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Quota Consolidation in Norwegian Coastal Fisheries

Keita Abe[1,2] · Linda Nøstbakken[3,4] · Mads Fjeld Wold[5,6,7]

Abstract

Balancing the trade-off between economic efficiency and social objectives has been a challenge for natural resource 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 the quota transfer scheme implemented in the Norwegian coastal cod fishery in 2004. 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 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 the quota transfer scheme accelerates the exit of vessels from the fishery by at least 5% points in the short run. The descriptive analysis reveals great heterogeneity in both the size and geographic location of exiting vessels, suggesting that the scheme has distributional impacts. 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

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✉ Linda Nøstbakken
linda.nostbakken@ssb.no

Keita Abe
keita.abe@cc.musashi.ac.jp

Mads Fjeld Wold
mads.wold@samforsk.no

1 Musashi University, Nerima, Tokyo, Japan

2 Iwate University, Morioka, Japan

3 Research Department, Statistics Norway, Akersveien 26, 0177 Oslo, Norway

4 SNF Centre for Applied Research at NHH, Bergen, Norway

5 NTNU Social Research, Trondheim, Norway

6 NHH Norwegian School of Economics, Department of Economics, Bergen, Norway

7 SNF Centre for Applied Research at NHH, Bergen, Norway

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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 is 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. In particular, the outcome may not be equally distributed under market-based management.[3] 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, which allowed fishers to consolidate the quota holdings of several vessels into 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 estimate if the quota transfer scheme triggered changes in fishers' decisions 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 Herfindahl–Hirschman Index (HHI) and Gini coefficient, and we measure the concentration of quotas in terms of pre-policy quota holdings and geographical distribution.

We observe significant shifts in the capture fisheries sector due to the implementation of the quota transfer scheme. Our estimation results indicate that there is a 5% increased likelihood for vessels to exit the fishery post-implementation. This suggests that the scheme promotes the exit of certain vessels. Notably, smaller and older vessels are more prone to depart from the fishery under the scheme. Further analyses also reveal that the industry

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[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 and Parker (2013) and Grainger and Costello (2016) present and analyze some of the opposition against market-based management in fisheries.

[3] The phenomenon of uneven outcome distribution is not unique to fisheries but is also observed in various environmental issues. For instance, Fowlie (2010) demonstrated that pollution permits under the U.S. NOx Budget Program tend to be concentrated in states with more stringent regulations. On the other hand, Fowlie et al. (2012) were unable to reject the hypothesis that pollution reductions were uniform across neighborhoods with varying demographic characteristics in the context of the NOx trading program in Southern California.

structure is changing, with a concentration of fishing activities in fewer hands. Such consolidation leads to larger entities within a group. Additionally, there has been a noticeable change in the geographic patterns of fishing since the introduction of the scheme.

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 and Grafton 2000; Sanchirico et al. 2006; Liew 2000; Hamon et al. 2009; Hartley and 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 and 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 and Dewees 2008; Stewart and Callagher 2011; Abayomi and 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 and 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. In Sect. 3, we describe our empirical research strategy, then we describe the data we use in our study in Sect. 4. In the fifth section, we present the empirical results on the direct effect of the policy change. Section 6 shows the analysis of the outcomes of the quota consolidation. 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, Sect. 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" (Sect. 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 9500 full-time fishers (0.17% of the population of 5328 million), and 1300 with fishing as a secondary occupation (Fig. 1). A similar restructuring has taken place in fisheries-related industries, also reducing the number of jobs 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° 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.[4] When the Northeast Arctic cod stock collapsed in the late 1980 s, the government introduced individual quotas (Hersoug 2005; Diekert and Schweder 2017).[5] 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.[6]

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 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

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[4] 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).

[5] 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.

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

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 and Aarset (2002) study measures taken by the Norwegian government during the 1990 s 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 and 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 ms, 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 ms, 10–14.99 ms, 15–20.99 ms, and 21–28 ms 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 2000 s, 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 ms 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.[7] 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 lengths below 15 ms were eligible for condemnation support from 2003, but the threshold was reduced to below 11 ms in 2008.[8]

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

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[7] 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).

[8] The regulation for the decommissioning scheme, 'Structural fees and structural funds for capacity adjustment of the fishing fleet,' FOR-2003-06-30-876.
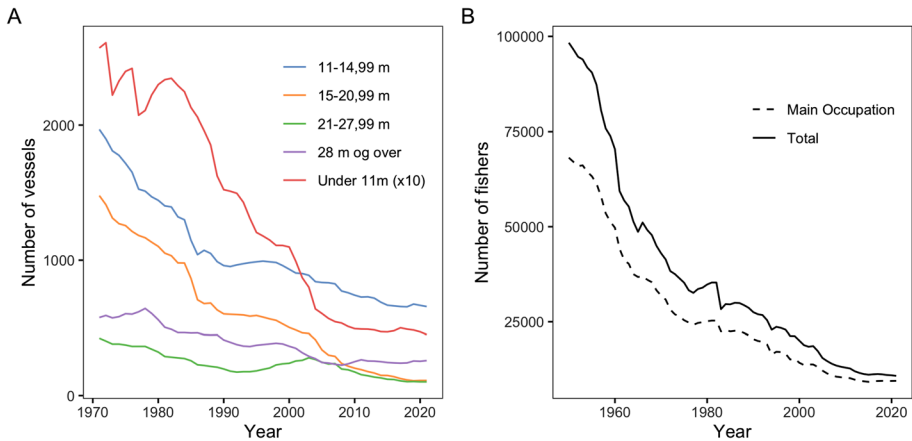
Fig. 1 **A** Number of active fishing vessels in Norway by length group (all fisheries), 1970–2019. **B** Number of registered fishers in Norway, 1950–2019

length of 11–14.99 ms (13–14.99 ms in the pelagic fishery) from 2007.[9] At the same time, the Finnmark model was revised by changing the cut-off length of the smallest group from below 10 ms to below 11 ms. The second smallest group thus became 11–14.99 ms. The vessels with license length 10–10.99 ms were given access to the 11–14.99 ms group.[10] In addition, the parliament lowered the cap on quotas per vessel for the coastal fleet,[11] and introduced a sunset provision for structural quotas (the 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 (15–20.99 m and 21–27.99 m). From 2007, such transfers also became available to the 11–14.99 m 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

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[9] 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."

