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Quota consolidation in Norwegian coastal fisheries

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Abstract

Balancing the trade-off between economic efficiency and social objectives has been a challenge for fisheries managers under rights-based management. While the actual prioritization should be guided by social preferences, the mechanisms and consequences of the quota transfer system need to be well understood. We investigate the effects of several quota transfer schemes implemented in the Norwegian coastal cod fishery during the 2000s. This is a small-scale fishery that has traditionally been important for employment in the northern part of Norway. Using vessel-level quota registry data, we estimate the effect of quota-trading and changes in quota distribution on vessel exit using a difference-in-differences approach that exploits variation in implementation timing between regulatory groups. In addition, we describe the outcome of quota consolidation with descriptive statistics. Our results confirm that quota trade triggers exit of vessels from the fishery. In addition, we quantify the consolidation in terms of catch per vessel and geographic distribution of quotas and landings. While the policy change has the expected effects in the short run, our results suggest that the implications of consolidation last longer. This has implications for policymakers trying to balance economic efficiency and social objectives of rational fishery management.

Keywords: Rights-based management, efficiency, equity, fisheries management
JEL classification: D23, Q2, R3

Ethical Statement

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1 Introduction

There is considerable evidence that market-based management improves the performance of fisheries and other natural resources, both in terms of economic efficiency and ecological outcomes.[1] Despite this, the number of fisheries worldwide with market-based management are relatively few and there is often considerable political opposition to these management schemes.[2] A common challenge is that of balancing the trade-offs between economic efficiency and social objectives. Many governments add various safeguards to alleviate undesirable social outcomes when introducing market-based management programs, despite the cost in terms of reduced efficiency.

The conflict between economic efficiency and social objectives is also present in Norwegian fisheries management. The Marine Resources Act states that the management of marine resources shall ensure sustainability and economic efficiency, while promoting employment and settlement in coastal communities. With ongoing consolidation in the fishing industry, both on- and offshore, the social objective of promoting employment and settlement along the coast has come under pressure. This is particularly evident in the coastal cod fishery, which traditionally consisted of a large number of smaller vessels targeting cod and other species along the coast in Northern Norway. This fleet has been important in fulfilling the government's objective of a differentiated and geographically dispersed fleet, with many smaller vessels (see e.g. Standal et al., 2016). In this study, we investigate consolidation in the Norwegian coastal cod fishery since 2001.

In particular, we empirically analyze the effect of quota consolidation schemes introduced in the coastal cod fishery in 2004 and 2007, which allowed fishers to consolidate the quota holdings of several vessels on one. In the long-run, trends in technical development and regulatory changes can lead to fewer fishers and vessels. It is an empirical question to what extent the number of vessels and fishers decline due to the policy, or because of other long-term trends. We test if the quota transfer schemes triggered changes in fisher behavior that led to consolidation. In addition, we study the effects of the policy in terms of consolidation and distribution. To do so, we use the HHI and Gini coefficient, and we

[1] See e.g. Costello et al. (2010).

[2] According to Costello et al. (2010), catch share systems accounted for less than a quarter of the volume from global fisheries at the time of their study, while Kroetz et al. (2022) show that there has been little or no growth in the number of catch share fisheries globally since 2010. Grainger & Parker (2013) and Grainger & Costello (2016) present and analyze some of the opposition against market-based management in fisheries.

measure the concentration of quotas in terms of pre-policy quota holdings and geographical distribution.

A central part of our analysis is to trace out the development of fishing right distribution over the period in question. The effects of the management system on who stays and who exits can be identified and in this way our study can contribute to understanding the social impacts of fortifying property rights. Consolidation of fishing rights is of interest to both resource managers and researchers because it affects the incentives and behavior of the agents. When considering market-based management systems and the trade-off between efficiency and social objectives, it is important to understand the implications of consolidation and the geographical distribution of activity following consolidation. This allows for a more accurate evaluation of social costs and economic benefits.

The situation in Norwegian fisheries resembles that of other developed country fisheries around the world. Most countries with substantial marine resources are implementing quota systems in various forms. These systems generally aim to help fish stocks recover and ensure economic efficiency, but they might also have other, unintended, effects. In consequence, a majority of nations are still making incremental changes to their regulatory systems in an attempt to balance different political goals. Our results on the trade-offs between political goals in Norway therefore apply also outside the Norwegian context.

Our study contributes to the literature on exit and investment behavior in the fisheries industry. It is clear from the literature that trade in quotas drives consolidation as it significantly reduces the size of the fishing fleet and the number of fishers participating in the fishery (Dupont & Grafton, 2000; Sanchirico et al., 2006; Liew, 2000; Hamon et al., 2009; Hartley & Fina, 2001). We add to this literature by empirically analyzing both the direct effects and the distributional effects of quota concentration.

The decision to enter or leave a fishery is typically costly due to non-malleable capital or sunk costs that are present under fisheries management (Clark et al., 1979; Chavas, 1994). Empirical work finds that decommissioning schemes induce exit behavior (Tidd et al., 2011), and while catch shares may help fishers liquidize capital and facilitate exit, the existence of sunk costs may slow the transition to an optimal fleet size (Vestergaard et al., 2005). There is also empirical evidence that the spatial dimension matters. For example, using data on Hawaiian longliners, Pradhan & Leung (2004) find that vessels are more likely to stay in the fishery if owned by local residents. Nøstbakken (2012) finds that firm-specific factors such as the geographic location of firms are important for fishing firms' investments. Our study builds on this work and explores drivers of exit from the

Norwegian coastal cod fishery, including the effects of geographical location.

Our study also contributes to the vast literature on the effects of market-based management schemes on industry structure. The relationship between industry concentration and the Icelandic quota management system has received considerable attention in the literature (see e.g. Agnarsson et al., 2016; Edvardsson et al., 2018; Byrne et al., 2020). Economic studies on New Zealand fisheries have found evidence of a link between quota transferability and market concentration (see e.g. Yandle & Dewees, 2008; Stewart & Callagher, 2011; Abayomi & Yandle, 2012). In the Norwegian context, Cojocaru et al. (2019) have investigated the landings of fish and argued for the existence of fishing industry clusters. While early stages of concentration may not give rise to market power (Adelaja et al., 1998), researches have highlighted how privatization could create social issues in the sector (Olson, 2011; Carothers & Chambers, 2012). We contribute to this literature on consolidation in fisheries by analyzing the effects of a transferable quota scheme in the Norwegian coastal cod fishery, with a particular focus on geographical consolidation and heterogeneous effects between different regulatory groups.

In the next section, we give a short outline of the quota system in the Norwegian coastal cod fishery, and how it has evolved over time. Next, we describe our empirical research strategy, before we describe the data we use in our study. In the fifth section, we present the empirical results on the direct effect of the policy change, before we analyze the outcomes of the quota consolidation in the following section. The last section concludes.

2 Institutional Background

Fish and fisheries have long been regarded as fundamental rights of the Norwegian people, with a particular emphasis on coastal communities. This is reflected in the laws governing marine resources and fisheries management. The Marine Resources Act states that "[w]ild living marine resources belong to Norwegian society as a whole" (Marine Resources Act, section 2). The purpose of this Act is threefold, "to ensure sustainable and economically profitable management of wild living marine resources and genetic material derived from them, and to promote employment and settlement in coastal communities" (section 1). While the objectives of sustainability and economic efficiency are well aligned, the third objective of promoting employment and settlement in coastal communities is often at odds with efficiency.

Historically, fisheries have secured employment for a significant number of people living along the coast of Norway. In 1940, some 80,400 people, or about 2.7%, out of the total Norwegian population of 2.964 million had fishing as their main occupation, while an additional 41,600 reported fishing as their secondary occupation (Director General of Fisheries, 1942). There were also a significant number of jobs in fisheries related industries. By 1970, the total number of people with fishing as their main occupation had dropped to 31,900, and 11,100 with fishing as a secondary occupation (Director General of Fisheries, 1974). This decline continued: in 2021 there were only 9,500 full-time fishers (0.17% of the population of 5,328 million), and 1,300 with fishing as a secondary occupation (Figure 1). A similar restructuring has taken place in fisheries related industries, reducing the number of jobs also there. Over the same period, however, the volume of landed fish increased considerably, from 1.02 mill. tonnes in 1940 to 2.71 and 2.57 mill. tonnes, respectively, in 1970 and 2021. The value of landed fish increased by 79% in real terms from 1970 to 2021, despite a slight drop in volume over the same period.

The coastal cod fishery north of the 62 degrees line, which we study in this paper, was regulated with total allowable catch (TAC) until 1989. This implied low barriers for new entrants, but also that all qualified coastal vessels competed for shares of the TAC.[3] When the Northeast Arctic cod stock collapsed in the late 1980s, the government introduced individual quotas (Hersoug, 2005; Diekert & Schweder, 2017).[4] At the time, there was a proposal to introduce a system of individual transferable quotas, inspired by the rights-based management systems in New Zealand and Australia, but this met strong opposition and was abandoned (see e.g. Hersoug et al., 2000).

As in many other fisheries both in Norway and other countries, the change of policy in the coastal cod fishery away from the excess-capacity inducing race-for-fish, was initiated by a stock crisis, rather than a desire to improve economic efficiency in the fishery. The change of policy from open to closed access was strongly opposed by fishers and others who argued that closing the fishery represented a privatization of property rights.[5]

Although individual quotas reduced the incentive to race for fish, fishers had little incentive to reduce excess capacity in the fishery. First, since not every vessel caught its full quota during the season, the Norwegian government allocated more quota to each

[3]During this period, there was a cap on how much each vessel could land, but the cap was generous and only constrained the largest and most efficient vessels (NOU, 2016).

[4]When the fishery closed, a small share of the quota was set aside for an open group to which those not qualified for the closed group were assigned and where new entrants more easily could enter.

[5]Grainger & Costello (2016) illustrate how distributional concerns could make individual fishers oppose welfare-improving policies.

vessel than the fleet's TAC (so-called 'over-regulation'). This was to ensure that the entire Norwegian quota was taken, and implied that each vessel's quota was a maximum rather than a guaranteed quantity. Each vessel could potentially land its full quota, but the regulator could also close the fishery before that time, if the total landings of the fleet reached the TAC. It follows that this system did not fully eliminate the race for fish. Secondly, the quota system gave little or no incentives for fishers to retire vessels from the fishery. A fisher wanting to leave the fishery could sell the fishing vessel with its accompanying quotas, but the buyer would have to keep the vessel to be able to fish with its quotas, even if the buyer had another vessel with sufficient capacity to catch both vessels' quotas. The number of fishing vessels would therefore remain unchanged even if a fisher sold out and left the fishery. Standal & Aarset (2002) study measures taken by the Norwegian government during the 1990s to renew the coastal fleet without increasing its fishing capacity. They conclude that the policy at least partly failed, as the fleet's capacity increased over this period.

