quota

[6]A bankruptcy problem is defined as any situation where, in the allocation of a single resource, the amount is insufficient to simultaneously satisfy the aggregated claims of all agents (Inarra and Skonhoft, 2008).

regulation and ex ante rent-seeking. With individual quotas the fishermen feel less responsible for the future of the stock as a whole. This relates to Ostrom's 1990 findings on common property management regimes, in which a community is motivated to cooperate and secure the long-term interest of the group.

There are definitions of $h_{i,t-1}$ less likely to induce a race for quotas. Especially the choice of time frame used in the calculations can reduce the incentive for rent-seeking behaviour, either through the choice of random unknown years or going further back along the timeline (Bergland et al., 2002). The latter option has the apparent drawback of favouring tenure. In Estonia 90% of the TAC is allocated according to historic catch while the remaining 10% is auctioned. This method can to some extent facilitate the start up process of new entrants (Armstrong, 2008).

Uniform Allocation Rules

The more egalitarian choice is the uniform allocation rule based on equal sharing. Uniform allocation may be an attractive choice as it avoids the transaction costs associated with auctions or with verifying claims based on past production (Anderson et al., 2010).

'The Constrained Equal Award Rule' discussed in Inarra and Skonhoft (2008) is one such rule where everyone receives equal shares, subject to the constraint that no agent receives more than his claim. Uniform allocation rules also include lotteries where each claimant is given an equal random draw in the assignment of rights (Libecap, 2007). Seasonal rights to the cod trap fishery in Newfoundland are allocated with lotteries. In order to qualify for the lottery the fishermen must belong to the local community (Schlager and Ostrom, 1992).

Alternative methods

It is worth mentioning that most vessels are not exactly environmental friendly. The trawlers of the Norwegian cod fishery use about 6 times as much CO_2 per kg fish caught compared to the coastal fleet (Røed, 2013). Taking this into consideration there is scope for an allocation method where environmentally friendly fishermen, with less greenhouse gas (GHG) emissions per kg harvested are rewarded with more quotas (Røed, 2013). Such an allocation key could create incentives to innovate and invest in cleaner technology.

Using a dynamic framework Armstrong (2008) studies three different allocation mechanisms in relation to market power. Essential here is that although initial allocation is important, certain characteristics of the right may be altered to combat market power and its inherent inefficiency. It is mainly the durability of the rights that can affect the scope for market power. The first allocation mechanism is the durable quota method, which mimics that of ideal ITQ with perpetual rights, these will (as shown in chapter 6) be inefficient in the presence of market power. Secondly, there is the short-term quotas which may only be leased for one period. In the third allocation method, the so called history dependent method, the rights are only durable for one period and an agent's allocation in the second period is some function of his quota trade in the first period. This method has the possibility to eliminate market power. A system similar to this has been successfully implemented in Namibia (Armstrong, 2008).

3.1.2. Criticism

As mentioned, much of the criticism is focused on the ethical implications of ITQ, though some also concern compliance and the framework of ITQ models. For instance ITQ models assume a single species fishery, in multi-species fisheries the level of effort that is optimal for one species may not be optimal for another. The issue of bycatch[7] also arise within multi-species fisheries, and even with separate quotas for each relevant species and transferability of quotas it will be difficult to perfectly match quotas and harvest. Other contexts where ITQ is an unsuitable management tool are when there are great uncertainties related to determining the TAC at the beginning of the season. This includes situations with unstable stocks[8], flash fisheries[9], fisheries subject to large seasonal variations and fisheries where the catch is residual to a managed escapement target[10] (Copes, 1986).

Illegal and Unreported

With a limited harvest there will always be an incentive to exceed the quota and increase profits, i.e. quota busting. This is a free riding problem where the myopic fisherman may view his excess landings as insignificant to stock if the rest follow the rules. Fishermen with knowledge of cheating colleagues lose the incentive to stay compliant and this may, as with the Bay of Fundy herring fishery, cause the ITQ regime to collapse (Copes, 1986). In order to induce compliance ITQ regimes require rigorous monitoring. The fishermen must be assured that others cannot diminish the value of their rights by fishing illegally, and that any impropriety will be detected

[7]Bycatch is the unintended catch of other species or age-classes when targeting one specific species or age-class.
[8]Stocks of species with highly variable year classes (Copes, 1986).
[9]When the fish has to be caught in a particular condition which only lasts for short periods of time e.g. when the priority of the catch is roe and not the fish itself (Copes, 1986).
[10]Some fisheries may have escapement targets to ensure a sufficient spawning population (Copes, 1986).

and sufficiently penalized. Such monitoring will be costly and the costs of enforcing may be higher than the benefits of IFQ (Anderson, 1995).

Due to the illegality of quota busting, excess landings will generally not be reported and a correlation between the introduction of quota regimes and a decline in data quality have been observed. Consequently the estimates concerning the state of the fishery are less certain and hence there is increased difficulty in determining an appropriate TAC (Copes, 1986).

This consequence also follow from the alternative to quota busting, namely highgrading. When catch is restricted an incentive to obtain the most from the fixed amount arise. In other words the agents are encouraged to fill the quota with only the best quality fish, and less valuable fish are discarded (Copes, 1986). For instance, many species face multiple product prices including one relatively high price per kg for larger sized fish, thus motivating the agents to discard the smaller low quality fish in order to not exceed the quota. Anderson (1994) find that discarding will take place when the price differential between the low and high quality fish is greater than the cost of discarding and replacing the catch. Outlawing discarding, would if properly enforced, increase this cost. Yet, although not always illegal discarding is usually not reported and it contributes to false information, overfishing and diminishing the aggregate net revenue obtainable from the fishery (Copes, 1986). The EU's previous policy on discarding is seen as a major reason for its fisheries crisis and new reforms attempt to slowly illegalise discarding (Grytås, 2014).

The consequences of quota busting and highgrading highlight the important role of monitoring and enforcement in IFQ fisheries. It is evident that the behaviour of fishermen depend on the severity of penalties and the likelihood of detection. However monitoring and enforcement are undoubtedly some of the more difficult aspects relating to ITQ fisheries, especially in fisheries where there are many vessels and points of landing (Copes, 1986). The ITQ regime of British Colombia's groundfish trawl fishery is said to have had significant success. A success which may be attributed to the observer program which require all trawlers to bring on-board observes while at sea (Clark, 2006).

Markets and Transaction Costs

The concentration of quotas may facilitate the emergence of market power (McCay, 1995). As a response to this threat most markets and ITQ regimes are regulated, and the rights are often limited with respect to duration and transferability (Grafton, 1996; Copes, 1986). Such restrictions motivate the argument that advocates of ITQs exaggerate the quality of the rights and thus its potential. Moreover restrictions might generate high transaction costs and 'thin' markets[11] which amplify each other and distorts the outcome. With less transferability the entire TAC may not be caught. If the TAC is set to mark the optimal catch any shortfall will result in a non-optimal catch and distort the optimal biomass (Copes, 1986). Nevertheless, 'thin' markets does not seem to be a problem in neither Iceland nor New Zealand, and in year 2000 the latter had an annual average of 300 transactions in the short-term market and 1500 in the long-term market (Eythórsson, 1996; Newell et al., 2005).

Permanent quota sales often include the vessel, either because they are tied by law as in IVQs or because a high demand for quotas raise the bargaining power of the seller who does not need a vessel which has few alternative usages without the quota. The vessel acts as an transaction cost hindering trade. Moreover, when these goods are bundled together it may be difficult to identify the real quota price and monitor the efficiency of the fishery (McCay, 1995).

Social Issues and Equity

The concentration of rights will strongly affect the social structure of the community, and especially coastal communities which often depend on the resources of the ocean (McCay, 1995). An inherent consequence of reducing excess capacity is the decline in effort and loss of jobs. Many IFQ regimes, including Norway and Iceland has features aimed at protecting the social structure and division of equity, e.g. the trawl ladder and geographical restrictions on trade. Still, in spite of the authorities' efforts to hinder concentration of wealth, a group of quota barons have risen (McCay, 1995; Grytås, 2014; Von Der Fehr, 1993). The moment access to the fishery is restricted the right to fish increase in value. There are huge welfare consequences connected to the distribution of rights and it is often the crew, that lose out. While the crew often contribute to the firm's purchase of more quotas, through deductions in wages, the revenue from selling quotas only accrue to the owners. The suddenly very valuable rights to fish also hinder new entrants, and only the initial generation receiving the rights for free benefits. Future generations collect no resource rents (Grytås, 2014; McCay, 1995; Copes, 1986). Nevertheless, Newell et al. (2005) find that New Zealand had, on average 90 new entrants per year, still there was a net exit from the industry indicating reduced overcapacity.

[11]Thin markets refer to markets with few participants and trades (McCay, 1995).

In Norway, the concentration of rights does not seem to be an issue within the IVQ regime of the coastal fleet. Within the structural quota system of the offshore fleet however, the number of licenses per vessel has increased by approximately 21% since the 1980s (Directorate of Fisheries, 2016)[12]. Kjell Inge Røkke is probably the most 'famous' quota baron in Norway. With about 29 quota factors for cod, his company Havfisk[13] controls about 78% of the licenses for cod trawling. How large share of TAC this amounts to, is more difficult to determine as the cod licenses also contain quotas for haddock and other bycatch species, and the actual size of the quota depends on vessel capacity. Nevertheless, in 2015 Havfisk landed 28 875 tonnes of cod which was 6.9% of the cod landed by Norwegian vessels that year (Grytås, 2014; Havfisk, 2016). With an additional 31 licenses for saithe Havfisk may be regarded as a major actor in the Norwegian fisheries industry.

In the 1990s Iceland were among the most profitable and efficient fisheries in the world. Its quota system was close to a true ITQ regime, and with few barriers to trade the right to fish quickly concentrated between even less hands than in Norway. (Røed, 2013). The TAC share of the 25 largest firms increased from 38.2% in 1984 to 82.6% in 2014/15, with the largest firm increasing its share from 4.1 to 11.9 percent (Matthíasson et al., 2015). During this increase in concentration the ITQs were treated as financial assets and used for mortgage collateral and speculation. In 2002 the value of ITQs were equal to 40% of the country's GDP, but this value was dependent on uncertain future fish stocks. Simultaneously as the subprime mortgage market collapsed, the TAC declined and ITQ had played its role in Iceland's devastating fallout from the 2007/08 financial crisis (Røed, 2013; Durrenberger and Palsson, 2015).

Private or Common Property?

If ITQs are property rights the regime is giving away the right to what used to be a commonly owned resource. Although politicians have claimed the Norwegian IVQ system is far from the private property regime of ITQ, a silent move towards privatisation spurred a debate that would decide the future of the Norwegian marine resources. During the spring of 2005 the Bondevik-II government with Svein Ludvigsen as the minister of fisheries introduced perpetual quotas for the trawlers. The change was supported by the Conservative-, Christian Democratic-, Liberal- and Progress Party, yet the move towards privatisation was not an open process discussed in parliament (Røed, 2013).

[12] Data collected in April 2016.
[13] Formerly Aker Seafoods.

As the second Stoltenberg government entered in the autumn of 2005 the new minister of fisheries Helga Pedersen placed a two year moratorium on all restructuring and quota trade. During these years an assembly was constructed to decide the future of Norwegian fisheries management. The resulting decision was practically a declaration of war; the fish, as a natural resource, belonged to the Norwegian people and could not be perpetual. The duration of the trawl and coastal fleet's quotas were set respectively to 25 and 20 years (Røed, 2013). Restructuring (trade) was once again allowed within the given restrictions, and opened up for a group of smaller vessels.

The trawl owners were not pleased. On the basis of lost income and investment costs hinging upon perpetual quotas Eivind Volstad filed a lawsuit against the state. He claimed the new duration had a retroactive force, breaking §97[14] of the Norwegian Constitution (Lindi and Tomassen, 2013). Volstad won in the Court of Appeal (Jury Courts), but the state appealed the case in the Supreme Court. Here the case was declared so principal that regulation should be changed in accordance with the final decision, hence applying to all those in a situation equivalent to that of Volstad (Røed, 2013; Hersoug, 2005). If Volstad won the Norwegian fish resource would be private property, a property the vessel owners had received free of charge. Within other industries it is commonplace to pay some tax or charge for the exploitation of a common pool resource, yet the Norwegian people had received nothing in payment for the resource they no longer had access to (Røed, 2013).

On the other hand, the resource rent, now accruing to the quota owners is a result of limited access. It is argued its existence is a 'bi-product' of the individual rights as all rents are dissipated within an open access regime. Taxing the quota owners and implicitly transferring the resource rent back to the state and the common is one solution. However it is this income that incentivises the owner to take stock effects and future harvests into account, thus maximising resource rents (Hannesson, 2002). This relates to Anderson et al.'s 2010 argument concerning the dynamic efficiency of grandfathered and auctioned quotas.

The state won with nine against eight votes (Røed, 2013). Volstad attempted to appeal the case in the European Court of Human Rights, but his request was denied, thus the official position is that the fish belong to the Norwegian common (Stige, 2015; Øyehaug, 2015). Despite

[14]§97 state that no law can have retroactive effect (Lovdata, 2016).

this, many quota owners consider their rights, for all intents and purposes to be perpetual. The quotas are supposed to be transferred back to the sate after 20 and 25 years, though most are sold before this, starting a new 20-25 year period. The current Solberg administration, then with Elisabeth Aspaker as minister of fisheries, said the decision of the Supreme Court did not restrict the administrations structuring politics and both the Conservative- and the Progress party base their policies on perpetual structural quotas (Røed, 2013). Moreover, if the resource for all practical purposes is privatised, why should Norwegian tax payers continue to pay for the research contributing towards ecologically sustainable management?

The Icelandic quotas also reached Supreme Court, albeit on a different claim. The Court claimed the resource still was national property and the decision only a technical matter for tax purposes, yet the ITQs were declared private property (Eythórsson, 1996).

Seeing as all ITQ regimes differs to such a great extent it is futile to attempt a conclusion concerning the property right status of ITQ. However the observations indicate that many of the industry's participants act as though they are or should be private property rights.

3.1.3. State Control or Privatisation, Not Just Either or

Behind the prediction that resource users inevitably will overexploit a common pool resource lies the assumption that all individuals are rational. The assumption entails a self-interested individual who, in the global perspective has a relatively high discount rate, i.e. he maximises short term interests. Moreover, the rational agent is norm free (Ostrom et al., 1999).

Ostrom (1990) have pioneered the research on local common resources and find that some communities have managed to escape the tragedy of the commons. In a relatively small inshore fishery in Alanya, Turkey, self-governed common property arrangements became the solution to a string of violent conflicts, increasing production costs and rising uncertainty concerning future harvest potential. All of which were brought about by unrestricted resource use. There emerged a lottery style management regime in which the rules were constructed, as well as monitored and enforced by the fishermen themselves (Ostrom, 1990). It is the self interest of the participants that drive them to enforce the contract, monitor each other and to report observed violations. Contrarily, the authority system protecting individual property rights need to hire monitors and thus encounter the principal-agent problem of ensuring that the monitors are sufficient at their jobs. Moreover a central authority will have more trouble, than a local community, in accurately estimating the carrying capacity of a resource and the appropriate penalties to induce cooperative behaviour (Ostrom, 1990). The case of Alanya show that if optimal, a system resembling that of ITQs might emerge within the common, and that without the need to grant individual property rights (Ostrom, 1990)

Even well-defined common property regimes require consensus among all the co-owners. Without this, the economic and non-economic incentives that encourage compliance and self enforcement fall through. The cost of bargaining and reaching an agreement increase with the number of co-owners and might be the root of a tragedy (Bromley, 1991). There are certain factors both external and internal to the group which affect whether or not a local common will succeed in managing a resource in an efficient and sustainable manner. There are in particular three essential internal features. The first relates to the group's capacity to communicate, where frequent face to face communication is seen to increase the possibility of a well functioning common property management regime. This also relates to the second aspect which concerns the group's ability to develop trust. Finally there should be a perception that the group share a common future. For instance, this include cases where, say, an entire community is heavily dependent on the economic return of the resource and thus they are motivated to cooperate and act in the long-term interest of the community (Ostrom, 1990). Thus it is argued that a common property management regime is viable in cases where the resource is located within one country and the number of participants is relatively small. This is supported by coalition models, in which a stable beneficial coalition can only be reached when there are few relevant parties (Barrett, 1994).

The total Norwegian marine resources that make up the Norwegian common may be too large to be able to reach an efficient solution on the basis of negotiations. Yet, a case could be made for dividing up this common by granting rights or individual quotas to coastal communities within which a sustainable and efficient local common property regime might emerge. Such a system may be found in certain Alaskan fisheries and was in fact considered for the Norwegian coastal fleet when the 1989/90 cod crisis called for regime change (Hersoug, 2005; NOAA, 2016).