[10] The commission argued that the harvesting patterns of 10–10.99 m 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 ms if the vessel has a legal length between 10 and 11 ms 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).

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

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.[12] 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 lengths below 11 ms. 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).[13] 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, 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.

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 divest 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.

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[12] In Norwegian the scheme was called "driftsordningen for kystflåten" (the operational arrangement for the coastal fleet, in English).

[13] In Norwegian this scheme was called the *samfiskeordningen* (the joint fishing scheme, in English).

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 Fig. 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 (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. The first round implementation in 2004 is a straightforward case of the DiD setup because those larger than 15 meters are the treatment group, and the 11–14.99 m group is the control. We are not able to estimate the effect of the second round implementation in 2007 because there are no appropriate control groups. One may think that there are other groups in the data, but 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 (i.e., owner ID is identified each year, but it is not a complete panel data.[14] 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.

The exit of vessels is defined based on the registrations in the public vessel registry. We use an indicator variable to capture this; if a vessel is in the vessel registry, a dummy is set to zero, and if not, it is set to one. In most cases, vessels seem to exit the fishery entirely once it disappears from the registry, but some vessels reappear in the registry several years

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[14] The data uniquely identifies the owner through an owner ID, which enables to count the number of vessels per owner. However, it is unable to identify the exit decision by an owner because 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.)

later, with the same vessel ID. In these cases, we include them by setting the dummy variable back to zero when they reappear.

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:

$$Exit_{imjt} = \sum_{\tau=2001}^{2002} \beta_\tau D_{j\tau} + \sum_{\tau=2004}^{2017} \beta_\tau D_{j\tau} + x'_{imjt}\theta + \gamma_j + \upsilon_t + \mu_m + \varepsilon_{imjt}$$

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 $\tau = 2004$. The year before the implementation ($\tau = 2003$) is dropped to avoid perfect multicollinearity. The coefficient of $\tau = 2003$ is set to zero as a reference. 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 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 (e.g. demand in the export market), natural conditions, and the size of TAC allocated to the coastal fishery is captured by the fixed effects.

The identification of the policy effect requires the stable unit treatment value assumption (SUTVA). The first condition of the SUTVA is that potential outcomes for any unit do not vary with the treatments assigned to other units. We assume that the treatment of the 15–20.99 m group does not affect the decisions made for vessels in the 11–14.99 m. A possible spillover effect is the reverse agglomeration effect in each area or municipality. For example, vessels and fishers exiting from an area may affect the other fishers in the same area because the common infrastructures and businesses shrink (e.g. baits, supplies, and vessel maintenance services). We assume that such spillover does not occur in the short run. Even if it does, the impact of the spillover is positive (i.e., more exits), and hence the effect may be underestimated. Another possible spillover is through the ex-vessel market. The exits of some vessels could lower the supply of fish in the local market, which could increase local prices and thereby raise profits for those remaining. They would then be less likely to exit. However, cod is integrated into the global fish market and the local price is unlikely to depend on local supply (Asche et al. 2007; Pettersen and Myrland 2016). The second condition of the SUTVA, that the treatment is consistent, is fulfilled as every vessel in the group is under the same policy treatment.

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 and 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 and 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 and 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 and 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 and Callagher 2011; Abayomi and 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. We calculate the distribution effect as the ratio of Euclidian distance between the actual data and the perfectly equal distribution (everyone's share is equal to the average), and the Euclidian distance between the extremely biased distribution (one holds all shares while the rest has nothing) and the completely equal distribution given the number of firms.[15] This allows us to analyze both the intensive and extensive margins of quota consolidation.

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[15] We discuss the details of this measure in Appendix A.1

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 landing 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 licenses, vessels, and owners. Vessels are registered in the database by the geographic location of their owners (177 municipalities). Table 1 shows the summary statistics of the data.

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 license record contains information on the regulatory group to which the vessel belongs. All of a vessel's licenses 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 the regulatory group for the coastal cod fishery north of the 62° line. The figure shows a clear reduction in the number of vessels in the 15–20.99 m and 21–27.99 m groups after the introduction of SQS in 2004. We see a similar decline in the number of vessels in the 11–14.99 m 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 11 m), 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 11 m 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 including only 11–14.99 m and 15–20.99 m. This sub-sampling method allows us to observe instances where one regulatory group undergoes a policy change, while the policies for the other groups remain unchanged until 2006.

5 Results for Short-Run Policy Effects

5.1 The Effects of the SQS Policy

In this section, we present our estimation results for the effect of the SQS policy on quota consolidation. Panel A and B in Fig. 3 shows the coefficient estimates for the SQS in 2004. The difference 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 average magnitude of

the impacts is around 0.21 (21 p.p.) without covariates, and it is 0.11 (11 p.p.) with covariates. Interpreting these results requires caution. The findings rely on a sample spanning the period 2001–2017. Consequently, the estimated effect for the 15–20.99 m group is based on the SQS policy implemented in 2004, while the 11–14.99 m group became subject to the SQS policy in 2007. Thus, both groups received treatment post-2007. In fact, the observed effect showed a consistent increase until 2007 but appears to have stagnated thereafter. Therefore, we cannot confidently state that the estimated impact solely reflects the effect of the SQS.

Panel C and D in Fig. 3 show the estimated result for the SQS implementation in 2004, but the sample is limited up to 2006. With this sample, we can do a "pure" comparison between the 11–14.99 m (control group) and the 15–20.99 m (treated) groups. In the short run, the average magnitudes are 0.11 (11 p.p.) without covariates and 0.05 (5 p.p.) with covariates. These results indicate that the SQS accelerated the exit (i.e., vessels disappearing from the vessel registry) by at least 5 percentage points. As shown in Table 2, covariates also explain the exit behavior. In other words, the results indicate that the SQS has an effect on vessel exits even if we control for the heterogeneity among the vessels.

