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Fishing methods for Atlantic cod and haddock: Quality and price versus costs

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ABSTRACT

This study explores trade-offs between fish quality, fishing efficiency, costs and profitability across three different vessel groups in the Norwegian groundfish fishery, that is, vessels fishing with bottom trawls, longlines and Danish seines. The results of hedonic price analysis at the ex-vessel level of the value chain indicate substantial differences in fish quality as Atlantic cod caught with longlines obtain price premiums of 15.0 % and 12.6 % compared with bottom trawling and Danish seining, respectively, holding other variables constant. For haddock, longlining obtains a price premium of 20.0 % compared with Danish seining and 13.3 % compared with bottom trawling. However, despite better quality and prices, the costs of fishing are substantially higher for longliners than for bottom trawlers and Danish seiners, which explains the differences in profitability favoring the more technically efficient bottom trawlers and Danish seiners. Policy implications are discussed considering trade-offs between fish quality, ex-vessel prices and vessel profitability. In a highly regulated fishery such as the Norwegian groundfish fishery, with individual vessel and vessel group quotas based on historical fishing rights, policy intervention is important for optimal use of limited fish stocks but is not necessarily straightforward.

1. Introduction

It is well known that different fishing methods influence the quality of landed fish differently. For example, Rotabakk et al. (2011) found that Atlantic cod caught by longline had a better overall quality compared with cod caught by trawl. An important quality issue for Atlantic cod and haddock is discoloration of fillets due to poor draining of blood (Botta et al., 1986; Margeirsson et al., 2007; Olsen et al., 2014). When fish is caught in large hauls, which is often the case with bottom trawling and Danish seine, the fish often dies before bleeding (Olsen et al., 2014). In addition, it is not unusual for the fish to be kept in storage bins for hours before bleeding (Olsen et al., 2014). This simplifies the slaughtering process (Van de Vis et al., 2003), but the fish must be bled while it is still alive to facilitate good drainage of blood.

Differences in fish quality caused by different fishing gear may lead to different prices at the ex-vessel level of the value chain, as indicated by studies focusing on Atlantic cod in Canada (Lee, 2014) and Norway (Asche et al., 2015), Baltic cod in Sweden (Blomquist et al., 2015; Hammarlund, 2015), and bluefin tuna in Hawaii (McConnell and Strand, 2000) and Japan (Carroll et al., 2001). Different fishing methods may also impact the environment in different ways, which may influence the market value of the fish. Sogn-Grundvåg et al. (2013, 2014) estimated price premiums in the UK grocery retail market in the 10.4–24.6 % range for line-caught chilled and frozen Atlantic cod and haddock compared with fish caught with other fishing methods. In addition, Sogn-Grundvåg et al. (2019a) showed enhanced product longevity for products of Atlantic cod and haddock with the line-caught label compared to similar products without the label, implying reduced costs. This suggests that longlining is preferred for Atlantic cod and haddock, at least in the UK market. These price premiums for line-caught fish may relate to better product quality (Rotabakk et al., 2011) and also to the well-documented negative environmental effects of other fishing methods, including the detrimental effect that bottom trawling may have on the seabed and habitat (Puig et al., 2012). Knowledge of these issues among retail management and consumers alike may have influenced the demand for line-caught fish (Sogn-Grundvåg et al., 2013; Zhang et al., 2018a).

Vessels using different fishing methods also differ in technical efficiency, influencing the costs of fishing, which may vary between vessels and vessel groups (Guttormsen and Roll, 2011; Asche and Roll, 2018). And, importantly, the cost of fishing and fisher behavior may be influenced by the way fisheries are managed, for instance, by restrictions related to vessel size and gear types to limit fishing effort and by subsidizing input factors such as capital and fuel to support fishers'

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incomes (Asche et al., 2020). Thus, an issue with substantial policy implications is the potential trade-off between fish quality, prices gained and the costs of fishing caused by gear restrictions and quota allocations between vessel groups fishing with different gear. For example, the most efficient fishing methods and vessels may provide fish of low quality but may still be more profitable than less technically efficient fishing methods providing fish of high quality and at better prices. This may be further complicated by the fact that fishing vessels often hold quotas for several different species with sometimes overlapping seasons which may lead to inefficiency because fishers may choose to fish too much of some species relative to other species, as found by Asche and Roll (2018) for the Norwegian trawler fleet. This indicates that fishery management excessively focused on input restrictions and profitability in the harvesting sector may result in landings of fish of reduced quality, which may affect negatively the opportunities for value-adding and marketing in subsequent links in the value chain (Larkin and Sylvia, 1999; Homans and Wilen, 2005). Thus, regulators risk missing out on the FAO's request to utilize fish stocks in a way that contributes to the nutritional, social and economic value of wild fish stocks (Food and Agriculture Organization (FAO, 2018).