In the first years after the closure of the coastal cod fishery, a vessel's annual quota assignment was determined by the length of the vessel. As described by Standal & Aarset (2002), this gave fishers incentives to obtain longer vessels to get a higher share of the annual quota. To stop this, the government in 2002 divided the group of coastal vessels, which all were under 28 meters, into four smaller regulatory groups based on their length, each with a separate group quota. This protected smaller vessels in competition with larger ones. The four resulting groups were as follows, based on the vessels' actual lengths at the time of implementation: up to 10 meters, 10-14.99 meters, 15-20.99 meters, and 21-28 meters overall length. This division is known as the Finnmark model, as it was based on a proposal from the Finnmark Fishers' Association. Fishers increasing the length of their vessels after this date, would not get a larger quota; regardless of their vessel's actual length, their quota was based on the original license length of the vessel (for details, see NOU, 2016).

Up until the early 2000s, the government offered decommissioning schemes to reduce excess capacity in the fishery. These measures, however, were costly and had limited effect: the oldest vessels with the lowest fishing capacity were typically removed first. This led the regulator to consider more market-oriented methods, and in 2004, the government opened up for quota exchange between vessels in the coastal fleet. This new policy allowed fishers to add quota from one vessel to that of another vessel, provided both vessels belonged to the same regulatory group. This so-called structural quota system (SQS), was available to vessels with a license length of 15 meters or above from 2004. A condition for consolidating quota on fewer vessels was that fishers had to decommission the vessel from which they transferred quota.[6] The scheme came with several other restrictions on transferability, such as a cap on the number of quotas per vessel and a ban on quota trading across county borders, motivated by the social objectives of the Marine Resources Act (i.e., to promote employment and settlement in coastal communities). The smallest vessel groups had access to decommissioning schemes instead. Vessels with license length below 15 meters were eligible for condemnation support from 2003, but the threshold was reduced to below 11 meters in 2008.[7].

In 2005, after a change of government in Norway, the new administration instigated a temporary pause in the processing of applications for structural quotas from December 31st of that year. In addition, the new government appointed a commission to evaluate the SQS and propose a way forward. The commission presented its recommendations in August 2006. Based on these recommendations, the government proposed a revised structural policy for the fishing fleet to the Norwegian parliament (NOU, 2006). In June 2007, the parliament decided to continue the SQS for all regulatory groups with access to the scheme prior to the pause and to extend the policy to vessels in the coastal fishing fleet with a license length of 11-14.99 meters (13-14.99 meters in the pelagic fishery) from 2007.[8] At the same time, the Finnmark model was revised by changing the cut-off length of the smallest group from below 10 meters to below 11 meters. The second smallest group thus became 11-14.99 meters. The vessels with license length 10-10.99 meters were given access to the 11-14.99 meters group.[9] In addition, the parliament lowered the cap on quotas per vessel for the coastal fleet,[10] and introduced a sunset provision for structural quotas (the

[6]Some studies state that the structural quota scheme started in 2003. This is the year when the government announced the regulation that included the scheme and when part of the regulation came into effect (on November 7th). However, the allocation of structural quota was only permitted from January 1st, 2004 (Regulation FOR-2003-11-07-1309, Section 13).

[7]The regulation for the decommissioning scheme, 'Structural fees and structural funds for capacity adjustment of the fishing fleet,' FOR-2003-06-30-876

[8]Some studies say that the SQS expansion was implemented in 2008, but the amendment of the regulation (FOR-2007-06-08-586) was made on June 8th, 2007, with a statement that "the changes take effect immediately."

[9]The commission argued that the harvesting patterns of 10-10.99 meter vessels are similar to those in the smallest group (e.g. one-man operation) in the report (NOU, 2006). However, according to the regulation on special quota schemes for the coastal fishing fleet: "Exceptions are also made from the lower limit of the legal length of 11 meters if the vessel has a legal length between 10 and 11 meters and the same registered owner(s) since before 16 March 2007" (FOR-2003-11-07-1309, section 9; see also the current version of the regulation, FOR-2020-11-27-2483).

[10]The new cap was twice the vessel's original quota, down from three prior to the pause. According to

quotas transferred from a retired vessel as part of the SQS); structural quotas obtained prior to the pause were valid for 25 years, and those obtained after for 20 years.

Thus, from 2004, structural quota transfers were available to coastal cod vessels in the two largest regulatory groups as defined by license length (15-20.99m and 21-27.99m). From 2007, such transfers became available also to the 11-14.99m group. Hereafter, we refer to these two structural quota scheme implementations as SQS2004 and SQS2007, respectively. While the SQS in the coastal cod fishery can be seen as a de-facto system of ITQs, there are a series of restrictions on trade, including the aforementioned sunset provision, regional restrictions, the decommissioning requirement, and caps on structural quotas per vessel. During the first years, the regional restriction was defined by county, but from 2016, the restriction was eased to only distinguish between two regions; north and south, where the north comprised the three northernmost counties (Finnmark, Troms, and Nordland) and the south is the rest. Furthermore, all quota transferred as part of the SQS was subject to a 20% deduction. The deducted quota was distributed among the remaining vessels in the regulatory group in which the transfer took place.

Quota leasing has not been an option in the coastal cod fleet. There was, however, a system in place between 2004 and 2007 that allowed coastal vessels to temporarily exchange their annual quota for some or all species. This scheme resembled the SQS, but only applied within a year. Contrary to the SQS, it required both giving and receiving vessels to remain operational and to have taken an active part in the fishery for at least two of the past five years. This quota-exchange scheme offered a within-year supplement to the more long-term quota adjustments made possible by the SQS. Importantly, the system did not promote permanent vessel exit.

While most coastal cod vessels gradually received access to the SQS, this opportunity was not made available to the smallest vessels with license length below 11 meters. The decision to not extend the SQS to all segments of the coastal cod fishery was motivated by a desire to balance the social objective of promoting employment and settlement in coastal communities against the objective of economic efficiency. Nonetheless, in 2010, the government introduced a new scheme for vessels in this group that allowed them to jointly harvest their quotas (the 'joint fishing' scheme). The policy change was based on a proposal from the fishers' association, which argued joint fishing would increase the safety of the fishers. The scheme increased the fishers' flexibility in a similar way as the SQS,

the Office of the Auditor General of Norway (2020), the share of vessels that reached the cap was below 10 percent for the majority of the years between 2004 and 2018.

but with the important restriction that all involved vessels had to be kept operational, regardless of whether they were actively used for fishing. From 2011, fishers were allowed to do 'joint fishing' with themselves as part of this scheme, which meant sharing quotas between vessels they owned. Although this may have given fishers incentives to further consolidate, the restriction that all involved vessels must be operational ensured that the number of vessels in the fleet was not directly affected.

In this paper, we analyze the effects of the structural quota system for the Norwegian coastal cod fishery, with a particular focus on geographical consolidation and heterogeneous effects between different regulatory groups.

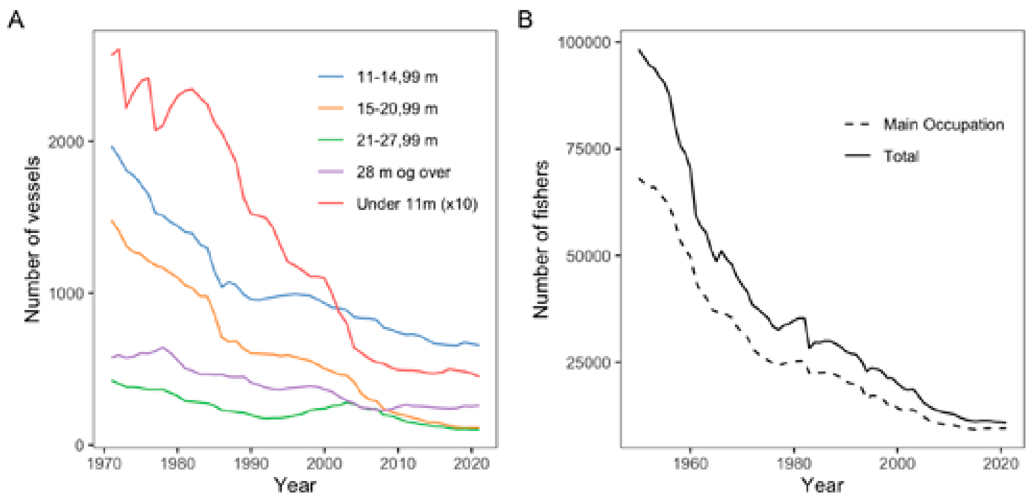

Figure 1: (A) Number of active fishing vessels in Norway by length group (all fisheries), 1970–2019. (B) Number of registered fishers in Norway, 1950–2019.

3 Empirical Research Method

In the present study, we investigate the impact of the SQS on consolidation in the Norwegian coastal cod fishery using two methods. First, we estimate the direct impact of the policy on vessel reduction. Second, we analyze descriptive measures of long-run consolidation trends in the Norwegian coastal cod fishery.

The impact of ITQs on vessels or fishers is inherently heterogeneous because some will invest in capital and purchase quotas, while others will disinvest and exit (Boyce, 1992;

Vestergaard et al., 2005). Policy evaluation methods usually estimate the average effect on those who are treated, but it may obscure the actual change caused by the policy. In particular, the ITQ could promote exiting vessels/fishers from the fishery, hence the sample is not consistent over time. For these reasons, we analyze the problem from multiple perspectives.

We first describe our strategy for estimating the effect of the structural quota policy on consolidation and quota distribution in the Norwegian coastal cod fishery. Then we introduce how we measure consolidation in our analysis.

3.1 Estimation of the short-run policy effect

To quantify the effects of the SQS and the subsequent consolidation on the coastal cod fleet, we adopt the difference-in-differences (DiD) estimator. As discussed earlier, this estimator quantifies the average effect of a policy (treatment) variable on outcomes based on data from before and after the policy implementation. However, as we saw in Figure 1, the number of vessels has been decreasing over time regardless of the SQS, hence the changes in outcomes we observe, such as the quantity of quota held by fishers, are not necessarily due to policy changes, but could simply be a result of general trends.

In this study, we estimate the probability of a vessel exiting the coastal cod fishery. If the policy effectively promotes consolidation, a vessel in a treated group is more likely to exit, all else equal. Given the heterogeneity within the fleet in terms of e.g. innate skill or fishing costs, we expect fishers with lower efficiency to exit. In theory, fishers who are closer to the threshold of exit are more likely to exit under individual transferable quotas. Hence, if the SQS policy is effective, it increases the probability of vessel exit, thereby facilitating consolidation.

In the context of our study, the treatment is the application of the SQS to specific vessel groups in the coastal cod fishery. As described above, the government introduced SQS to different regulatory groups at two different times, first in 2004 for vessels with a license length larger than 15 meters, and then in 2007, for vessels down to 11 meters. This gives us multiple cases from which to define the control and treatment groups; we have a DiD setup with a roll-out of policy. For the SQS2004 effect, the control group is the 11-14.99 meters group, and the treated group is the 15-20.99 meters group. For the SQS2007 effect, we invert the treatment assignment as the 15-20.99 meters group at this time already is under the scheme when it is expanded to include the 11-14.99 meters group in 2007. We exclude the smallest vessel group (less than 11 meters) and the largest group (above 21 meters). The smallest vessels were under another policy to eliminate the overcapacity as described above (a decommissioning scheme). We exclude the largest vessel group as it differs both in fleet structure and behavior. We discuss this in Appendix A2.