4. The Benchmark Model

Consider a single species fishery with an appropriately set TAC. The following model is a static biomass model[1] which assumes perfect information and no within-season variation in stock. In contrast to the standard Gordon-Schafer model, this model studies the fishery at the agent level, and the exogenous number of fishermen[2] n, are all assumed to myopic price takers. The individual profit function is

$$\pi_i(h_i, E) = Ph_i - C_i(E_i)E_i \quad \forall i = 1, 2, ..., n. \tag{4.1}$$

P (NOK/ton) is the landing price of fish, $C_i(E_i)$ the unit cost of effort and h_i the harvest in tonnes. Harvest is given by the Schaefer harvesting function $h_i = E_i q_i x$ where x is stock, and E_i and q_i the effort and catchability of agent i. Instead of Gordon-Schaefer's cost function which is linear in effort this model applies a convex cost function inspired by Péreau et al. (2012) and Clark (2006), in combination with a linear revenue function. The convexity is necessary for a well defined maximisation problem and simply an alternative to the standard Gordon-Schaefer setup. Specifically, the unit cost of effort is increasing in effort $C_i(E_i) = \frac{\hat{c}_i}{2}E_i$. The parameter $\hat{c}_i$ is positive and given. With h_i as the model's strategic variable total harvesting cost of agent i is specified as

$$C_i(h_i, x) = \frac{\hat{c}_i}{2}\left(\frac{h_i}{q_i x}\right)^2. \tag{4.2}$$

The benchmark model will be a point of reference throughout the thesis.

4.1. The Social Planner Solution

In the benchmark scenario where price (P) is given, the social planner solution is equivalent to maximising total profits, subject to the constraint that total harvest cannot exceed the TAC (denoted by Q). Assuming the social planner trusts the TAC is set appropriately stock is not considered, and the decision problem is

$$\max_{h_1, h_2, ..., h_n} \sum_{i=1}^{n} \Pi_i(h_i, x) = \sum_{i=1}^{n} \Big(Ph_i - C_i(h_i, x)\Big), \; s.t. \sum_{i=1}^{n} h_i \leq Q. \tag{4.3}$$

[1]The use of a biomass model implies that the age or demographic structure of the population is not explicitly considered (Inarra and Skonhoft, 2008).

[2]Please note that the terms agent, fisher, fisherman and vessel are used interchangeably.

With λ as the shadow price of the constraint and the first order derivative denoted as $\frac{\partial C_i}{\partial h_i} = C_{ih_i}$, the first order condition (FOC) is

$$P - C_{ih_i} \leq \lambda \quad , h_i \geq, 0 \quad \forall i = 1, 2, ..., n. \tag{4.4}$$

When the condition holds with equality, i.e. $h_i > 0$ the optimum allocation of harvesting is characterised by the equi-marginal prinicple. The equi-marginal principle is a requirement for cost-efficiency and is fulfilled when marginal cost is equalised across all agents. Here this holds given that all agents are price takers in the product market.

$$C_{1h_1} = C_{2h_2} = ... = C_{nh_n}, \ \forall h_i > 0, \tag{4.5}$$

or

$$\frac{\partial \Pi_1}{\partial h_1} = \frac{\partial \Pi_2}{\partial h_2} = ... = \frac{\partial \Pi_n}{\partial h_n} = \lambda, \ \forall h_i > 0. \tag{4.6}$$

The shadow price λ may be interpreted as the cost (benefit) of reducing (increasing) the constraint by one unit. A positive shadow price illustrate the scarcity of the resource and in optimum it is equal to the marginal net benefit of harvesting, which represents the resource rent. One may also regard λ as the opportunity cost of fishing and when this exceeds marginal net benefit the agent will find it unprofitable to continue fishing. Moreover, λ is equivalent to the pigou tax that would internalise the externality of open access behaviour (Clark, 1990). With a renewable resource such as fish, the aim is to maintain some stable population size, e.g. x^{MSY}, and quantity regulation is preferred as price regulation is exposed to volatile quantities (Tietenberg, 2001).

With the above optimality condition and the specified cost function, in which marginal cost is $C_{ih_i} = \frac{\hat{c}_i}{(q_i x)^2} h_i$, each agent's optimal harvest is

$$h_i = \begin{cases} \frac{(q_i x)^2}{\hat{c}_i}(P - \lambda), & \text{if } P - C_{ih_i} = \lambda \\ 0, & \text{if } P - C_{ih_i} < \lambda. \end{cases} \tag{4.7}$$

When the constraint does not bind the shadow price is equal to zero ($\lambda = 0$) and optimal harvest of the price taking agent (4.8) is equivalent to that of a restricted open access regime, in which each agent harvest until price equal marginal cost ($P = C_{ih_i}$). Still assuming P is given this solution also fulfill the equi-marginal principle for cost-efficiency.

$$h_i = \frac{(q_i x)^2 P}{\hat{c}_i}. \tag{4.8}$$

The theoretical conditions of such a situation may not be realistically applicable as it implies an exsessively large TAC or marginal cost[3], making it unprofitable to harvest the entire TAC.

4.2. ITQ

The government introduce ITQ as a management regime with $Q = TAC$ as the total supply of quota. $\tilde{Q}_i$ is the amount of quota, measured in tonnes, initially allocated to agent i for free (e.g. with grandfathering as mentioned in section 3.1.1). The market for quotas is assumed to be unregulated implying that there are no restrictions on quota trade. The myopic agents are assumed to be price takers in both the product and quota market. They are also assumed to be compliant, i.e. their harvest do not exceed their quota. With m as the quota price in the short-term market the decision problem of the agent is

$$\max_{h_i \geq 0} \; \pi_i(h_i, x) = Ph_i - C_i(h_i, x) - m(h_i - \tilde{Q}_i), \quad \forall i = 1, 2, ..., n. \tag{4.9}$$

An optimal outcome is conditioned upon the FOC.

$$P - C_{ih_i} \leq m \quad , h_i \geq 0. \tag{4.10}$$

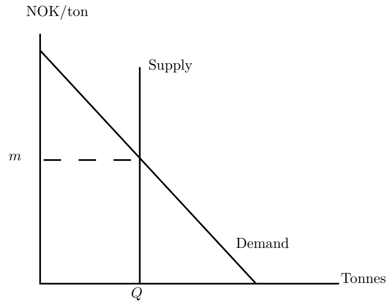
Provided that the fishermen are heterogeneous with respect to their marginal cost, or initial quota endowment, a market for quotas will arise. All trades are assumed to take place at the beginning of the period, and whenever $h_i > (<) \tilde{Q}_i$ the agent is a net buyer (seller) of quotas. Some might find it more profitable to sell all their rights and leave the industry (i.e. $P - C_{ih_i} < m$ with $h_i = 0$) (Grafton, 1996). The remaining agents will trade and adjust so that the marginal net benefit equal the opportunity cost of fishing, now represented by the quota price m. Concurrently the outcome fulfill the requirement of the equi-marginal principle for efficiency and, quite similar to the social planner solution, optimal harvest is

$$h_i = \begin{cases} \frac{(q_i x)^2}{\hat{c}_i}(P - m), & \text{if } P - C_{ih_i} = m \\ 0, & \text{if } P - C_{ih_i} < m. \end{cases} \tag{4.11}$$

[3] A high marginal cost of harvesting may be driven by a a large $\hat{c}_i$, a small stock x or low catchability.

With the assumption that the entire TAC is caught, the market clearing condition ($\sum_{i=1}^{n} h_i = Q$) must hold. Applying this, and the assumption of an interior solution, the quota price may be expressed as a function of total quantity (Q) and stock.

Figure 4.1.: The quota market equilibrium



$$m(Q,x) = P - \frac{Q}{\sum_{i=1}^{n} \frac{(q_i x)^2}{\hat{c}_i}}. \tag{4.12}$$

Because the quota price mimic the marginal net benefit of the industry it will increase with the price of fish ($\frac{\partial m}{\partial P} > 0$), and decrease with the unit cost of fishing ($\frac{\partial m}{\partial \hat{c}_i} < 0$). Additionally the larger the TAC (the supply of quota), the lower the quota price ($\frac{\partial m}{\partial Q} < 0$). The more agents in the industry, the higher is the competition, the demand for quota, and thus quota price ($\frac{\partial m}{\partial n} > 0$). The positive effect of stock ($\frac{\partial m}{\partial x} > 0$) follows from that for a given quota a larger stock implies less effort is required to catch a given harvest, h_i, creating an incentive to buy more quotas thus increasing the demand for quotas and raising the price (Péreau et al., 2012).

Combining the harvesting expression for an interior solution (4.11) and the market clearing price (4.12) it is now possible to solve for the reduced form expression for harvesting.

$$h_i = Q \frac{\frac{q_i^2}{\hat{c}_i}}{\sum_{i=1}^{n} \frac{q_i^2}{\hat{c}_i}}. \tag{4.13}$$

From the reduced form expression, it is clear that the allocation of harvesting is, as expected, independent from initial quota endowment $\tilde{Q}_i$. Moreover, as the agents are price takers in both the product and quota market both P and m are given, and from (4.11) it follows that the equi-marginal principle holds. Consequently ITQ is cost-effective, regardless of the initial allocation of quotas.

The initial allocation of quotas does however have equity effects. It is evident that even though the agents may receive their initial quotas free of charge they do embody exclusive rights to a profitable resource and thus have large values attached (Grafton et al., 2000). The equity effects of being a net buyer or seller will depend on the agent's cost efficiency relative to others, as well as the initial allocation of quotas.

Comparative Statics

If all agents are homogeneous it follows from (4.13) that all receive equal fractions of the quota

$$h = \frac{Q}{n}. \tag{4.14}$$

Concurrently the harvesting level of each agent decline with the number of fishing vessels ($\frac{\partial h}{\partial n} < 0$) and increase with the TAC ($\frac{\partial h}{\partial Q} > 0$). In the more realistic case of heterogeneous agents (4.13) harvest is determined by the marginal harvesting cost of agent i relative to that of the other agents. The harvest of agent i is negatively dependent on its own costs ($\frac{\partial h_i}{\partial \hat{c}_i} < 0$). This is easily illustrated in the case of two agents where the harvest of agent i is given by

$$h_i = Q\frac{\frac{\hat{c}_j}{q_j^2}}{\frac{\hat{c}_i}{q_i^2} + \frac{\hat{c}_j}{q_j^2}}, \ \forall i = 1,2 \ \ i \neq j. \tag{4.15}$$

With $\hat{c}_i/q_i$ defined as efficiency as in Clark (1990), the more efficient agent i becomes compared to agent j more of the quota agent i will harvest.

The reduced form expression for harvesting does not depend upon the price of fish, (P). This may be explained by the fact that while the decision to stay in the industry given by (4.11) depends on the price of fish, the distribution of quotas once the agent has decided to harvest only depends on relative cost levels.

5. Market Power in the Product Market

In the product market all the agents are sellers, suppliers of the product fish. The agents have market power when they realise they face a downward sloping demand curve and can affect price through their choice of the quantity supplied. It is argued that tradable permits are the perfect instrument for monopolisation as they often result in a concentration of production and restrict the entry of new agents (Von Der Fehr, 1993). A key aspect of ITQs is that they are output quotas and thus entail a share of the product market (Hatcher, 2012). It follows that market power in the quota market may carry through to market power in the output market. The case of simultaneous market power in ITQ fisheries is to some extent examined by Hatcher (2012). In spite of this connection I assume market power is already established and will for simplicity look at a situation in which the agents only have market power in the product market, i.e. they are price takers in the quota market.

Given that they choose to exert their market power the strategies available to each agent are the harvesting levels h_i. The price of fish is defined as a function of supply, $P = P(\sum_{i=1}^{n} h_i)$ (Gibbons, 1992). More specifically inverse demand is assumed to be linear and given by (5.1) in which a is the choke price and b the slope parameter.

$$P(\sum_{i=1}^{n} h_i) = a - b\Big(\sum_{i=1}^{n} h_i\Big). \tag{5.1}$$

In ITQ fisheries total quantity is fixed and equal to the TAC. Consequently price is exogenously determined and in order to introduce market power the assumption that the entire quota is caught must be relaxed. This might be the case when the TAC is excessive. Formally it implies the problem is now subject to the constraint $\sum_{i=1}^{n} h_i \leq Q$ rather than $\sum_{i=1}^{n} h_i = Q$. There are four scenarios under which we can imagine this condition not to hold with equality. Firstly there is the case where the TAC is excessive and there for all practical purposes is no quota restraint, i.e. the TAC is set above the profit maximising amount of output and $m = 0$ (Anderson, 2008). Secondly the agents can choose to strategically catch less and hold excess quota or keep frozen fish off the market. The third scenario entail a series of unforseen exogenous events such as bad weather, damages to the vessel or poor environmental conditions which may result in the agents simply not having enough time to catch or sell their entire quota that year. Lastly with a combination of poor enforcement and a 'non-compliance culture' the agents may not feel restricted by the TAC, a situation which intuitively resembles the first scenario.

Seeing as catchability q_i always operates coincidentally with cost, the cost parameter will for simplicity be redefined as $c_i = \frac{\hat{c}_i}{q_i^2}$ for the remainder of the thesis. All else remain.

5.1. The Social Planner Solution

Taking the optimal price $P(\sum\limits_{i=1}^{n} h_i^*)$ as given, the social planner maximise social surplus, i.e. the sum of consumer and producer surplus[1].

$$\max_{h_1,h_2,\ldots,h_n} \int\limits_0^{\sum_{i=1}^{n} h_i^*} P(\sum_{i=1}^{n} h_i)\, d\Sigma h_i - \sum_{i=1}^{n} C_i(h_i, x), \text{ s.t. } \sum_{i=1}^{n} h_i \leq Q. \tag{5.2}$$

The following scenarios emerge from the FOCs of maximisation

$$h_i = \begin{cases} \frac{x^2(a-\lambda-bh_{-i})}{bx^2+c_i}, & \text{if } \sum\limits_{i=1}^{n} h_i = Q,\ \lambda > 0,\ P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} = \lambda \\ 0, & \text{if } \sum\limits_{i=1}^{n} h_i \leq Q,\ \lambda \geq 0,\ P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} < \lambda \\ \frac{x^2(a-bh_{-i})}{bx^2+c_i}, & \text{if } \sum\limits_{i=1}^{n} h_i < Q,\ \lambda = 0,\ P(\sum\limits_{i=1}^{n} h_i) = C_{ih_i}. \end{cases} \tag{5.3}$$

Assuming all agents are homogeneous ($c_i = c_j = c$, $\forall i \neq j$)[2] and an interior solution (i.e. $h > 0$), the individual agent's socially optimal harvesting level may be expressed as a function of the shadow price.

$$h^* = \frac{x^2(a-\lambda)}{nbx^2 + c}, \text{ with } \lambda \geq 0. \tag{5.4}$$

Heterogeneity is illustrated with a case of two agents, here the socially optimum harvesting of agent i is given by

$$h_i^* = \frac{x^2 c_j (a-\lambda)}{(bx^2+c_i)(bx^2+c_j) - (bx^2)^2}, \text{ with } \lambda \geq 0,\ \forall i = 1,2 \ \&\ i \neq j. \tag{5.5}$$

For future reference, let $\sum_{i=1}^{n} h_i^* = Q$ denote the case in which the constraint binds and it is optimal to harvest the entire TAC ($\lambda > 0$), whereas $\sum_{i=1}^{n} h_i^* < Q$ denotes the case where the

[1] The complete calculation can be found in appendix C.

[2] From here the use of subscripts i and j will denote the possibility of heterogeneity, whereas no subscript denote homogeneity.

TAC is set above the optimal aggregated harvest ($\lambda = 0$).

Efficiency

The social planner solution is cost-efficient, regardless of whether or not the constraint binds. This may be verified with the equi-marginal requirement for efficiency $\frac{\partial C_i}{\partial h_i} = \frac{\partial C_j}{\partial h_j}$, which holds for both the homogeneous case with n agents[3] and the heterogeneous scenario[4]. Consequently, the social planner solution is always cost-effective.

5.2. Cournot Competition

Inherent in the biomass model is the assumption of product homogeneity, and with the harvest commonly sold at auctions it is reasonable to expect price to be determined by the quantity available (NOU, 2014). Consequently quantity is the natural strategic variable, and the Cournot model of quantity competition a suitable framework for market power within the product market of ITQ managed fisheries.

Note that the choice of model and strategic variable greatly dictate the outcome within an oligopoly. While the Cournot equilibrium approaches the competitive equilibrium as n approaches infinity, the Bertrand equilibrium of price competition is identical to that of perfect competition (Gibbons, 1992). Hence, a second reason for choosing Cournot agents is that Bertrand competition will immediately yield the same results as the benchmark model discussed above, and is thus of less interest. In the classical Cournot game the agents choose their harvesting levels simultaneously. Market power could also be analysed within the dynamic Stackelberg model, though this is more relevant when one agent holds a dominant position, e.g. as the sole owner of quotas or vessels, which the remaining agents have to lease. The choice between these will however, apart from the expected differences, not have major implications for the interpretation (Dockner, 1989; Gibbons, 1992).