5.2 Quota Investment

The results in the previous section show that the SQS increased vessel exits and that smaller and older vessels are particularly likely to exit the fishery (Table 2). 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 the quota holdings of a vessel. Among these remaining vessels, we observe heterogeneity in quota investments. Table 3 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 acquire 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.

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 the 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.

Table 1 Summary Statistics of the data

Vessel groups		N	Mean	SD	Min	Max
11–14.99 m	Exit	14,365	0.37	0.48	0.00	1.00
	Vessel Age	14,365	27.48	18.61	0.00	103.00
	No. of Vessels under Owner	14,365	1.21	0.62	1.00	10.00
	Cod Revenue relative to average	14,365	0.62	0.75	0.00	9.59
	Cumulative Structural Quota	14,365	0.28	1.16	0.00	26.64
15–20.99 m	Exit	8330	0.50	0.50	0.00	1.00
	Vessel Age	8330	36.01	17.72	0.00	116.00
	No. of Vessels under Owner	8330	1.15	0.54	1.00	10.00
	Cod Revenue relative to average	8330	0.46	0.71	0.00	17.51
	Cumulative Structural Quota	8330	0.83	2.90	0.00	37.68
10–10.99 m	Exit	16,065	0.48	0.50	0.00	1.00
	Vessel Age	16,048	27.08	15.32	0.00	93.00
	No. of Vessels under Owner	16,065	1.13	0.47	1.00	10.00
	Cod Revenue relative to average	16,065	0.46	0.71	0.00	12.58
	Cumulative Structural Quota	16,065	0.06	1.17	0.00	55.08
21–27.99 m	Exit	3927	0.50	0.50	0.00	1.00
	Vessel Age	3927	29.81	19.85	0.00	103.00
	No. of Vessels under Owner	3927	1.20	0.63	1.00	10.00
	Cod Revenue relative to average	3927	0.52	0.98	0.00	27.35
	Cumulative Structural Quota	3927	2.12	5.78	0.00	55.71
Less than 10 m	Exit	28,033	0.57	0.49	0.00	1.00
	Vessel Age	28,033	26.04	14.66	0.00	88.00
	No. of Vessels under Owner	28,033	1.11	0.45	1.00	10.00
	Cod Revenue relative to average	28,033	0.37	0.70	0.00	12.07
	Cumulative Structural Quota	28,033	0.08	1.23	0.00	47.39

The data period is from 2001 to 2017. We only use the 11–14.99 m and the 15–20.99 m groups for the short-run policy effect estimation

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.[16] 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 Fig. 4, vessel-level quota consolidation is prominent in all length groups greater than 11 ms after the introduction of the SQS.

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[16] 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.
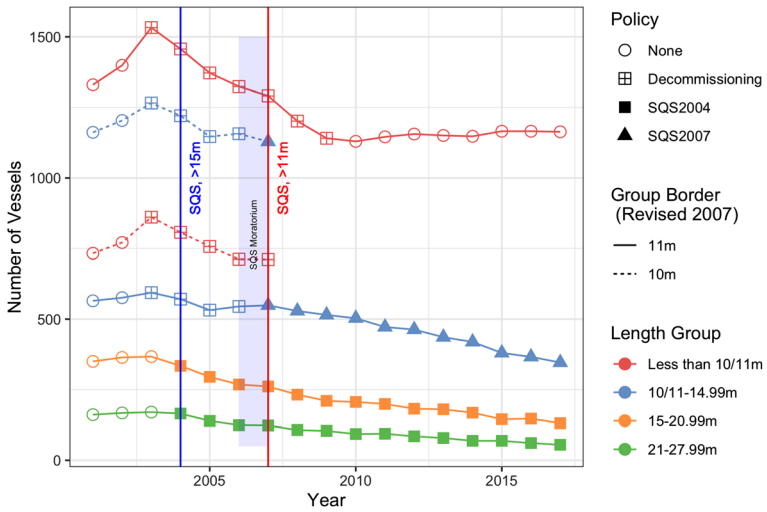
Fig. 2 Number of registered vessels holding a coastal cod license by regulatory length groups
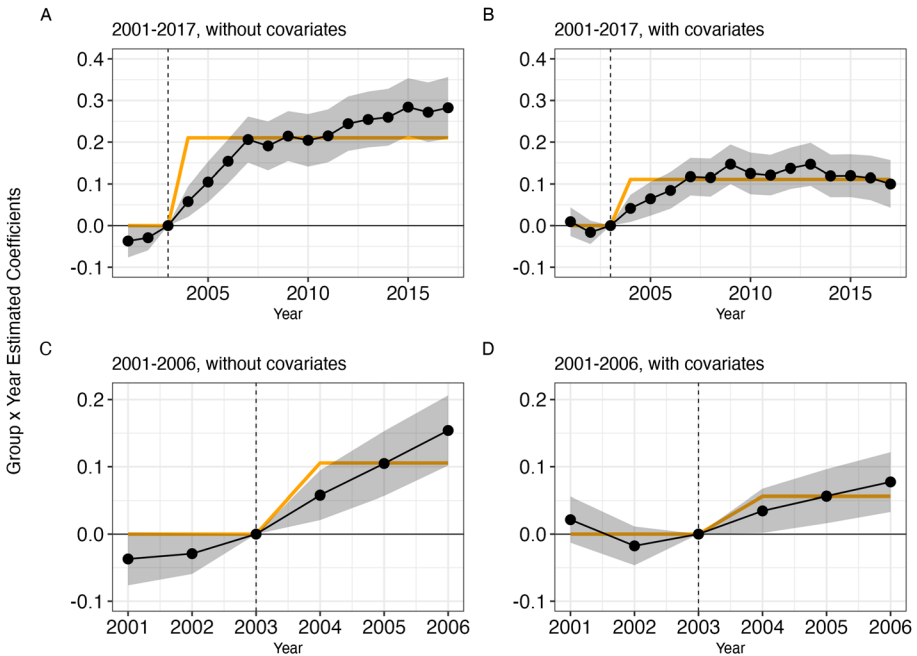

