ITQs, Market Power and the Potential Efficiency Loss

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Abstract

Individual transferable quota (ITQ) regimes have been adopted in a number of fisheries. While the issue of market power in such regimes has been discussed, this paper adds to the literature by solving for explicit harvesting- and quota price expressions. The paper supports the standard result that efficiency loss is increasing in the deviation between the leader's demand for, and initial allocation of quotas. In addition, the explicit solution indicates that the relative cost of the market leader, as well as the size of the fringe, will have an effect on the magnitude of the efficiency loss. Certain differences between emission permits and ITQs suggest that the potential efficiency loss of market power could be greater in an ITQ regime that in an emission permits market. Inspired by the North-East Arctic cod fishery the paper is among the first to provide a numerical illustration of the potential efficiency loss of market power in a rights-based regime for fisheries. The numerical results support the theoretical findings, though market power does not appear to be a major issue in ITQ regimes.

Keywords: ITQs, Tradable quotas, Market power.

1 Introduction

The theoretical efficiency properties of transferable rights regimes, such as ITQs are well documented, and the regime has been implemented with varying success in New Zealand, Australia and Iceland. Non-transferable property rights regimes are found in, among others, Norway, Canada, USA, South-Africa, the Netherlands, Namibia, Sweden, Denmark and the UK (Eythórsson, 1996; Asche et al., 2008; Hersoug, 2005). An ITQ regime allocates the total allowable catch (TAC) among agents by granting exclusive rights to a share of the total harvest (Grafton, 1996; Tietenberg, 2001). Due to the rights' transferability, they are traded until only the most efficient agents remain in the fishery. Thus, under certain conditions, ITQ can deal with the problem of overcapacity and yields a cost-effective outcome, independent of the initial allocation of quotas; an advantage not as easily available in the reciprocal tax regime which requires more information about the individual vessel's cost structure (Copes, 1986; Libecap, 2007).

The ITQ regime's ability to reduce overcapacity in the fishing fleet relies on the concentration of rights, and 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

(Grafton, 1996; Tietenberg, 2001; Von Der Fehr, 1993). Looking at the market for emission permits, Hahn (1984) was the first to examine how market power affects the cost-effectiveness of transferable property rights. Within a one period model, one dominant firm manipulates the price, using price as the strategic variable, while the remaining firms (the fringe) are perfectly competitive price takers. Hahn (1984) finds that market inefficiency is related to the initial allocation of rights and varies with the market leader's excess demand for, or supply of permits. In other words, cost-ineffectiveness increase the further the number of permits allocated to the dominant firm deviates from its demand for permits, and thus cost-effectiveness is no longer independent of the initial allocation of rights. Westskog (1994) extends upon this by increasing the number of agents with market power and letting the leaders act as Cournot players. Still, the results are similar to those of Hahn (1984). In their numerical analyses both Hahn (1984) and Westskog (1994) find that the potential efficiency loss, which varies between 0.6% and 12%, is in general relatively small.

Hagem and Westskog (1998) develop a two-period model for a tradable permits market with market power, and find a tradeoff between cost-effectiveness 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. Egteren and Weber (1996) extend Hahn's model to allow for noncompliance, and though generally similar to Hahn (1984) the results suggest that studies which ignore noncompliance tend to underestimate the social cost of market power. 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. Von Der Fehr (1993) analyse how and under what conditions strategic interaction can or will occur. With two symmetric Cournot firms he finds that monopolisation is more likely when permits are essential to production and that the number of permits held determines the frims' strategic behaviour.

While ITQs are considered property rights to a resource, a marketable good; emission permits are rights to a bi-product, waste created as a consequence of producing the marketable good of interest (Anderson, 1991). Another key difference between emission permits and ITQs is that ITQs are output quotas and thus, quotas are necessary in order to participate in the fishery (Hatcher, 2012). Emission permits, on the other hand, concern waste from inputs to production, and there may be technological alternatives that that enables substitutions between inputs, allowing continued production with less waste and fewer emission permits. Correspondingly, the fringe's demand for quotas in an ITQ regime could be less elastic than the fringe's demand for permits in an emission permits market.

Anderson (1991) was the first to study the issue of market power within a market for harvesting rights. With quantity as the leader's strategic variable he confirms the results of Hahn (1984), but the paper mainly focus on the case of dual market power, i.e. a situation in which market power in the quota market generate market power in the corresponding product market. The dual market power may motivate a net buyer to hold excess quota and restrict output in order to raise both product price and the value of the quotas. In a second paper, Anderson (2008) derives a formula for the maximum percentage of the TAC the market leader can hold without benefiting from monopoly behaviour. Hatcher (2012) find that a dominant firm always will be non-compliant if the firm's initial allocation of quotas is zero, with a non-zero allocation the compliance decision will be parameter specific. In a dynamic setting similar to that of Hagem and Westskog (1998). Armstrong (2008) find that, under specific conditions, it is possible to eliminate market power with an optimal history dependent mechanism to allocate the rights.

Both Anderson (1991; 2008) and Hatcher (2012) mainly focus on dual market power and compliance, respectively. Moreover, neither particularly discuss the potential efficiency loss of market power in an ITQ regime. This paper adds to the literature by solving for explicit harvesting- and quota price expressions, which takes the theoretical analysis one step further than the general cases considered in Hahn (1984), Westskog (1994), Anderson (1991) and Hatcher (2012). The findings support the standard result that efficiency loss is increasing in the deviation between the leader's demand for, and initial allocation of quotas. In addition, the explicit solutions indicates that the relative cost of the market leader, as well as the size of the fringe, will have an effect on the magnitude of the efficiency loss. The paper is, to the best of my knowledge, the first to provide a numerical illustration of the potential efficiency loss of market power in a rights-based regime for fisheries. The model is illustrated numerically for two different cost functions, though neither indicate that market power generate major efficiency losses in ITQ regimes.

The rest of the paper is structured in the following manner; firstly section two discuss the idea of ITQs and property rights. Section three presents some experiences from countries with ITQ regimes. For the purpose of comparison section four presents the benchmark model of an ITQ regime with perfect competition, whereas the introduction of market power and a discussion of the efficiency loss is found in section five. A numerical illustration inspired by the North-East Arctic (NEA) cod fishery is provided in section six, while section seven concludes the paper.

2 ITQ and property rights

Ever since Hardin's 1968 concept of the 'tragedy of the commons' the field of resource economics have been overflowing with misconceptions and inconsistency. Nevertheless, there seem to be a consensus that open access issues, though often referred to as common property resource issues, result from a lack of well defined property rights (Copes, 1986; Grafton et al., 2000). Given that a common property resource is in fact a resource managed by a property regime where the rights are collectively exercised by a group, the issues of resources subject to such regimes are due to a lack of cooperation and enforcement within the common rather than the lack of well defined rights. Such a common property regime will be in line with Ostrom's idea of a local common pool resource, and when cooperation and the authority system within such regimes fail, for all practical purposes the resource become a case of restricted open access[1] (Bromley, 1992, 2016; Ostrom, 1990; Boyce, 1992; Arnason, 2012). Problems related to open access may however, be alleviated with property rights. Accordingly, the ITQ regime granting individual rights to a share of the total harvest, is often suggested.