The Cournot agent's maximisation problem is

$$\max_{h_i \geq 0} \ \pi_i(h_i, x) = P(\sum_{i=1}^{n} h_i)h_i - C_i(h_i, x) - m(h_i - \tilde{Q}_i), \ \forall \ i = 1, 2, ..., n. \tag{5.6}$$

[3] $\frac{\partial C_i}{\partial h_i} = \frac{\partial C_j}{\partial h_j} \implies \frac{c}{x^2}\frac{x^2(a-\lambda)}{nbx^2+c} = \frac{c}{x^2}\frac{x^2(a-\lambda)}{nbx^2+c}$, $\forall i = 1, 2, ..., n$ & $i \neq j$.

[4] $\frac{\partial C_1}{\partial h_1} = \frac{\partial C_2}{\partial h_2} \implies \frac{c_1}{x^2}\frac{x^2 c_2(a-\lambda)}{(bx^2+c_1)(bx^2+c_2)-(bx^2)^2} = \frac{c_2}{x^2}\frac{x^2 c_1(a-\lambda)}{(bx^2+c_1)(bx^2+c_2)-(bx^2)^2}$.

With h_{-i} denoting all agents except i (i.e. the remaining $n-1$), the FOC yields the individual harvesting level for the n fishermen. There are two distinct scenarios; one in which the social planner's aggregated constraint binds ($\sum_{i=1}^{n} h_i^* = Q$) and one in which it does not ($\sum_{i=1}^{n} h_i^* < Q$). In the first case the agents may choose to exercise their market power such that aggregated harvest is less than the TAC, or they may harvest the entire TAC allowing the price of fish to be exogenously determined. A nonbinding constraint implies a quota price of zero and it is assumed the agents always exercise their market power when the constraint does not bind.

$$h_i = \begin{cases} \frac{x^2(a-m-bh_{-i})}{2bx^2+c_i}, & \text{if } P_{h_i}h_i + P(\sum_{i=1}^{n} h_i) - C_{ih_i} = m > 0 \\ 0, & \text{if } P_{h_i}h_i + P(\sum_{i=1}^{n} h_i) - C_{ih_i} < m \geq 0 \\ \frac{x^2(a-bh_{-i})}{2bx^2+c_i}, & \text{if } P_{h_i}h_i + P(\sum_{i=1}^{n} h_i) = C_{ih_i},\ m = 0. \end{cases} \tag{5.7}$$

Assuming homogeneous agents and an interior solution, harvesting with the subscript C for Cournot, can be expressed as

$$h^C = \frac{x^2(a-m)}{b(1+n)x^2+c}, \text{ with } m \geq 0. \tag{5.8}$$

The solution is a Nash equilibrium as no agent has an incentive to unilaterally choose another harvesting level (Gibbons, 1992). Given that the constraint binds the market clearing condition may be used to find an expression for the quota price. While the general market clearing condition is $\sum_{i=1}^{n} h_i = Q$, the possibility of market power implies $\sum_{i=1}^{n} h_i^C \leq Q$ and thus only partial solutions can be found.

$$m^C(Q,x,n) \geq a - \frac{Q}{n}\frac{b(1+n)x^2+c}{x^2}. \tag{5.9}$$

The expression holds with equality when the agents choose not to exert market power. Concurrently the quota price is greater when the agents choose to do so, i.e. land less than the TAC. When quotas are retained, price increase with the decline in supply. Intuitively price also rise because the harvest of each quota has become more valuable in product market. The reduced form harvesting level is simply

$$h^C \leq \frac{Q}{n}. \tag{5.10}$$

When this holds with equality this is equivalent to the benchmark case of homogeneous agents, (4.14). Stating the obvious $P \geq a - b(Q)$, as aggregated harvest may be less than Q. The expression will only hold with equality when market power is not exercised. With market power the harvest will fall behind, while quota and product price will exceed the benchmark case.

5.2.1. A Cournot Duopoly

Consider a duopoly consisting of two heterogeneous agents. The decision problem of agent i is given by (5.6). Following the same procedures as above the optimal harvest of agent i may be expressed as a function of quota price. In the event that the aggregated constraint does not bind the quota price m in the following expression would equal zero.

$$h_i^C = \frac{x^2\big(bx^2+c_j\big)}{(2bx^2+c_i)(2bx^2+c_j)-(bx^2)^2}(a-m),\ \forall i=1,2\ \&i\neq j,\ \ \text{with } m\geq 0. \tag{5.11}$$

The associated quota price, and reduced form harvest is found by applying $h_1^C + h_2^C \leq Q$.

$$m^C(Q,x) \geq a - Q\left(\frac{(2bx^2+c_1)(2bx^2+c_2)-(bx^2)^2}{x^2\big(2bx^2+c_2+c_1\big)}\right), \tag{5.12}$$

$$h_i^C \leq Q\frac{bx^2+c_j}{2bx^2+c_j+c_i}. \tag{5.13}$$

Similarly to (5.9) and (5.10) the expressions hold with equality when market power is not exercised, and inequality when market power is exercised.

5.2.2. Comparative Statics

From the duopoly quota price expression (5.12) it is evident that m is symmetric with respect to the two agents' cost levels. As cost heterogeneity is the fundamental difference between the two quota price expressions(5.9) and (5.12), I assume the duopoly quota price will behave similarly to homogeneous case and will for simplicity be using (5.9) for the analysis of m with respect to a change in any of the relevant parameters.

As the quota price expression may hold with an inequality only three of the effects are definitely positive, i.e. $\frac{\partial m}{\partial n} > 0, \frac{\partial m}{\partial x} > 0$ and $\frac{\partial m}{\partial a} > 0$. These are equivalent to the benchmark model, with a mimicking the role of the exogenous price of fish (P). The marginal effect of cost[5] and total quantity[6] cannot be determined with certainty, but intuitively these should be negative,

[5] $\frac{\partial m}{\partial c} \geq -\frac{Q}{nx^2}$.
[6] $\frac{\partial m}{\partial Q} \geq -\frac{b(1+n)x^2+c}{nx^2}$.

as in the benchmark model. Similarly the effect of the slope parameter b[7] should be negative, though no definite answer can be determined. The steeper the demand curve, the smaller the price ($P(\sum_{i=1}^{n} h_i)$) of fish for a given total harvest which result in less earnings from a given quota and thus the agents are willing to pay less for quotas.

For the harvest, the benchmark comparative statics concerning cost still apply, ($\frac{\partial h_i}{\partial c_i} < 0$ and $\frac{\partial h_i}{\partial c_j} > 0$). With two homogeneous agents it is still optimal for each to harvest half the TAC. In the event that at least one agent exercise their market power total landings will be less than the TAC. With heterogeneous agents the additional terms (bx^2 and $2bx^2$) dampen the effect of any cost differences. In other words, in the presence of market power heterogeneous costs have less effect on the final distribution of quotas and harvesting, than in the absence of market power. Yet, with a sufficiently high c_j agent j will leave the industry ($h_j = 0$) and agent i will have monopoly power.

With a downward sloping demand curve the agents' harvesting level will depend on the slope parameter b.

$$\frac{\partial h_i^C}{\partial b} \leq Q\frac{x^2(c_i - c_j)}{(2bx^2 + c_j + c_i)^2}. \tag{5.14}$$

Whenever there is market power, the quantity supplied is less than optimal and as expected the marginal effect of a downward sloping demand curve is definitely negative for agent i's harvest when agent i has a cost advantage. If agent j has the cost advantage the effect of b upon agent i's harvest cannot be determined unless the entire TAC is harvested, at which point the effect is positive. With homogeneous cost the effect is definitely negative when market power is exercised and quite naturally zero when the agents do not exert market power.

Contrary to the benchmark model, the reduced form Cournot harvesting level depend on stock.

$$\frac{\partial h_i^C}{\partial x} \leq Q\frac{2bx\big(c_i - c_j\big)}{\big(2bx^2 + c_i + c_j\big)^2}. \tag{5.15}$$

The interpretation is equivalent to that of (5.14). For instance, stock has a definite negative effect upon the harvesting levels of agent i if he has the cost advantage. Additionally the case of homogeneous costs yield a negative or zero effect. While an increase in stock initially reduce the marginal cost of harvesting the adverse effect of stock upon harvesting may follow from the increased quota price ($\frac{\partial m}{\partial x} > 0$).

[7] $\frac{\partial m}{\partial b} \geq -\frac{Q(1+n)x^2+c}{nx^2}$.

5.2.3. Efficiency

In general there are six different scenarios that may have various efficiency implications, these are summarised in table 5.1. In the event that the Cournot agents are homogeneous the harvesting levels (5.8) and (5.10) fulfill the requirement for cost efficiency. This is corroborated by the duopoly harvesting level which is only efficient if $c_i = c_j$. With heterogeneous costs $\frac{\partial C_i}{\partial h_i} \neq \frac{\partial C_j}{\partial h_j}$, $\forall i \neq j$. Consequently the total harvest may be harvested in a cost efficient manner when the Cournot agents are homogeneous, but never when they are heterogeneous.

Table 5.1.: Cournot harvesting levels

	Homogeneous costs		Heterogeneous costs	
	Market power		Market power	
	Exercised	Not exercised	Exercised	Not exercised
$\sum_{i=1}^{n} h_i^* = Q$	$h^C < \frac{Q}{n}$	$h^C = \frac{Q}{n}$	$h_i^C < Q\frac{bx^2+c_j}{2bx^2+c_j+c_i}$	$h_i^C = Q\frac{bx^2+c_j}{2bx^2+c_j+c_i}$
$\sum_{i=1}^{n} h_i^* < Q$	$h^C = \frac{x^2 a}{b(1+n)x^2+c}$	n/a	$h_i^C = \frac{x^2(bx^2+c_j)a}{(2bx^2+c_i)(2bx^2+c_j)-(bx^2)^2}$	n/a

First consider the case in which the agents exercise their market power. In general it is expected that $h_i^C < h_i^*$[8] and $h^C < h_i^*$, thus the aggregated Cournot harvest will be less than optimal regardless of homogeneity ($\sum_{i=1}^{n} h_i^C < \sum_{i=1}^{n} h_i^* \leq Q$) (Gibbons, 1992). At this point there are two scenarios to examine, one in which the constraint binds ($\sum_{i=1}^{n} h_i^* = Q$) and one in which it does not ($\sum_{i=1}^{n} h_i^* < Q$). The two scenarios are separated by the fact that while the agents in the latter case maximise own profits, given the competitors' best response functions, the agents in the first scenario harvest (supply) less than their individual profit maximising levels.

When the constraint binds the agents may choose to not exercise their market power, that is when (5.13) and (5.10) holds with equality and $\sum_{i=1}^{n} h_i^C = Q$. At this point the optimal aggregated harvesting level (the TAC) is attained, but with heterogeneous costs it is reached in an inefficient manner.

Unless the agents harvest less than the TAC there is (for all practical purposes) no market power and price will be exogenously determined by the TAC. Analogous to the results of Anderson (2008) who studied ITQ fisheries with dual market power, the Cournot solution is, regardless of

[8] This is conditioned upon $2bx^2 c_j + 2c_j^2 > bx^2 c_i + c_j$, which is reasonable unless agent j has a significant cost advantage.

homogeneity, only optimal for the agent when the TAC is sufficiently large. While the harvest may be distributed in a cost effective manner with homogeneous agents, the Cournot solution will never be cost efficient when agents are heterogeneous. Thus there is one scenario which coincide with the social optimum, when the constraint binds and the homogeneous agents choose to not exercise their market power, i.e. $h^c = \frac{Q}{n}$, which is equivalent to the efficient benchmark scenario, (4.14).

Whether they choose to exercise their power or not, the final distribution of quotas however, remain independent of the initial allocation. Consequently market power in the product market do not present a problem in relation to how the quota should be distributed.

6. Market Power in the Quota Market

Due to the large number of emitters Tietenberg (1985; 2003; 2001) argues that market power is unlikely to be a significant problem within emission permit markets. He is supported by the numerical analysis carried our by Maeda (2003). Inspired by the UK electricity industry which, if regulated by a cap-and-trade program, would consist of relatively few agents, Von Der Fehr (1993) suggest that strategic manipulation could be more problematic in relatively local permit markets. With his study of oligopolistic interaction within markets for tradable emission rights Von Der Fehr (1993) find monopolisation to be more likely when permits are essential to production. With an ITQ regime quotas are necessary in order to participate in the fishery and when regulations are nonexistent or inadequate, the concentration of quotas inherent in ITQ regimes may facilitate the emergence of market power (Tietenberg, 1995). Many of the world's fisheries, especially inshore ones, may generate relatively local permit markets. Considering that there only are 37 licenses (29 of which is controlled by one company) for Norwegian cod trawlers and that 25 firms control 82.6% of the Icelandic quotas, market power may be a realistic problem within ITQ managed fisheries (Directorate of Fisheries, 2016; Matthíasson et al., 2015).

In the quota market, market power may be exerted as a means towards gaining power in the related output market (Tietenberg, 1985). This relates to dual market power and theories on raising rival's costs, which generates the possibility of dominant agents' withholding quotas to raise product price (Tietenberg, 1985; Hatcher, 2012). In the case where separately regulated fisheries all sell their products in a global market for fish, there might not be an opportunity to gain dual market power (Hatcher, 2012). This is the scenario I consider, and thus I assume the dominant agent is a price taker in the product market and only has the ability to manipulate the quota price.

6.1. A Dominant Firm Price Leadership Model

I apply Hahn's (1984) model of market power in the quota market to the fishery presented in the benchmark model. The quota price is set by the dominant agent, agent 1. The remaining firms, i.e. $2, ..., n$, are all price takers and may be identified as a competitive fringe. Moreover as Hahn (1984, p.745) specifies, the agents "are allowed to trade permits in a market that lasts for one period", thus in the case of ITQ this model is mainly applicable to the short-term quota market. All agents are price takers in the product market, i.e. P is given. To simplify, this model returns to the earlier assumption that the entire TAC is caught, in other words the aggregate constraint binds. Moreover, assuming that all agents are compliant, an agent's demand for quota is equivalent to the agent's harvesting level.

6.1.1. Strategic Variable

The model is structured as a two-stage game and solved with backward induction. First the market leader, agent 1, choose the quota price (m) that maximises his profits. Then the competitive fringe take quota price as given and maximise with respect to their harvesting levels. The framework resembles that of a Stackelberg model, but the rivals are viewed as competitive, not Cournot players. Additionally, price is the leader's strategic variable. These are obvious deviations from the Stackelberg model and this model more closely illustrates that of the dominant firm price leadership model (Schenzler et al., 1992).

In the dominant firm price leadership model the market is split between one dominant firm who moves first and a competitive fringe that moves second. The dominant firm behaves as if it were a monopolist, albeit subject to the residual demand curve[1]. The fringe, acting as price takers, will accept the price set by the leader (Tasnádi, 2010). In general the fringe limits the market power of the leader and the equilibrium outcome in dominant firm markets will lie somewhere between that of perfect competition and complete monopoly power (Schenzler et al., 1992).

My choice of price as the dominant agent's strategic variable mainly rests on the result that with quantity as choice variable it is necessary to specify the functional form of the quota price ex ante, in order to explicitly solve for harvesting levels. With price as the leader's strategic variable a specified cost function is sufficient to solve for the agents' quota demand and respective harvesting levels.

This choice however, should not have major implications on the results or their interpretation. While Hahn (1984) used price as strategic variable for the dominant firm, both Westskog (1994) and Hatcher (2012) used quantity and yet, they all found similar results. Within oligopolistic markets the choice between a Cournot or Bertrand game have major implications on the final

[1] The residual demand curve is the market demand less the quantity supplied by the fringe. This is later formalised as $h_1 = Q - \sum_{i=2}^{n} h_i(m)$.

price and quantity outcome. In a monopoly situation the outcome is the same whether price or quantity is the strategic variable. It seems that under certain conditions a dominant price leadership model, in which the dominant agent either acts as a monopolist (monopsonist), approximate that of the true monopolist (monopolist) and thus the choice of strategic variable has little implication. This is supported by the studies of Sadanand and Sadanand (1996) and Tasnádi (2010)[2]. Do note that my case differs from the dominant firm price leadership model by the fact that total quantity is fixed. It may also be noted that while Westskog (1994) had multiple leaders acting as Cournot agents I have found no equivalent study where a group of leaders use price as strategic variable. Similarly to a Bertrand model such a framework might be expected to yield deviating results.

6.1.2. The Decision Problem

In the second stage of the game the competitive fringe maximises individual profits.

$$\underset{h_i}{max}\ \pi_i = Ph_i - C_i(h_i, x) - m(h_i - \tilde{Q}_i),\ \forall\, i = 2, ..., n. \tag{6.1}$$

This is equivalent to the benchmark model where the first order condition for a maximum implies the standard optimality condition

$$P - C_{ih_i} \leq m,\ h_i \geq 0. \tag{6.2}$$

Assuming an interior solution, the FOC implicitly defines the price takers' demand for harvest and thus quota, $h_i = h_i(m, x)$. As in Hahn (1984), quota demand is downward sloping in price for $i = 2, ..., n$, ($h_{im} < 0$).

In the game's first stage the dominant agent maximise profits with respect to quota price, and subject to residual demand or equivalently the constraint that the market clear. The structure of the residual demand curve is important in determining the extent to which the leader can exert market power. If the fringe's demand for (supply of) quota is inelastic there is a possibility for complete monopoly (monopsony) power. In other words, the more elastic the fringe's demand (supply) the more limited is the leader's ability to manipulate price.