The contribution of this study is to investigate the ex-vessel prices obtained by vessel groups using bottom trawl, Danish seine and longlines while also considering the costs and profitability of the same vessel groups. Covering a period of 9 years (2009–2017), the study analyzes 26,639 transactions for Atlantic cod and 10,489 transactions for haddock, which consist of 464,311 tons of Atlantic cod and 240,101 tons of haddock. This covers about all the frozen cod and haddock landed by the three vessel groups under analysis. The fish is headed and gutted and frozen at sea to preserve the quality and allow longer trips. The fish is typically packed and frozen in 20-kilogram boxes and sold for secondary processing in downstream markets. Reported ex-vessel prices obtained by the three vessel groups are discussed, considering accounting data from the Norwegian Directorate of Fisheries for the same vessel groups. In this way, important implications for fishery management can be highlighted and discussed.

2. Material and methods

2.1. Fishery management

The Norwegian groundfish fishery is the most valuable fishery in Norway, and by far the most important species in this fishery is Atlantic cod, followed by haddock. The fishing fleet participating in the groundfish fishery is diverse, ranging from small coastal vessels fishing with jig machines, gillnets and hand-baited longlines, delivering fresh catches to local fish plants daily, to large oceangoing bottom trawlers and longliners, freezing their catch at sea. In addition, medium-sized and large coastal vessels using gillnets or Danish seines deliver fresh daily catches, and some of these also freeze a share of their catch at sea.

The Norwegian fishery management system is based on several policy goals, including preventing overfishing and maintaining sustainable coastal communities (Standal and Aarset, 2008). In addition, resource rent and fleet profitability are key objectives of the management system, as in many other countries (Flåten and Heen, 2004; Hannesson, 2013; Zhang et al., 2018b).

The groundfish fishery is regulated on a single species basis with a total allowable catch (TAC) for the main groundfish species. The yearly TAC for Atlantic cod and haddock is set based on scientific advice from the International Council for the Exploration of the Seas (ICES). Although scientific recommendations are given within a range, the quotas tend to fluctuate more or less in accordance with the variation in biomass estimates, which fluctuated substantially during the period studied.

The management system divides the large and diverse fishing fleet into a number of different vessel groups based on gear type, target species and vessel sizes. The TAC for the main species is allocated among vessel groups based on the so-called "trawl ladder", the objective of which is to provide predictability and stability in quotas for smaller vessels and, as such, to contribute to regional policy goals (Guttormsen and Roll, 2011). When fish stocks are low or modest, a higher share of the TAC is allocated to smaller coastal vessels. Quotas cannot be transferred between vessel groups. Quotas are, however, transferable within vessel groups as quotas can be transferred by purchasing a vessel, removing it from the fishery and transferring the quota to the acquirer's vessel. Vessel quotas have been raised several times to further stimulate consolidation, reduce the overall fishing capacity and enhance profitability. This has been successful in the sense that overcapacity has been reduced and the profitability of the remaining vessels has improved (Zhang et al., 2018b). The size of vessel quotas is restricted and differs among vessel groups, with bottom trawlers holding the largest quotas for cod and haddock.

In addition to vessel quotas, the fishery is strictly regulated by a mixture of measures, such as time and location closures and various technical regulations relating to vessel size and fishing gear, some of which are described in more detail below. The Norwegian Food Safety Authority enforces technical legislation regarding how to handle and store fish on board the vessels in order to preserve the quality of the fish.

2.2. The ex-vessel market

The ex-vessel sale of wild-caught fish in Norway is legally protected by the Raw Fish Act and is organized by sales organizations that have the exclusive right to coordinate the primary sale of fish. This includes the right to set minimum prices to secure the fishers a price that reflects the market prices and to avoid powerful buyers using their bargaining power to set prices that are too low for small independent fishers (Holm, 1995).

Several different sales organizations exist, covering different fish species or geographical regions according to where the fish is landed. The on-board frozen fish included in this study is sold through the largest sales organization, the Norwegian Fishermen's Sales Organization, which records all transactions in the market and has provided the data for this study.

Fishers selling their frozen Atlantic cod and haddock through the Norwegian Fishermen's Sales Organization can choose an online auction organized by the sales organization or direct sales (for a more detailed description of the ex-vessel market for groundfish, see Helstad et al. (2015) and Pettersen et al., 2018). There are two large vertically integrated companies that own both vessels (bottom trawlers) and plants for primary processing (that is, gutting and packing whole fish or salting or drying the fish for various export markets) and secondary processing (that is, making consumer-ready products), with in-house sales and marketing activity. There are also a few vertically integrated companies, in which fishing companies have acquired onshore processing facilities. The vertically integrated companies have different production and sales strategies for their vessels, with some buying their own fish directly and others selling their fish to other buyers directly or through the auction. Some of the fish is used in their own processing, and some is exported. It should be noted that the share remuneration payment system whereby the crew receives a fixed share of the revenues rather than a fixed wage (see, e.g., McConnell and Price, 2006)—and the strong position of the Norwegian Seafarers' Union—-makes it difficult for vertically integrated companies to buy the fish directly from their own vessels at low prices. If they do, skilled crew members may leave for jobs on other vessels or industries. Autonomous fishing companies sell fish both directly to buyers and through the auction. Some have developed long-term relationships with processing companies to which fish is sold directly. These differences in the relationships between buyers and sellers may lead to market imperfections, thereby influencing the prices (Gobillon et al., 2017).