[1] if the group, or authority system, fail to exclude non-owners there is unrestricted open access

ITQ is a cap-and-trade program for fisheries which allocates the TAC among agents by granting exclusive rights to a share of this TAC (Grafton, 1996; Tietenberg, 2001). The rights are then traded among the agents until only the most efficient remain, thus under certain conditions ITQ may be cost efficient, independent of the initial allocation of quotas (Copes, 1986; Libecap, 2007). The market in which the ITQs are traded can be separated into a short- and a long-term market, or as they are often referred to, the quota leasing 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, usually one year. 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 (Grafton, 1996).

There are several mechanisms for the initial allocation of 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). While some studies (e.g. Morgan, 1997, Cramton and Kerr, 2002, Tietenberg, 2001) indicate that auctions are the most economically efficient method of distributing the TAC, auctions are rarely used when allocating fishing rights. 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. Moreover, 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).

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). Giving away property rights to a natural resource is highly controversial. In addition to creating entry barriers the distribution of TAC according to grandfathering reward agents whom with large historical catches have contributed the most to the overexploitation of the resource (Inarra and Skonhoft, 2008; Libecap, 2007).

Bromley (1991) defines a property right as the claim to a stream of benefits, that the state will agree to protect. Most ITQ regimes are subject to a number of restrictions that hinder the quotas ability to behave as ideal property rights. Particularly, the quotas' permanence and transferability are often limited. Additionally, as emphasized by Arnason (2005), ITQs are harvesting rights, not property rights in the underlying resource, that is, the fish stocks and their habitat. Thus ITQ does not solve the issue of lacking property rights in the natural resource itself and quota holders will not have the incentives to behave as private property owners maximising the net present value of the resource, instead the underlying resource will still be subject to open access. Hence, the quota holders may continue to behave as myopic individuals. Even if the ITQs may be regarded as perpetual, as in the case of New Zealand, harvesting still requires a positive and sufficient TAC and the aspect of future uncertainty further reduce the quota owners' incentive to act in the long-term benefits of the underlying resource. Moreover, returning to the definition of Bromley (1992), with the aspect of future uncertainty ITQs do not secure a stream of benefits, but rather a potential option to a share of the harvest. On the other hand, the stewardship argument assert that right to a percentage of the TAC may induce more prudent behaviour with agents hoping to increase next years' TAC and their harvesting share through reducing quota busing and highgrading.

Within such a regime to whom does the underlying resource belong? In Iceland and Norway it is stated that the wild marine resources belong to the country's residents in common. That said, the resources are not managed as a common properties where the rights are collectively exercised by the entire nation's population (Grytås, 2014; Regjeringen.no, 2007). Instead, the fisheries are managed as a state property regime which is distinguished by the separation of ownership, management and actual use. While the resource is owned by the entire population it is managed by some governmental authority that determines a subset of the population which is allowed to exploit the resource (Bromley, 1992). Correspondingly ITQ may be regarded as the method through which the government grants the harvesting rights to the relevant subset. This regime creates a somewhat peculiar situation in which the state carries the full responsibility of acting in the best interest of the common, thus enabling the quota holders to act as myopic agents only aimed at maximising short-run profits. This may aggregate the issue of discards as the quota holders only have a right to the harvested fish and thus only consider the value of the fish in the market, and not its value in the ocean. Moreover while the resource is owned by the entire country's population only the subset of quota holders reap the monetary benefits that follow from ownership. Nevertheless, in spite of their myopic behaviour, the quota holder consider their quotas as property rights. This setup clearly creates an argument for taxing quota holders such that at least some of the resource rent benefits all the owners.

If the fishermen's behaviour remain myopic the introduction of ITQ will not combat issues of illegal and unreported fishing such as quota busting, and it may induce highgrading and rent-seeking. 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 rider problem where the myopic fisherman may view his excess landings as insignificant to stock if the rest follow the rules. 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 and sufficiently penalized. Such monitoring will be costly and the costs of enforcing may be higher than the benefits of ITQ (Anderson, 1995). Nevertheless, while quota busting to some extent can be regulated with onshore monitoring, its alternative highgrading is even more difficult and expensive to combat. When catch is restricted there is an incentive to obtain the most from the fixed amount. 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 a relatively higher price per kg for larger sized fish, this motivates agents to discard smaller low quality fish in order to not exceed the quota. Moreover, although discarding is not illegal everywhere it 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 illegalize discarding (Grytås, 2014).

The consequences of quota busting and highgrading highlight the important role of monitoring and enforcement in quota based 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).

If fishermen anticipate the introduction of an individual quota regime they may change their behaviour in an attempt to increase historical catch levels and secure more property rights in the future. Such rent-seeking activity will magnify the problem of excess capacity and overexploitation. Yet, myopic 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). When 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). 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 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.

Another main branch of criticism relates to the welfare implications of the ITQ regime. 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 quota regimes, including Norway and Iceland has features aimed at protecting the social structure and division of equity e.g. 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 a fishery is restricted the right to fish increase in value, and while the initial generation often receive their rights for free, new entrants and future generations will be hindered by steep quota prices and only collect resource rents if the fishery increase in value over time (Grytås, 2014; McCay, 1995; Copes, 1986).

3 Experience with ITQ

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 regimes that eventually emerged in New Zealand and Iceland are 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; Arnason, 2005). A key difference between the two ITQ regimes relates to the durability of the rights; while ITQs in New Zealand are explicitly perpetual, the duration of Icelandic ITQs is indefinite, but may be withdrawn without compensation if the regime is terminated (Arnason, 2005). For Iceland this is in line with the fisheries management act of 1990 which states that the fish stocks in Icelandic waters are the common property of the Icelandic people, accordingly only the people of Iceland can hold quotas for the Icelandic fisheries (Runolfsson and Arnason, 1996). The Faroe Islands had a brief period with ITQs between 1994 and 1996 before switching to a system of effort quotas, but are currently in a process of changing back to an ITQ regime (Danielsen and Agnarsson, 2018; Ministry of Fisheries , 2018)

In Iceland quota shares in the long-term market are freely transferable, whereas short-term leasing of quotas are subject to some geographical restrictions, as well as a condition that the quota holders themselves must harvest at least 50% of their own share every second year. Additionally, no individual or company is allowed to hold more than an upper bound percentage of the TAC, this ranges from 12% of the TAC for cod to 35% of the TAC for ocean redfish (Runolfsson and Arnason, 1996). The new Faroese regime also include an upper cap stating that no person or company can own more than 35% of the total quota in any one of a number of species. In addition, the quotas must go through a public auction and cannot be transferred on a permanent basis (Ministry of Fisheries , 2018).

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%, whereas the increase in catch is almost tenfold (Arnason, 2005; Runolfsson and Arnason, 1996). 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). However, with few barriers to trade the right to fish in Iceland quickly concentrated and from 1984 to 20154/15 the TAC share of the 25 largest firms increased from 38.2% to 82.6%, with the largest firm increasing its share from 4.1 to 11.9 percent (Matthíasson et al., 2015).

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(Arnason, 1993; Clark, 2006), 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 (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). That said, after the introduction of ITQs Iceland's fisheries went from frequently facing negative profits to becoming one of the most profitable and efficient fisheries in the world (Røed, 2013; Runolfsson and Arnason, 1996). Additionally, 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).

Both New Zealand and Iceland allocated the quotas for free, based on historic catches (Arnason, 2005; Mace et al., 2014). However, both regimes have also attempted to introduce a fee intended to ensure that the industry itself covers the cost of administration and enforcement. New Zealand has fee per quota share, or tonne, for each of the relevant species (Tietenberg, 2003; Clark, 2006; NOU, 2016). The system in Iceland includes a general fee per quota share and a particular resource rent tax on profits(NOU, 2016). That said, studies indicate that the fees, including the Icelandic resource rent tax, only cover about fifty percent of total administration cost (Tietenberg, 2003; Clark, 2006; Matthiasson, 2008). The Faroe Islands also has a fee per kilo of landed harvest and are also among the few who have tried to allocate their licences through auction (NOU, 2016).