[2]Tasnádi (2010) find that the price-quantity outcome of a game with quantity as the leader's strategic variable converge with the outcome in a dominant price leadership model. The result is conditioned upon the leader's position as first mover being exogenously determined and that there are sufficiently many, small agents within the fringe.

$$\max_{m} \pi_1 = Ph_1 - C_1(h_1, x) - m(h_1 - \tilde{Q}_1), \tag{6.3}$$

$$\text{s.t. } h_1 = Q - \sum_{i=2}^{n} h_i(m). \tag{6.4}$$

After substituting for the constraints, the FOC reads

$$\frac{\partial \pi_1}{\partial m} = -P\sum_{i=2}^{n} h_{im} + C_{1h_1}\sum_{i=2}^{n} h_{im} + m\sum_{i=2}^{n} h_{im} - \Big(Q - \sum_{i=2}^{n} h_i(m) - \tilde{Q}_1\Big) \leq 0,\ m \geq 0. \tag{6.5}$$

Assuming an interior solution, the condition may be rearranged[3] for a more intuitive comparison to the competitive benchmark case or the fringe's optimal demand.

$$P - C_{1h_1} + \frac{(h_1 - \tilde{Q}_1)}{\sum\limits_{i=2}^{n} h_{im}} = m. \tag{6.6}$$

There are two scenarios under which ITQ may result in a cost-effective outcome. The first case is when agent 1's quota demand equals his initial allocation of quota, at this point marginal net benefit will, similarly to the competitive fringe (6.2), equal the quota price ($P - C_{1h_1} = m$). This solution will fulfill the equi-marginal principle for efficiency. Secondly, the cost-efficient solution may be reached when the marginal demand of the fringe approach infinity[4]. Thus as predicted, when the residual demand of the fringe approaches perfect elasticity the leader's ability to manipulate price is reduced and the outcome approaches that of perfect competition.

Let m^* denote the price and h_1^* the demand which corresponds to the competitive outcome. If neither of the two above scenarios apply, the quota price, will either be above or below the cost-effective price m^*. Recalling that $h_{im} < 0$ the results may be summarised as follows

$$h_1 < \tilde{Q}_1 \implies m > m^* \tag{6.7}$$

$$h_1 = \tilde{Q}_1 \implies m = m^* \tag{6.8}$$

$$h_1 > \tilde{Q}_1 \implies m < m^*. \tag{6.9}$$

[3]Here I have inserted for residual demand, divided through by $\sum_{i=2}^{n} h_{im}$ and rearranged.

[4]When marginal demand approach infinity the price elasticity of demand approaches infinity, $\lim\limits_{\sum_{i=2}^{n} h_{im} \to \infty} \frac{\partial\left(\sum_{i=2}^{n} h_i\right)}{\partial m} \frac{m}{\sum_{i=2}^{n} h_i} = \infty$

When the market leader is allocated ($\tilde{Q}_1$) more quotas than he demands (h_1) he has an excess supply of quota. The leader will act as a monopolist and sell some of his supply at a quota price above the efficient price m^*. However, the leader will sell less than the cost efficient amount and hence harvest more than optimal ($h_1 > h_1^*$). Reciprocally, when the market leader has an excess demand for quota he will act as a monopsonist and buy less quotas than optimal at a price less than the efficient quota price.

Comparative Statics

More formally, by deriving agent 1's FOC with respect to m and $\tilde{Q}_1$ it can be shown that quota price increase with the dominant agent's initial quota endowment.

$$\frac{\partial m}{\partial \tilde{Q}_1} = \frac{1}{\Big(P - C_{1h_1} - m\Big)\sum\limits_{i=2}^{n} h_{imm} + C_{1h_1h_1}\big(\sum\limits_{i=2}^{n} h_{im}\big)^2 - 2\sum\limits_{i=2}^{n} h_{im}} > 0. \tag{6.10}$$

Assuming a linear demand curve, i.e. $h_{imm} = 0$, the effect is positive as, albeit $h_{im} < 0$ the second term is squared and the third preceded by a minus sign. Intuitively this result follows from the idea that the more of the quota initially distributed to the dominant agent, the higher will the aggregated demand of the fringe be, and hence agent 1 is able to demand a higher price. Accordingly it may be shown that agent 1's own quota demand increase with his initial allocation of quota.

$$\frac{\partial h_1}{\partial \tilde{Q}_1} = \frac{\partial h_1}{\partial m}\frac{\partial m}{\partial \tilde{Q}_1} > 0. \tag{6.11}$$

With the latter known to be positive only $\frac{\partial Q_1}{\partial m} > 0$ must be verified. Seeing as $h_1 = Q - \sum_{i=2}^{n} h_i(m)$ it follows that $h_{1m} = -\sum_{i=2}^{n} h_{im} > 0$, i.e. the leader's residual demand curve is increasing in price and thus demand is increasing in his initial allocation of permits. In other words, the leader will harvest above or below h_1^* depending on initial allocation.

6.2. Specified Functions

So far much of the analysis is equivalent to previous studies including that of Hahn (1984) Hatcher (2012) and Westskog (1994). However, as far as I know no one have introduced specified functions and solved for explicit harvesting expressions. With the cost function $C_i(h_i, x) = \frac{c_i}{2}\left(\frac{h_i}{x}\right)^2$, the competitive price taking agent's harvesting level and concurrent individual quota demand is

$$h_i(m) = \frac{x^2}{c_i}(P - m), \ \forall i = 2, ..., n, \ h_i > 0. \tag{6.12}$$

Subsequently aggregated quota demand of the fringe is $\sum_{i=2}^{n} h_i(m)$. Equation(6.12) and the dominant agent's FOC (6.5) implies

$$h_1 = 2\frac{x^2}{c_1}(P - m) + \frac{\tilde{Q}_1 - Q}{\sum\limits_{i=2}^{n} \frac{c_1}{c_i}},\ m > 0. \tag{6.13}$$

The immediate interpretation is that whenever the dominant agent is in possession of the entire quota he will harvest twice as much as the benchmark case (4.11), or with homogeneous costs, twice as much as the fringe. Imposing the market clearing condition ($\sum_{j=1}^{n} h_j = Q$)[5] quota price can be expressed as a function of the TAC, stock and initial allocation ($\tilde{Q}_1$).

$$m(x, Q, \tilde{Q}_1) = P - \frac{Q - (\tilde{Q}_1 - Q)\sum\limits_{i=2}^{n} \frac{c_i}{c_1}}{x^2\left(\frac{2}{c_1} + \sum\limits_{i=2}^{n} \frac{1}{c_i}\right)}. \tag{6.14}$$

With the specified cost function and inherent linearly declining fringe demand ($h_{im} < 0$, $h_{imm} = 0$) the comparative statics from (6.10) and (6.11) may be verified, ($\frac{\partial m}{\partial \tilde{Q}_1} > 0$, $\frac{\partial h_1}{\partial \tilde{Q}_1} > 0$). Additionally some of the comparative statics from the benchmark case are easily confirmed, that is ($\frac{\partial m}{\partial x} > 0$, $\frac{\partial m}{\partial Q} < 0$). The marginal effect of the number of competitors, or the size of the fringe n is more ambiguous as it depends on relative cost levels and the leader's initial share of the TAC. Assuming a homogeneous fringe $\frac{\partial m}{\partial n} = x^2(\frac{Q}{c_i} + \frac{2c_i(\tilde{Q}_1 - Q)}{c_1^2})$, intuitively there are two counteractive forces at work. Similarly to the benchmark case a rise in the number of competitors increase demand for, and thus the price of quotas. However, an increase in n implies that the size of the fringe rise, diminishing the leader's ability to manipulate price. This would pull price in the direction of m^*, an effect that could be either positive or negative depending on the leader's initial position as either monopsonsit or monopolist and thus initial allocation ($\tilde{Q}_1$).

6.2.1. A Case of Two Agents

To simplify the analysis, consider a case of two agents. The competitive firm now denoted by 2 may also be interpreted as the aggregate of the fringe. In this scenario the respective quota demand and subsequent harvesting levels of the leader and the fringe are

$$h_2(m) = \frac{x^2}{c_2}(P - m), \tag{6.15}$$

[5]The similar result may be found by inserting for the specified functions in equation 6.6, this is illustrated for two agents in appendix D.

$$h_1(m) = 2\frac{x^2}{c_1}(P-m) + \frac{c_2}{c_1}(\tilde{Q}_1 - Q). \tag{6.16}$$

The effect of initial distribution is here, more transparently, weighted by relative costs. In the following reduced form expressions, the higher the aggregated cost of the fringe relative to the leader, the larger the effect of initial quota allocation upon quota price and agent 2's harvesting level. Note that $\tilde{Q}_1 + \tilde{Q}_2 = Q$ and thus $\tilde{Q}_i = Q - \tilde{Q}_j$, ($\forall i = 1,2$ and $i \neq j$).

$$m(x, \tilde{Q}_1) = P - \frac{Q + \tilde{Q}_2\frac{c_2}{c_1}}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)}, \tag{6.17}$$

$$h_1(\tilde{Q}_1) = \left(Q + \tilde{Q}_1\right)\frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}}, \tag{6.18}$$

$$h_2(\tilde{Q}_1) = \left(Q + \tilde{Q}_2\frac{c_2}{c_1}\right)\frac{\frac{1}{c_2}}{\frac{2}{c_1} + \frac{1}{c_2}}. \tag{6.19}$$

6.2.2. Comparative Statics

With market power in the quota market, harvesting and quota price will in addition to the standard parameters of the benchmark case, depend upon the initial distribution of quotas. The comparative statics are summarised in table 6.1. With two agents $\tilde{Q}_2$ is given by $\tilde{Q}_1$, and from

Table 6.1.: Comparative statics

	c_1	c_2	Q	$\tilde{Q}_1$	x	P
m	$-$	$-$	$-$	$+$	$+$	$+$
h_1	$-$	$+$	$+$	$+$		
h_2	$+$	$-$	$+$	$-$		

The expressions behind the table is found in appendix B.

$\tilde{Q}_2 = Q - \tilde{Q}_1$ it follows that the marginal effect of a change in $\tilde{Q}_2$ will be of equal size, but opposite sign compared to that of $\tilde{Q}_1$. Intuitively this is because an increase in agent 1's initial quota endowment will be at the expense of agent 2 or the fringe's initial endowment and vice versa.

The marginal effect of cost (c_i) upon quota price is in line with the previous models (benchmark and Cournot). The effect of supply (for a given initial distribution), stock and the price of fish also remain equivalent to the previous models. For a given TAC the price for quotas depend respectively positively and negatively on the amount of quotas initially allocated to agent 1 and

2. The more quotas the leader receive, the higher the demand for quotas from the fringe and thus the greater is the leader's ability to raise price. The more of the quotas initially allocated to the fringe, the less they demand (if the leader is a monopolist) and thus agent 1 is less able to manipulate price. If the leader is a net buyer acting as a monopsonist it will manipulate price downward to buy quotas at a cheaper rate.

The agents' demand for quota and corresponding harvesting levels also respond to a marginal change in cost levels and total supply of quotas similarly to the previous models. The harvesting levels depend positively on the agent's own initial endowment of quota and negatively on the competitors initial endowment.

homogeneous Costs

In a scenario of homogeneous costs i.e. $c_1 = c_2$ (see chapter 7 for numerical illustrations with heterogeneous costs), the expressions are reduced to $h_1 = \frac{Q+\tilde{Q}_1}{3}$, $h_2 = \frac{Q+\tilde{Q}_2}{3}$ and $m = P - \frac{Q+\tilde{Q}_2}{3x^2}$. With homogeneous costs only equal harvesting levels will yield an outcome that satisfy the equi-marginal principle for cost efficiency[6]. Accordingly $h_1^* = \frac{Q}{2}$ is agent 1's cost efficient harvesting level. To achieve this, initial allocation must be equal for both agents, i.e. $\tilde{Q}_1 = \tilde{Q}_2 = \frac{Q}{2}$, such that trade is unnecessary. This may be verified by inserting for $\tilde{Q}_1 = \frac{Q}{2}$ in the leader's harvesting expression. At this point the quota price will be $m^* = P - \frac{Q}{2x^2}$ which is equivalent to the benchmark scenario with homogeneous costs.

In the event that agent 1 is allocated either more or less than h_1^* he will harvest respectively more or less than the fringe. This is easily illustrated in table 6.2. With homogeneous costs the leader must receive more (less) than half the TAC in order to engage in monopolistic (monopsonistic) behaviour. With an initial allocation of $\tilde{Q}_1 = \frac{2}{3}Q$, the leader's resulting harvest will

Table 6.2.: The market leader's harvest

$\tilde{\boldsymbol{Q}}_1$	0	$\frac{1}{3}Q$	$\frac{1}{2}Q$	$\frac{2}{3}Q$	Q
$\boldsymbol{h_1}$	$\frac{1}{3}Q$	$\frac{4}{9}Q$	$\frac{1}{2}Q$	$\frac{5}{9}Q$	$\frac{2}{3}Q$

be $h_1 = \frac{5}{9}Q$. Agent 1 will harvest more than his cost-effective amount, but less than his initial allocation, implying that some of the quota is sold at a price higher than the cost-effective price ($m > m^*$). Reciprocally if initial allocation is one third of the TAC the leader will harvest

[6] Specifically the requirement is $\frac{\partial C_1}{\partial h_1} = \frac{\partial C_2}{\partial h_2} \implies \frac{c_1 h_1}{x^2} = \frac{c_2 h_2}{x^2}$.

$h_1 = \frac{4}{9}Q$ indicating that he has bought some, but not enough to harvest his competitive quantity, at a quota price less than that which is efficient ($m < m^*$). When costs are homogeneous, the leader will never find it advantageous to take full control of the market and harvest the entire TAC himself. If the entire TAC is allocated to agent 1 he will as suggested above (6.13), harvest twice as much as the competitive fringe.

Consequently, with the existence of market power trade will not generate the perfectly competitive outcome of the benchmark model. Instead the deviation from the benchmark equilibrium implies an efficiency loss and hence ITQ does not guarantee a cost-effective harvest of the TAC regardless of initial allocation.

6.3. The Efficiency Loss

It has been established that cost-efficiency require marginal cost of harvesting to be equal across all agents. With two agents and market power in the quota market this is only fulfilled when the ratio of initial allocation equal the inverse cost ratio.

$$\frac{\partial C_1}{\partial h_1} = \frac{\partial C_2}{\partial h_2} \implies \frac{\tilde{Q}_1}{\tilde{Q}_2} = \frac{c_2}{c_1}. \tag{6.20}$$

In the event that this does not hold, the difference between total cost in the cost minimising benchmark model and the market power outcome will represent the efficiency loss. In general total cost is given by $TC = \sum_{j=1}^{n} C_j(h_j, x)$. With two agents total cost of the benchmark scenario and with market power are given by (6.21) and (6.22), respectively.

$$TC^* = \frac{Q^2}{2x^2\left(\frac{1}{c_1} + \frac{1}{c_2}\right)}, \tag{6.21}$$

$$TC = \frac{Q^2}{2x^2\left(\frac{1}{c_1} + \frac{1}{c_2}\right)} + \frac{\frac{1}{c_1^2}}{2x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)} \left(\frac{\tilde{Q}_1^2 c_1 + \tilde{Q}_2^2 c_2 - Q^2}{\left(\frac{2}{c_1} + \frac{1}{c_2}\right)\left(\frac{1}{c_1} + \frac{1}{c_2}\right)} \right). \tag{6.22}$$

The second term of (6.22) demonstrate the efficiency loss of market power. Concurrently $\tilde{Q}_1^2 c_1 + \tilde{Q}_2^2 c_2 > Q^2$ is a requirement for an interior solution to the maximisation problem.

A natural corollary from the above result is that the level of inefficiency will be related to initial allocation. Hahn (1984) illustrates the loss by differentiating total abatement cost with respect to agent 1's initial endowment of pollution permits. In the case that cost-efficiency is independent of initial allocation this should be zero. To examine the equivalent in the case of fisheries we can either compare the total cost of harvesting the entire TAC or the effect on total profits. Following the procedure in Hahn (1984), which is also used by Westskog (1994), I examine the total cost (TC) of harvesting the TAC. When the leader's demand and initial allocation do not match ($h_1 \neq \tilde{Q}_1$), total cost will, as seen in (6.22), be a function of initial allocation.

$$TC = C_1(h_1(\tilde{Q}_1), x) + \sum_{i=2}^{n} C_i(h_i(\tilde{Q}_1), x). \tag{6.23}$$

While the entire derivation is presented in appendix D, the final expression reads

$$\frac{\partial TC}{\partial \tilde{Q}_1} = \frac{\partial m}{\partial \tilde{Q}_1}\Big(C_{1h_1} + m - P\Big) \sum_{i=2}^{n} \frac{1}{C_{ih_ih_i}}. \tag{6.24}$$

It has been verified that $\frac{\partial m}{\partial \tilde{Q}_1} > 0$ and with convex costs $\sum_{i=2}^{n} \frac{1}{C_{ih_ih_i}} > 0$. Again if agent 1 harvests according to the optimality condition total cost are not influenced by initial allocation ($\frac{\partial TC}{\partial \tilde{Q}_1} = 0$). The inefficiency results may be summarised as

$$\frac{\partial TC}{\partial \tilde{Q}_1} > 0 \text{ if } P - C_{1h_1} < m, \tag{6.25}$$
$$\frac{\partial TC}{\partial \tilde{Q}_1} < 0 \text{ if } P - C_{1h_1} > m. \tag{6.26}$$

The first case is true when the allocated quota exceed quota demand , i.e. $h_1 < \tilde{Q}_1$ and the latter when demand exceed initial endowment ($h_1 > \tilde{Q}_1$). The same result is found when examining total profits. This is because the product market is assumed perfectly competitive and any equity effects of the quota market fall out as it is only redistributive, proof of this may be found in appendix D.