While the decision-making unit of a vessel is its owner, and one owner might own several vessels, our data do not allow us to perfectly identify owners over time.[11] For this reason, we study the owners' decisions about their vessel(s) at the vessel level, and we use reduced-form estimation to quantify the effect of the policy change. As discussed earlier, the number of vessels in Norwegian fisheries has been declining over the years. The SQS facilitates consolidation of fishing quotas, and should therefore have accelerated the exit of eligible vessels. Many vessels that are registered as active in our data, have no record of catch over the course of a year. These inactive vessels tend to disappear from the registry in later years. To capture this, we use both exit (disappearance from the registry) and inactivity (no record of catch in a year) as outcome variables.

Our empirical strategy looks at changes in the probability of exit in the groups that implemented the SQS relative to the groups that did not, or the group that was already under the SQS, before and after the implementation of the SQS. We estimate this using an event study model that enables us to evaluate the changes in exit probability over time. The estimating equation is:

$$Exit_{imjt} = \sum_{\tau=-q}^{-2} \beta_\tau D_{j\tau} + \sum_{\tau=0}^{T} \beta_\tau D_{j\tau} + x'_{imjt}\theta + \gamma_j + \upsilon_t + \mu_m + \varepsilon_{imjt}$$

where $D_{j\tau}$ is a dummy variable. It is equal to 1 if the period t relative to the group j's first treated period is the same value as τ. The policy is implemented in year $\tau = 0$, and q and T are the greatest numbers of lags and leads. The one lag ($\tau = -1$) is dropped in order to avoid perfect multicollinearity. The coefficient of $\tau = -1$ is set as zero as a reference. Recall that we have two policy implementations for which we can retrieve estimates: the introduction of SQS in 2004 and 2007. x_{imjt} is a vector of covariates, which includes the license length of the vessel relative to the group mean, vessel age, and past investments in quota and vessels (total structural quota added in the past). γ_j represents group fixed

[11] The data uniquely identifies the owner through an owner ID, but there are other events that could cause a change in the quota's registered owner, such as succession or change of company type (e.g. from sole proprietorship to shared company.)

effects, υ_t indicates year fixed effects, and μ_m captures municipality fixed effects of the municipality m in which vessel i is registered. A possible concern of omitted variables such as business conditions, natural conditions, and the size of TAC allocated to the coastal fishery is captured by the fixed effects.

One of the advantages of the event study model is that it enables us to check the parallel trend assumption of the DiD estimation. The development for our untreated vessels should represent the development of the vessels that come under the SQS, had they not done so. In addition, the anticipation of the policy change may affect the trend and bias the estimates (Malani & Reif, 2015). In our context, anticipation that one would soon get access to the SQS could cause firms to postpone exit until the fleet received access. The introduction of the scheme had been discussed prior to the actual implementation. The recommendation from the Ministry of Fisheries was submitted and approved in March 2003, hence the system could have been expected at least a year prior to its introduction (Norwegian Ministry of Trade, Industry and Fisheries, 2003). A fisher who owns a vessel with quota could sell this both before and after the introduction of the SQS. Prior to the SQS, however, the buyer would not be able to add the acquired quota to the quota holdings of their existing vessels. We therefore argue that in our context, anticipation would positively affect the number of active vessels immediately before the policy change (i.e., reduce the number of vessel exits just before the SQS introduction), but not the number of quota owners. If the market anticipated the SQS, quota prices would adjust accordingly. Therefore, it would not be necessary for quota owners to postpone selling their vessels with quota until the policy is implemented to benefit from it.

3.2 Measuring long-run consolidation trend

Quota consolidation occurs when fishers exit from the fishery and sell their quotas to the remaining fishers. This represents the consolidation of fishing quotas both along the intensive and the extensive margins. The extensive margin relates to the number of vessels or fishing firms. The intensive margin measures the amount of quota held by each active fishing firm. In this study, we consider both of these margins when analyzing quota consolidation in the Norwegian coastal cod fishery.

We consider two commonly used measures of concentration and inequality: the Herfindahl-Hirschman index (HHI) and the Gini coefficient. The Herfindahl-Hirschman index (HHI) is a popular index for measuring industry concentration (Herfindahl, 1950; Hirschman, 1980;

Curry & George, 1983), while the Gini coefficient is a commonly used measure of inequality of income or wealth in a society (Gini, 1912). Both measures have been applied to the analysis of fisheries.

Several studies apply the Gini coefficient to analyze quota holding consolidation (see e.g. Pálsson & Helgason, 1995; Liew, 2000; Agnarsson et al., 2016). This measure, however, does not distinguish between the distribution among remaining quota holders and those who exit. Pálsson & Helgason (1995) point at this issue and discuss how the Gini coefficient might underestimate how unequal a distribution is by not taking into account those who exit: the so-called null components. The HHI is better suited for capturing these null components, as this index accounts for both the number and distribution effects. The HHI has been adopted in a wide area of research settings, including the fisheries context to measure quota concentration (Stewart & Callagher, 2011; Abayomi & Yandle, 2012; Haynie, 2014; Agnarsson et al., 2016). It is also used by government agencies such as the U.S. Department of Justice when applying antitrust laws regarding mergers (Rhoades, 1993).

A drawback of the HHI in our context is that it is a function of both the number of fishing firms (quota holders) and the distribution of quotas among these firms. We circumvent this issue by decomposing the HHI into two components following de Gioia (2017): one that captures the effect of a change in the number of quota holders, and one that reflects the distribution of quota holdings among firms. This allows us to analyze both the intensive and extensive margins of quota consolidation.

4 Data

We use data from the Norwegian Directorate of Fisheries (DoF) to estimate our model. The DoF is responsible for implementing and enforcing marine resource management policy in Norway, in addition to aquaculture and coastal zone management. Our dataset consists of data from the fishing license registry and landings tickets. The license registry contains information about all licenses and associated fishing rights (quotas) held by all registered fishing vessels since 2001. Each license specifies the vessel's license length and quotas. Unique ID numbers identify licences, vessels and owners. Vessels are registered in the database by the geographic location of their owners.

As discussed above, quotas can be transferred and aggregated on vessels within the same regulatory group under the SQS. The transferred quota is registered as another license on the vessel (structural quota). Each licence record contains information on the regulatory group to which the vessel belongs. All of a vessel's licences and quotas must be associated with one distinct regulatory group, thereby making it straightforward to assign vessels to regulatory groups. We restrict our dataset to include only vessels that for at least one year during our study period held a license valid in the coastal cod fishery.

Figure 2 shows the number of registered vessels by regulatory group for the coastal cod fishery north of the 62-degree line. The figure shows a clear reduction in the number of vessels in the 15-20.99m and 21-27.99m groups after the introduction of SQS in 2004. We see a similar decline in the number of vessels in the 11-14.99m group after it gained access to the SQS in 2007. The decline continues in the years after the SQS introduction for all groups. The smallest vessel group (license length below 11m), which did not have access to the SQS, experienced a significant drop in the number of vessels from 2003 to 2009. This period overlaps perfectly with the availability of a vessel decommissioning scheme for this group, which suggests that the policy was successful in reducing the number of vessels in this group.

Figure 2 also illustrates the timing of the policy implementations. The decommissioning scheme for the smallest vessel category was in effect between 2003 and 2009. From 2010 onward, vessels in the below 11m group could make use of the joint fishing scheme. The fact that this regulatory group had access to different policies, complicates our estimation strategy, as it would violate the parallel trends assumption discussed above. To deal with this, we exclude the smallest vessel group from our main estimations. Specifically, we use a subset of the data from before 2006 without the below-11m license length group to identify the effect of the SQS2004 for the 15m-and-above vessels. Similarly, we use a subset of the data from 2004 and later, excluding the smallest group, to estimate the effect of the SQS2007 for the vessels with license length 11-14.99m relative to the larger groups. This sub-sampling method allows us to observe cases where one regulatory groups experiences a policy change, while the policies affecting the others remain constant.

5 Results for short-run policy effects

5.1 The effects of the SQS policy

In this section, we present our estimation result on the effect of the SQS policy on quota consolidation. Figure 3 shows the coefficients estimates for the SQS in 2004. The difference

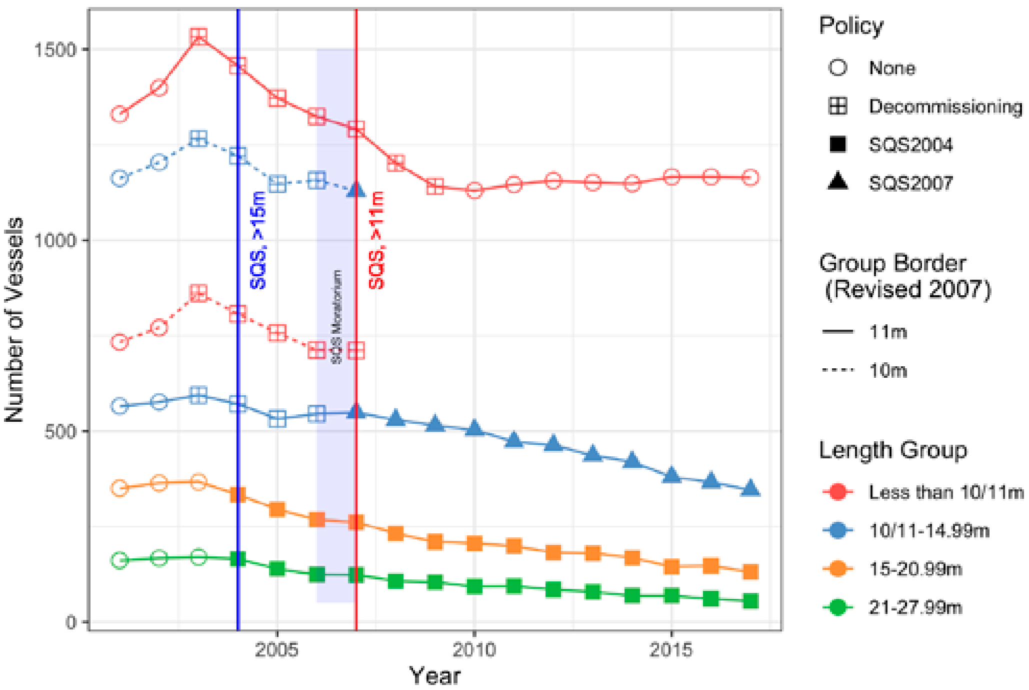

Figure 2: Number of registered vessels holding a coastal cod license by regulatory length groups.

in the probabilities of exit is not statistically different before the SQS introduced in 2004, but the difference emerges after the introduction. This result clearly shows that there is an impact of SQS on the exit in the larger group (15-20.99 meters). The magnitude of the impacts are around a 6 percentage point increase in 2004 and more than 10 percentage points in 2005. The estimated impact is lower in 2006, but this is likely due to the SQS moratorium that was introduced toward the end of 2005. Regardless of this, the policy change had a significant short-run impact on the consolidation of the fleet.