4 ITQ with perfect competition

For the benchmark model of an ITQ regime with perfect competition consider a single species fishery with an appropriately set TAC. The TAC is the total supply of quota, and is denoted by Q, whereas $\tilde{Q}_i$ is the amount of quota, measured in tonnes, initially allocated to agent i for free (e.g. using grandfathering). The market considered here is the short term- or the quota leasing market. The model is static and only considers one period, within this period there are three consecutive events; first initial allocation of quotas, then the quotas are traded and finally the agents harvest their quota. Unlike markets for emission permits for stock pollutants, the timing of harvesting is of high importance for the stock's reproductive ability. Accordingly, Q is often fixed within the relevant time period and there is little to no opportunity to shift the quota between periods, thus the dynamic equivalent of the model is simply a series of static decisions. There are no restrictions on trade, and for now all agents are assumed to be price takers in both the product-, and quota market, i.e. the landing price of fish p (NOK/ton) and the quota price m is given. Additionally, it is assumed that the entire TAC is caught and that all agents are compliant. The profit function of the individual agent is given by

$$\pi_i(h_i, E_i) = ph_i - C_i(E_i) - m(h_i - \tilde{Q}_i), \quad \forall i = 1, 2, ..., n. \tag{1}$$

h_i is the harvest in tonnes and 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. The model applies a convex cost function specifically, the unit cost of effort is increasing in effort $C_i(E_i) = \frac{c_i}{2}E_i^2$. The cost function may also be motivated by the idea that we for each additional unit of effort employ less efficient units of effort, such as gear, crew, as well as visiting less productive fishing locations. With the Schaefer harvesting function we also account for the fact that each unit of harvesting is more costly when the stock is reduced. For simplicity catchability is embedded in the cost parameter, such that $c_i = \frac{\hat{c}_i}{q_i^2}$, and where c_i is positive and given[2]. With h_i as the model's strategic variable total harvesting cost of agent i is specified as

$$C_i(h_i) = \frac{c_i}{2}\left(\frac{h_i}{x}\right)^2, \tag{2}$$

with $\frac{dC_i}{dh_i} = \frac{c_i}{x^2}h_i$. The first order condition (FOC) associated with the individual agent's maximisation problem result in the following condition for optimum.

$$p - \frac{dC_i}{dh_i} \leq m \quad , h_i \geq 0. \tag{3}$$

Provided that the fishermen are heterogeneous with respect to their marginal cost, or initial quota endowment, a market for quotas will arise 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. 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 marginal cost will be equalised across all agents and cost efficiency is achieved, thus the corresponding optimal harvesting level, is

$$h_i = \frac{x^2}{c_i}(p - m) \tag{4}$$

In this case, the cost function ensures an interior solution, as marginal cost is proportional to the harvest and thus tends towards zero as harvesting approaches zero. It follows that everyone will continue to harvest and no one exits the fishery. The numerical illustrations in section 6 considers a cost function that allows for the exit of agents.

With the assumption that the entire TAC is caught, the market clearing condition ($\sum_{i=1}^{n} h_i = Q$) must hold, and the quota price may be expressed as a function of total quota quantity and stock, where superscript $*$ denotes the reduced form perfect competition and cost-effective solution.

$$m^* = p - \frac{Q}{\sum\limits_{i=1}^{n} \frac{x^2}{c_i}}. \tag{5}$$

The 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). Because the quota price mimic the marginal net benefit of the industry it

[2]With $h_i = q_i E_i x$ and $C_i(E_i) = \frac{\hat{c}_i}{2}E_i^2$, then $C_i(h_i) = \frac{\hat{c}_i}{2}\left(\frac{h_1}{q_i x}\right)^2$ can be written as in eq. (2), where $c_i = \frac{\hat{c}_i}{q_i^2}$

will increase with the price of fish ($\frac{dm^*}{dp} > 0$), and decrease with the cost parameter ($\frac{dm^*}{dc_i} < 0$). Additionally the larger the TAC, the lower the quota price ($\frac{dm^*}{dQ} < 0$). The positive effect of stock ($\frac{dm^*}{dx} > 0$) 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).

The reduced form harvesting expression follows from eqs.(4) and (5)

$$h_i^* = Q\frac{\frac{1}{c_i}}{\sum_{i=1}^{n}\frac{1}{c_i}}. \tag{6}$$

It is evident that the allocation of harvesting is, as expected, independent from initial quota endowment $\tilde{Q}_i$. Moreover, the reduced form harvesting is also independent from both the product and quota price, p and m. In the general case these prices help determine whether or not the agent remains in the fishery, but with a cost function that guarantees an interior solution and everyone stays in the fishery, p and m do not affect the result as they are equal for all agents. Hence, the only factor that varies between the agents, and thus determine the final distribution of harvesting is the cost parameters. If the agents are homogeneous with respect to cost even this variable disappear and the TAC is divided equally among the participants, i.e., $h_i^* = \frac{Q}{n}$. Moreover, it may be shown that, due to increased competition for a fixed amount of quota, the quota price increase with the number of agents in the fishery ($\frac{dm^*}{dn} > 0$). Specifically, this effect is driven by the fact that an increase in n reduces each agent's harvesting level ($\frac{dh_i^*}{dn} < 0$), thus reducing marginal cost of harvesting.

5 Market power

Market power in the market for harvesting quotas is studied using the approach employed in Hahn (1984) and Hatcher (2012). The quota price is set by the dominant agent, agent 1. The remaining agents, i.e. $2, ..., n$, are all price takers and may be identified as a competitive fringe. The emergence of market power is assumed to occur outside and prior to the analysis conducted in the model. However, as mentioned Maeda (2003) find that market power can emerge under certain scenarios of initial allocation, and choosing the lowest cost agent as the leader would be in line with the simulation in Hahn (1984). All other assumptions from the perfect competition benchmark case remain. The model is structured as a two-stage game and solved with backward induction. First the market leader, agent 1, choose either the harvesting level or 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.

In the second stage the competitive fringe maximises individual profits.

$$\max_{h_i} \pi_i = ph_i - C_i(h_i) - m(h_i - \tilde{Q}_i), \ \forall\ i = 2, ..., n. \tag{7}$$

As the fringe behave as competitive agents, their result is equivalent to the case of perfect competition. The fringes' demand for harvest and thus quota, is thus the same as equation

(4)

$$h_i = \frac{x^2}{c_i}(p-m), \forall i = 2, ..., n \tag{8}$$

The fringe's harvesting level and quota demand is linearly decreasing in price,($\frac{dh_i}{dm} < 0$).