In conclusion, inefficiency increase when initial allocation deviates from quota demand in either direction. $\frac{\partial TC}{\partial \tilde{Q}_1} > 0 (< 0)$ when $h_1 < \tilde{Q}_1 (h_1 > \tilde{Q}_1)$, if agent 1 initially has an excess supply of quota a further increase in his initial amount will increase total cost and thus inefficiency. In the event that the agent's initial allocation of quota implies excess demand further increase in his amount of quota will reduce total cost and inefficiency as $\tilde{Q}_1$ is brought closer to h_1. In fisheries where there are agents with market power the authority will benefit from rigorous information gathering in order to ensure that these agent are allocated quotas equal to h_1 so that they do not participate in the quota market.

Hahn (1984) and Westskog (1994) find that the efficiency loss, in general, is relatively small and Tietenberg (1985) argue that cap-and-trade is less costly than the command and control alternative, even in the presence of market power. This highlights the importance of effect sizes and empirical analysis of theories. If the loss is not of any significance the existence of market power need not affect the authority's allocation method.

7. Numerical Illustrations

The theoretical implications of introducing market power in the market for ITQs mirror that of market power within markets for emission permits. Nevertheless the relatively small efficiency loss found by Hahn (1984) and Westskog (1994) calls for an attempt to measure the inefficiency in an ITQ scenario.

With data from sulfur dioxide control in Los Angeles Hahn (1984) examined the case of a hypothetical market leader and a competitive fringe. Total cost with respect to initial allocation were relatively flat up until more than 60 percent of the permits were allocated to the leader, enabling him to act as a monopolist. Though few statistics are reported the efficiency loss seem to correspond to, at most, a 10% increase in total cost. Monopsony appear not to be a problem, but the results are presumed to be sensitive to parameter changes (Hahn, 1984).

Taking on a broader perspective Westskog (1994) studies the percentage increase in total control cost relative to the cost efficient solution within a hypothetical emissions reducing cap-and-trade program for Europe. The analysis is conducted for 12 different assumptions and her results range from a 0.60-10.41 percent increase in total cost, with only two of the scenarios reaching an increase above 2.7%.

7.1. Scenario

Consider a hypothetical scenario with two separate agents, namely the trawler fleet and the coastal fleet. To fit the model the agents are assumed to operate in the same product and quota market, taking the price of fish P as given. In comparison to the many participants of the coastal fleet, the trawler fleet, with less vessels, is better organised, and better represented when regulatory decisions are made (Grytås, 2014; Røed, 2013; Hersoug, 2005). I thus assume the trawler fleet is the market leader and that its dominance have been established prior to this study. Accordingly the trawler fleet will be referred to as agent 1 whereas agent 2 is the coastal fleet. The model will be illustrated with data that approximate the Northeast Atlantic Norwegian cod fishery.

7.1.1. Data

The price of fish P is the 2015 average, reported by The Norwegian Fishermen's Sales Oranization (2016). The remaining data are based on Inarra and Skonhoft (2008). Due to differences in the cost function, the cost parameter have been adjusted for effort using the information available in Armstrong (1999)[1]. To allow the use of 2015 fish prices cost has also been adjusted for inflation according to Statistics Norway's (2016) consumer price index. The net intrinsic growth rate[2], which takes gear selectivity into account, assumes the TAC was equally divided between the two agents prior to the introduction of ITQ. Moreover, the Northeast Atlantic cod is co-managed with Russia whom is assumed to harvest their, approximately fifty percent, share entirely with trawlers. Assuming we are examining a fishery at its MSY level, the baseline values are presented in table 7.1.

Table 7.1.: Baseline parameter values

Parameter	Parameter description	Value
$\hat{r}$	Net intrinsic growth rate	0.275
K	Carrying Capacity	5 000 (1 000 tonnes)
X^{MSY}	Maximum sustainable yield stock	2 500 (1 000 tonnes)
TAC	The TAC corresponding to $F(X^{MSY}) = h^{MSY}$	343.75 (1 000 tonnes)
Q	The Norwegian share of the TAC, the total amount of quota	171.875 (1 000 tonnes)
c_1	Unit cost of harvesting for agent 1, inflation, catchability and effort adjusted	16156.27 (mill NOK)
c_2	Unit cost of harvesting for agent 2, inflation, catchability and effort adjusted	5886.29 (mill NOK)
P	Price of fish	19.3 (mill NOK/1 000 tonnes)

7.2. Results

Table 7.2 presents harvesting levels and quota prices for the benchmark model and the market power case, under four different distribution scenarios. $\tilde{Q}_1 = 0.28Q$ corresponds to the allocation of the trawl ladder. As expected the benchmark results are independent of initial distribution, and represent the optimal quota price and allocation of harvesting. The market power outcome is also as predicted, with $m < (>) m^*$ when $\tilde{Q}_1 < (>) h_1^*$. Additionally, in this scenario the leader wil never choose to harvest the entire TAC himself.

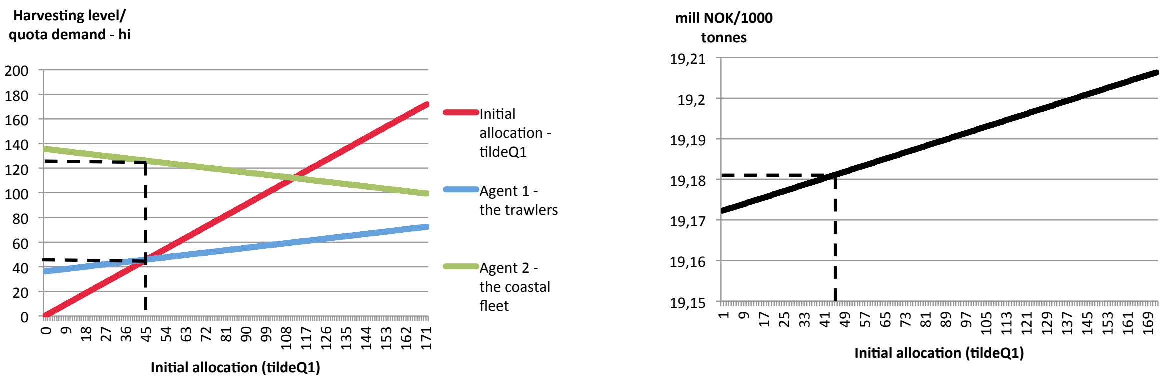
[1]Further information concerning the construction of the cost parameter is found in appendix E.
[2]Further information concerning the net intrinsic growth rate is found in apppendix E.

Table 7.2.: Harvesting levels and quota price

	Benchmark model				Market power			
Initial allocation of quotas $\tilde{Q}_1$	0	$0.28Q$	$0.5Q$	Q	0	$0.28Q$	$0.5Q$	Q
h_1 (1 000 tonnes)	45.9	45.9	45.9	45.9	36.22	46.37	54.33	72.45
h_2 (1 000 tonnes)	125.9	125.9	125.9	125.9	135.65	125.5	117.54	99.43
m (mill NOK/ 1 000 tonnes)	19.181	19.181	19.181	19.181	19.172	19.182	19.189	19.2

Figure 7.1.: Harvesting and quota price with market power

(a) Harvesting (b) Quota price, m



Please note that tildeQ1 corresponds to $\tilde{Q}_1$.

Demand and quota price are linearly increasing in initial allocation and in figure 7.1 the dotted line represents the cost efficient solution at which point initial allocation equal the leader's quota demand. It may also be shown that agent 1's demand curve is flatter, and has a lower intersect the greater the cost ratio. Intuitively the leader will be less able to influence the market when relative cost ($\frac{c_1}{c_2}$) increase, and thus harvest will be less influenced by initial allocation. Accordingly the quota price with respect to initial allocation converge as the cost ratio increase.

Initial allocation has less effect upon quota price when stock increase or the TAC decrease, i.e. when the relative relationship between catch and stock ($\frac{Q}{x}$) decrease. A decrease in this ratio suggest the constraint (Q) is more stringent relative to the possibilities. The effect upon quota price stem from the second term of the quota price expression (6.17), which is reduced when the constraint become more stringent.

Harvesting is increasing, and the quota price decreasing in the net intrinsic growth rate $\hat{r}$, but for a given TAC this effect collapse indicating it is only an indirect effect as a higher intrinsic growth rate increases the maximum sustainable yield harvest ($\frac{\partial h_i}{\partial Q} > 0$, $\frac{\partial m}{\partial Q} < 0$).

7.2.1. The Efficiency Loss

Total cost and efficiency loss are found in table 7.3. As expected total cost in the benchmark model is unaffected by initial allocation, and as the benchmark model corresponds to the least cost solution the question of efficiency loss is not applicable. As illustrated in figure 7.4a to-

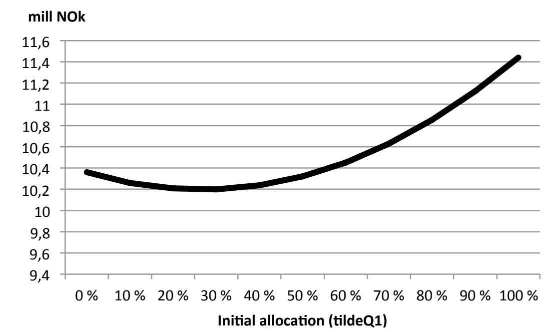
Table 7.3.: Total cost and efficiency loss

	Benchmark model				Market power			
Initial allocation of quotas $\tilde{Q}_1$	0	$0.28Q$	$0.5Q$	Q	0	$0.28Q$	$0.5Q$	Q
Total cost (mill NOK)	10.196	10.196	10.196	10.196	10.361	10.197	10.322	11.439
Efficiency loss (mill NOK)	n/a	n/a	n/a	n/a	0.165	0.00039	0.126	1.243
% increase in cost relative to the cost efficient solution	n/a	n/a	n/a	n/a	1.618%	0.0038%	1.23%	12.19%

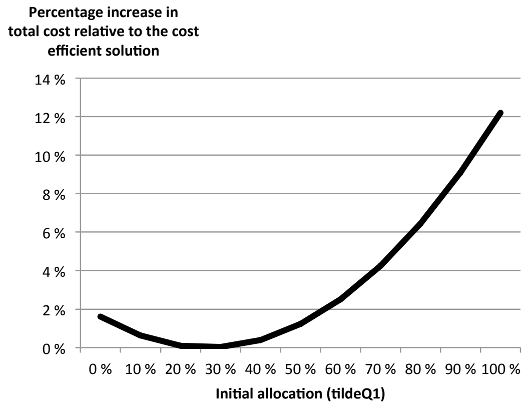
tal cost is increasing and convex in initial allocation $\tilde{Q}_1$. It has a minimum at approximately $\tilde{Q}_1 = 0.26Q$ which is where $\tilde{Q}_1 = 45.9 = h_1^*$. This is very close to the allocation of the trawl ladder, suggesting the trawl ladder could be a relatively good allocation key, even with the existence of market power. Total cost is sensitive to changes in the TAC and stock. This however, is true both for the benchmark and market power scenario, and efficiency loss as the percentage increase in total cost relative to the cost efficient outcome is unaffected by Q and x. Similarly to harvesting and quota price, total cost may appear to increase with r, but the effect disappear for a given TAC, and efficiency loss is unaffected.

Figure 7.3.: Total cost and efficiency loss

(a) Total cost



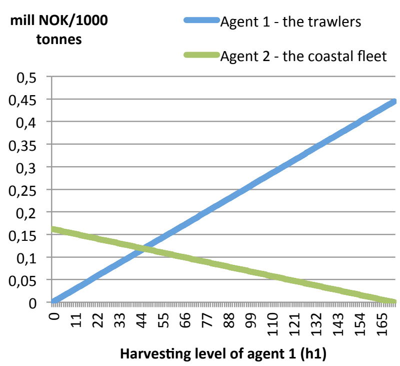
(b) Efficiency loss



In this scenario the cost of monopoly is greater than that of monopsony. This is not unexpected as theory predicts the loss will increase with the deviation from optimum, and here $\tilde{Q}_1 = Q$ is further away from optimum allocation, than $\tilde{Q}_1 = 0$. This result is of course rooted in the relative cost advantage of the follower and is easily demonstrated with a comparison of the two marginal cost functions (figure 7.8a). In line with the equi-marginal principle, total cost is minimised where the marginal cost curves intersect. Due to the relative cost advantage of the follower, the cost of monopoly ($h_1 < h_1^*$) is greater than that of monopsony ($h_1 > h_1^*$).

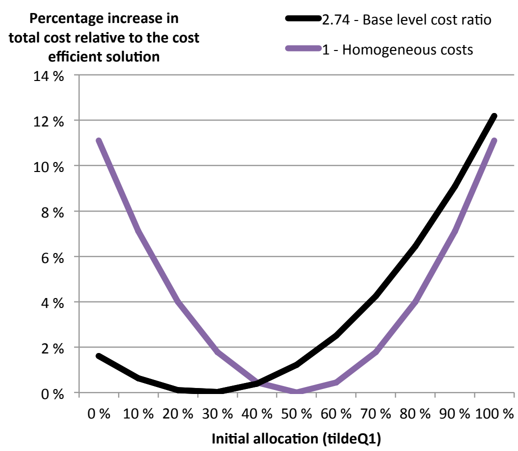
Figure 7.5.: Relative cost levels

(a) Marginal cost



The harvesting level of agent 2 is equal to $Q - h_1$, i.e. it decrease towards the right.

(b) Efficiency loss and relative cost



As the relative cost advantage of the follower decrease, the efficiency loss of monopoly decrease, whereas the efficiency loss of monoposony increase. When costs are homogeneous the efficiency loss is symmetric around a fifty-fifty division of the quotas. The efficiency loss of a situation with either two trawlers or two coastal vessels, in which one has market power may lie around the homogeneous cost curve.

7.3. Discussion

The numerical illustrations estimate the possibility of a 12.9% increase in total cost when there is market power in the quota market of an ITQ fishery. This is similar, though somewhat above the results of Hahn (1984) and Westskog (1994). Some of the difference could be attributable to Von Der Fehr's (1993) claim that market power might be more prominent and thus cause more harm when quotas are necessary to production; while polluting firms may find other methods of production, quotas are an absolute necessity for a fisherman.

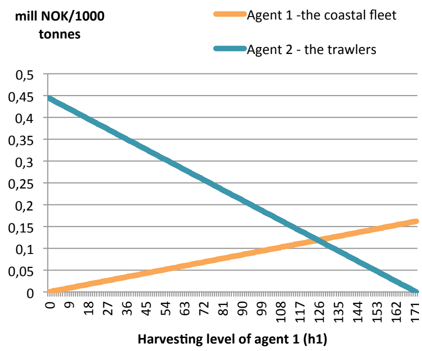
Compared to Hahn (1984), my scenario generate a more curved total cost, and a greater loss from monopsony. In Hahn (1984) the cost of controlling emissions is decreasing convexly in permits (i.e. emissions) and presumably relatively flat when the leader is allocated enough permits to behave as a monopolist. In the event that the market leader's initial allocation is in accordance with monopsonistic behaviour the leader will be at the steep end of the cost function, while the fringe will be operating at the relatively flat portion. Yet, with a stringent aggregate constraint as in Hahn (1984) the supply of permits from the fringe will be quite receptive to any change in price, diminishing the leader's ability to manipulate it. Hahn (1984) suggests the inefficiencies from monopsony will increase as the constraint is relaxed.

A natural corollary is that a more stringent TAC should flatten my total cost curve, decreasing the inefficiency of monopsony. Whilst this appears to hold there is no change in the percentage efficiency loss, suggesting that a less stringent constraint in Hahn (1984) might not enhance the percentage increase in total cost from monopsony behaviour. An alternative explanation to the lack of inefficiency from monopsony may be the shape of the demand functions. With my convex cost function the leader's demand for quotas with respect to initial allocation ($\tilde{Q}_1$) is linearly increasing. The equivalent in Hahn (1984) is illustrated as increasing and convex. Accordingly at low levels of initial allocation demand, with respect to $\tilde{Q}_1$, would be relatively flat. Depending on the various intercepts, the deviation from optimum h_1^* might be less for low levels of $\tilde{Q}_1$, hence yielding a smaller efficiency loss in the case of monopsonistic behaviour and a larger efficiency loss for monopolistic behaviour, compared to my scenario with a linear demand curve.