Figure 4 shows the estimated result for the SQS implementation in 2007. Recall that the treatment group is now 11-14.99 meters, while the control group, 15-20.99 meters, is already in the SQS. In the pre-SQS periods, the small group has lower probability of exit than the larger ones. This is the opposite of the estimates of SQS in 2004 as the data period overlaps. The estimates in the period after the introduction are around zero although some years are statistically different from zero. While the parallel trend between the treatment and the control is not as clear in this case, we see the shifted level before and after the

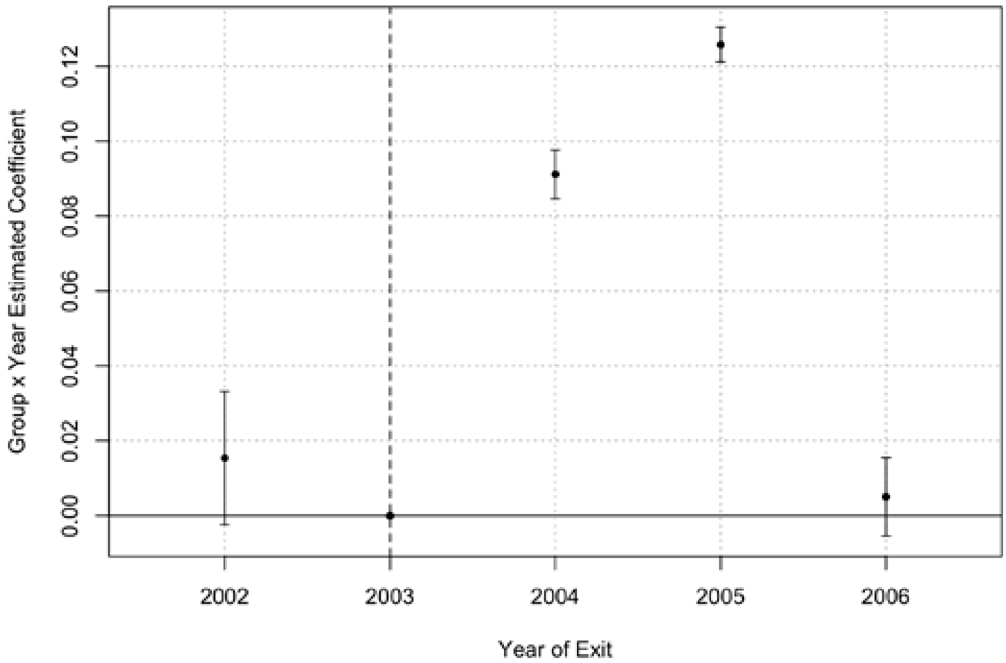

Figure 3: Coefficient estimates (β_τ) of the event study model for SQS in 2004.

expansion of the SQS. Year 2006 is in the pre-policy period, but it was covered by the moratorium and we therefore expect the effect to be small, in line with the estimates for this year for SQS2004. Year 2007 also appears to be a peculiar year, as the estimate is positive, while we expected it to be zero after the SQS expansion. This implies that the policy has a short-run effect on the likelihood of exit of a vessel. We also find the results in year 2015 to differ from previous years, but this likely captures that 2016 was the year when the government opened up for vessel/license transfer across counties.

In addition, the coefficients are precisely estimated in early periods, while the standard errors become larger in later years. This suggests increased heterogeneity over time within fleet. Because consolidation changes the composition of the fleet and the more efficient vessels remain, the characteristics of the vessels that exit will also change over time. Table 1 shows the estimated coefficients on the covariates for both models. Vessels with large license length, low vessel age, and high total value (relative to the average of the group) are less likely to exit. However, large standard errors in later years suggest that such tendencies may no longer be valid in more recent years.

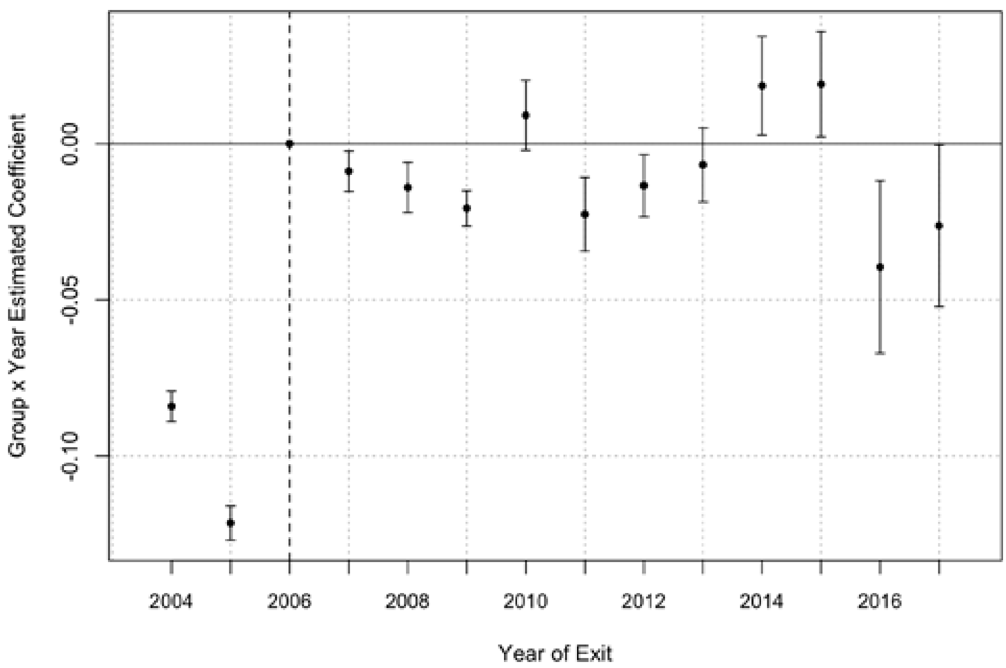

Figure 4: Coefficient estimates (β_τ) of the event study model for SQS in 2007.

5.2 Quota Investment

The structural quota scheme opened up for consolidation of quota on vessels. Our estimation results indicate that the SQS increased vessel exit, and that smaller and older vessels are particularly likely to exit the fishery (see Table 1). To learn more about vessel level quota consolidation, we estimate the effect of observable characteristics on quota investment at the vessel level, after the SQS implementation. In this estimation, we use data on vessels under the SQS that did not leave the fleet during the study period.

We define quota investment as events when additional structural quotas are added to

Model:	SQS 2004 (1)	SQS 2007 (2)
Variables		
Ref. Length	-0.0188**	-0.0180***
	(0.0060)	(0.0033)
Vessel Age	0.0042***	0.0048***
	(0.0008)	(0.0003)
No. of Vessels under Owner	0.0614**	0.0684***
	(0.0206)	(0.0081)
Total Value of Cod Landings	-0.1375**	-0.0933***
	(0.0452)	(0.0265)
Fixed-effects		
Year	Yes	Yes
Length Group	Yes	Yes
Municipality	Yes	Yes
Fit Statistics		
Observations	4,517	9,771
R^2	0.19892	0.18098
Within R^2	0.11818	0.13729

Clustered (Year) standard-errors in parentheses
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 1: Covariates estimates of the event study models. The dependent variables are the dummy variable of exit/inactive for both models.

the quota holdings of a vessel. Among these remaining vessels, we observe heterogeneity in quota investments. Table 2 shows the results of our estimations using quota investment as the dependent variable. We find that vessels that belong to owners who have several vessels, vessels with longer license lengths and vessels with higher landing values tend to gather more quotas in the wake of the SQS implementation. According to our results, vessels that already have realtively large quotas (large license length) tend to gain more when quota consolidation is an option. This suggests that the SQS implementation promoted further consolidation and increased the inequality in quota distribution among vessels.

Table 2: Estimation result: Quota Investment by Vessels

	SQS2004 (≥15m)	SQS2007 (11-14.99m)
Ref. Length	0.472***	0.156***
	(0.061)	(0.031)
Vessel Age	−0.024**	−0.007**
	(0.008)	(0.002)
Total Value of Cod Landing	0.138***	0.245***
	(0.034)	(0.064)
Cumulative Str. Quota	−0.319***	−0.232***
	(0.035)	(0.053)
No. of Vessels under Owner	0.690***	0.109*
	(0.180)	(0.047)
Observations	2545	4989
R2	0.247	0.169
R2 Adj.	0.215	0.146
Year FE	Yes	Yes
Group FE	Yes	No
Municipality FE	Yes	Yes

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note:
SQS2004 estimation subsample period from 2001 to 2006, and SQS2007 uses from 2004 to 2017. In SQS2004, the groups of 15-20.99 meters and 21 meters and above are used, and the group of 11-14.99 meter is used in SQS2007.

6 Long-run consolidation trend

In the previous section, our estimation of the effect on vessel exit probabilities showed that SQS facilitated consolidation at least in short run. To investigate the broader impacts of the SQS policy, we will now use descriptive analyses to further explore the possible impact of SQS on different levels. We analyze the consolidation process at the following three levels: vessel, owner and geographic area.

6.1 Vessel-level quota consolidation

Quotas must be registered to a vessel in the Norwegian fisheries management system. It is therefore relevant to explore quota consolidation at the vessel level.[12] Finally, the geographical distribution of fishing quotas is a concern in Norwegian society, as the fishing activity enabled by the quota has implications for employment and livelihood in coastal regions (cf. Norway's Marine Resources Act). In this section, we present calculations of the HHI and the Gini coefficient for quota holdings at the vessel level.

As shown by the HHI values presented in Figure 5, vessel-level quota consolidation is prominent in all length groups greater than 11 meters after the introduction of the SQS. Comparing the absolute values of HHI across regulatory groups, we see that the HHI is greater for the larger vessels. This is expected because the number of vessels per group falls with the regulatory vessel length of the group. Figure 5 also shows the decomposition of the HHI into distribution and number effects. Recall that the distribution effect accounts for how quota is distributed among the vessels, while the number effect captures the effect of fewer vessels. For all vessel groups, we find that the number effect is greater than the distribution effect, and steadily increasing except for the below-11m group as consistent with the number of vessels shown in Figure 2. A large portion of the HHI is explained by the number effect before the SQS introduction, but the total HHI and the number effect start diverging after the SQS introduction.

In figure 6, we show Gini coefficients for vessel quota holdings in the coastal cod fishery for each of the vessel length groups. The figure reflects how quotas accumulate on some vessels, thereby gradually raising the inequality in quota holdings within each regulatory

[12] Recall that we have the owner ID of each vessel, but we do not use them for the estimation in section5 because we do not have consistent owner IDs over time to create a complete panel dataset. In this section, we use the owner IDs to aggregate the data by year. In this case, it is not necessary to identify owners over time.