Frozen Atlantic cod and haddock are sold for secondary processing worldwide. In 2017, 69,291 tons of frozen whole Atlantic cod (headed and gutted) were exported (source: the Norwegian Seafood Council). In addition, some of the frozen Atlantic cod is purchased and processed by processors in the Norwegian clipfish industry, in which cod of a large size is in demand. In the UK, frozen Atlantic cod and haddock are mostly thawed and filleted by wholesalers and used for different types of chilled and frozen consumer packs for the large grocery retailers (Sogn-Grundvåg et al., 2013, 2014).

2.3. The three vessel groups

In this study, three vessel groups are in focus, that is, oceangoing bottom trawlers and longliners as well as large coastal vessels fishing with Danish seines. The bottom trawlers are licensed to fish with bottom trawling only and are allocated about 30 % of the yearly Norwegian TAC for Atlantic cod and haddock. In 2017, the trawler group consisted of 35 vessels, a decrease from 51 vessels in 2009, indicating substantial consolidation in the group. Bottom trawlers mostly freeze their catch on board as headed and gutted fish. Freezing is conducted to preserve the quality and to allow longer trips. In addition, the prices for frozen headed and gutted Atlantic cod have generally been higher than those for fresh fish (Pettersen et al., 2018). The trawlers are not allowed to fish within 12 nautical miles of the Norwegian coastline. Some of the trawlers have quotas for prawns (Pandalus borealis) in addition to groundfish. It should be noted that new technology is being developed that may improve the quality of fish, such as on-board live storage, so that the fish can be slaughtered effectively (Digre et al., 2017), and improved trawl technology (Brinkhof et al., 2018).

As of 2017, the group of oceangoing longliners consisted of 20 vessels, a decrease from 33 vessels in 2009, implying considerable consolidation in the group. Longliners can use gillnets in addition to longlines. Gillnets are used to fish for saithe, as saithe is not a typical bottom feeder, thus making gillnets more effective than longlines. The vessels in this group are allocated about 8% of the yearly Norwegian TAC for Atlantic cod and haddock. The longliners are not allowed to fish with trawls, but in 2018, they were allowed to use Danish seines to fish their quotas for Atlantic cod, haddock and saithe. This liberalization in gear use came about after pressure from the Norwegian Fishermen's Association, which argued to the Norwegian Ministry of Trade, Industry and Fisheries that, due to the high costs of fuel and bait, this vessel group should be allowed to use Danish seines on account of the lower costs associated with this fishing method. This illustrates how fishers try to adapt to and even change regulatory constraints (Salas and Gaertner, 2004). The cost of changing from longline to Danish seine is, however, substantial, as these two fishing methods require rather different technologies. Interestingly though, two oceangoing longliners are currently (2020) being built and set up for both longline and Danish seines.

The longliners fish with around 50–70,000 hooks, which are baited automatically when setting the line. The oceangoing longliners are not allowed to fish within 4 nautical miles of the Norwegian coast, and their access is restricted in certain areas outside the 4-mile limit to avoid conflicts of interest with smaller coastal vessels. Most of the oceangoing longliners freeze their catch on board as headed and gutted fish.

The group of large coastal vessels (above 21 m in length) consisted of 32 vessels in 2017, a decrease from 35 in 2009. These vessels can use several types of gear, including longline, gillnets, Danish seine and purse seine but not trawl. The fleet is allocated about 8% of the yearly Norwegian TAC for Atlantic cod and haddock. The size of the quotas depends on the length of the vessel. Only a few of the vessels in this group freeze the fish on board, and these are mainly the newest and largest vessels. Several of the vessels in this group have licenses to fish for pelagic fish, such as herring and mackerel, in addition to Atlantic cod, haddock and saithe. For the pelagic species, the purse seines are used. Of the three vessel groups in focus here, this group has the greatest flexibility in terms of the choice of fishing method. Compared with trawlers and longliners, it also has the broadest spectrum of quotas (species) and few restrictions in terms of fishing areas.

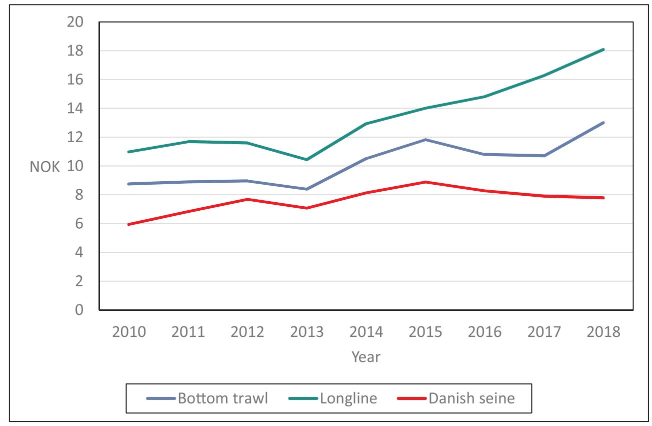

Fig. 1. The average costs per kilogram (NOK) of landed fish (all species) for the three vessel groups for 2010–2018. Source: Directorate of Fisheries (2020).