Fig. 3 The estimated effects of the SQS on the exit of vessels. Panel A shows the result with the whole sample (2001–2017) with the model excluding covariates. Panel B is with the whole sample, but includes the covariates. Panel C and D show the results without and with covariates, respectively, estimated with the sample limited between 2001 and 2006. The orange lines show the average magnitudes of the effects. The ribbons indicate the standard errors, which are clustered at the individual vessel level

Table 2 The estimated coefficients in the event study models

Model	Whole sample (1)	Until 2006 (2)
Variables		
15 m ≤ groups × 2001	0.0072 (0.0170)	0.0117 (0.0161)
15 m ≤ groups × 2002	−0.0182 (0.0139)	−0.0222 (0.0138)
15 m ≤ groups × 2004	0.0430** (0.0163)	0.0348* (0.0160)
15 m ≤ groups × 2005	0.0634** (0.0204)	0.0524** (0.0196)
15 m ≤ groups × 2006	0.0827*** (0.0220)	0.0717*** (0.0212)
15 m ≤ groups × 2007	0.1184*** (0.0224)	
15 m ≤ groups × 2008	0.1216*** (0.0226)	
15 m ≤ groups × 2009	0.1536*** (0.0237)	
15 m ≤ groups × 2010	0.1307*** (0.0247)	
15 m ≤ groups × 2011	0.1255*** (0.0240)	
15 m ≤ groups × 2012	0.1431*** (0.0245)	
15 m ≤ groups × 2013	0.1519*** (0.0254)	
15 m≤ groups × 2014	0.1231*** (0.0254)	
15 m ≤ groups × 2015	0.1249*** (0.0255)	
15 m ≤ groups × 2016	0.1168*** (0.0261)	
15 m ≤ groups × 2017	0.1055*** (0.0284)	
License Length	−0.0107** (0.0035)	−0.0106 (0.0085)
Vessel Age	0.0372*** (0.0050)	0.0100 (0.0097)
Vessel Agesquare	0.0003*** (2.52×10^{-5})	0.0004*** (7.61×10^{-5})
No. of Vessels under owner	−0.1588*** (0.0088)	−0.1434*** (0.0126)
Total value of cod landing	−0.2597*** (0.0130)	−0.3376*** (0.0174)
Fixed-effects		
Year	Yes	Yes
Vessel	Yes	Yes
Municipality	Yes	Yes
Fit statistics		
Observations	22,695	8,010
R^2	0.72516	0.80785
Within R^2	0.38883	0.31839

Clustered (Vessel) standard-errors in parentheses

Signif. Codes: ***0.001, **0.01, *0.05, †0.1

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 4 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-11 m group as consistent with the declining number of vessels shown in Fig. 2. A large portion of the HHI

Table 3 Estimation result: quota investment by vessels

Model	15–20.99 m		11–14.99 m	
	(1)	(2)	(3)	(4)
Variables				
License length	0.6091***	0.6494***	0.3972***	0.4160***
	(0.0820)	(0.0935)	(0.0403)	(0.0435)
Vessel age	−0.0307***	−0.0277**	−0.0099***	−0.0128***
	(0.0076)	(0.0089)	(0.0024)	(0.0030)
No. of vessels under owner	0.8110***	0.7156***	0.3736***	0.3361***
	(0.1741)	(0.1543)	(0.0848)	(0.0801)
Cumulative str. quota	−0.2122***	−0.2899***	−0.2618***	−0.3095***
	(0.0412)	(0.0456)	(0.0548)	(0.0575)
No. of vessels in municipality	0.0014	0.0177	0.0024·	0.0063
	(0.0025)	(0.0137)	(0.0013)	(0.0122)
Fixed-effects				
Year	Yes	Yes	Yes	Yes
Municipality		Yes		Yes
Fit statistics				
Observations	2828	2828	4227	4227
R^2	0.16623	0.23800	0.12827	0.17625
Within R^2	0.13572	0.15752	0.11219	0.11548

15–20.99 m model includes the sample after 2004. 11–14.99 m model includes the sample after 2008