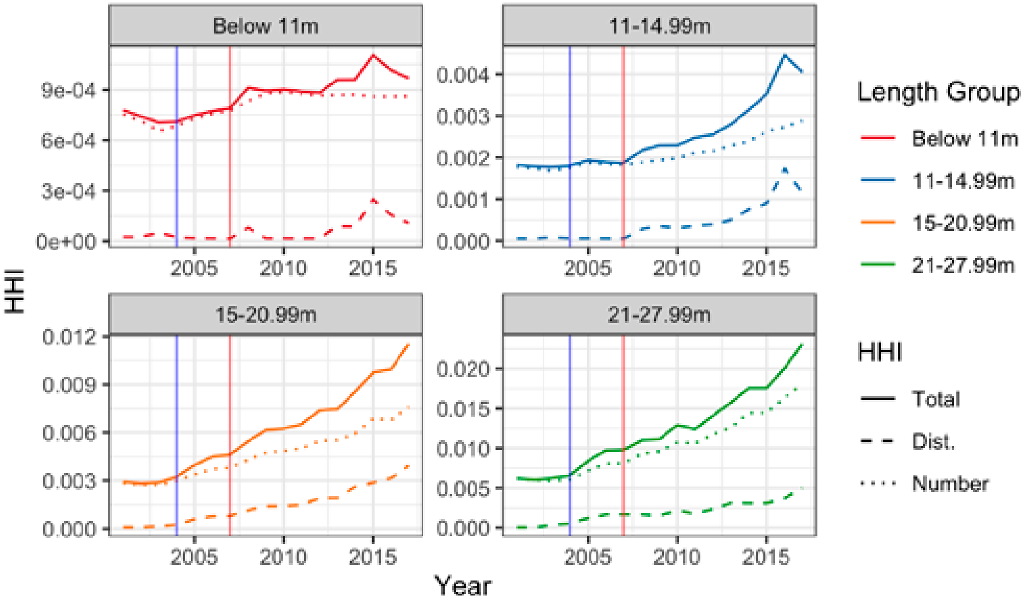

Figure 5: Vessel-level HHI for coastal cod license by length groups. Total HHI (Solid line) is decomposed into the distribution effect (dashed line) and the number effect (dotted line). The vertical lines indicate the year of SQS introduction (blue: 2004, red: 2007).

group after the SQS introduction. Because the Gini coefficient omits null components, our results are not affected by vessels exiting the fishery. Contrary to the groups under SQS, the smallest regulatory group, which did not have access to quota consolidation (SQS), displays a fairly stable level of the Gini coefficient, particularly after the end of the decommissioning scheme that was available to this group until 2009.

Our estimation results from section 5 and the figures above show that the Norwegian coastal cod fishing fleet is becoming increasingly consolidated. Figure 7, which shows the distribution of quota factors on the license length of the vessels, provides additional evidence of this process. In 2003, license length and quota factors are perfectly proportional because the quotas are distributed across vessels based on the license length, shown in red (dots and fitted line). However, the distribution of quota is concentrated at larger license lengths for each group in 2017, which is the most recent year (shown in blue). Only for the smallest group is the distributions almost unchanged between 2003 and 2017. This is

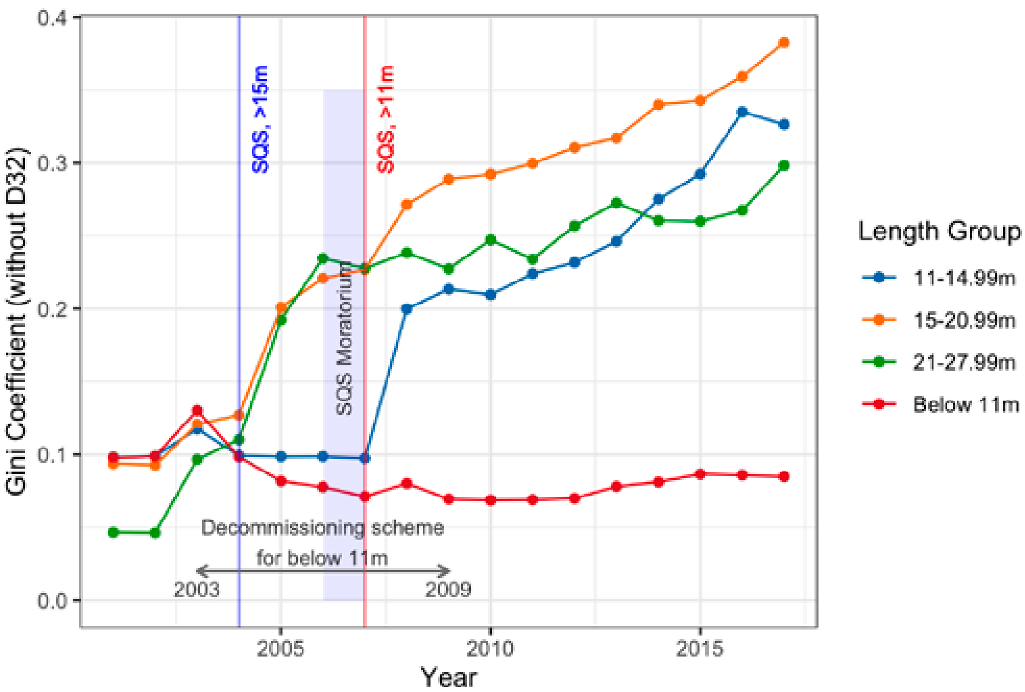

Figure 6: Vessel-level Gini coefficient for coastal cod license by length groups

in line with within-group consolidation occurring after the introduction of the SQS.

6.2 Owner-level quota consolidation

Since one fishing firm can own several vessels, we get a more complete picture of quota consolidation by also exploring the owner level. Figure 8 shows how owner-level quota concentration evolves from 2001 through 2017 in the coastal cod fishery.[13] The HHI and the two components we decompose it into, exhibit a gradually increasing trend after 2004. Furthermore, the distribution effect exceeds the number effect from 2004 and exhibits more rapid growth. As Panel B of Figure 8 shows, the number of owners with multiple vessels increases sharply up until 2007. This consolidation comes in addition to the vessel-level consolidation explored above. The number effect depicted in panel (A) is nonetheless modest compared to the distribution effect. This is because the total number of owners

[13]Recall that our dataset does not allow us to identify owners over time in a time-consistent manner. Owners are, however, consistently identified in cross sections of the data.

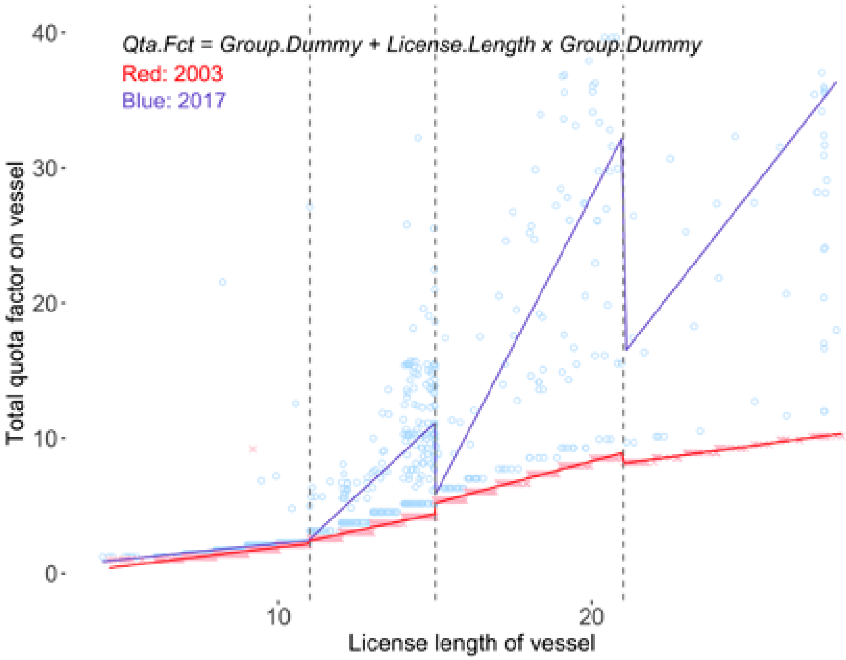

Figure 7: License length of vessels and total quota factor distribution on license length of vessels in 2003 (before the SQS is implemented) and 2017 (the most recent year in the dataset).

(and vessels) is large. There were 2,483 owners in 2003 and 1,377 in 2017.

Panel B of figure 8 shows a clear drop in the number of owners with multiple vessels immediately after the revised SQS policy came into effect in 2007, followed by considerable growth in the number of owners with two or three vessels after 2013. The drop from 2007 to 2009, indicates that many owners who held several vessels with quota prior to this, immediately made use of the SQS to transfer their quota to one or fewer of their vessels, while retiring (scrapping) the vessel(s) left without quota. There are likely several factors contributing to this. First, consolidation occurred in the coastal cod fisheries also prior to the introduction of the SQS and during the SQS pause in the mid-2000s, but then consolidation required owners to obtain and operate additional vessels with quota. In addition, there was excess capacity in this fishery, implying that the fleet could harvest its quota more efficiently using fewer vessels.[14] When the government in 2007 reinstated the SQS for vessels above 15m and introduced it for the 11-14.99m vessels, many fishing firms could benefit from the scheme. They could then consolidate quotas they had accumulated over previous years when they did not have access to the SQS (cf. figure 5), enabling them to more efficiently harvest their quota using fewer vessels.

Fishers with a vessel and a quota wanting to increase their quota share in the fishery, had to buy a vessel with a cod license and quota from someone already in the fishery. Once they obtained the new vessel with quota, they could choose to use the structural quota scheme to transfer the quota to one vessel, while scrapping the other, or they could continue fishing with both vessels and their respective quotas. In the first case, the quota of the vessel that is taken out of the fishery becomes a structural quota, after a 20% deduction, and it gets an expiration date (20 years if after 2007). In the latter case, there is no vessel-level quota consolidation, so the quota remains the same. It follows that the expected gain from quota consolidation must be sufficiently large to outweigh these costs (deduction and sunset provision) for fishers to prefer this option. Over time, as the largest gains from quota consolidation are realized, we would expect to see more vessel acquisitions without accompanying consolidation. This is also what our data show; in figure 8(B) there is a

[14]As mentioned above, the coastal cod fleet had access to a quota-exchange scheme between 2004 and 2007. This scheme allowed coastal vessels to temporarily exchange quota within the regulatory group provided that both giving and receiving vessels remained operational. 13% and 16%, respectively, of the coastal cod vessels, exchanged quota through this scheme in 2006 and 2007, and it was common for owners of multiple vessels to use this scheme to harvest their quotas with a subset of these vessels (NOU, 2006, p. 67). This is evidence that it was more efficient both for the fleet as a whole and for individual quota owners to harvest the total quota using only a subset of the available vessels.