The three vessel groups described above apply different fishing methods. However, the bottom trawl and Danish seine methods share some key characteristics, such as a very large capacity to catch fish in a single haul. It is not unusual to keep the fish in storage bins for hours before bleeding and gutting (Olsen et al., 2014), and to simplify the slaughtering process, bleeding is often done after suffocation in air (van de Vis et al., 2003), which implies reduced fish quality (Botta et al., 1986; Rotabakk et al., 2011; Olsen et al., 2013, 2014). Longliners, on the other hand, when pulling in the longline, catch only one fish at a time. This makes it possible to bleed and process each fish immediately after catching, which is the main reason for the higher quality provided by longliners (Rotabakk et al., 2011). Longliners, however, are less technically efficient than bottom trawlers and Danish seiners, implying higher costs of fishing. This is illustrated in Fig. 1, which shows the average costs per kilogram of fish landed for the three vessel groups.

Fig. 1 shows that the average cost of fishing is substantially higher for longliners than for bottom trawlers and Danish seiners. The cost differences are relatively stable from 2010 to 2015 but increase after that in disfavor of longlining. The costs of fishing are about 30 % higher for longliners than for bottom trawlers and Danish seiners. However, because all vessels included fish for several fish species and because the profitability survey of the Directorate of Fisheries (2020) does not provide accounting data for individual species, the graphs in Fig. 1 must be interpreted with caution. For example, some of the bottom trawlers also fish for prawns, which generally is a less technically efficient form of fishing than trawling for cod and haddock. This indicates that the cost of fishing for haddock and cod is somewhat lower than what is shown in Fig. 1. Further, several Danish seiners also have large quotas for mackerel and herring caught with purse seine, which is a very technically efficient gear. This indicates that the costs of fishing for cod and haddock is somewhat higher for this vessel group than what is shown in Fig. 1. The reduction in fishing costs for Danish seiners after 2015 is probably due to larger catches of mackerel and herring compared to cod and haddock.

Despite the back-of-the-envelope nature of these calculations, it seems reasonable to argue that longliners have the highest costs of fishing when fishing for cod and haddock. This implies that bottom trawlers and Danish seiners can, to a larger extent than longliners, earn profits through swift and intense fishing strategies where lower quality and prices are compensated for by large quantities caught at low cost. Such fishing strategies are relevant in a multi-species fishery such as this, with sometimes overlapping seasons and where the number of operating days are very high, but the resultant fish quality may be compromised (Bertheussen and Dreyer, 2019).

Table 1
[a]Average yearly turnover (NOK), key costs (NOK), profitability and operating days for the three vessel groups for 2009-2017.
Source: Directorate of Fisheries (2020).

	Bottom trawlers	SD	Longliners	SD	Danish seiners	SD
Turnover	87,266,127	29,341,411	46,207,512	15,456,942	15,972,066	6,064,068
Salary	25,618,196	8,182,403	18,102376	7,126,327	5,634,277	1,964,444
Fuel	12,250,122	2,488,370	3,939,830	823,156	1,166,995	353,409
Bait, ice, packaging	712,906	153,395	3,021,599	755,243	101,142	96,385
Other costs	38,581,224	9.990,096	1,162,942	271,840	653,809	127,603
Total costs	68,989,286	17,667,728	26,226,748	8,303,135	7,670,408	2,407,564
Operating margin (%)	19,0	6,7	41,522,774	12,303,474	13,786,236	4,263,031
Operating days	311,3	13,0	333,4	11,2	215,6	7,9
No. vessels in sample	32,2	3,8	9,0	3,8	11,9	7,4
No. vessels in population	41,1	6,1	15,3	2,1	14,2	2,6

[a] The numbers are calculated from the yearly profitability survey of Norwegian fisheries conducted by the Directorate of Fisheries (Directorate of Fisheries, 2020). To save space, only the most relevant costs are included. We use the operating margin as a measure of profit rather than the more commonly used return on investments to reflect better how the cost of fishing methods relates to earnings. Even though cod and haddock are the main species, bottom trawlers also catch other groundfish species and some also have quotas for prawns, which may influence their profitability. Oceangoing longliners mainly fish for cod, haddock and saithe, whereas several Danish seiners fish for pelagic species, such as mackerel (*Scomber scombrus*) and herring (*Clupea harengus*) in addition to groundfish.

Table 1 shows the average turnover, key costs relating to fishing methods and the operating margin for the three vessel groups for the time period covered by the study. An inspection of Table 1 shows that the average turnover differs substantially among the three groups, with trawlers (NOK 87 million) having a higher turnover than longliners (NOK 46 million) and Danish seiners (NOK 16 million), reflecting substantial differences in the size of the quotas. The table also shows that the average operating margin was 19 %, 9 % and 11.9 % for bottom trawlers, longliners and Danish seiners, respectively, indicating differences in the technical efficiency and prices gained. For 2017, the operating margin for bottom trawlers and Danish seiners was 28.4 % and 21.6 %, respectively, much higher than the 12.3 % operating margin gained by oceangoing longliners in 2017.