The leader choose either the level of harvesting or the quota price, with the other being chosen indirectly. The most realistic scenario may be to imagine that the leader will use harvesting as the strategic variable according to which he maximises his profits, hence manipulating the quota price indirectly. However, in this case where all other parameters are exogenous, the choice of strategic variable does not matter in the theoretical solution of the problem[3]. Hence, in the first stage the leader maximise profits with respect to either the quota price or the harvesting level, and subject to residual demand which here is equivalent to the market clearing constraint.

$$\begin{aligned} \max_{m \ or \ h_1} \ \pi_1 = ph_1 - C_1(h_1) - m(h_1 - \tilde{Q}_1), \\ \text{s.t.} \ \ h_1 = Q - \sum_{i=2}^{n} h_i(m). \end{aligned} \tag{9}$$

Continuing with harvesting as the strategic variable, substituting for the constraint and rearranging, the FOC of an interior solution may be expressed as:

$$p - \frac{dC_1}{dh_1} = m\left(1 + \frac{dm}{dh_1}\frac{(h_1 - \tilde{Q}_1)}{m}\right), \tag{10}$$

When the leader is a net seller of quotas ($h_1 < \tilde{Q}_1$), the left-hand side of equation (10) represents the leader's marginal cost of selling quotas, in terms of lost harvesting profits. The right-hand side is the marginal revenue from selling quotas, where the second term is the price elasticity of demand facing the leader. The quota price is defined as a function of h_1 through the residual demand curve, and the quota price is increasing in the harvest of the leader ($\frac{dm}{dh_1} > 0$)[4]. Intuitively the quota price increase with h_1 as the residual supply available to the fringe decreases. Accordingly $\frac{dm}{dh_1}(h_1 - \tilde{Q}_1)$ is negative and represent the amount by which the leader must reduce the price in order to sell one more quota. When the leader is a net buyer of quotas ($h_1 > \tilde{Q}_1$), the left-hand side of eq. (10) would be the marginal revenue from quota purchase, whereas the right-hand side would be the marginal cost. Moreover, if the entire fringe are net sellers, i.e., the leader has monopsony power, $\frac{dm}{dh_1}(h_1 - \tilde{Q}_1)$ represents the leader's cost from having to pay an increased price for all the quotas bought.

There are two scenarios under which ITQ may result in a cost-effective outcome. Firstly, when agent 1's quota demand equals his initial allocation of quota ($h_1 = \tilde{Q}_1$) the second

[3]The first order conditions of eq. (9) with respectively h_1 and m as the strategic variable are $\frac{d\pi_1}{dh_1} = p - \frac{dC_1}{dh_1} - m - \frac{dm}{dh_1}(h_1 - \tilde{Q}_1) = 0$ and $\frac{d\pi_1}{dm} = (p - \frac{dC_1}{dh_1} - m)\frac{dh_1}{dm} - (h_1 - \tilde{Q}_1) = 0$. According to the inverse function theorem $\frac{1}{\frac{dh_1}{dm}} = \frac{dm}{dh_1}$, and thus the two first order conditions yield the same outcome This would hold for any cost- and production function combination that does not introduce more endogenous variables.

[4]Inserting for eq. (8) the constraint can be rearranged to express m as a function of h_1, i.e. $m = p - \frac{Q-h_1}{x^2 \sum_{i=2}^{n}}$.

term on the right hand side of eq. (10) collapse to zero and the quota price would equal the marginal net benefit of harvesting. More specifically, the leader would not need to enter the quota market and would therefore not manipulate the price. Secondly, the structure of the residual demand curve determines the extent to which the leader can exert market power. Note that $\frac{dh_1}{dm} = -\sum_{i=2}^{n} \frac{dh_i}{dm}$, thus the second term of eq. (10)'s right hand side may also be interpreted as the fringe's price elasticity of demand. 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. The outcome may thus approach that of the cost-efficient solution when the fringe's price elasticity of demand, as faced by the leader, approaches infinity. This result also indicate that the leader's ability to exert market power will decline as the number of competitive agents increase, particularly if the leader does not have full monopoly or monopsony power.

Let m^* and h_1^* continue to denote the price and quota demand which corresponds to the cost-effective competitive outcome. If neither of the two above scenarios apply, the quota price, will either be above or below the cost-effective price m^*. When the market leader is allocated more quotas than he demands 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.

The explicit quota demand of the dominant agent is

$$h_1 = 2\frac{x^2}{c_1}(p - m) + \frac{\tilde{Q}_1 - Q}{\sum\limits_{i=2}^{n} \frac{c_1}{c_i}}. \tag{11}$$

Applying the market clearing condition, the quota price can be expressed as a function of stock, TAC and initial allocation:

$$m^{**} = p - \frac{Q - \frac{(\tilde{Q}_1 - Q)}{\sum\limits_{i=2}^{n} \frac{c_1}{c_i}}}{x^2\left(\frac{2}{c_1} + \sum\limits_{i=2}^{n} \frac{1}{c_i}\right)}, \tag{12}$$

where $**$ denote the market power reduced form solutions. The reduced form harvesting expressions, for the leader and the fringe, respectively, are thus given by the following expressions

$$h_1^{**} = \frac{\frac{1}{c_1}}{\frac{2}{c_1} + \sum\limits_{i=2}^{n} \frac{1}{c_i}}(Q + \tilde{Q}_1), \tag{13}$$

$$h_i^{**} = \frac{\frac{1}{c_i}}{\frac{2}{c_1} + \sum\limits_{i=2}^{n} \frac{1}{c_i}}\left(Q - \frac{(\tilde{Q}_1 - Q)}{\sum\limits_{i=2}^{n} \frac{c_1}{c_i}}\right). \tag{14}$$

Most of the comparative statics from the perfect competition model are easily confirmed, that is $\frac{dm^{**}}{dp} > 0$, $\frac{dm^{**}}{dx} > 0$ and $\frac{dm^{**}}{dQ} < 0$. 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 it can be shown that $\frac{dm^{**}}{dn} > 0$, intuitively there are two counteractive forces at work. Similarly to the perfect competition case a rise in the number of competitors increase demand for, and thus the price of quotas[5]. 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^*. Nevertheless, the effect of increased demand and decreased marginal cost dominates, and the total effect of n on price is positive regardless of initial allocation. In a similar manner $\frac{dh_1^{**}}{dn} < 0$ and $\frac{dh_i^{**}}{n} < 0$. In addition, both the quota price and the leader's harvesting level is increasing in the leader's initial allocation, $\frac{dm^{**}}{d\tilde{Q}_1} > 0$ and $\frac{dh_1^{**}}{d\tilde{Q}_1} > 0$.

5.1 A Case of two agents

To simplify, consider a case of two agents. The competitive firm now denoted by 2 may also be interpreted as the aggregate of the fringe where $c_2 = \left(\sum_{i=2}^{n} \frac{1}{c_i}\right)^{-1}$. In this scenario the respective quota demand and subsequent harvesting levels of the dominant agent and the fringe are

$$h_2 = \frac{x^2}{c_2}(p - m), \tag{15}$$

$$h_1 = 2\frac{x^2}{c_1}(p - m) + \frac{c_2}{c_1}(\tilde{Q}_1 - Q). \tag{16}$$

It is evident from the following reduced form expressions, that initial allocation will affect the harvesting levels, as well as the quota price.

$$h_1^{**} = \left(Q + \tilde{Q}_1\right)\frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}}, \tag{17}$$

$$h_2^{**} = \left(Q + \left(Q - \tilde{Q}_1\right)\frac{c_2}{c_1}\right)\frac{\frac{1}{c_2}}{\frac{2}{c_1} + \frac{1}{c_2}}, \tag{18}$$

$$m^{**} = p - \frac{Q - \frac{c_2}{c_1}(\tilde{Q}_1 - Q)}{x^2\left(\frac{2}{c_1} + \frac{1}{c_2}\right)}, \tag{19}$$

For a more convenient comparison to the case of perfect competition, harvesting may be rearranged as

$$h_1^{**} = h_1^* + \frac{\frac{1}{c_1}}{\frac{2}{c_1} + \frac{1}{c_2}}\left(\tilde{Q}_1 - h_1^*\right) \tag{20}$$

[5]With an homogeneous fringe $m^{**} = p - \frac{Q - \frac{(\tilde{Q}_1 - Q)}{(n-1)\frac{c_1}{c_i}}}{x^2\left(\frac{2}{c_1} + (n-1)\frac{1}{c_i}\right)}$., and thus $\frac{dm^{**}}{dn} = \frac{1}{x^2(\frac{2}{c_1} + \frac{(n-1)}{c_i})^2}(\frac{1}{c_i}Q - \frac{2(\tilde{Q}_1 - Q)}{(n-1)^2}(\frac{c_i}{c_1^2} + \frac{(n-1)}{c_1}) > 0$.