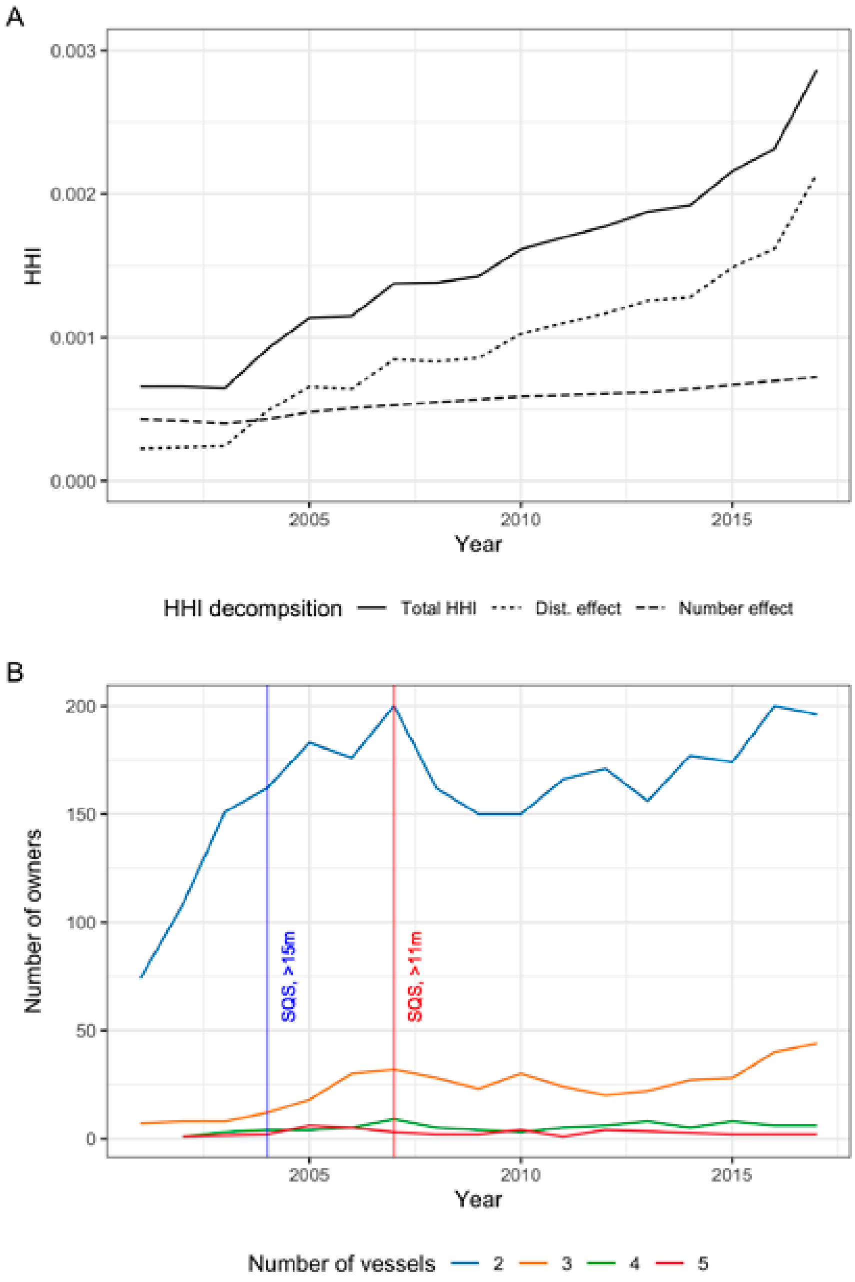

Figure 8: (A) Owner level HHI in the coastal cod fishery. (B) Number of owners holding multiple coastal cod fishing vessels.

clear increase in owners holding multiple vessels after 2013.[15]

6.3 Geographical quota consolidation

Figure 9 shows the change in quota holdings and landings by municipality for the northern coastal cod fishery between 2003 and 2017. In the northern region, we observe quota concentrating in certain municipalities. In particular, we see considerable quota consolidation in municipalities such as Berg, Lenvik, and Tromsø in Troms county, and Øksnes and Moskenes in Nordland county in the northern part of Norway (all red in the map). Furthermore, many municipalities both in the north and south of Norway gained or lost quotas over this period, indicating considerable quota movement. With restrictions on quota transfers between the north and the south of Norway, the majority of quotas move between municipalities within these two main regions. As shown in Figure 10, there is no leakage from the northern region after the introduction of SQS. Instead, we see a shift in quota distribution within these two main regions. While Troms county increases its share of the total quota, we see a reduction of quota shares in the counties Finnmark and Nordland for groups above 15m. This result is in line with the map shown in Figure 9. The quota shares for the 11-14.99 meters group are relatively stable.

Figure 9(B) maps the change in the distribution of cod landings in the northern coastal cod fishery from 2003 to 2017. This figure shows a similar development as for quota shares, and most municipalities that gain shares of fish landings also accumulate more quota. However, there are some exceptions. First, since the vast majority of the fleet's cod catches are landed in the north, there is relatively little change in landings in the southern part of Norway, despite shifts in quota holdings in this region. In addition, some municipalities that accumulate a significant share of the quota, still experience reduced landings. An example is Moskenes, located at the tip of the Lofoten islands.

The coastal fleet is less mobile than the larger offshore fleet, which contributes to the close relationship between quota holdings and cod landings. In addition, the fleet's cod landings rely heavily on the annual migration of the Northeast Arctic cod to spawning areas along the northern Norwegian cost, such as Lofoten and Vesterålen. Finally, while landing plants are located all along the Norwegian coast, considerable consolidation oc-

[15] In 2016, this effect could have been affected by the policy change implemented that year, which allowed owners to transfer vessels and quotas across county borders within regions (north and south of Norway), rather than only within the county.

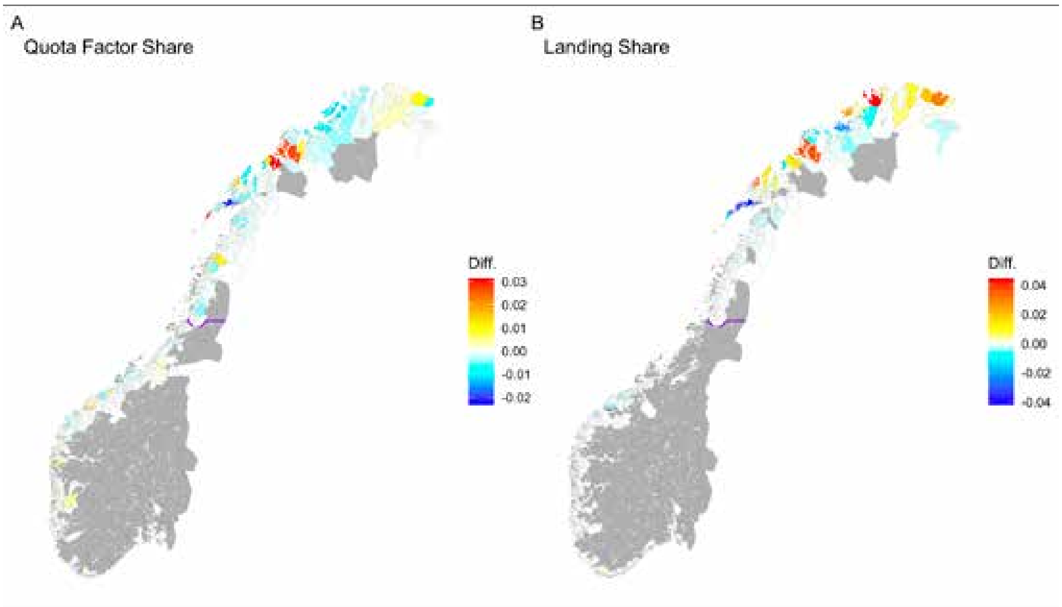

Figure 9: (A) Difference in quota factor of northern coastal cod between 2003 and 2017. (B) Differences in cod landing share by coastal vessels holding northern cod quota between 2003 and 2017. On both maps, the purple line marks the border between the two main regions (north and south).

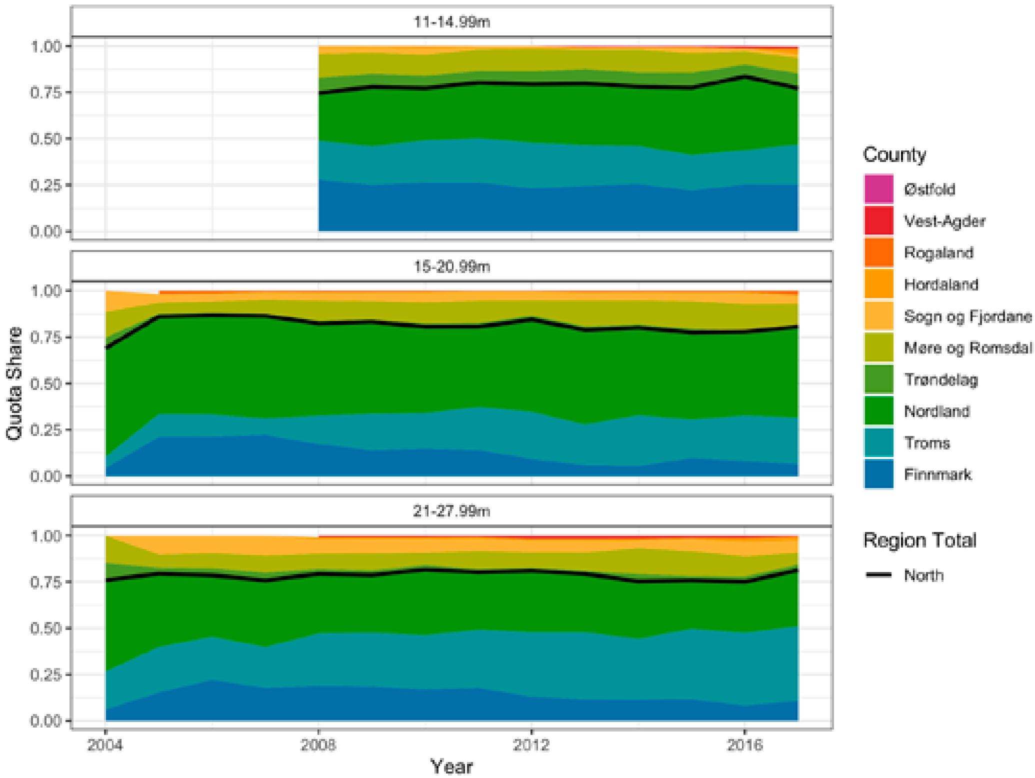

Figure 10: Changes of quota share by county (colors) and region (bold line) after SQS introductions.

curred between 2003 and 2017, resulting in fewer but larger plants (Cojocaru et al., 2019). Therefore, although the correlation between quota ownership and landings in the coastal cod fishery is strong, not every municipality with a significant quota share has landing plants. The location of landing plants relies on several other factors, including the existing distribution of landing plants, proximity to key fishing grounds, market access, and agglomeration effects (Cojocaru et al., 2019).