Clustered (Vessels) standard-errors in parentheses

Signif. Codes: ***0.001, **0.01, *0.05, †0.1
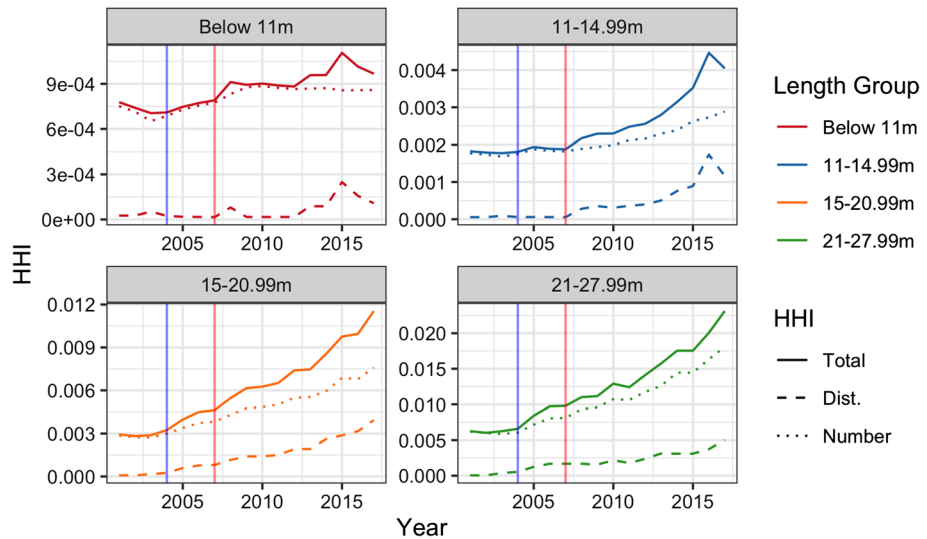
Fig. 4 Vessel-level HHI for coastal cod license by length groups. Total HHI (Solid line) is decomposed into the distribution effect (dashed line) and the number effect (dotted line). The vertical lines indicate the year of SQS introduction (blue: 2004, red: 2007)
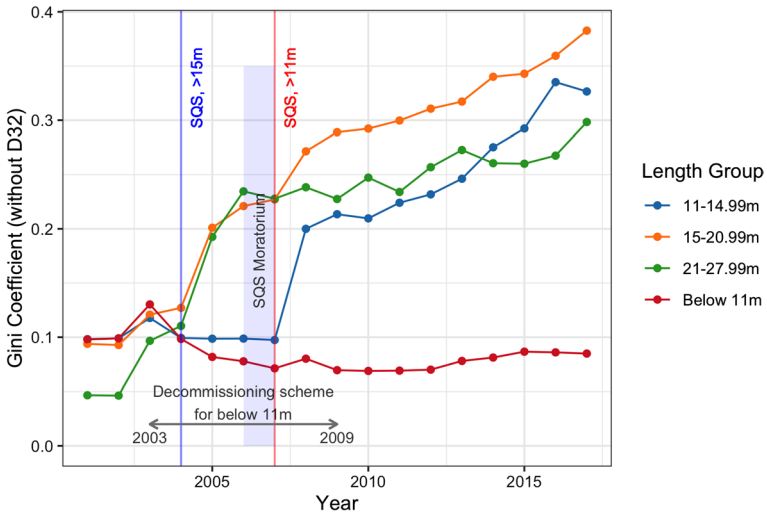
Fig. 5 Vessel-level Gini coefficient for coastal cod license by length groups
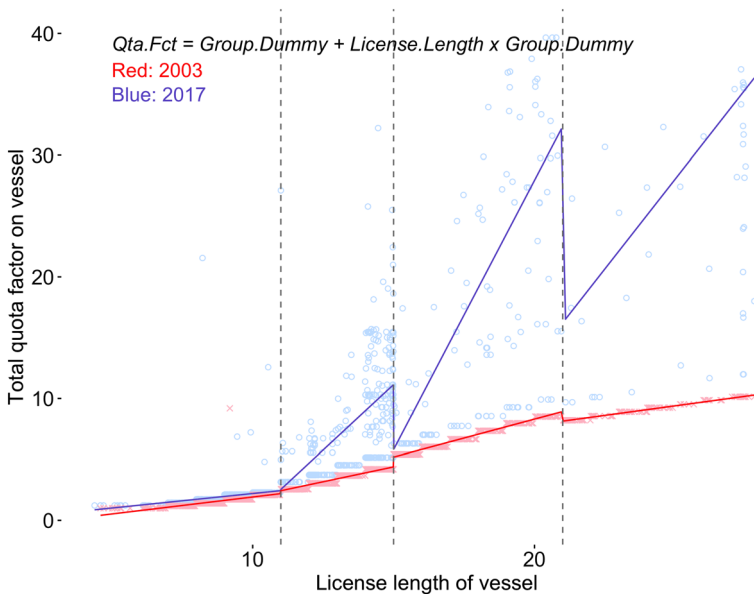
Fig. 6 License length of vessels and total quota factor distribution on license length of vessels in 2003 (before the SQS is implemented) and 2017 (the most recent year in the dataset)

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 Fig. 5, 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

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 Sect. 5 and the figures above show that the Norwegian coastal cod fishing fleet is becoming increasingly consolidated. Figure 6, which shows the distribution of quota factors on the license length of the vessels, provides additional evidence of this process.[17] 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, the distributions were almost unchanged between 2003 and 2017. This is 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 7 shows how owner-level quota concentration evolves from 2001 through 2017 in the coastal cod fishery.[18] 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 Fig. 7 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 (and vessels) is large. There were 2483 owners in 2003 and 1377 in 2017.

Panel B of Fig. 7 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-2000 s, 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.[19] When the government in 2007 reinstated the SQS

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[17] 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.

[18] 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.

[19] 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.

for vessels above 15 m and introduced it for the 11–14.99 m 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. Fig. 4), 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 Fig. 7B there is a clear increase in owners holding multiple vessels after 2013.[20]

6.3 Geographical Quota Consolidation

Figure 8 shows the change in quota holdings and landings by municipalities 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 Fig. 9, 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 15 m. This result is in line with the map shown in Fig. 8. The quota shares for the 11–14.99 ms group are relatively stable.

Figure 8B 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

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[20] 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.
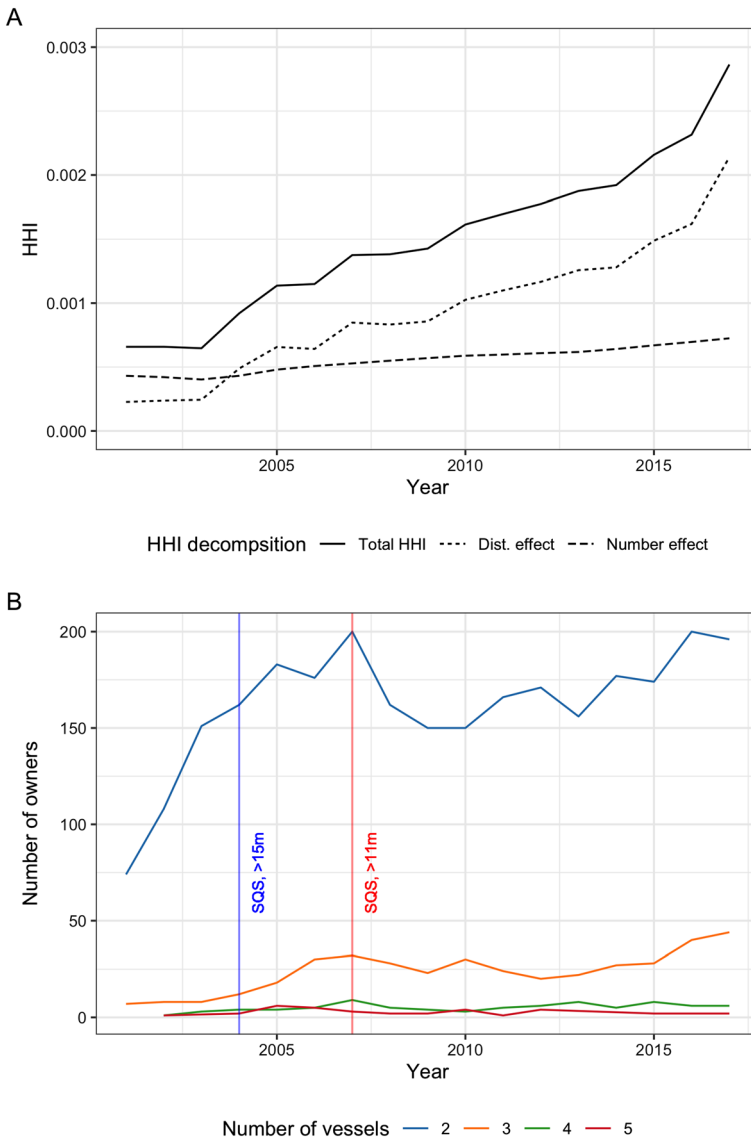
A