I also note that Hahn (1984) does not specify the relative cost of his agents. While the trawler's were chosen as the market leader on the basis of organisation, one might imagine a scenario in which the cost advantage of the coastal fleet have resulted in market power. In this reversed scenario where the market leader has a cost advantage and all else remain, the potential efficiency loss is much greater. Compared to the initial scenario (figure 7.5) it is evident that the great efficiency loss of monopsony in figure 7.7 is due to relative cost levels. Firstly, the leader's ability to manipulate the market diminish when his costs, relative to that of the follower, increase. Secondly, when agent 1 has a cost advantage and is allocated few quotas, the leader's harvesting cost will increase as he moves towards the efficient distribution. Contrarily when the

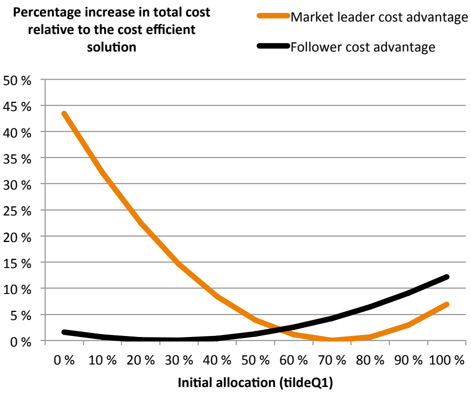
Figure 7.7.: A market leader with cost advantage

(a) Marginal cost



The harvesting level of agent 2 is equal to $Q - h_1$, i.e. it decrease towards the right.

(b) Efficiency loss and relative cost



leader has a cost disadvantage and is allocated all or most of the quotas harvesting cost will, relatively steeply, decrease as he moves towards the efficient distribution. Concurrently, with a cost advantage the monopsonistic leader has less incentive to move towards the cost efficient distribution of harvesting, than the monopolistic leader with a cost disadvantage.

The study of Westskog (1994) differs more distinctly as there, in addition to the competitive fringe, are multiple market leaders. As mentioned, the leader's ability to exert market power diminish as the fringe increase. In Westskog (1994) only 2 out of 41 countries are initially identified as Cournot countries, and the efficiency loss is found to increase as the number of Cournot countries increase, at the expense of the size of the fringe. This might suggest the fringe is too large, for the leaders to generate a considerable efficiency loss. Moreover, initial allocation of permits are based on historic emission levels and consequently there are only small deviations between initial allocation and permit demand, resulting in a small efficiency loss. Accordingly it is under the three scenarios with a different allocation rule the efficiency loss increase above 1.66%. These results highlight the importance of initial allocation, indicating that history based allocation may be the more efficient method as historical catch and emission levels closely resemble the agents' demand for quotas and permits. This relates to Armstrong's (2008) findings concerning allocation mechanisms, and it is now evident that her history dependent method may eliminate the effect of market power because, as allocation in one period depends on trade in the previous period $\tilde{Q}_1$ will converge with h_1 over time.

8. Concluding Remarks

Many favour ITQ as management regime because it supposedly leads to an economically efficient outcome, regardless of the initial allocation of quotas. This result is contingent upon a number of assumptions, including perfect competition. For a long time the excess capacity of the fishing fleet have hindered the creation of rents. A subgoal of ITQ have been to reduce this excess capacity, and this is achieved through the concentration of rights. Concurrently through the concentration of rights ITQ regimes balance between increased efficiency and market power. In this thesis I have studied how ITQ is affected when the assumption of perfect competition is relaxed and there is market power, either in the market for fish or in the market for quotas.

8.0.1. Market Power in the Product Market

When there is market power in the market for fish the agents are modeled as Cournot players. There are six possible outcomes, of which only one is socially efficient, i.e. it is both cost efficient and generate the optimal aggregated harvest ($\sum_{i=1}^{n} h_i^*$).

Total harvest may be caught in a cost efficient manner when the Cournot agents are homogeneous, but never when they are heterogeneous. The optimal aggregated harvest is only reached when the aggregate constraint binds ($\sum_{i=1}^{n} h_i^* = Q$) and the agents choose not to exercise their market power. These two specifications coincide at one point where the individual harvesting level ($h^C = \frac{Q}{n}$) is equal to that of the socially efficient benchmark scenario.

Whenever the agents choose to exert their market power total harvest will be less than optimal. This will only be profit maximising for the individual agent whenever the aggregate constraint does not bind, ($\sum_{i=1}^{n} h_i^* < Q$). Concurrently exercising market power is, regardless of homogeneity, only optimal for the agent when the TAC is sufficiently large and it is never socially efficient.

Realistically, positive quota prices (Røed, 2013; Hersoug, 2005; Grytås, 2014) suggest the constraint binds and assuming profit maximising agents no one will find it profitable to exercise market power. Accordingly the entire TAC will be harvested, albeit in an inefficient manner if the agents are heterogeneous. Nevertheless the outcome is independent of the initial allocation of quotas and product market power do not present a problem in relation to how the quota should be distributed.

8.0.2. Market Power in the Quota Market

The theoretical analysis of market power in the quota market find, similarly to Hahn (1984) and Westskog (1994), that the distribution of quotas and harvesting no longer is independent of initial allocation. When the market leader is allocated ($\tilde{Q}_1$) more (less) quotas than he demands (h_1) he will behave as a monopolist (monopsonist) and harvest more (less) than his efficient amount. Accordingly the quota price will be higher (lower) than the efficient price m^*. The efficiency loss of market power is increasing in the deviation between the leader's demand for and initial endowment of quotas.

The numerical illustration indicate that market power within the quota market of ITQ fisheries has the potential to generate a relatively large efficiency loss. These results however, are sensitive to the functional form of quota demand and accordingly the structure of the cost function. The relative costs of the two agents is also crucial to the outcome, and a market leader with a cost advantage present the greatest potential loss. When the leader has a cost disadvantage, or with homogeneous costs the potential efficiency loss is around 10-12 percent, which is at the higher end of the range found in Hahn (1984) and Westskog (1994).

8.0.3. Areas for Further Research

The results of this thesis suggest market power could be a significant issue within ITQ fisheries, and it would be beneficial to conduct further analysis of actual ITQ regimes, such as Iceland and New Zealand. Is market power a realistic problem in spite of the restrictions on trade and concentration of rights? And if that is the case, what are the actual efficiency losses? How well does the model constructed here fit reality and what amendments could be made to create a better fit?

Egteren and Weber (1996) found that the exclusion of non-compliance underestimated the social cost of market power in cap-and-trade regimes. Hatcher (2012) examined this in ITQ fisheries, though no specific functions were used. For further studies the model presented here could be expanded to include compliance, especially the issue of highgrading is found to be relevant within quota managed fisheries. Highgrading within ITQ regimes is discussed in Anderson

(1994) though, as far as I know, not in the context of market power. One could also examine the effect of market power under different methods of initial allocation, e.g. auctions and lottery.

As ITQ often are introduced to rebuild stocks, TAC would change over time. Thus it would be interesting to develop a dynamic, two-period expansion of the model. This could also take account of how a change in the distribution of harvesting affect the net intrinsic growth rate, and thus the model's outcome. The system of banking and borrowing of quotas analysed in Hagem and Westskog (1998) would not be applicable to fisheries because timing is of importance to the growth of the resource and harvesting both periods' quota within one period could severely deplete or render the species extinct. Accordingly the model would resemble that of Armstrong's (2008) leasing model. Additionally, it would be interesting to use an expanded dynamic framework to examine how the agents' position as net seller or buyer affect future decisions to stay in the fishery and invest in new equipment. Compliance and highgrading would also be a relevant factor to consider within the dynamic framework.

Lastly there seem to be a gap in the theoretical studies concerning the topic of market power in quota markets. While the examination of a competitive fringe in combination with a single dominant agent using either price or quantity as strategic variable obtained the same result, the same cannot be expected when there are multiple market leaders. Westskog's (1994) model with Cournot leaders and a competitive fringe yielded results similar to those of Hahn (1984), though one might anticipate that a framework with multiple market leaders using price as strategic variable and a competitive fringe, i.e. Bertrand leaders and a competitive fringe, in line with the Bertrand model, would yield the competitive outcome. Thus if there are multiple market leaders using quota or permit price as their strategic variable, market power may as Tietenberg (1985) argued, not be a significant issue.

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A. A Bioeconomic Model of Fisheries

Appendix A illustrates the standard Gordon-Schaefer model which is the basis for the different levels of stock, namely x^{MSY} and x^{MEY}.

The stock dynamics of a fishery can be illustrated with a biomass model where x is stock.

$$\frac{dx}{dt} = F(x) - h(t). \tag{A.1}$$

$F(x)$ is the natural growth of the population and $h(t)$ the harvest at time t. The fishery is at a steady state when the harvest equals natural growth $(h(t) = F(x))$, i.e. $(dx/dt = 0)$, this is also the sustainable harvest level, the amount of fish that can be harvested without depleting the resource (Clark, 1990).

A.1. The Logistic Growth Function

The natural growth function is ordinarily specified as the density dependent logistic function which is a simple yet useful illustration of the population dynamics[1].

$$F(x) = rx\left(1 - \frac{x}{K}\right). \tag{A.2}$$

$r > 0$ is the intrinsic or maximum growth rate of the population. The carrying capacity of the population is represented by K and it is the largest stable population a species can sustain in the absence of harvesting, given the environmental conditions such as size of habitat, level of predation, access to food etc. In the absence of harvesting the model in equation (A.1) becomes $\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right)$. Maximum growth is found at $F'(x) = 0$, with the associated stock size being

$$x^{MSY} = \frac{K}{2}. \tag{A.3}$$

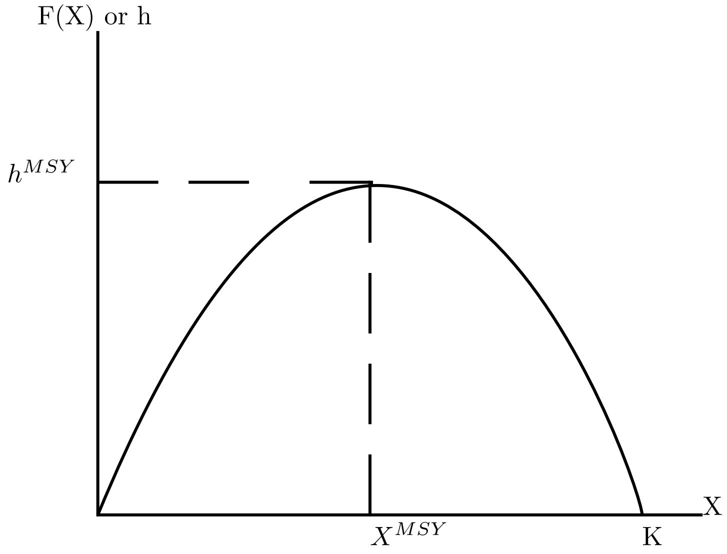
This is the stock size corresponding to the maximum sustainable yield (MSY), the largest harvest that can be harvested each year without depleting the stock. The logistic growth function is symmetric around x^{MSY}. Following the example of Clark (1990) and the FAO (2014) the

[1] More complex specifications of the logistic growth function including depensation could be applied to take account of threshold levels beyond which the population cannot be recovered (Perman et al., 2011).

term biological overexploitation or overfishing describes any situation where the stock size is reduced beyond that of the maximum sustainable yield i.e. $x(t) < x^{MSY}$. The level of natural growth corresponding to the MSY, also known as the maximum sustainable harvest/yield, is $F(x^{MSY})$. See figure A.1 for a graphical illustration.

$$F(x^{MSY}) = \frac{rK}{4} \text{ or } h^{MSY} = \frac{rK}{4}. \tag{A.4}$$

Figure A.1.: Maximum sustainable yield



A.2. The Gordon-Schaefer Model

In this classical model the economic theory presented in Gordon (1954) is integrated with Schaefer's (1957) combination of the linear harvesting function and the logistic growth function. The Schaefer harvesting function which is given by (A.5) consist of the catchability coefficient q, fishing effort $E(t)$ and stock $x(t)$. It relies upon the hypothesis that the catch per unit of effort (CPUE) (i.e. $h/E = CPUE$) is proportional to the the stock, x, with the catchability coefficient as the factor of proportionality (Clark, 1990).

$$h(t) = qE(t)x(t). \tag{A.5}$$

The Schaefer harvesting function is a specific variant of the Cobb-Douglas production function (i.e. $h(t) = qE(t)^{\alpha}x(t)^{\beta}$) with $\alpha = \beta = 1$[2]. Fishing effort $E(t)$ can be measured by a variety of relevant units, including the number of vessels per day and number of fishing days per season/year. More detailed methods can relate to the specific gears that are used, such as the number of nets (Clark, 1990).The catchability coefficient measures the efficiency of the fishery in relation to the stock size. Applying the logistic growth function and the Shcaefer harvesting function to (A.1) yields

$$\frac{dx(t)}{dt} = rx\Big(1 - \frac{x(t)}{K}\Big) - qE(t)x(t). \tag{A.6}$$

When assuming an equilibrium fishery ($\dot{x} = 0$) the time notation is dropped and the corresponding equilibrium stock and harvesting level are

$$x^* = K\Big(1 - \frac{qE}{r}\Big),\ h^* = qEK\Big(1 - \frac{qE}{r}\Big). \tag{A.7}$$

The graph of h^* known as the yield-effort curve is a parabola which combine the level of effort on the x-axis with harvest on the y-axis.

With P as the constant landing price of fish and c the marginal cost of fishing effort, profit of the fishery is given by $\Pi = Ph - cE$ or $\Pi = TR(E) - TC(E)$, and with the Schaefer specification

$$\Pi(E) = PqEK\Big(1 - \frac{qE}{r}\Big) - cE. \tag{A.8}$$

The total revenue (TR) curve is a mirror image of the yield-effort curve, albeit with monetary values on the y-axis (Clark, 1990).

A.2.1. Open Access

In an open access fishery there are no restrictions and all who wish can enter the fishery. In the situation of a newly opened previously unexploited fishery vessels will enter and increase the effort level until all economic rents are exhausted.ÂConsequently effort is exhausted until total revenue equal total cost, the open access level of effort, and the corresponding stock and harvesting levels are

$$E^{\infty} = \frac{r}{q}\Big(1 - \frac{c}{PqK}\Big),\ x^{\infty} = \frac{c}{Pq},\ h^{\infty} = \frac{cr}{Pq}\Big(1 - \frac{cr}{PqK}\Big). \tag{A.9}$$

[2] Empirical evidence suggest that the true harvesting relationship may be closer to a Cobb-Douglas function with $0 < \alpha < 1$ and $0 < \beta < 1$. Studies of cod fisheries find an α close to 1, whereas β is dependent on the choice of fishing gear (Flåten and Skonhoft, 2014).

This is the bionomic equilibrium at which both the level of effort and the stock is stable, the equilibrium is illustrated graphically in figure A.2.

A.2.2. Maximum Economic Yield

Consider the behaviour of a social planner or a sole owner, who would chose effort in order to maximise profits.

$$\max_{E \geq 0} \Pi(E) = PqEK\left(1 - \frac{qE}{r}\right) - cE. \tag{A.10}$$

The first order condition of an interior solution implies that the owner would exert effort until marginal revenue equals marginal cost. The associated profit maximising levels of effort, stock and harvesting are

$$E^{MEY} = \frac{c}{2q}\left(1 - \frac{c}{PqK}\right),\ x^{MEY} = \frac{K}{2} + \frac{c}{2Pq},\ q^{MEY} = \frac{Kr}{4}\left(1 + \left(\frac{c}{PKq}\right)^2\right). \tag{A.11}$$

The solution, which is illustrated in figure A.2, maximise economic rents and as long as there is some variable costs associated with fishing the stock associated with MEY will be larger than the x^{MSY}.