7 Conclusions

Individual fishing quotas reduce the race-to-fish. However, individual quotas that do not allow for transfer and consolidation do not provide incentives to reduce existing excess capacity. By opening up for quota trade and consolidation, the resulting quota market will eliminate excess capacity, promote allocative efficiency and improve economic performance. Still, the quota market could also yield undesirable distributional outcomes, such as concentration of catch and landings, which make it difficult to achieve social objectives. The trade-off between economic efficiency and social objectives such as equity is a major challenge in achieving the triple bottom line in fisheries management.

Norway's approach of gradual change differs from the approach taken by other countries that have introduced transferable quotas, such as New Zealand and Iceland. Norway's gradual approach where the possibility to trade and consolidate quotas was introduced with a number of constraints, which were later lifted, might be a solution to the challenge of achieving a triple bottom line. However, as Standal & Asche (2018) argue, this change was not so much designed as it was a product of a gradual shift of the fishery away from its role as a diverse coastal employment system to the pursuit of economic efficiency under sustainable resource management. The balance between social and economic objectives must ultimately be determined by consensus among stakeholders, and an important question in this respect is which policies will achieve which outcomes.

As shown by Kroetz et al. (2015), imposing restrictions on the transferability of quotas comes at the cost of lost economic efficiency. Such efficiency loss can be considered a cost to be balanced against gains from achieving social objectives. A problem occurs, however, if there are unintended (and undesired) consequences, such as a change in the distribution of fishing activities caused by the change in the quota scheme.

Our study identifies a direct effect on vessel exit of the structural quota policies introduced in the Norwegian cod fishery in 2004 and 2007. The policies encouraged efficiencyimproving vessel exits on average. Our result indicates that the behavior of fishers changed because of the SQS implementation. As a result, the distribution of quotas changed as they were distributed across fewer vessels and owners. Our empirical analyses reveal that the quotas concentrated on the largest vessels (license length), which held relatively large quotas before the SQS implementation. We also observe geographic quota concentration. Although it is not the sole factor, the SQS played an important role by triggering (or facilitating) these processes.

It is known that the introduction of a transferable quota system has led to increased geographic concentration Edvardsson et al. (2018), and our study finds a similar trend (Fig.9). In addition, our results suggest that geographic concentration also has an effect on individual decision-making. A reduction in a region's quota share can reduce the number of landing facilities and processing plants in the region, lower employment, and increase population outflows from fishery-dependent rural areas. Such feedback effects affect the decisions of remaining individual fishers. However, also factors outside the fishing industry can cause population outflows and shrinking local economies, which in turn can affect the decisions of individual fishers. In Norway, a study reports that fish landings do not directly affect population outflows at the municipal level (Iversen et al., 2020). If the observed decline in population size and economic activity in some municipalities is primarily due to other factors than consolidation in the fisheries industry, the negative impact of the quota system is overestimated.

Another potential indirect effect of quota trade, which was outside the scope of the current study, is changes in market power (Anderson, 1991). In Norway, the regulation imposes quota caps both on vessels and owners, but it is empirically not clear whether the cap is large enough to generate market power (Anderson, 2008). Our HHI calculations show that quota concentration is not sufficiently high to create monopoly power (Fig.8), but it is possible that the concentration of quotas and landings on some vessels and owners in the local market puts other fishers or landings plants at a competitive disadvantage.

Good resource management must be based on strong knowledge of both the direct and indirect effects of policy, such as the changes in quota distribution following the SQS. Norway's quota system has been described as a system of gradual change or 'hesitant reforms' (Standal & Asche, 2018; Hersoug, 2005), but many claim that economic efficiency gradually has been given priority over social equity, in the form of e.g. local employment and economic activity (Standal et al., 2016; Standal & Asche, 2018). This development could reflect changes in people's attitudes and be the result of political processes, but it could also be that the system has had some unintended consequenecs.[16] There is a need to deepen our understanding of the indirect effects through research for better policy design. To identify the actual mechanism of indirect effects, we need research on the behavior of fishers and their policy responses using more detailed data and models.

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[16]The report of Office of the Auditor General of Norway (2020) and the public debate that followed its publication, suggest that the quota system has had some unintended consequences.

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A Appendix

A.1 Decomposition of HHI

To measure industry consolidation, we calculate the HHI for quota holdings for each unit (vessel or firm). More specifically, we calculate the HHI as follows:

$$H_{jt} = \sum_{i=1}^{n_t} \left(\frac{x_{ijt}}{\sum_{i=1}^{n_{jt}} x_{ijt}} \right)^2 \tag{1}$$

where x_{ijt} is the quota share (or another variable under consideration) of unit i at time t within regulatory group j, which in our case is one of the four vessel length groups. We can use the same formula to calculate the HHI for other variables, such as landings of cod. The HHI takes on a value between 0 and 1, where a low (high) value indicates low (high) concentration. Hence, if the number of quota-holding firms (or vessels) decreases, the value of the index increases. The index will also increase if the distribution of quota among firms becomes more concentrated while the total number of firms remains unchanged. If all firms hold the same amount of quota, the value of the index is equal to 1 divided by the number of firms.[17]

The HHI (equation 1) gives a measure of the total concentration of quota holdings or landing shares, a measure which aggregates over the intensive and extensive margin. Since we are interested in each of these effects, we need to decompose the HHI. Following de Gioia (2017), we derive an index, τ, which represents the degree of concentration for a given number of components, n:

$$\tau_{jt} = \sqrt{\frac{n_{jt}}{n_{jt} - 1} \left(H_{jt} - \frac{1}{n_{jt}} \right)} \tag{2}$$

This τ index is similar to the Gini coefficient but without any null components.[18] τ essentially expresses the distance of the data from the most concentrated distribution (i.e., a distribution where one firm holds all quota, leaving the remaining $n_t - 1$ firms with no

[17] There is not one specific HHI value (or interval) that defines a concentrated industry. For example, the European Commission considers a market to have a high concentration if the HHI is at or above 0.1, while the US Department of Justice considers a market as moderately concentrated if the index is between 0.15 and 0.25, and highly concentrated if higher than 0.25.

[18] Note that the Gini coefficient can be expressed as: $G = \frac{1}{n}\left(n + 1 - 2\left(\frac{\sum_{i=1}^{n}(n+1-i)x_i}{\sum_{i=1}^{n} x_i}\right)\right)$, when x values are indexed in non-decreasing order ($x_i \leq x_{i+1}$).

quota) given the number of components. We provide the details on how to derive the τ index in Appendix A.1.

Noting that there is a one-to-one correspondence between H and τ, we can decompose the HHI into two parts, the distribution effect ($\tilde{H}_{jt}^D$) and the number effect ($\tilde{H}_{jt}^N$):

$$H_{jt} = \tilde{H_{jt}}^D + \tilde{H_{jt}}^N$$

where the distribution and number effects are expressed as follows:

$$\tilde{H}_{jt}^D = \tau^2 = \frac{n_{jt}H_{jt} - 1}{n_{jt} - 1}$$
$$\tilde{H}_{jt}^N = H_{jt} - \tau^2 = \frac{1 - H_{jt}}{n_{jt} - 1}$$

According to de Gioia (2017), the distribution effect dominates the number effect, as the HHI value becomes greater given the same number of components. That is, an additional firm entering the industry changes the distribution to a larger degree when there is little inequality. In our context, the industry concentration will increase when a firm or vessel exits, but this exit will also change the inequality for a given number of firms or vessels since quotas are transferred from the exiting vessel to the remaining ones. Our decomposition allows us to study both of these effects separately. This is useful since in our case study, reducing the number of vessels is an explicit policy goal, while increasing the inequality of quota holdings is not.

We decompose the Herfendahl-Hirschman Index (HHI) as follows: first, we consider the vector $\vec{x_i} = (x_1, x_2, \ldots, x_n)$ for the data of n quota holders. Note that this is a $\mathbb{R}_+^n$-vector as the quota holdings can only take one positive value or zero. Having defined a vector for the data, we similarly define the n-dimensional vector for the perfectly equal quota holdings, $\vec{\bar{x}} = (\bar{x}, \bar{x}_i, \ldots, \bar{x})$, where $\bar{x} = \sum_{i=1}^n x_i$. Conversely, n-dimensional vector for the most unequal distribution given the number of components and the total quota is defined as $\sum_{i=1}^n = n\bar{x}$, $\vec{x^*} = (n\bar{x}, 0, \ldots, 0)$. With these three vectors defined, we can calculate the Euclidean distances from the data vector to the perfectly equal distribution vector and from the perfectly unequal distribution vector to the perfectly equal distribution vector:

$$d(x, \bar{x}) = \sqrt{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}$$
$$d(x^*, \bar{x}) = \sqrt{(n-1)n\bar{x}^2}$$

Then a relative index of concentration is defined by taking the ratio of distances.

$$\tau = \frac{d(x, \bar{x})}{d(x^*, \bar{x})} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{(n-1)n\bar{x}^2}}$$

This index is what was shown in the main text. Again, this represents the degree of concentration <u>given</u> the number of components. The convenience of the relative index τ is its relation to the HHI. Using the definition of the HHI, we can express the relative index as follows:

$$\tau = \sqrt{\frac{(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2)/(\sum_{i=1}^{n} x_i)^2}{(n-1)n\bar{x}^2/(\sum_{i=1}^{n} x_i)^2}} = \sqrt{\frac{n}{n-1}\left(H - \frac{1}{n}\right)}$$

Here we observe a one-to-one correspondence between H and τ. Using this characteristic, we can decompose the HHI into two parts: the inequality effect and the numbers effect:

$$H = \tilde{H}^{\mathrm{I}} + \tilde{H}^{\mathrm{N}}$$

where

$$\tilde{H}^{\mathrm{I}} = \tau^2 = \frac{nH - 1}{n - 1}$$
$$\tilde{H}^{\mathrm{N}} = H - \tau^2 = \frac{1 - H}{n - 1}$$

Using the expression of τ^2, we can express the inequality- and numbers effect explicitly:

$$H(\tau, n) = \frac{(n-1)\tau^2 + 1}{n}$$

Holding τ constant taking the first order difference of HHI yields the pure number effect of concentration, which should be non-positive because concentration is negatively affected by an additional firm entering the industry.

$$\Delta H^{\mathrm{N}} = H(\tau, n+1) - H(\tau, n) = \frac{\tau^2 - 1}{n(n+1)} \leq 0$$

A.2 Additional estimation results

The main estimation of the effect takes the 11-14.99m and 15-20.99m groups to estimate the effect of the structural quota scheme. The 21-27.99m group is also included in the first wave of the SQS, but we do not include them in the main estimation because those vessels are large and practically different type of vessels although they are called coastal vessels.