Calculations from the data used in Table 1 show that for longliners, bottom trawlers and Danish seiners, the average cost of fuel constituted 9.5 %, 17.7 % and 15.2 % of the total costs, respectively, thereby implying that the fuel costs are substantially lower for longliners than for bottom trawlers and Danish seiners. In terms of fuel use, it has been found that the energy efficiency of all vessel groups in Norwegian fisheries has improved in recent years (Jafarzadeh et al., 2016). For the period 2003–2012, the average was 0.322–0.354 and 0.265 L of fuel per kilo of fish landed for bottom trawlers and longliners, respectively (Jafarzadeh et al., 2016). Danish seiners are part of a group of large coastal vessels (above 21 m in length) which also include large coastal vessels fishing with gillnets and longlines. For this group, the average fuel consumption per kilogram of fish landed for the period 2003–2012 was 0.058 L of fuel (Jafarzadeh et al., 2016). It should also be noted that fuel use varies substantially with catch rates (Schau et al., 2009). During the period studied here, the Norwegian fishing fleet paid a substantially lower CO_2 fuel surcharge compared to other commercial vessels (e.g., vessels involved in fish farming), namely NOK0.29 per liter of fuel for fishing vessels versus NOK1.65 per liter for other vessels. This subsidy represents about 20–25 % of the fuel costs in the period studied here (for a detailed description of the Norwegian fuel tax concession, see Isaksen et al. (2015)). As of January 1, 2020, fishing vessels must pay the same CO_2 fuel surcharge as other vessels, thus implying a substantial increase in fuel costs for vessels with high fuel consumption, such as trawlers. However, a compensation scheme will be introduced in which those vessels with the lowest fuel consumption within each vessel group will receive the highest compensation.

The average cost of labor (salary) was higher for longliners (43.6 % of total costs) than for bottom trawlers (37.1 % of total costs). In addition, the cost of bait, ice and packaging accounted for 7.3 % of the total costs for longliners versus less than 1% for bottom trawlers. Thus, even though the fuel costs are lower for longliners than for bottom trawlers, the additional cost of labor and bait implies a cost disadvantage for longliners. It should be noted that the costs of labor and bait are variable costs which depend on the size of quotas, suggesting that the larger the quotas, the more man hours and bait are required. Interestingly, Table 1 shows that the number of operating days is very high for both bottom trawlers and longliners, implying that their catching capacity is close to fully utilized.

Figs. 2 and 3 show the quantity of frozen headed and gutted Atlantic cod and haddock, respectively, sold by the vessels in the three vessel groups included in the nine-year period covered by the study. The graphs in Figs. 2 and 3 reflect large variations in the yearly Norwegian TACs for Atlantic cod and haddock. The graphs also show that bottom trawlers are the most important vessel group in our data in terms of sold frozen quantity of both cod and haddock.

2.4. Data and descriptive statistics

The transaction data used in this study include sales of on-board frozen Atlantic cod and haddock from oceangoing bottom trawlers and longliners as well as from large coastal vessels using Danish seines. In addition, a fourth group of smaller vessels is used in the econometric modelling as a base category for comparisons. This group consists of several vessels fishing with different methods, such as gillnets, traps and pots. The total ex-vessel value of frozen Atlantic cod and haddock for the nine-year period covered by the data was NOK 1.9 billion and 722 million, respectively, in 2017 (the average exchange rate for 2017 was NOK 1 = USD 0.1209/EUR 0.1071).

Figs. 4 and 5 show the yearly average prices by fishing methods for Atlantic cod and haddock. Fish caught with longline fetch the highest

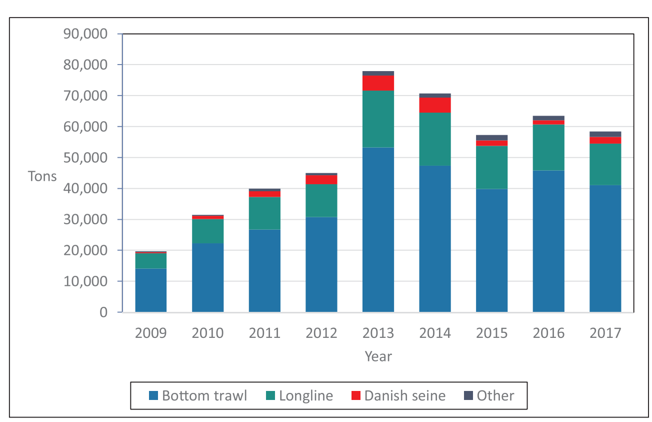

Fig. 2. Yearly quantities (tons) of frozen headed and gutted Atlantic cod sold by vessels in the three vessel groups.