B

Fig. 7 **A** Owner level HHI in the coastal cod fishery. **B** Number of owners holding multiple coastal cod fishing vessels

landings rely heavily on the annual migration of the Northeast Arctic cod to spawning areas along the northern Norwegian coast, such as Lofoten and Vesterålen. Finally, while landing plants are located all along the Norwegian coast, considerable consolidation occurred between 2001–2003 and 2015–2017, 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
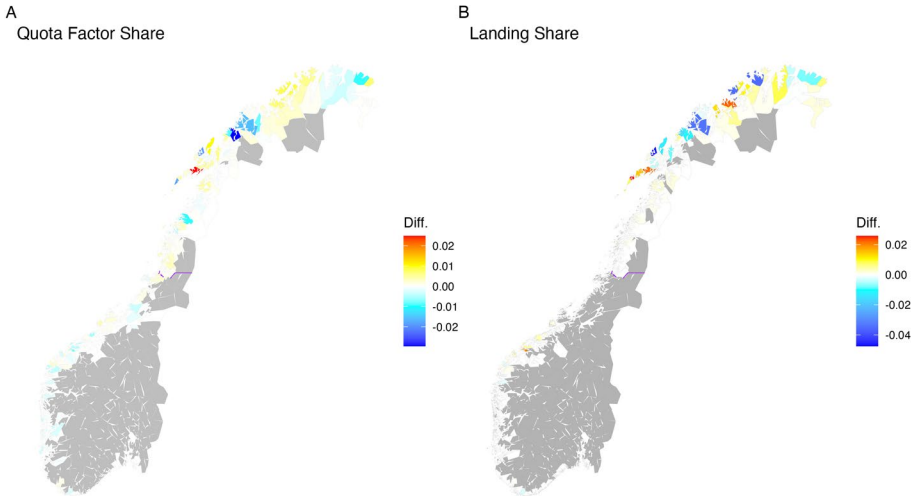
Fig. 8 **A** Difference in quota factor of northern coastal cod between averages in early periods (2001–2003) and late periods (2015–2017). **B** Differences in cod landing share by coastal vessels holding northern cod quota between averages in early periods (2001–2003) and late periods (2015–2017). On both maps, the purple line marks the border between the two main regions (north and south)
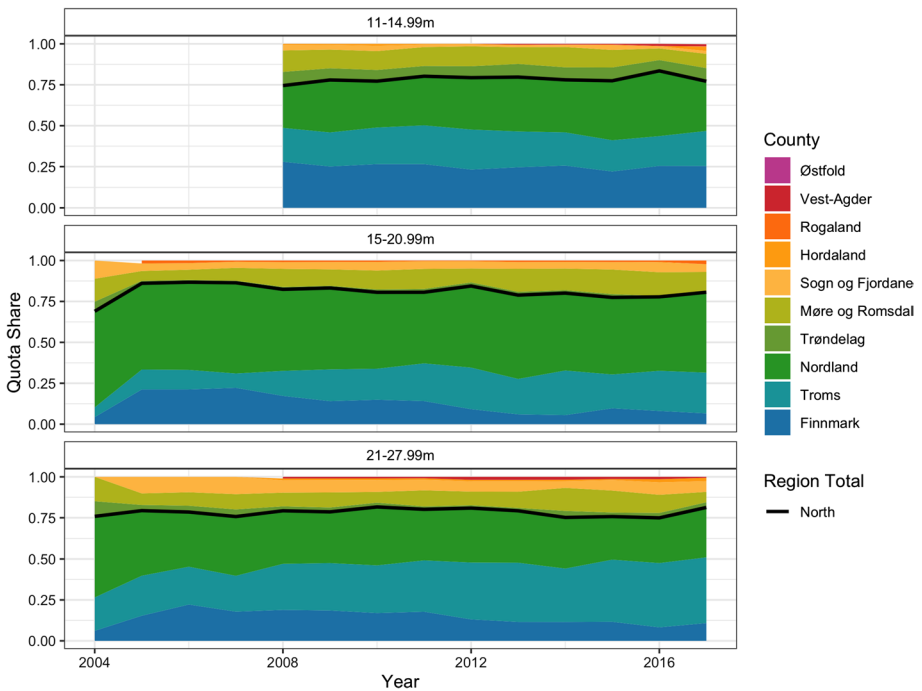
Fig. 9 Changes of quota share by county (colors) and region (bold line) after SQS introductions

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 and 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 coastal cod fishery in 2004. On average, the policies promoted vessel exits that improved efficiency. 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. 8). 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. 7), 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 and 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 and 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 consequences.[21] 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.

Appendix

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.[22]

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[21] 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.

[22] 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.

The HHI (Eq. 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.[23] 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 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 $\vec{x}_i = (x_1, x_2, \dots, x_n)$ 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, $\vec{\bar{x}} = (\bar{x}, \bar{x}_i, \dots, \bar{x})$, 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 $\sum_{i=1}^n = n\bar{x}$, $\vec{x}^* = (n\bar{x}, 0, \dots, 0)$. 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:

[23] 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 ($x_i \le x_{i+1}$).

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

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

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 *given* 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.

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

Exclusion of the Largest Group from the Estimation

The main estimation of the effect takes the 11–14.99 m and 15–20.99 m groups to estimate the effect of the structural quota scheme. The 21–27.99 m 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 types of vessels although they are called coastal vessels.