Similarly, the quota price can be expressed as

$$m^{**} = m^* + \frac{\frac{c_2}{c_1}(\tilde{Q}_1 - h_1^*)}{x^2(\frac{2}{c_1} + \frac{1}{c_2})} \tag{21}$$

Again it is the deviation of initial allocation $\tilde{Q}_1$ from the market leader's perfectly competitive harvesting demand h_1^*, as well as the cost ratio, that governs how much the quota price will deviate from the competitive outcome.

5.1.1 Comparative statics

When there is market power in the quota market, harvesting and quota price will in addition to the standard parameters in the case of perfect competition, also depend upon the initial allocation of quotas. The comparative statics are summarised in Table 1.

Table 1: Comparative statics

	c_1	c_2	Q	$\tilde{Q}_1$	x	p
m^{**}	$-$	$-$	$-$	$+$	$+$	$+$
h_1^{**}	$-$	$+$	$+$	$+$	0	0
h_2^{**}	$+$	$-$	$+$	$-$	0	0

With two agents $\tilde{Q}_2$ is given by $\tilde{Q}_1$, and from $\tilde{Q}_2 = Q - \tilde{Q}_1$ 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 case of perfect competition. The effect of supply, stock and the price of fish also remain equivalent to this previous model. 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, i.e. acting as a monopsonist, he 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 in the same manner as in the model of perfect competition. The harvesting levels depend positively on the agent's own initial endowment of quota and negatively on the competitors initial endowment.

5.2 Total cost and efficiency loss

With market power, there are only two scenarios that lead to the cost-efficient solution. In the event that none of these occur, the difference between total cost in the cost competitive benchmark model and the market power outcome will represent the efficiency loss. In general total cost is given by $TC = \sum_{j=1}^{n} C_j(h_j)$. With two agents total cost of the benchmark scenario and with market power are given by (22) and (23), respectively.

$$TC^{*} = \frac{Q^2}{2x^2\left(\frac{1}{c_1}+\frac{1}{c_2}\right)}, \tag{22}$$

$$TC^{**} = \frac{Q^2}{2x^2(\frac{1}{c_1}+\frac{1}{c_2})} + \frac{\frac{1}{c_1^2}}{2x^2(\frac{2}{c_1}+\frac{1}{c_2})^2}\Big((c_1+c_2)\tilde{Q}_1^2 - 2c_2 Q\tilde{Q}_1 + \frac{\frac{c_2}{c_1}Q^2}{\frac{1}{c_1}+\frac{1}{c_2}}\Big). \tag{23}$$

The second term of (23) demonstrate the efficiency loss of market power, and it holds as positive for all levels of initial allocation $\tilde{Q}_1$ and non-negative cost parameters. Following from eq. (23) the efficiency loss will be related to initial allocation, this can be illustrated by taking the derivative of total cost with respect to initial allocation, $\frac{dTC^{**}}{d\tilde{Q}_1} = \frac{\frac{1}{c_1^2}}{x^2(\frac{2}{c_1}+\frac{1}{c_2})^2}((c_1 + c_2)\tilde{Q}_1 - c_2Q)$. With some rearranging it may be seen that, as in Hahn (1984) and Westskog (1994), inefficiency increase when initial allocation deviates from quota demand in either direction. $\frac{dTC^{**}}{d\tilde{Q}_1} > 0 (< 0)$ when $\tilde{Q}_1 > h_1^*(\tilde{Q}_1 < h_1^*)$, 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.

Equation (10) and the related discussion suggest that the size of the fringe is a key driver of the outcome, as it could push the result towards a cost-efficient solution. In order to explore how the efficiency loss of market power is affected by the size of the fringe let $\Delta TC = TC^{**} - TC^{*}$. Then by assuming a homogeneous fringe wherein $c_2 = \frac{c_i}{n-1}$, and c_i is equal for all agents in the fringe, it can be shown that $\frac{d\Delta TC}{dn}\big|_{\tilde{Q}_1=0} < 0$. When $\tilde{Q}_1 = Q$ the result is more difficult to determine and appear to be parameter specific ($\frac{d\Delta TC}{dn}\big|_{\tilde{Q}_1=Q} \gtreqless 0$). A negative relationship is in line with the idea that an increased fringe reduces the leader's ability to exert market power, and thus the related efficiency loss. In a similar manner, $\frac{d\Delta TC}{dc_1}\big|_{\tilde{Q}_1=0} < 0$ while $\frac{d\Delta TC}{dc_1}\big|_{\tilde{Q}_1=Q} \gtreqless 0$. Intuitively a lower relative cost allows the leader to exert more market power thus generating a greater efficiency loss. Note that both the of the undetermined effects are negative in the numerical illustrations.

6 Numerical illustration

Norwegian fisheries are commonly considered to be well managed, yet the regime is also described as complicated, bureaucratic and restrictive. Thus, in line with an Official Norwegian Report (NOU2016:26) released in December 2016 a new management regime is currently in consideration (NOU, 2016). As the suggested regime strongly resembles ITQs it is of interest to study the potential efficiency loss of market power and ITQ in the Norwegian setting for North-East Arctic (NEA) cod.

The NEA cod stock is managed jointly by Russia and Norway, and where Norway receives 45 percent of the TAC. The current management regime in Norwegian fisheries was created to serve a dual purpose; to secure an efficient and sustainable management of the resource, and to ensure employment in the coastal communities. The Norwegian TAC is first divided between the trawlers and the coastal fleet according to the trawl ladder[6], both fleets are subject to their own licensing regime which restricts the access to the fishery (NOU, 2016). Within the trawler fleet the TAC is further divided based on so-called quota factors which represent the vessel's share of its group's total quota. Within the coastal fleet the TAC is divided between one open- and six length based vessel groups. Within the vessel groups each vessel's quota is based on the average harvest of the group during some period prior to the quota regime, thus all vessels within each vessel group receive the same quota (NOU, 2016; Directorate of Fisheries, 2017*a*).

For the vessels that receive some form of quota, the ability to trade these quotas both in the short- and the long-term market is quite restricted, and more so in the short-term market. The regulations also vary between the different vessel groups (Hersoug, 2005; NOU, 2016). The structuring regime, introduced to combat the issue of overcapacity, allows fishermen to combine the quotas of two vessels (within the same vessel group) if one of the vessels are scrapped. All vessel groups for vessels above 11m can acquire structural quotas, but there are some variation concerning the number of structural quotas that can be collected and the time period for which they are valid. The trawler fleet can currently collect up to four quota factors and where the structural quotas may be allocated for 25 or 20 consecutive years (Armstrong, 2008; Grytås, 2014; Hersoug, 2005; NOU, 2016).