The figure A1 shows the same estimation model as the main estimation, but the control group is 15-20.99m and the treated group is 21-27.99m group. Both groups are included in the SQS in 2004, but the probability of exit after the implementation differs after 2004. The largest group has fewer probabilities of exit in the early phase of the scheme, but later it has higher probabilities. This indicates that the different exit behaviors are exhibited between 15-20.99m and 21-27.99m groups, which is the reason why we exclude 21-27.99m group from the main estimation.

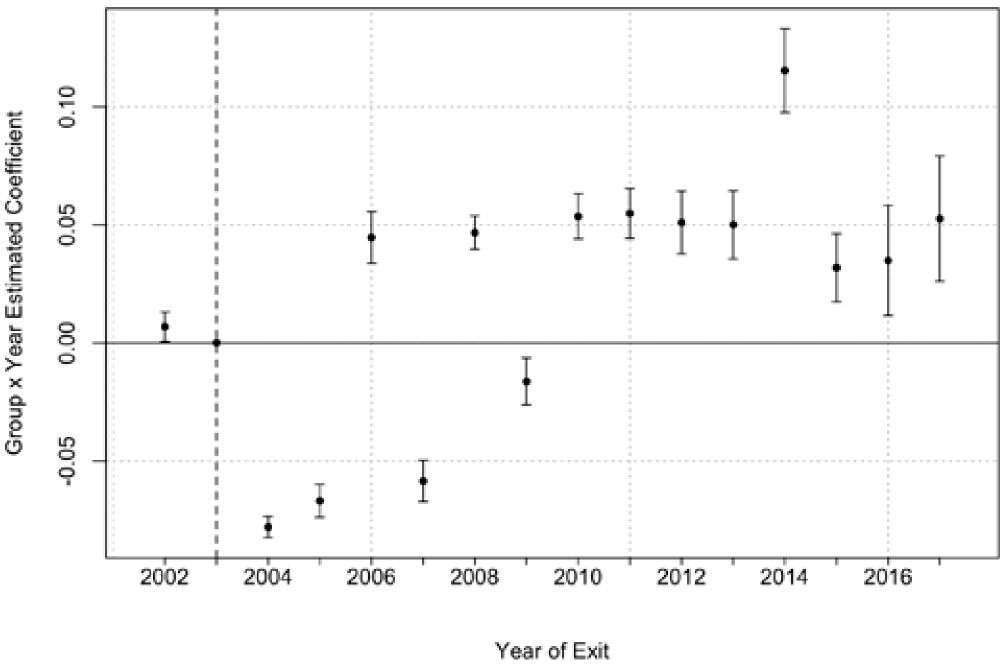

Figure A1: Effect on 21-27.99m group exit relative to 15-20.99m.

A.3 Additional figures of consolidation trends

Figure A2 shows quota holdings by vessel length. The figure depicts, for one regulatory group and for three important years in our period of study, the relationship between the total number of so-called quota factors held by vessels and their actual length.[19] Recall that the actual length of a vessel might differ from its regulatory length. We show the marginal distributions of the two variables at the top and to the right of the main plot, respectively.

There is a clear linear relationship between the size of the vessel and the number of quota units. This relationship is weaker in 2017. This is as expected, as little consolidation had taken place in 2004 compared to 2017. Only a few years prior to 2004, quota shares were allocated to vessels based on the vessels' actual length at the time; this length then became their (fixed) regulatory length for the cod fishery (cf. section 2). Quota consolidation started in 2004 for vessels with a regulatory length above 15m, and by 2017, considerable consolidation had taken place in all fleet segments above 11m.

Comparing 2003, 2006, and 2017, we see that the linear relationship between length and quota units have become steeper over time; the larger the vessels, the more quota they hold. Over the same period, vessels have become larger. In 2003, no vessel was longer than 28 meters, while in 2017 a number of vessels exceed this threshold; the longest vessel with a coastal cod license was 55 meters, almost twice the maximum regulatory length for the group. Related to this, we see that the length-range of vessels with a given amount of quota factors increases significantly between 2003 and 2017. The distribution of quota factors had already shifted toward the right (shift up in the figure) in 2006 as the SQS had been implemented.

Although vessels are not constrained by the regulatory length given by their cod license, we see significant bunching just below 15m actual length also in 2017. A policy incentive to keep vessels below 15m can explain this; vessels below 15m have the advantage that they are allowed to fish within the so-called fjord lines. Fjord lines were established in 2004 as a measure to protect coastal cod stocks. The fjord lines define a zone along the coast of Norway, behind which vessels over 15 meters are prohibited from fishing cod. The zone stretches almost all the way along the Norwegian coast, from Vågsøy in the south-west to the Russian border. The bunching just below 15 meters is particularly strong for

[19] A quota factor is the base unit for measuring each vessel's (or quota owner's) share of the total quota in a particular fishery.

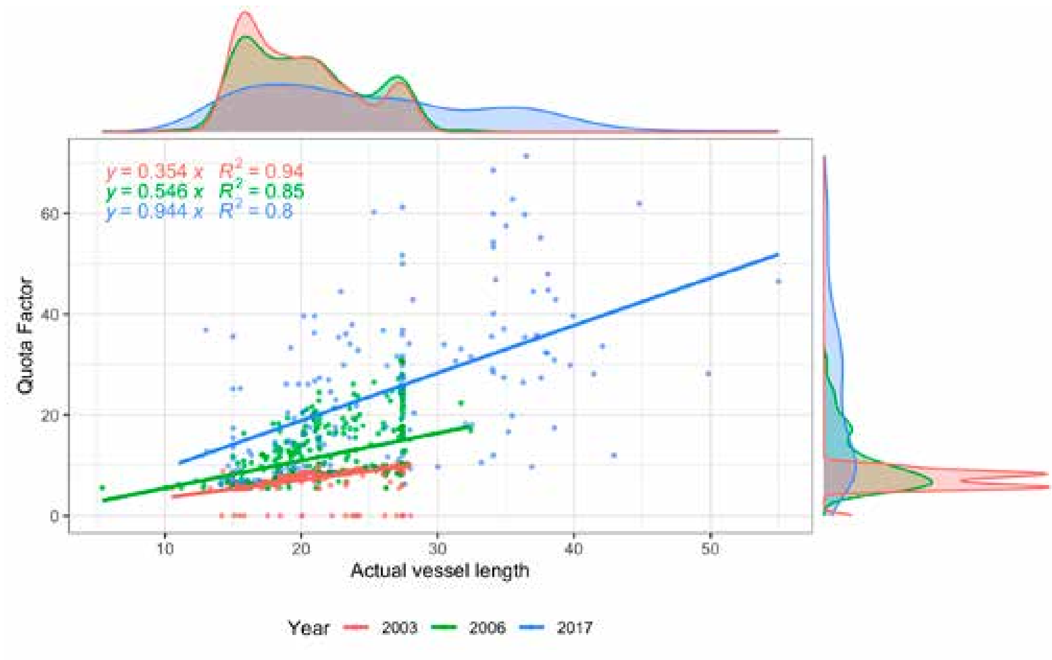

Figure A2: Comparison of quota factor and vessel length between 2004 and 2017: Coastal cod vessels with regulatory length 15-27.99m

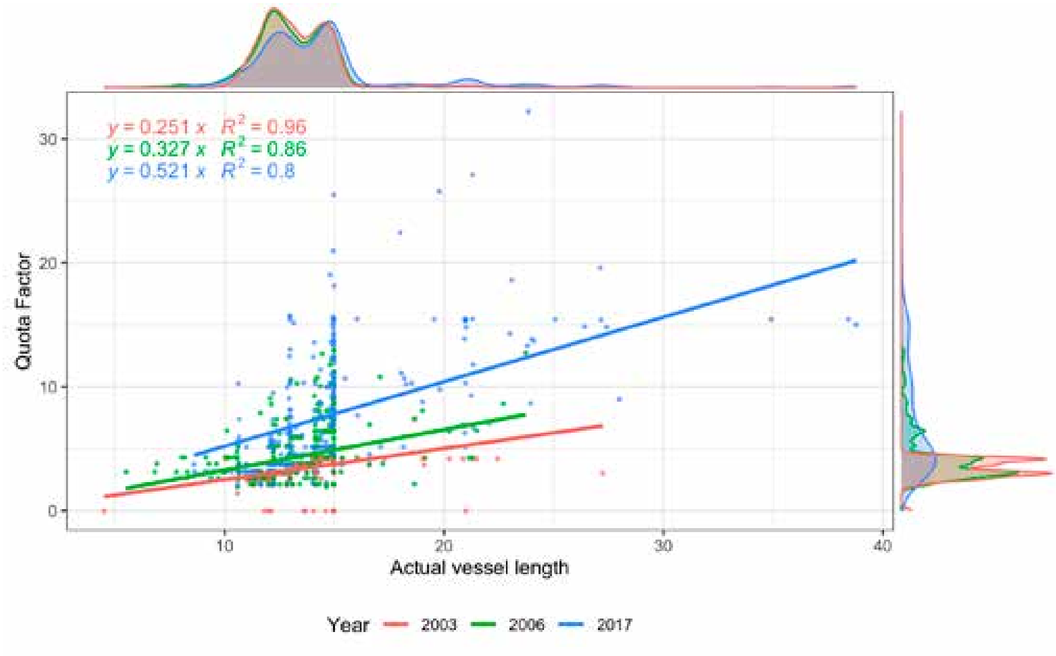

Figure A3: Comparison of quota factor and vessel length between 2003, 2006 and 2017: Coastal cod vessels with regulatory length 11-14.99m

The figure shows the distribution of the actual vessel length on the top and the distribution of the quota factor on the right of the main part. The main part of the figure is the scatter plot of the actual length and the quota factor with the fitted line for each year.

vessels belonging to the 11-14.99m regulatory group, for which we observe that the vessel distribution has shifted right toward this limit from 2003 to 2017 (figure A3). This implies that the option to fish inside the fjord lines is particularly attractive to vessels in this group, which can have fewer quota factors per vessel than the larger vessel length groups. Considering only fishing activity, this bunching reflects an inefficiency, as it implies that, given their quota, some fishers use shorter vessels than they would have used without this constraint.

Balancing the trade-off between economic efficiency and social objectives has been a challenge for fisheries managers under rights-based management. While the actual prioritization should be guided by social preferences, the mechanisms and consequences of the quota transfer system need to be well understood. We investigate the effects of several quota transfer schemes implemented in the Norwegian coastal cod fishery during the 2000s. This is a small-scale fishery that has traditionally been important for employment in the northern part of Norway. Using vessel-level quota registry data, we estimate the effect of quota-trading and changes in quota distribution on vessel exit using a difference-in-differences approach that exploits variation in implementation timing between regulatory groups. In addition, we describe the outcome of quota consolidation with descriptive statistics. Our results confirm that quota trade triggers exit of vessels from the fishery. In addition, we quantify the consolidation in terms of catch per vessel and geographic distribution of quotas and landings. While the policy change has the expected effects in the short run, our results suggest that the implications of consolidation last longer. This has implications for policymakers trying to balance economic efficiency and social objectives of rational fishery management.

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