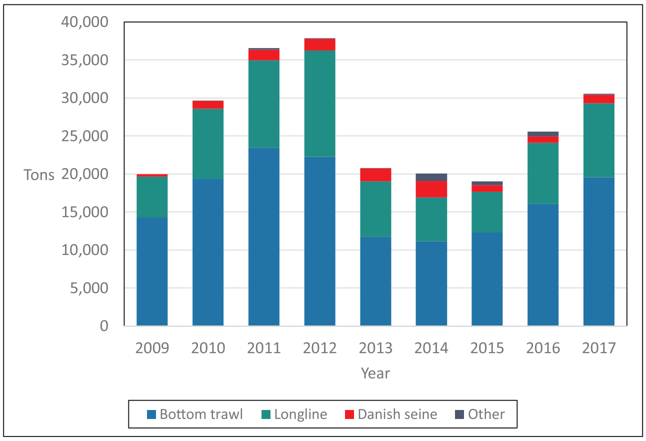

Fig. 3. Yearly quantities (tons) of frozen headed and gutted haddock sold by vessels in the three vessel groups included.

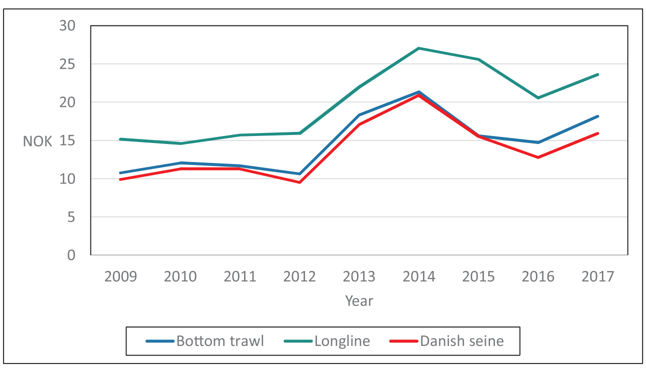

Fig. 4. Yearly average prices per kilogram (NOK) by fishing methods for frozen headed and gutted Atlantic cod.

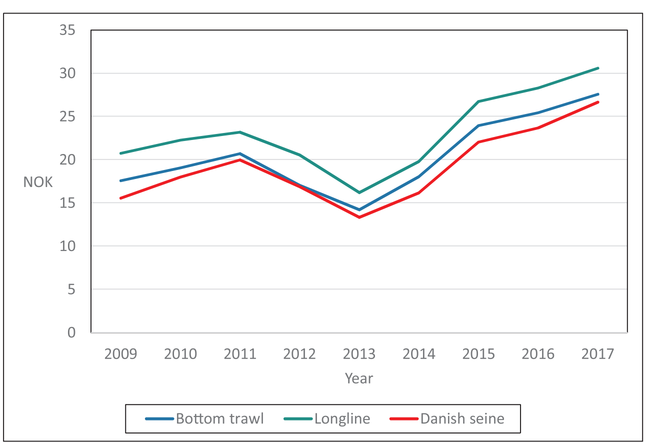

Fig. 5. Yearly average prices per kilogram (NOK) by fishing methods for frozen headed and gutted haddock.

prices, followed by bottom trawl and Danish seine. However, the gap in prices between longline and the two other capture methods is larger for haddock than for Atlantic cod. The figures also show that the price differences between fishing methods were relatively stable over the nine-year period. The econometric modelling will estimate the differences in prices between fishing methods, holding other factors such as the fish size, seasonality, seller and buyer heterogeneity and so on constant.

Each market transaction in the data includes information about the species (Atlantic cod or haddock), total weight of the lot in kilograms, fishing method, average size of the fish, vessel name, buyer name, price and so on. Table 2 presents the descriptive statistics of the variables included in the econometric models outlined below. The table shows that the average price of Atlantic cod was substantially higher than that for haddock. Note also that the standard deviations for the Atlantic cod and haddock prices are substantial, probably reflecting seasonal and yearly price differences due to seasonal differences in the traded quantity and large yearly changes in the TAC for both species. In addition, the standard deviations for the daily quantity and transaction quantity are substantial, indicating large variations in the traded quantity. For Atlantic cod, the average fish size is 2.70 kg (headed and gutted weight), with a substantial standard deviation indicating a large size variation between lots. For haddock, the fish size is a dummy variable with an average weight below 0.8 kg as the base.

Table 2
Descriptive statistics of the variables included in the econometric models.

Variable	Atlantic cod		Haddock	
	Mean	Std deviation	Mean	Std deviation
Price (NOK)	21.3	5.8	16.8	5.6
Daily quantity (kg)	375,395	333,809	16,437	250,032
Transaction quantity (kg)	17,430	30,366	22,891	35,967
Fish size (kg)	2.70	2.42	0.50	
Quality (base: downgraded)				
Quality 1			0.19	
Quality 2	0.94		0.75	
Downgraded (base)	0.06		0.06	
Fishing methods				
Bottom trawl (base)	0.62		0.59	
Longline	0.25		0.31	
Danish seine	0.10		0.07	
Other	0.03		0.02	
Sales methods				
Auction	0.42		0.29	
Direct sale (base)	0.58		0.71	

Table 2 also shows two groups of dummy variables, that is, dummies for quality and fishing methods. The reported mean for each dummy variable is the number of observations (transactions) within each category as a proportion of the total number of observations. *Quality-1* is a dummy that takes the value one for transactions of large haddock (> 0.8 kg, headed and gutted weight) caught with longline, which has a specific minimum price. There is no specific minimum price for Atlantic cod caught by longline. *Quality-2* for Atlantic cod and haddock refers to fish of regular quality as opposed to fish that was downgraded due to poor quality. Under the Raw Fish Act, buyers may downgrade fish based on its quality and reduce the price by 40 % compared with the minimum price. As can be seen from Table 2, there is a larger share of Atlantic cod of regular quality than of haddock. The table also shows that bottom trawling of Atlantic cod and haddock accounted for 62 % and 59 %, respectively, of the transactions during the sample period. Longliners accounted for 25 % and 31 % of the Atlantic cod and haddock catches, respectively. Table 2 also shows that 42 % and 29 % of the Atlantic cod and haddock, respectively, was sold by auction as opposed to by direct sales.