A.3. The Tragedy of the Commons

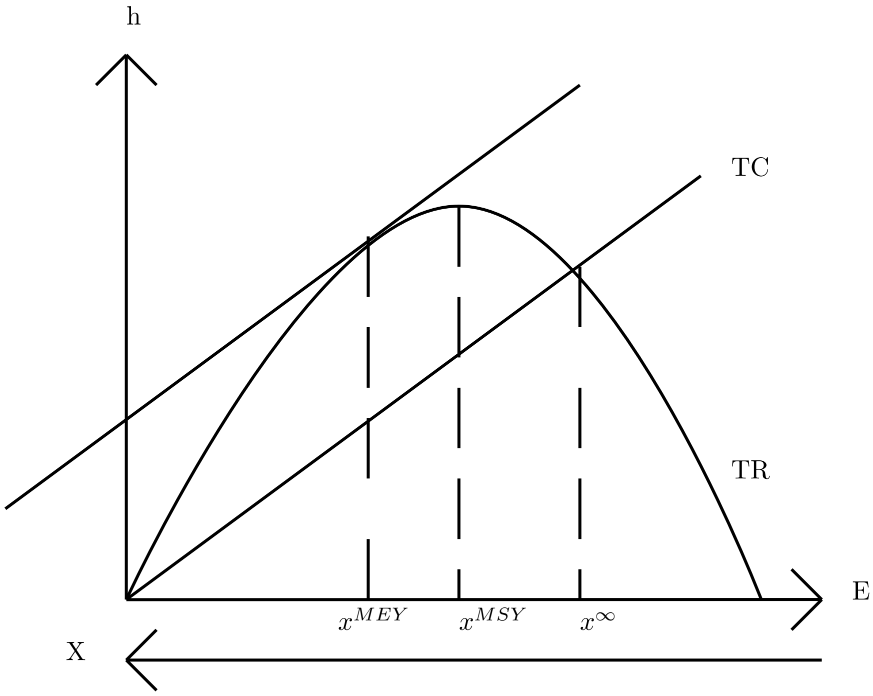
Made famous by Hardin (1968) in his seminal paper the concept that is 'the tragedy of the commons' relates to any situation where the independent actions of rational agents is contrary to what is collectively optimal. For the sake of comparison the expressions for the maximum economic yield solution for stock and effort can be rewritten as functions of the open access solutions.

$$X^{MEY} = \frac{K}{2} + \frac{1}{2}X^{\infty} \implies X^{MEY} > X^{\infty},\ E^{MEY} = \frac{1}{2}E^{\infty} \implies E^{MEY} < E^{\infty}. \tag{A.12}$$

It is apparent that an open access fishery always will be subject to economic overfishing. Whether it will be biologically overexploited however depends upon the cost structure of the fishery (Clark, 1990). A graphical illustration and comparison is illustrated in figure A.2.

As many other problems relating to the tragedy of the commons the behaviour of fishermen can be analysed in a game-theoretic framework. The open-access solution corresponds to the Nash competitive equilibrium where no agent can gain by unilaterally deviating from the equi-

Figure A.2.: The Gordon-Schaefer model



librium strategy, here the bionomic equilibrium.ÂThis non-cooperative game is also applicable to TAC regulated fisheries where the fishermen still compete for their share of the catch, hence explaining why so many input management regimes have failed to generate an economic efficiency (Clark, 2006; Gibbons, 1992).

B. Section 6.2.2 Comparative Statics

Appendix B illustrate the comparative statics behind table 6.1, in chapter 6, section 6.2.2.

Recall that $\tilde{Q}_1 + \tilde{Q}_2 = Q$, and thus $\tilde{Q}_i = Q - \tilde{Q}_j$, $\forall i = 1, 2$ and $i \neq j$.

Quota price, m

$$m(x, Q, \tilde{Q}_1) = P - \frac{Q + \tilde{Q}_2(\tilde{Q}_1)\frac{c_2}{c_1}}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)}. \tag{B.1}$$

The derivative of quota price with respect to c_1

$$\frac{\partial m}{\partial c_1} = \frac{\frac{x^2}{c_1^2}(\tilde{Q}_2 - 2Q)}{\left(x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)\right)^2} < 0. \tag{B.2}$$

The expression is negative because $2Q > \tilde{Q}_2$.

The derivative of quota price with respect to c_2

$$\frac{\partial m}{\partial c_2} = -\frac{\frac{2\tilde{Q}_2 x^2}{c_1^2} + \frac{2\tilde{Q}_2 x^2}{c_1 c_2} + \frac{Q x^2}{c_2^2}}{\left(x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)\right)^2} < 0. \tag{B.3}$$

The derivative of quota price with respect to Q

$$\frac{\partial m}{\partial Q} = -\frac{1}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)} < 0. \tag{B.4}$$

The derivative of quota price with respect to $\tilde{Q}_1$.

$$\frac{\partial m}{\partial \tilde{Q}_1} = \frac{\frac{c_2}{c_1}}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)} > 0. \tag{B.5}$$

The derivative of quota price with respect to $\tilde{Q}_2$.

$$\frac{\partial m}{\partial \tilde{Q}_2} = -\frac{1 + \frac{c_2}{c_1}}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)} < 0. \tag{B.6}$$

The derivative of quota price with respect to x

$$\frac{\partial m}{\partial x} = \frac{Q + \tilde{Q}_2(\tilde{Q}_1)\frac{c_2}{c_1}}{x^3\left(\frac{2}{c_1} + \frac{1}{c_2}\right)} > 0. \tag{B.7}$$

The leader's demand for quota, h_1

$$h_1(\tilde{Q}_1) = \left(Q + \tilde{Q}_1\right)\frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}}. \tag{B.8}$$

The derivative of the leader's quota demand with respect to c_1

$$\frac{\partial h_1}{\partial c_1} = -\frac{\frac{1}{c_1^2 c_2}(Q + \tilde{Q}_1)}{\left(\frac{2}{c_1} + \frac{1}{c_2}\right)^2} < 0. \tag{B.9}$$

The derivative of the leader's quota demand with respect to c_2

$$\frac{\partial h_1}{\partial c_2} = \frac{\frac{1}{c_1 c_2^2}(Q + \tilde{Q}_1)}{\left(\frac{2}{c_1} + \frac{1}{c_2}\right)^2} > 0. \tag{B.10}$$

The derivative of the leader's quota demand with respect to Q

$$\frac{\partial h_1}{\partial Q} = \frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}} > 0. \tag{B.11}$$

The derivative of the leader's quota demand with respect to $\tilde{Q}_1$

$$\frac{\partial h_1}{\partial \tilde{Q}_1} = \frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}} > 0. \tag{B.12}$$

The derivative of the leader's quota demand with respect to $\tilde{Q}_2$

$$\frac{\partial h_1}{\partial \tilde{Q}_2} = -\frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}} < 0. \tag{B.13}$$

The fringe's demand for quota, h_2

$$h_2(\tilde{Q}_1) = \left(Q + \tilde{Q}_2 \frac{c_2}{c_1}\right) \frac{\frac{1}{c_2}}{\frac{2}{c_1} + \frac{1}{c_2}}. \tag{B.14}$$

The derivative of the fringe's quota demand with respect to c_1

$$\frac{\partial h_2}{\partial c_1} = \frac{\frac{1}{c_1^2}(2Q - \frac{\tilde{Q}_2}{c_2})}{\left(\frac{2}{c_1} + \frac{1}{c_2}\right)^2} > 0. \tag{B.15}$$

The expression is positive because $2Qc_2 > \tilde{Q}_2$.

The derivative of the fringe's quota demand with respect to c_2

$$\frac{\partial h_2}{\partial c_2} = \frac{\frac{1}{c_2^2 c_1}(\tilde{Q}_2 - 2Q)}{\left(\frac{2}{c_1} + \frac{1}{c_2}\right)^2} < 0. \tag{B.16}$$

The expression is negative because $\tilde{Q}_2 \leq Q$.

The derivative of the fringe's quota demand with respect to Q

$$\frac{\partial h_2}{\partial Q} = \frac{\frac{1}{c_2}}{\frac{2}{c_1} + \frac{1}{c_2}} > 0. \tag{B.17}$$

The derivative of the fringe's quota demand with respect to $\tilde{Q}_1$

$$\frac{\partial h_2}{\partial \tilde{Q}_1} = -\frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}} < 0. \tag{B.18}$$

The derivative of the fringe's quota demand with respect to $\tilde{Q}_2$

$$\frac{\partial h_2}{\partial \tilde{Q}_2} = \frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}} > 0. \tag{B.19}$$

C. Proofs and Calculations - Market Power in the Product Market

C.1. The Social Planner Solution

Here the calculations for the social planner solution in Chapter 5, section 5.1 are presented.

Consumer surplus, with $d\Sigma h_i = d\sum_{i=1}^{n} h_i$ as the integrating factor.

$$CS = \int_{0}^{\sum_{i=1}^{n} h_i^*} P(\sum_{i=1}^{n} h_i)\, d\Sigma h_i - P(\sum_{i=1}^{n} h_i^*) \sum_{i=1}^{n} h_i^*. \tag{C.1}$$

Producer surplus

$$PS = P(\sum_{i=1}^{n} h_i^*) \sum_{i=1}^{n} h_i^* - \sum_{i=1}^{n} C_i(h_i, x). \tag{C.2}$$

And thus social surplus is

$$SS = \int_{0}^{\sum_{i=1}^{n} h_i^*} P(\sum_{i=1}^{n} h_i)\, d\Sigma h_i - P(\sum_{i=1}^{n} h_i^*) \sum_{i=1}^{n} h_i^* + P(\sum_{i=1}^{n} h_i^*) \sum_{i=1}^{n} h_i^* \sum_{i=1}^{n} C_i(h_i, x). \tag{C.3}$$

The maximisation problem of the social planner is

$$\max_{h_1, h_2, \ldots, h_n} \int_{0}^{\sum_{i=1}^{n} h_i^*} P(\sum_{i=1}^{n} h_i)\, d\Sigma h_i - \sum_{i=1}^{n} C_i(h_i, x) \text{ s.t. } \sum_{i=1}^{n} h_i \leq Q. \tag{C.4}$$

The corresponding lagrangian is

$$L = \int_{0}^{\sum_{i=1}^{n} h_i^*} P(\sum_{i=1}^{n} h_i)\, d\Sigma h_i - \sum_{i=1}^{n} C_i(h_i, x) - \lambda\big(\sum_{i=1}^{n} h_i - Q\big). \tag{C.5}$$

And the first order conditions are

$$\frac{\partial L}{\partial h_i} = P(\sum_{i=1}^{n} h_i)(1) - C_{ih_i} \leq \lambda,\ h_i \geq 0,\ \forall i = 1, 2, ..., n, \tag{C.6}$$

$$\frac{\partial L}{\partial \lambda} = \sum_{i=1}^{n} h_i \leq Q,\ \lambda \geq 0. \tag{C.7}$$

Inserting for the cost function and the inverse demand function, i.e. $P(\sum_{i=1}^{n} h_i) = a - b\big(\sum_{i=1}^{n} h_i\big)$ into the first order condition (C.6) we may solve for h_i. h_{-i} still represent all other agents except agent i.

$$a - b(h_i + h_{-i}) - \frac{c_i}{x^2} h_i \leq \lambda. \tag{C.8}$$

Whenever the condition holds with inequality $h_i = 0$. Thus we continue with the case when the condition holds with equality.

$$a - b(h_i + h_{-i}) - \frac{c_i}{x^2} h_i = \lambda, \tag{C.9}$$

$$h_i\big(b + \frac{c_i}{x^2}\big) = a - \lambda - bh_i, \tag{C.10}$$

$$h_i \frac{bx^2 + c_i}{x^2} = a - \lambda - bh_i, \tag{C.11}$$

$$h_i = \frac{x^2(a - \lambda - bh_{-i})}{bx^2 + c_i}. \tag{C.12}$$

Whenever the constraint does not bind i.e. $\sum_{i=1}^{n} h_i < Q\ \lambda = 0$ and the harvesting expression becomes

$$h_i = \frac{x^2(a - bh_{-i})}{bx^2 + c_i}. \tag{C.13}$$

The different scenarios are collected and presented in the following, which is equivalent to (5.3) found in section 5.1.

$$h_i = \begin{cases} \frac{x^2(a-\lambda-bh_{-i})}{bx^2+c_i}, & \text{if } \sum\limits_{i=1}^{n} h_i = Q,\ \lambda > 0,\ P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} = \lambda \\ 0, & \text{if } \sum\limits_{i=1}^{n} h_i \leq Q,\ \lambda \geq 0,\ P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} < \lambda \\ \frac{x^2(a-bh_{-i})}{bx^2+c_i}, & \text{if } \sum\limits_{i=1}^{n} h_i < Q,\ \lambda = 0,\ P(\sum\limits_{i=1}^{n} h_i) = C_{ih_i}. \end{cases} \tag{C.14}$$

The expressions may be simplified, first by assuming cost homogeneity, which implies $\sum_{i=1}^{n} h_i = nh_i$ or as used here nh. Starting from the first order condition for an interior solution we have.

$$a - b(nh) - \frac{c_i}{x^2}h = \lambda, \tag{C.15}$$

$$h(b + \frac{c_i}{x^2}) = a - \lambda. \tag{C.16}$$

$$h^* = \frac{x^2(a-\lambda)}{nbx^2 + c}, \text{ with } \lambda \geq 0. \tag{C.17}$$

The case of heterogeneous costs is illustrated with a case of two agents.

$$a - b(h_i + h_j) - \frac{c_i}{x^2}h_i = \lambda, \tag{C.18}$$

$$h_i = \frac{x^2(a - \lambda - bh_j)}{bx^2 + c_i}. \tag{C.19}$$

Equivalently for agent j

$$h_j = \frac{x^2(a - \lambda - bh_i)}{bx^2 + c_j}. \tag{C.20}$$

Inserting for agent j's harvesting expression into that of agent i we find

$$h_i = \frac{x^2(a-\lambda)}{bx^2 + c_i} - \frac{x^2}{bx^2 + c_i}\frac{bx^2(a - \lambda - bh_i)}{bx^2 + c_j}, \tag{C.21}$$

$$h_i = \frac{x^2(a-\lambda)}{bx^2 + c_i}\Big(1 - \frac{bx^2}{bx^2 + c_j}\Big) + \frac{(bx^2)^2}{(bx^2 + c_i)(bx^2 + c_j)}h_i, \tag{C.22}$$

$$h_i\Big(1 - \frac{(bx^2)^2}{(bx^2 + c_i)(bx^2 + c_j)}\Big) = \frac{x^2(a-\lambda)}{bx^2 + c_i}\Big(\frac{bx^2 + c_j - bx^2}{bx^2 + c_j}\Big), \tag{C.23}$$

$$h_i\Big(\frac{(bx^2 + c_i)(bx^2 + c_j) - (bx^2)^2}{(bx^2 + c_i)(bx^2 + c_j)}\Big) = \frac{x^2(a-\lambda)}{bx^2 + c_i}\Big(\frac{c_j}{bx^2 + c_j}\Big), \tag{C.24}$$

$$h_i = \frac{x^2(a-\lambda)}{bx^2 + c_i}\Big(\frac{c_j}{bx^2 + c_j}\Big)\Big(\frac{(bx^2 + c_i)(bx^2 + c_j)}{(bx^2 + c_i)(bx^2 + c_j) - (bx^2)^2}\Big). \tag{C.25}$$

And finally

$$h_i^* = \frac{x^2 c_j(a-\lambda)}{(bx^2 + c_i)(bx^2 + c_j) - (bx^2)^2}, \text{ with } \lambda \geq 0, \ \forall i = 1, 2, \ \& \ i \neq j. \tag{C.26}$$

C.2. Cournot Competition

Here are the calculations for section 5.2.

The Cournot agent's maximisation problem is given by

$$\underset{h_i \geq 0}{max} \;\; \pi_i(h_i, x) = P(\sum_{i=1}^{n} h_i)h_i - C_i(h_i, x) - m(h_i - \tilde{Q}_i) \;\forall\; i = 1, 2, ..., n. \tag{C.27}$$

The first order condition for maximisation is

$$P_{h_i}h_i + P(\sum_{i=1}^{n} h_i) - C_{ih_i} - m \leq 0, \;\; h_i \geq 0. \tag{C.28}$$

With specified functions $P(\sum_{i=1}^{n} h_i) = a - b\sum_{i=1}^{n} h_i$ and $C_i(h_i, x) = \frac{c_1}{2}(\frac{h_i}{x})^2$ the FOC is

$$-bh_i + a - b\sum_{i=1}^{n} h_i - \frac{c_i}{x^2}h_i - m \leq 0. \tag{C.29}$$

With $\sum_{i=1}^{n} h_i = h_i + h_{-i}$ we get

$$h_i\big(b + \frac{c_i}{x^2}\big) \leq a - m - bh_{-i}. \tag{C.30}$$

and thus the following harvesting expressions

$$h_i = \begin{cases} \frac{x^2(a-m-bh_{-i})}{2bx^2+c_i}, & \text{if } \; P_{h_i}h_i + P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} = m > 0 \\ 0, & \text{if } \; P_{h_i}h_i + P(\sum\limits_{i=1}^{n} h_i) - C_{ih_i} < m \geq 0 \\ \frac{x^2(a-bh_{-i})}{2bx^2+c_i}, & \text{if } \; P_{h_i}h_i + P(\sum\limits_{i=1}^{n} h_i) = C_{ih_i}, \; m = 0. \end{cases} \tag{C.31}$$

Assuming homogenous agents, $\sum_{i=1}^{n} h_i = nh_i = nh$ that all remain in the industry (i.e. interior solution), harvesting with the subscript C for Cournot is

$$-bh^C + a - bnh^C - \frac{c}{x^2}h^C - m = 0, \tag{C.32}$$

$$h\big(b(n+1) + \frac{c}{x^2}\big) = a - m. \tag{C.33}$$

$$h^C = \frac{x^2(a-m)}{b(1+n)x^2 + c} \tag{C.34}$$

With two heterogeneous agents and an interior solution we have

$$-bh_i + a - b(h_i + h_j) - \frac{c_i}{x^2}h_i - m = 0, \; \forall i = 1, 2, \; \& \; i \neq j, \tag{C.35}$$

$$h_i\big(2b + \frac{c_i}{x^2}\big) = a - m - bh_j. \tag{C.36}$$

$$h_i = \frac{x^2}{2bx^2 + c_i}(a - m - bh_j). \tag{C.37}$$

And equivalently for agent j

$$h_j = \frac{x^2}{2bx^2 + c_j}(a - m - bh_i). \tag{C.38}$$

Inserting for agent j into agent i's harvesting expression yields

$$h_i^C = \frac{x^2\big(bx^2 + c_j\big)}{(2bx^2 + c_i)(2bx^2 + c_j) - (bx^2)^2}(a - m),\ \forall i = 1, 2 \text{ \& } i \neq j. \tag{C.39}$$

D. Proofs and Calculations - Market Power in the Quota Market

In appendix D some of the expressions from the thesis are proved. First you find the illustration of the alternative method of deriving the duopoly quota price expression with market power in the quota market. Secondly you will find the total calculations from the analysis of the efficiency loss in section 6.3.