Inspired by the NEA cod fishery, the following numerical illustration aim to provide a picture of the potential efficiency loss arising from market power in fisheries with ITQ. The parameter values are reported in Table 2. The stock size is based on estimates from ICES (2018). The TAC reported here is the entire TAC for the NEA cod fishery, i.e., it is not only the 45% harvested by Norwegian vessels, but also the amount harvested by Russia and other European countries. Moreover, while the theoretical model assumes an appropriately set TAC that corresponds with goals of either maximum sustainable yield or maximum economic yield, the actual TAC is often set above biological recommendations. As we will see in the numerical section, the choice of TAC does not affect the efficiency loss of market power, but it would most definitely affect the potential resource rent of the fishery, as well as the fishermen's profits. The issue of an inappropriate TAC could be included in a dynamic model that takes account of the reproduction and changing biomass of the fish stock, this is however, outside the scope of this paper. The price of fish in the product market is based on the average price of cod in the profitability survey from the Directorate of Fisheries (2017*b*). The cost and embedded catchability parameters are simulated, and finally the model is simulated for a number of fringe sizes and initial quota allocations.

[6]The trawl ladder is a sharing rule that, depending on the size of the TAC, determines the allocation of the TAC between the two fleets, see

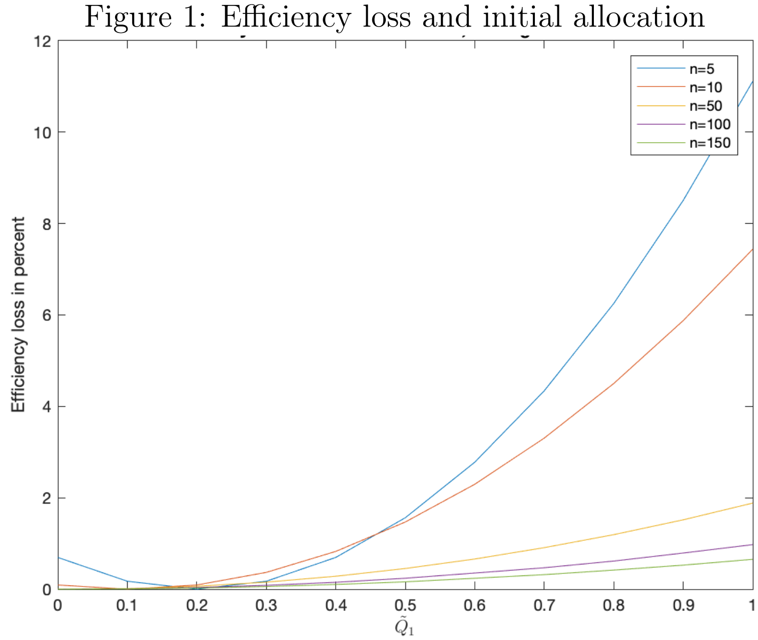
Table 2: Parameter values

Parameter	Description	Value	Source
x	Stock	2624 (thousand tonnes)	Based on ICES (2018)
Q	Total allowable catch	900 (thousand tonnes)	Based on Institute of Marine Research (2018)
p	Price of fish	16 (million NOK/thousand tonne)	Based on Directorate of Fisheries (2017*b*)
$c_i = \frac{\hat{c}_i}{q_i^2}$	Cost and catchability		Simulated
n	Number of agents	5-150	
$\tilde{Q}_1$	Initial allocation of quota	0-Q	

6.1 Homogeneous agents

Figure 1 illustrates the potential efficiency loss when the leader and the fringe are homogeneous with respect to cost and catchability, i.e. $c_1 = c_2 = ... = c_n$, and where initial allocation $(\tilde{Q}_1)$ is defined as a fraction of the TAC. The efficiency loss is calculated as the percentage increase in total cost between the competitive and market power solution.

Figure 1: Efficiency loss and initial allocation



The potential efficiency loss is relatively large for a small fringe size, but rapidly declines as the size of the fringe increases. Depending on wether or not the quotas will be gear specific the potential number of vessels within each vessel group can range from 4 to around 2000 making relatively large increases in total cost feasible, but not particularly common (Greaker et al., 2017; Directorate of Fisheries, 2017*a*). An initial allocation equal to $\tilde{Q}_1 = 0.35Q$ in Figure 1 is of particular interest as this corresponds to the upper limit of quota holdings for certain fisheries in Iceland and the Faroe Islands (Runolfsson and Arnason, 1996; Ministry of Fisheries , 2018). While there is some efficiency loss related to this scenario, maximum increase in total cost is only 0.39% for a market size of five agents, that is, one leader and four followers. With homogeneous agents, the potential efficiency loss of monopoly power ($\tilde{Q}_1 > h_1^*$) is much greater than that of monopsony power ($\tilde{Q}_1 < h_1^*$). This is not unexpected as theory predicts the loss will increase with the distance between initial allocation and the competitive optimum. In the case of homogeneous agents optimum will simply be $h_i^* = \frac{Q}{n}$ (for all $i = 1, 2, .., n$). Even with as few as five agents, optimum will be no higher than an initial allocation of $\tilde{Q}_1 = 0.2Q$, and there is little scope for efficiency loss arising from monopsony power. A cost dispersion in favour of the leader could push h_1^* towards a higher level of initial allocation, and thus increase the scope for monopsony power.

6.2 Heterogeneous agents

As mentioned, the current management regime in Norway allows for some trade of quotas, but mainly within vessel groups. This restriction is partly to ensure employment in the coastal communities and it is reasonable to imagine that it would continue in an ITQ regime. Based on the assumption that trading is contained within each vessel group, the cost parameters of the vessels within each vessel group are assumed to follow a normal distribution. The model and the efficiency loss is then illustrated using 100 Monte Carlo simulations where the combined cost and catchability parameters (c_i) of the fringe are drawn from a normal distribution.

The cost of the leader is defined relative to the mean cost of the fringe; ranging from 7 std. deviations below, to 7 std. deviations above the mean[7]. This wide range is partly based on Steinshamn (2005) who reports that the most efficient vessel within a vessel group can have a variable cost that is up to 76% less than the mean. Without any upper bound for the least efficient vessel I start with an assumption of symmetry though, it may be more reasonable to assume that the market leader would have a cost advantage, rather than a cost disadvantage.

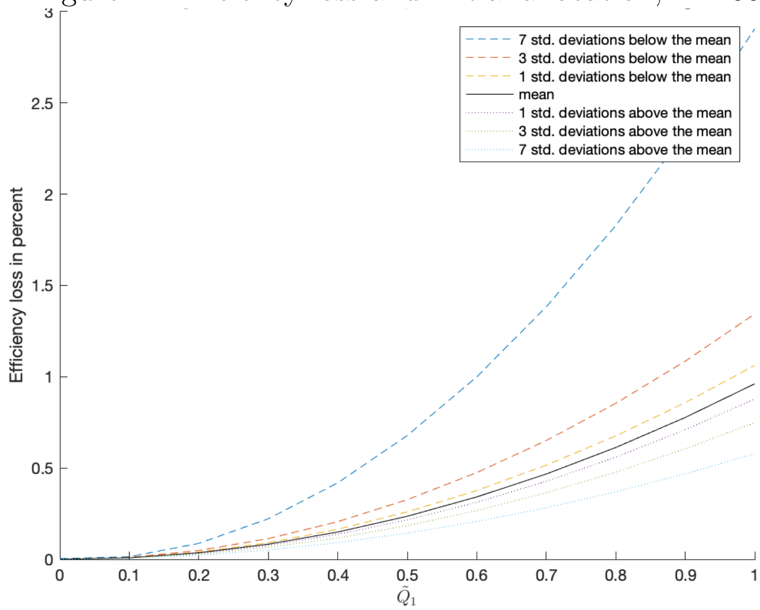
Figure 2 illustrates the potential efficiency loss for 7 different cost scenarios, where each plot refers to the cost of the leader relative to the mean of the fringe. The dashed lines represent scenarios where the cost of the leader is below the mean, the solid black line is the scenario where the cost of the leader is equal to the mean cost of the fringe, and finally the dotted lines represent the scenarios where the cost of the leader is above the mean.