2.5. Model and econometric analysis

To examine the influence of fishing methods on the ex-vessel prices of frozen Atlantic cod and haddock, this study follows the hedonic price modelling literature which has been applied to estimate the value of seafood attributes along the value chain, including at the initial point of landing and port auctions (McConnell and Strand, 2000; Carroll et al., 2001; Kristofersson and Rickertsen, 2007; Lee, 2014; Asche et al., 2015; Gobillon et al., 2017), wholesale markets (Kristofersson and Rickertsen, 2004; Asche and Guillen, 2012) and the retail level (Roheim et al., 2011; Asche et al., 2015).

Hedonic price modelling relies on characteristics theory, which assumes that consumers derive utility directly from the quality attributes inherent in a good (Lancaster, 1966; Rosen, 1974). Thus, the actual price of a good can be considered as the sum of the implicit prices of those attributes (Rosen, 1974). This indicates that the price of an individual lot of Atlantic cod or haddock depends on its characteristics, such as the average size of the fish, its quality and the fishing method. Fish prices may, however, also be influenced by factors such as the transaction quantity, daily sales quantity and seasonality (Kirman and Vriend, 2001; Guillioni and Bucciarelli, 2011; Fluvià et al., 2012; Gobillon et al., 2017; Sogn-Grundvåg et al., 2019b). In past research, hedonic price modelling has used either the linear price or the logarithmic price as the dependent variable. Our test results, based on Vuong (1989) likelihood ratio test, show that the model with the logarithmic price as the dependent variable fits the data better than the model with linear price formulation. Thus, the basic model (Model A) is:

$$\begin{aligned}\log(p_i) &= a_0 + b_1\log(Daily\_Quantity_i) + b_2\log(Transaction\_Quantity_i)\\ &+ b_3Fish\_Size_i + \sum\nolimits_{o=1}^{2} c_o Quality\_2_{o,i} + d_1Longline_i\\ &+ d_2Danish\_Seine_i + +d_3Other\_Fishing\_Methods_i + e_1Auction_i\\ &+ \sum\nolimits_{o=2}^{9} f_o Year_{o,i} + \sum\nolimits_{o=2}^{12} w_o Month_{o,i} + Residual_i \qquad (1)\end{aligned}$$

where, for either the cod or the haddock model, i indexes transactions, and log is the natural logarithm function; P_i is the prices, which are deflated by the Norwegian consumer price index for food; *Daily Quantity* is the daily traded quantity; *Transaction Quantity* is the quantity of each transaction. The two main fishing methods (*Longline* and *Danish Seine*) and other fishing methods together are dummies, with bottom trawl as the base. The dummy variable for a particular fishing method may also capture the impact on price of some unobservable factors which are related to this fishing method. *Auction* is a dummy for Atlantic cod sold by auction with contract sales as a base. The *Year* and *Month* dummies are included in the model to control for any seasonality patterns and yearly variations in prices due to changes in catches and the TAC. The error term *Residual* captures any other unobserved factors, such as seller and buyer heterogeneity, that might influence the prices (Gobillon et al., 2017).

Regarding fish size and quality dummies, the measures are different for cod and haddock. For the cod model, *Fish Size* is the average size of the fish in kilograms. For haddock, the size is registered as either larger or smaller than 0.8 kg. Thus, *Fish Size* in the haddock model is a dummy variable, which is one for a weight larger than 0.8 kg and zero otherwise. In the two models, *Quality-2* is for set for fish with regular quality with downgraded fish as the base. Additionally, *Quality-1* is an additional quality dummy reflecting the specific minimum price set for large haddock ($>$ 0.8 kg) caught with longline. Thus, *Quality-1* is an interaction term between *Fish Size* and *Longline*.

Since the fish prices are probably affected by market imperfections caused by heterogeneity among buyers (e.g., different degrees of willingness to pay for different fish quality and fish size, depending on the markets and the customers whom they serve (Sogn-Grundvåg et al., 2019b), sellers (e.g., differences in skipper and crew skills, which may result in differences in fish quality) and buyer-seller relationships (e.g., some buyers and sellers are vertically integrated, which may influence the prices), we modify the basic model (A) by including dummies for sellers, buyers and seller-buyer pairs. We include dummies for the 50 largest buyers in terms of the quantities purchased during the 9-year period (and the 50 largest sellers) to avoid multicollinearity. These buyers and sellers accounted for more than 95 % of the total traded quantity in the period covered by the data. For seller-buyer pairs, dummies for 99 pairs are included in the model. In terms of the traded quantity, these are the most significant pairs and accounted for about 36 % of the total transaction quantity over the sample period for cod and about 49 % for haddock. This leads to the following five models:

Model A: the basic model represented by Eq. (1)

Model B: Model A with additional seller dummies

Model C: Model A with additional buyer dummies

Model D: Model A with additional seller and buyer dummies

Model E: Model D with additional dummies for buyer–seller pairs

Of the five models, Model A is nested under Model B and Model C, which are further nested under Model D. Model E is a complete specification. F-tests are used to test Models A–D until rejection occurs.