D.1. Quota Price Expression

$$\Big(P - C_{1h_1}\Big)\sum_{i=2}^{n} h_{im} = m\sum_{i=2}^{n} h_{im} - \Big(h_1 - \tilde{Q}_1\Big). \tag{D.1}$$

Using equation (6.6) as the starting point, inserting for the cost function as well as (6.19) and (6.18) will yield 6.17.

$$m = P - C_{1h_1} + \frac{(h_1 - \tilde{Q}_1)}{\sum\limits_{i=2}^{n} h_i'(m)}. \tag{D.2}$$

$$m = P - \frac{c_1}{x^2}\left(2\frac{x^2}{c_1}(P-m) + \frac{c_2}{c_1}(\tilde{Q}_1 - Q)\right) - \frac{2\frac{x^2}{c_1}(P-m) + \frac{c_2}{c_1}(\tilde{Q}_1 - Q) - \tilde{Q}_1}{\frac{x^2}{c_2}}, \tag{D.3}$$

$$m = P - 2P + 2m - 2\frac{c_2}{c_1}P + 2\frac{c_2}{c_1}m + \frac{c_2}{x^2}Q - \frac{c_2^2}{c_1 x^2}(\tilde{Q}_1 - Q), \tag{D.4}$$

$$m\left(\frac{-(c_1+2c_2)}{c_1}\right) = P\left(\frac{-(c_1+2c_2)}{c_1}\right) + \frac{c_2}{x^2}Q - \frac{c_2^2}{c_1 x^2}(\tilde{Q}_1 - Q), \tag{D.5}$$

$$m = P - \frac{c_1 c_2 Q - c_2^2(\tilde{Q}_1 - Q)}{x^2(c_1 + c_2)}. \tag{D.6}$$

$$m(x, Q, \tilde{Q}_1) = P - \frac{Q - \frac{c_2}{c_1}(\tilde{Q}_1 - Q)}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)}. \tag{D.7}$$

Which is equivalent to the expression in section 6.2.1.

D.2. Comparative Statics, (6.10)

The total derivative of agent 1's FOC with respect to m and $\tilde{Q}_1$, i.e. expression 6.10. Starting with the first order condition for an interior solution

$$\frac{\partial \pi_1}{\partial m} = -P\sum_{i=2}^{n} h_{im} + C_{1h_1}\sum_{i=2}^{n} h_{im} + m\sum_{i=2}^{n} h_{im} - \Big(Q - \sum_{i=2}^{n} h_i(m) - \tilde{Q}_1\Big) = 0. \tag{D.8}$$

Recall that $h_1 = Q - \sum_{i=2}^{n} h_i$, and take the total derivative with respect to m and $\tilde{Q}_1$.

$$\begin{aligned} -P\sum_{i=2}^{n} h_{imm}dm + C_{1h_1h_1}\big(-\sum_{i=2}^{n} h_{im}\big)\sum_{i=2}^{n} h_{im}dm + C_{1h_1}\sum_{i=2}^{n} h_{imm}dm \\ + \sum_{i=2}^{n} h_{im}dm + m\sum_{i=2}^{n} h_{imm}dm - \Big(-\sum_{i=2}^{n} h_{im}dm - d\tilde{Q}_1\Big) = 0. \end{aligned} \tag{D.9}$$

Collect the terms

$$-dm\Bigg(\big(P - C_{1h_1} - m\big)\sum_{i=2}^{n} h_{imm} + C_{1h_1h_1}\big(\sum_{i=2}^{n} h_{im}\big)^2 - 2\sum_{i=2}^{n} h_{im}\Bigg) = -d\tilde{Q}_1. \tag{D.10}$$

And thus the final result is, as in (6.11)

$$\frac{dm}{d\tilde{Q}_1} = \frac{1}{\Big(P - C_{1h_1} - m\Big)\sum_{i=2}^{n} h_{imm} + C_{1h_1h_1}\big(\sum_{i=2}^{n} h_{im}\big)^2 - 2\sum_{i=2}^{n} h_{im}} > 0. \tag{D.11}$$

D.3. The Efficiency Loss

Total Cost

Total cost in the presence of market power is given by

$$TC = C_1(h_1(\tilde{Q}_1), x) + \sum_{i=2}^{n} C_i(h_i(\tilde{Q}_1), x). \tag{D.12}$$

$$\frac{\partial TC}{\partial \tilde{Q}_1} = C_{1h_1}\frac{\partial Q_1}{\tilde{Q}_1} + \sum_{i=2}^{n} C_{ih_i}\frac{\partial h_i}{\tilde{Q}_1}. \tag{D.13}$$

Given that $Q = h_1 + \sum_{i=2}^{n} h_i(\tilde{Q}_1)$

$$0 = \frac{\partial h_1}{\tilde{Q}_1} + \sum_{i=2}^{n} \frac{\partial h_i}{\tilde{Q}_1}, \tag{D.14}$$

$$\frac{\partial h_1}{\tilde{Q}_1} = -\sum_{i=2}^{n} \frac{\partial Qhi}{\tilde{Q}_1}. \tag{D.15}$$

Inserting for this yields

$$\frac{\partial TC}{\partial \tilde{Q}_1} = \sum_{i=2}^{n} \Big(C_{ih_i} - C_{1h_1} \Big) \frac{\partial h_i}{\tilde{Q}_1}. \tag{D.16}$$

By differentiating the optimality condition of the competitive agents, $P - C_{ih_i} = m$, with respect to $\tilde{Q}_1$ and rearranging we get

$$\frac{\partial h_i}{\tilde{Q}_1} = -\frac{\frac{\partial m}{\partial \tilde{Q}_1}}{C_{ih_ih_i}}, \tag{D.17}$$

$$\frac{\partial TC}{\partial \tilde{Q}_1} = -\frac{\partial m}{\partial \tilde{Q}_1} \sum_{i=2}^{n} \frac{\big(C_{ih_i} - C_{1h_1}\big)}{C_{ih_ih_i}}. \tag{D.18}$$

Once again using the optimality condition the expression reads

$$\frac{\partial TC}{\partial \tilde{Q}_1} = \frac{\partial m}{\partial \tilde{Q}_1} \Big(C_{1h_1} + m - P \Big) \sum_{i=2}^{n} \frac{1}{C_{ih_ih_i}}. \tag{D.19}$$

From above we know that $\frac{\partial m}{\partial \tilde{Q}_1} > 0$ and with convex costs $\sum_{i=2}^{n} \frac{1}{C_{ih_ih_i}} > 0$. Moreover, if agent one is allocated an amount of quota equal to h_1^* he will produce the competitive/efficient amount and thus according to the optimality condition $\frac{\partial TC}{\partial \tilde{Q}_1} = 0$, costs are unaffected by the initial allocation of quota. The inefficiency results are

$$\frac{\partial TC}{\partial \tilde{Q}_1} > 0 \;\text{ if }\; P - C_{1h_1} < m, \tag{D.20}$$

$$\frac{\partial TC}{\partial \tilde{Q}_1} < 0 \;\text{ if }\; P - C_{1h_1} > m. \tag{D.21}$$

The first case is true when the allocated quota exceed quota demand , i.e.$h_1 < \tilde{Q}_1$ and the latter when demand exceed initial endowment, $h_1 > \tilde{Q}_1$.

Total Profits

Total profits are given by

$$\Pi = PQ_1(\tilde{Q}_1) - C_1(h_1(\tilde{Q}_1)) - m(x,Q,\tilde{Q}_1)\big(h_1(\tilde{Q}_1) - \tilde{Q}_1\big) \tag{D.22}$$

$$+\sum_{i=2}^{n}\Big(Ph_1(\tilde{Q}_1) - C_i(h_i(\tilde{Q}_1)) - m(x,Q,\tilde{Q}_1)\big(h_i(\tilde{Q}_1) - \tilde{Q}_i\big)\Big). \tag{D.23}$$

Initial distribution of quotas cannot exceed the TAC and thus $\sum_{i=2}^{n}\tilde{Q}_i = Q - \tilde{Q}_1$, inserting for this the first order derivative of total profits with respect to $\tilde{Q}_1$ is

$$\begin{aligned}\frac{\partial\Pi}{\partial\tilde{Q}_1} &= P\frac{\partial Q_1}{\partial\tilde{Q}_1} + C_{1h_1}\frac{\partial h_1}{\partial\tilde{Q}_1} - \frac{\partial m}{\partial\tilde{Q}_1}\Big(h_1(\tilde{Q}_1) - \tilde{Q}_1\Big) - m\Big(\frac{\partial h_i}{\partial\tilde{Q}_1} - 1\Big)\\ +P\sum_{i=2}^{n}\frac{\partial h_i}{\partial\tilde{Q}_1} &- \sum_{i=2}^{n}C_{ih_i}\frac{\partial h_i}{\partial\tilde{Q}_1} - \frac{\partial m}{\partial\tilde{Q}_1}\sum_{i=2}^{n}\Big(h_i(\tilde{Q}_1) - \tilde{Q}_i\Big) - m\Big(\frac{\partial h_i}{\partial\tilde{Q}_1} + 1\Big).\end{aligned} \tag{D.24}$$

$$\frac{\partial\Pi}{\partial\tilde{Q}_1} = \Big(P - C_{1h_1} - m\Big)\frac{\partial h_1}{\partial\tilde{Q}_1} + \sum_{i=2}^{n}\Big(P - C_{ih_i} - m\Big)\frac{\partial h_i}{\partial\tilde{Q}_1}. \tag{D.25}$$

The same modifications made to the derivative of total cost can be made to (D.25), with the final results being

$$\frac{\partial\Pi}{\partial\tilde{Q}_1} = \frac{\partial m}{\partial\tilde{Q}_1}\Big(P - C_{1h_1} - m\Big)\sum_{i=2}^{n}\frac{1}{C_{ih_ih_i}}. \tag{D.26}$$

The results are a mirror image of those above, driven by the change in total cost.

E. Data

This appendix will outline how the data in the numerical illustrations have been established.

E.1. Net Intrinsic Growth Rate

According to the estimates of Inarra and Skonhoft (2008) the net intrinsic growth rate, which take gear selectivity into account, is $\tilde{r} = 0.20$ in the hypothetical scenario where the trawlers harvest the entire TAC and $\tilde{r} = 0.50$ if the coastal fleet were the only agent. I assume the TAC was equally divided between the two agents prior to the introduction of ITQ. Moreover, the North-East Atlantic cod is co-managed with Russia whom is assumed to harvest their share entirely with trawlers. The divide between Norway and Russia is roughly fifty-fifty and subsequently the weighted intrinsic growth rate used in this model is $\hat{r} = 0.275$

$$\hat{r} = 0.5 * \frac{1}{4} + 0.2 * \frac{3}{4} = 0.275 \tag{E.1}$$

E.2. The Cost Parameter

The original data collected from Inarra and Skonhoft (2008) are presented in table **??**. Note that I have used different parameter symbols.

I have assumed a steady state fishery at MSY, and thus x^{MSY} and TAC is calculated according to the formulas presented in section A.1.

Inarra and Skonhoft (2008) operate with constant marginal cost, and thus I need to adjust the harvesting cost parameter according to effort. Seeing as Inarra and Skonhoft (2008) have based their cost data on Armstrong (1999) I have used the Appendix in Armstrong (1999) to collect some data on effort. The appendix in Armstrong (1999) only provide a calculated example from 1992, though because I only attempt to provide an illustration to the theoretical model I find this sufficient to adjust the cost parameter, which is based on the 1990-93 average. The table presented in Armstrong's appendix is found in figure E.1.

Using the information from both Inarra and Skonhoft (2008) and Armstrong (1999) the cost

Table E.1.: Baseline parameter values collected from Inarra and Skonhoft (2008)

Parameter	Parameter description	Value
$\hat{r_1}$	Net intrinsic growth rate if only the trawlers harvest	0.2
$\hat{r_2}$	Net intrinsic growth rate if only the coastal fleet harvest	0.5
K	Carrying Capacity	5 000 (1000 tonnes)
$\hat{c_1}$	Trawler fleet harvesting cost	18.8 (mill NOK/vessel)
$\hat{c_2}$	Coastal fleet harvesting cost	1.5 (mill NOK/vessel)
q_1	Trawler fleet catchability	0.0066 (1/coastal vessel)
q_2	Coastal fleet catchability	0.0011 (1/trawl vessel)

parameter presented in table 7.1 is given by equation (E.2) and (E.3), and adjusted for inflation.

$$c_1 = \frac{\frac{\hat{c_1}}{q_1^2}}{\sum_{i=25}^{28} f_i g_i}, \tag{E.2}$$

$$c_2 = \frac{\frac{\hat{c_2}}{q_2^2}}{\sum_{i=1}^{7} f_i g_i}. \tag{E.3}$$

Figure E.1.: The appendix in Armstrong (1999)

Appendix

Table A. Example of calculation of costs and q-values for Norwegian coastal vessels and trawlers, in NOK[a]

Coastal vessels: average vessel values in 1992

A. Vessel sub group[b]	1	2	3	4	5	6	7
B. Tot cost – labour costs[c]	627012	845095	850413	692547	689268	857628	2029354
C. Labour costs	458014	653228	716826	580301	666710	621051	1341257
D. Sum costs (B + C)	1085026	1498323	1567239	1272848	1355978	1478679	3370611
E. No. vessels/subgroup (f_i)	68	72	137	29	80	38	32
F. % time spent codfishing (g_i)	0.73	0.63	0.71	0.86	0.89	0.44	0.62
G. Weighted cost/vessel	165741	209139	469106	97685	297091	76079	205782
H. Weighted tot. vessels ($\sum f_i g_i$)	281.49						
I. Total weighted cost	1520623						
J. Total harvest[d]	0.146						
Y. Mature stock size[e]	0.364945						
L. q-value	0.0012311						

Trawlers; average vessel values in 1992

A. Vessel sub group[b]	25	27	28
B. Tot cost – labour cost[c]	5275173	9284051	29382885
C. Labour costs	2453106	4521571	9882711
D. Sum costs (B + C)	7728279	13805622	39265596
E. No. vessels/subgroup (f_i)	23	28	18
F. % time spent codfishing (g_i)	0.42	0.69	0.68
G. Weighted cost/vessel	1811140	6470757	11659653
H. Weighted tot. vessels ($\sum f_i g_i$)	41.22		
I. Total weighted cost (c_i)	19941550		
J. Total harvest[d]	0.277		
K. Immature stock size[e]	0.952604		
L. q-value	0.007054		

Calculated average cost and q-values for 1990–93

		Cost[f] (I)	q-values (L)
Coastal	1990	1195792	0.001013
	1991	1579806	0.001337
	1992	1520623	0.001231
	1993	1513142	0.001117
	average	**1452341**	**0.00117**
Trawl	1990	16177484	0.00567
	1991	18812537	0.006243
	1992	19941550	0.007054
	1993	19476842	0.007633
	average	**18602103**	**0.00665**

[a]Unless otherwise stated, Anon. (1992).

[b]The vessel subgroups are as follows: 1, 2 and 3 are fisheries with gillnet, handline and danish seine on the coast of Finnmark, Troms and Nordland, respectively. 4 is fisheries with long line on the coast of Finnmark and Troms. 5 is fisheries with long line on the coast of Nordland. 6 is miscellaneous fisheries off Trøndelag. 7 is off-coast fisheries with long-line, gillnet and trawl, North Norway. 25 is Trawling for cod and saithe, vessels $<$ 250 GRT, Møre and Romsdal and north. 27 are freshfish trawlers, vessels $<$ 250 GRT. 28 are factory trawlers.

[c]Includes fuel, bait, ice, salt, telephone, harbour fees, hired labour, social insurance, insurance on gear and vessel, maintenance of gear and vessel, and sundry unspecified costs.

[d]Actual harvest.

[e]Calculated using actual harvest in the bioeconomic model.

[f]Nominal values.

Calculations:

G. Weighted cost/vessel = FDE/H.

I. Total weighted cost $c_i = \sum$ (G for each vessel sub group).

L. q-value $=$ J/HK.