Figure 10 shows the same estimation model as the main estimation, but the control group is 15–20.99 m and the treated group is 21–27.99 m 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 model without covariates. Even with the model with covariates, the exit probability is low in the early phase of the scheme, but later it catches up. This indicates that the different exit behaviors are exhibited between 15–20.99 m and 21–27.99 m groups, which is the reason why we exclude 21–27.99 m group from the main estimation.

Exit and Inactive Status as the Outcome Variable

The main estimation focuses on the status being not in the public vessel registry. However, there are some vessels that are on the registry but do not have any catch record in a given year. There are a variety of reasons to be inactive but one of the reasons is to be on the operational arrangement scheme (see Sect. 2 for the details of the scheme). Also, some vessels may be inactive to be ready to exit from the fishery but the vessel registry may not capture such actions. Hence, we construct a new outcome variable which is a dummy taking one if a vessel is not in the registry or inactive (i.e., in the registry but no catch record).

Figure 11 shows the estimation results with the new outcome variable. The overall result is unchanged relative to our main estimation. The parallel trend in the pre-treatment period may not hold in the specification without covariates (Panels A and C), but it holds with the covariates. The magnitude of the estimates do not differ from the main estimation result. This result implies that the inactive decision is not largely impacted by the SQS scheme. In addition, the operational arrangement scheme does not play a large role in the decisions of exits.

Checking the No-Anticipation Assumption

We check if the no-anticipation assumption is valid. As discussed in Sect. 3, there is a possibility of refraining from reducing the number of fishing boats in 2003 as fishers may anticipate the introduction of SQS, which was recommended by the Ministry of Fisheries in 2003. Figure 12 shows the estimation result with the same model in the main estimation, but the reference year is 2002 instead of 2003. The estimated effect in 2003 is positive but statistically insignificant for both specifications with and without covariates. We rather expect that the effect is negative if the fishers anticipate the introduction because those who are willing to decommission their vessels would wait for the opportunity to sell out the vessels after the introduction. This result suggests that the anticipation effect is not present.

Additional Figures of Consolidation Trends

Figure 13 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. Recall that
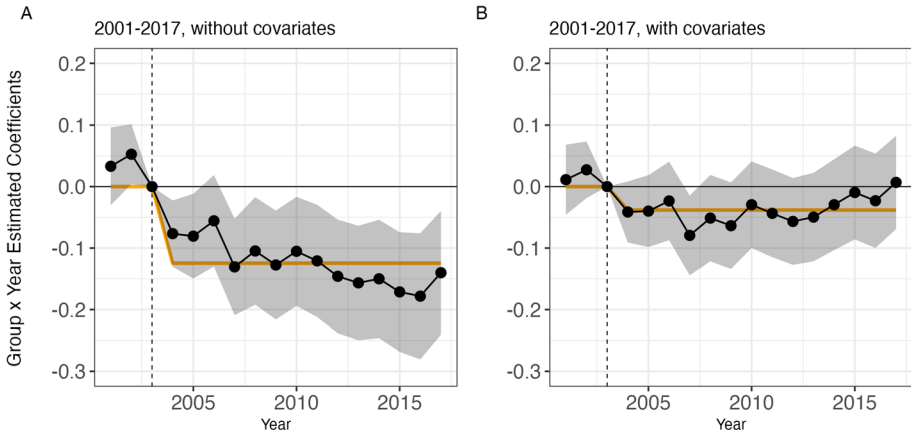
Fig. 10 The estimated effects of the SQS on the exit of vessels with data on the 21–27.99 m group included in the sample. Panel A shows the results for the whole sample (2001–2017) for the model excluding covariates. Panel B shows the results for the whole sample and includes the covariates. The orange lines show the average magnitudes of the effects. The ribbons indicate the standard errors, which are clustered at the individual vessel level

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. sect. 2). Quota consolidation started in 2004 for vessels with a regulatory length above 15 m, and by 2017, considerable consolidation had taken place in all fleet segments above 11 m.

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 ms, while in 2017 a number of vessels exceed this threshold; the longest vessel with a coastal cod license was 55 ms, 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 15 m actual length also in 2017. A policy incentive to keep vessels below 15 m can explain this; vessels below 15 m 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 ms are prohibited from fishing cod. The zone stretches almost all the way along the Norwegian coast, from Vågsøy in the southwest to the Russian border. The bunching just below 15 ms is particularly strong for vessels belonging to the 11–14.99 m regulatory group, for which we observe that the vessel distribution has shifted right toward this limit from 2003 to 2017 (Fig. 14). This implies that the
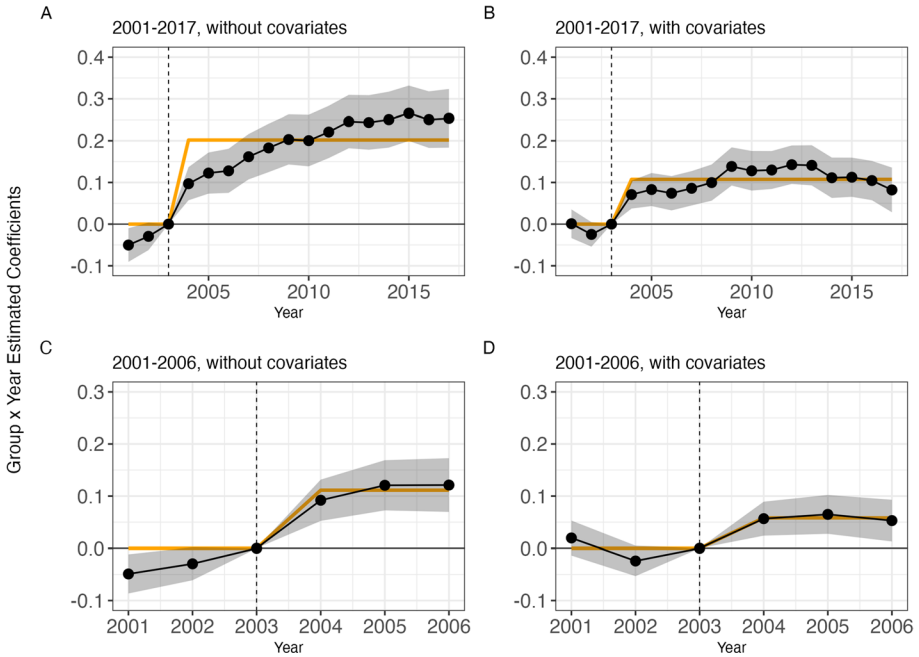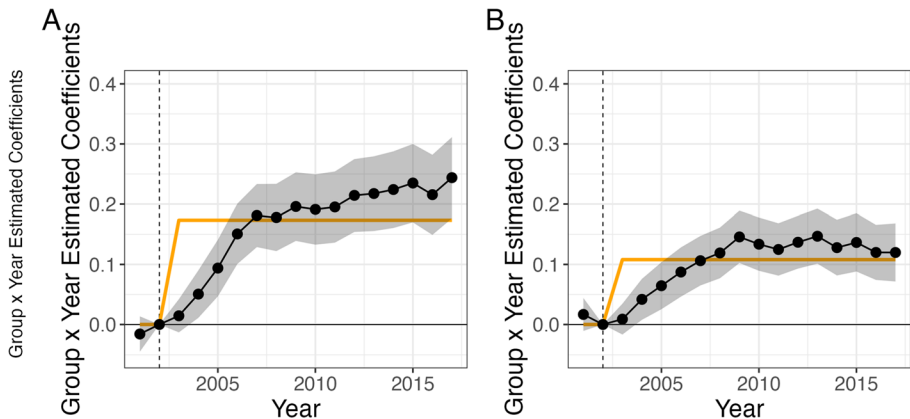
Fig. 11 The estimated effects of the SQS on the exit/being inactive of vessels. Panel A shows the result with the whole sample (2001–2017) with the model excluding covariates. Panel B is with the whole sample, but includes the covariates. Panels C and D show the results without and with covariates, respectively, estimated with the sample limited between 2001 and 2006. The orange lines show the average magnitudes of the effects. The ribbons indicate the standard errors, which are clustered at the individual vessel level