The efficiency loss is increasing in the leader's cost advantage, confirming that with the current parameter values $\frac{d\Delta TC}{dc_1} < 0$ holds, independent of initial allocation. The variance of the simulated efficiency loss increase with the difference between the cost of the leader and the mean cost of the fringe, and more so when the the leader has a cost advantage.

Despite including scenarios where the leader has a relatively large cost advantage, none of the simulations indicate that monopsony power is an issue as long as there is a large fringe.

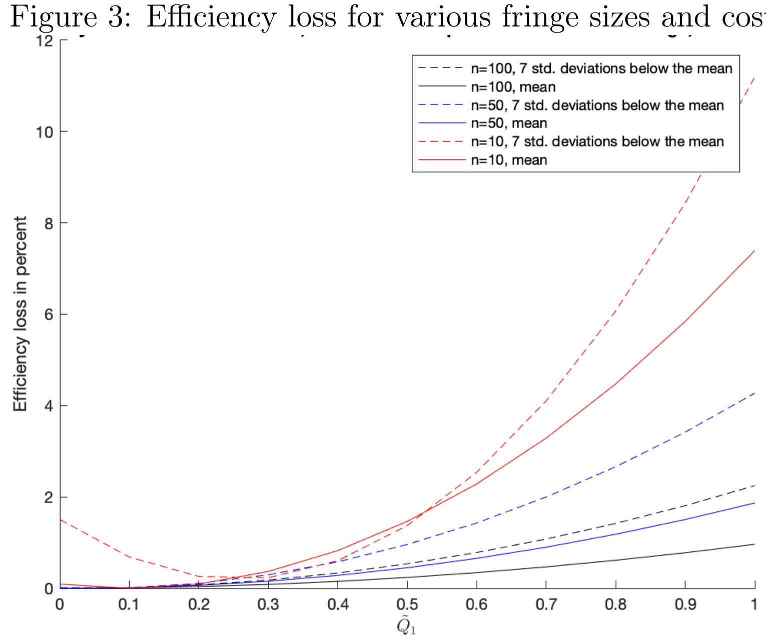
[7] The mean of the fringe is defined as $\frac{\sum_{i=2}^{n} c_i}{n-1}$

Figure 2: Efficiency loss and initial allocation, n=100



In Figure 3 however, the combination of a small fringe and a leader with a relatively large cost advantage generate an efficiency loss from monopsony power. For a large fringe, here n=100, the potential efficiency loss is just above 4%, but this is for the extreme case where the leader is allocated the entire TAC. Looking at the 35% cap for the total amounts of quota one agent or company can hold, the potential efficiency loss here is around 0.5% for a large fringe, and just below 2% for a small fringe. Note that $\frac{d\Delta TC}{dn} < 0$ also holds independent of initial allocation, though the view is not as clearcut as both n and c_1 vary.

Figure 3: Efficiency loss for various fringe sizes and cost.



With the assumption that trading occurs within each vessel group, most groups will only harvest a small part of the TAC applied here. Yet, while total cost is sensitive to changes in both TAC and the stock, this is true for both the competitive and the market power scenario, and thus neither has any effect upon the efficiency loss. Accordingly it should also be noted that the total efficiency loss could be greater if there are multiple vessel groups each with their own quota market subject to market power. Finally, as it is the cost of the leader relative to the cost of the fringe that matters, the scale of the cost parameter does not affect the numerical outcome.

Table 3: Relative cost advantage

3 std. deviations below the mean	1 std. deviation below the mean
0.7034	0.9010

Table 3 reports the relative cost advantage of the leader, where relative cost advantage is defined as the ratio of the leader's cost, to the mean cost of the fringe. Table 4 illustrate the percentage change in quota price and the leader's harvesting level when market power is introduced. In order to easily compare this case to the cost function considered in section 6.3 Table 4 only reports scenarios where the leader has a cost advantage, and where there are 30 agents. As expected both m^{**} and h_1^{**} increase, relative to m^* and h_1^*, with initial allocation. While the percentage increase in the quota price is surprisingly small, the leader almost double his harvesting level when he is allocated the entire TAC. The change in quota price is larger when the relative cost advantage of the leader is greater, supporting the idea that the leader exert more market power when his cost relative to the fringe is relatively low. Interestingly, the change in harvesting is quite similar for the two cost scenarios.

Table 4: Quota price and harvesting with market power compared to perfect competition

	3 std. deviations below the mean		1 std. deviation below the mean	
$\tilde{Q}_1$	Change in m in %	Change in h_1 in %	Change in m in %	Change in h_1 in %
0	-0.0001	-4.45	-0.00004	-3.52
0.1	0.0001	5.12	0.00006	6.13
0.2	0.0002	14.66	0.00016	15.77
0.3	0.0003	24.21	0.00026	25.42
0.4	0.0004	33.77	0.00036	35.07
0.5	0.0006	43.32	0.00046	44.71
0.6	0.0007	52.88	0.00055	54.36
0.7	0.0008	62.43	0.00065	64.01
0.8	0.0009	71.99	0.00075	73.66
0.9	0.0011	81.54	0.00085	83.31
1	0.0012	91.1	0.00095	92.95
n=30				

6.3 Including exit from the fishery

The exit of less efficient agents is an important aspect of ITQ regimes' ability to reduce overcapacity, but as mentioned, the cost function considered so far does not allow for this. Both the theoretical analysis and the above numerical illustrations indicate that the potential efficiency loss of market power is greater the smaller the fringe size, if the ITQ regime, in addition, generates exit of agents this may exaberate the efficiency loss of market power. On the other hand, as the relative cost of the leader also appear to be a driving force of the efficiency loss, the exit of more costly vessels may decrease the mean cost of the remaining fringe and decrease the relative cost advantage of the leader.

In order to allow for the exit of less efficient agents the model is simulated for the following cost function $C_i = c_{1i}\frac{h_i}{x} + \frac{c_{2i}}{2}\left(\frac{h_i}{x}\right)^2$. Again the cost parameters are drawn from a normal distribution, and the cost of the leader is determined in relation to the mean of the fringe[8]. The model however, becomes much heavier to simulate and is so far only simulated for up to 30 agents. Moreover, the code relies upon the exit of less efficient agents and thus the model is only simulated for scenarios where the leader has a cost advantage and definitely stay in the fishery.

The numerical results support the theoretical findings. Figure 4 displays the efficiency loss for n=30 and three different cost scenarios. In comparison to the previous cost function, the potential for monopsony power is more prominent yet, the magnitude of the efficiency loss is remarkably low when agents are allowed to exit. This indicate that the second effect, i.e., reduction in the leader's relative cost advantage could dominate. The fact that the leader's relative cost advantage is reduced when less efficient agents exit is confirmed in Table 5. Note that the relative cost advantage for c_2, the parameter corresponding to c in the previous cost function, is quite similar to the relative cost advantages reported in Table 3.

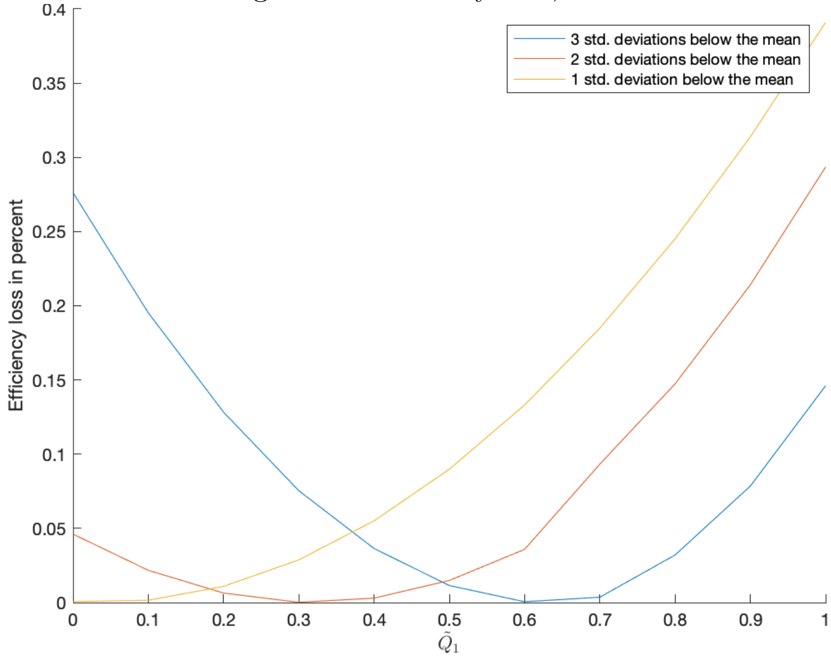
Table 5: Relative cost advantage

	3 std. deviations below the mean		1 std. deviation below the mean	
	c_1	c_2	c_1	c_2
All	0.6992	0.7879	0.8997	0.9293
Stay	0.8287	0.8929	1.0544	1.0412

Table 6 report the percentage change in quota price and harvesting level when market power is introduced, as well as the number of agents that stay in the fishery. n^* denote the number of agents that stay in the fishery under perfect competition, and n^{**} is the number of agents that stay in the market power scenario. The fact that the increase in both quota price and harvesting level is less when the relative cost advantage of the leader is greater is explained by the theoretical prediction that change increase with distance from optimum, which here appear to be between an initial allocation of 0.6 and 0.7. When the cost of the leader is defined as one std. deviation below the mean of the fringe, the leader actually end up with a

[8]To simplify I rearrange the costs such that $c_{12} < c_{13} < ... < c_{1n}$ and $c_{22} < c_{23} < ... < c_{2n}$.

Figure 4: Efficiency loss, n=30.



cost disadvantage after the exit. Correspondingly the optimal harvest is quite small leading to a relatively large percentage increase when the leader has full monopoly power.

Table 6: Quota price, harvesting and the number of agents that stay with market power, compared to perfect competition

	3 std. deviations below the mean				1 std. deviation below the mean			
$\tilde{Q}_1$	Change in m in %	Change in h_1 in %	n^*	n^{**}	Change in m in %	Change in h_1 in %	n^*	n^{**}
0	-0.0212	-17.94	5	5	-0.0008	-13.88	6	6
0.1	-0.0178	-15.09	5	5	0.0013	21.25	6	6
0.2	-0.0145	-12.23	5	5	0.0034	56.38	6	6
0.3	-0.0111	-9.37	5	5	0.0055	91.51	6	6
0.4	-0.0077	-6.52	5	5	0.0076	126.64	6	6
0.5	-0.0043	-3.66	5	5	0.0097	161.77	6	6
0.6	-0.0009	-0.8	5	5	0.0119	196.91	6	6
0.7	0.0024	2.05	5	5	0.014	232.04	6	6
0.8	0.0075	6.11	5	4	0.016	267.17	6	6
0.9	0.0129	9.5	5	4	0.0182	302.3	6	6
1	0.0182	12.89	5	4	0.0203	337.43	6	6
n=30								

The number of agents that stay in the fishery appear surprisingly small, but may be explained by the fact that there is no capacity restriction limiting the amount each vessel can harvest. There is also no restriction on concentration and in the current model one vessel could end up buying the entire TAC, becoming a sole harvester. Moreover, assuming the simulation is on the vessel group level, there would still be multiple vessel groups, each with a reduced number of vessels. Nevertheless, a drastic reduction in capacity is somewhat in line with studies that, in relation to potential resource rent, study the efficiency of various fleet compositions in Norwegian fisheries (Grimsrud et al., 2015; Steinshamn, 2005). The results reported in Table 6 also indicate that optimal fringe size increase as the leader's optimal harvest decrease.

7 Concluding remarks

This paper has analysed the issue of market power in an ITQ regime and contributed to the literature by solving for explicit harvesting and quota price expressions. The theoretical analysis 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 explicit solution indicate that the cost of the leader, relative to that of the fringe, as well as the size of the fringe will have an effect upon the leader's ability to exert market power, and thus on the quota price and magnitude of the efficiency loss.

Despite similarities in the theoretical models and findings, certain differences between emission permits and ITQs suggest that the potential efficiency loss of market power could be greater in an ITQ regime that in an emission permits market. Inspired by the NEA cod fishery, the paper is the first to provide a numerical illustration of the potential efficiency loss of market power in a rights-based regime for fisheries. The numerical illustrations support the finding that the efficiency loss of market power increase as initial allocation $\tilde{Q}_1$ deviates from the leader's optimal harvest under perfect competition (h_1^*). The model is simulated for two cost functions.

With the first cost function considered the illustrations strongly indicate that the efficiency loss will be declining in the size of the fringe, as suggested by the theoretical model. Moreover, there seem to be little scope for monoposony power. This result appear despite a relatively large cost advantage in favour of the leader, and is mainly driven by fringe size. For monopoly power the maximum potential efficiency loss lie around 11%, but this only occur for small fringe sizes, when the leader has a significant cost advantage, and is allocated the entire TAC. For more feasible scenarios, in line with current upper limits on quota holdings, potential efficiency loss lie just under 2%. The numerical results are thus within the scope of what has been found for emission permits (Hahn, 1984; Westskog, 1994).

For the second cost function where agents are able to sell their quotas and exit the market the potential efficiency loss is much lower, with a 0.4% increase in total cost for the case of

30 agents. There is also relatively few agents that end up staying in the fishery, but this may be explained by the lack of a capacity or quota concentration constraint.

Most fisheries base their quota allocation on historical catch, hence it is reasonable to assume that the deviation between initial allocation and optimal harvest is relatively small. Coupled with the numerical findings reported here this suggest that market power is not major issue in ITQ regimes. Additionally, the potential efficiency loss should also be considered in relation to the potential gains from switching to an ITQ regime, which as indicated by Steinshamn (2005) and Greaker et al. (2017), could be quite significant. That said, the second cost function predicts a relatively large exit from the industry, which may not be in line with the dual purpose of the current management regime in Norway. Consequently, though the issue of market power may not be of significance there are still a number of social considerations that needs to be taken into account when considering an ITQ regime.

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