Fig. 12 The estimated effects of the SQS on the exit of vessels. The reference year is set to 2002 instead of 2003 as in the main estimation. Panel A shows the result with the whole sample (2001–2017) with the model excluding covariates. Panel B is with the whole sample, but includes the covariates. The orange lines show the average magnitudes of the effects. The ribbons indicate the standard errors, which is clustered at individual vessel level
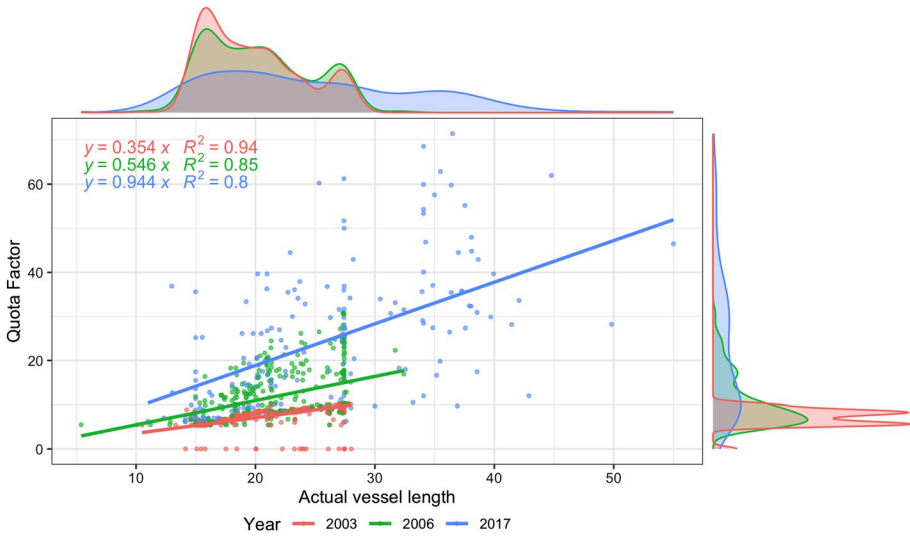
Fig. 13 Comparison of quota factor and vessel length between 2004 and 2017: coastal cod vessels with regulatory length 15–27.99 m
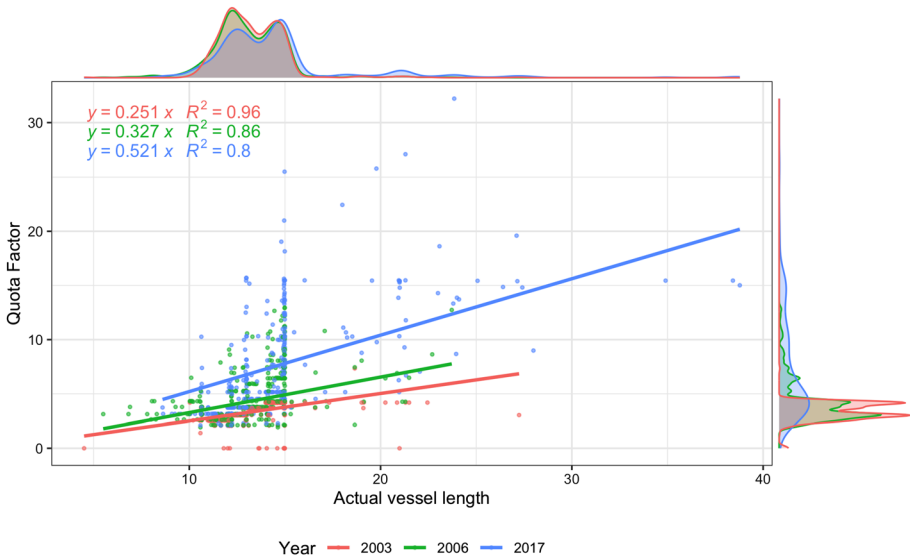
Fig. 14 Comparison of quota factor and vessel length between 2003, 2006 and 2017: Coastal cod vessels with regulatory length 11–14.99 m. The figure shows the distribution of the actual vessel length on the top and the distribution of the quota factor on the right of the main part. The main part of the figure is the scatter plot of the actual length and the quota factor with the fitted line for each year

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.

Declarations

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