Since the dependent variable is expressed in logarithm form, the estimated coefficients for *Daily Quantity* and *Transaction Quantity* are explained as elasticities, that is, percentage changes in price (b_1% or b_2%) in response to a 1% change in the daily quantity or transaction quantity. For the dummy variables, we follow Kennedy (1981) and derive the percentage impact on prices by taking the standard deviation into account. For example, for a significant estimation d_2, the impact (price premium) of fish caught by longliners relative to the base (fish caught by bottom trawler) is calculated as:

$$100[\exp(d_2\text{-}0.5{*}V(d_2))\text{-}1]\% \qquad (2)$$

where the notation exp is the exponential function of $V(d_2)$, which is the square of the standard error for d_2.

2.6. Functional form and match effect

As the estimation results are probably subject to the functional form of the models, we have relied on Vuong (1989) likelihood ratio test and chose the specification with the logarithmic price as the dependent variable. As a robustness check, the Box-Cox transformation, the other most common test, is applied to test/choose the functional form.

In the models, we include dummies for the dominant buyers and sellers to control for buyer and seller heterogeneity. In the auction, the match effect between buyer and seller is probably more important than the heterogeneity of individual buyers and sellers. In our sample, there are 3559 seller-buyer pairs for Atlantic cod and 1631 for haddock. In the models, we include the dummies for the top 99 pairs to control for match effect; they account for about 36 % of total transaction quantity in the sample period for cod and about 49 % for haddock. Therefore, the other pairs are aggregated to the base group. Ignoring heterogeneity between these pairs may lead to low explanatory power for the model and may affect estimates of fishing methods (and other determinants). We follow Gobillon et al. (2017) and use the Frisch-Waugh theorem to estimate the models after controlling for the whole match effect.

3. Results

3.1. Testing models

Tables 3 and 4 present the econometric results from estimating the hedonic price models for Atlantic cod and haddock, respectively. For both models, the Newey-West covariance matrix is applied to correct for heteroskedasticity and serial correlation in the error terms, from which the robust standard error is estimated for inference. The adjusted R^2 ranges are between 0.707 and 0.73 for the Atlantic cod models and 0.718 and 0.749 for the haddock models, indicating a high level of overall goodness of fit for these models. Moreover, the models with more variables have a greater adjusted R^2 than the models with fewer variables. This indicates the raised goodness of fit due to the additional variables, such as seller dummies, buyer dummies and dummies for seller-buyer pairs. As shown in Table 5, the F-test results indicate that for the two series of models, the restricted models (with fewer variables) are firmly rejected. Thus, Model E fits the data better than the other models. Next, we focus on the estimation results of Model E and calculate the price premiums/discounts using Eq. (2).

Table 3
Econometric results from estimating the hedonic price models for Atlantic cod.

Variable	Model A		Model B		Model C		Model D		Model E		Impact of dummies in Model E
	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	
Intercept	2.5442	***	2.5528	***	2.5404	***	2.5414	***	2.5406	***	
	[0.0159]		[0.0161]		[0.016]		[0.0161]		[0.0161]		
log (Daily-Quantity)	−0.0027	***	−0.0026	***	−0.0034	***	−0.0032	***	−0.0032	***	
	[0.0008]		[0.0008]		[0.0008]		[0.0008]		[0.0008]		
log (Transaction-Quantity)	0.0008	*	0.0009	*	0.0017	***	0.0016	***	0.0016	***	
	[0.0005]		[0.0005]		[0.0005]		[0.0005]		[0.0005]		
Fish-Size	0.0255	***	0.0255	***	0.0204	***	0.0203	***	0.0203	***	
	[0.0004]		[0.0004]		[0.0005]		[0.0005]		[0.0005]		
Quality-2	0.3749	***	0.3754	***	0.3676	***	0.3660	***	0.3654	***	44.1 %
	[0.0083]		[0.0083]		[0.0086]		[0.0085]		[0.0085]		
Longline	0.0854	***	0.0650	***	0.0838	***	0.0751	***	0.0745	***	7.73 %
	[0.0025]		[0.0047]		[0.003]		[0.0049]		[0.0049]		
Danish-Seine	−0.0593	***	−0.0746	***	−0.0616	***	−0.0686	***	−0.0681	***	−6.58 %
	[0.0032]		[0.0049]		[0.0034]		[0.005]		[0.0051]		
Other fishing methods	−0.0173	***	−0.0015		−0.0407	***	−0.0099		−0.0062		
	[0.0055]		[0.0078]		[0.006]		[0.0081]		[0.0083]		
Auction	0.0284	***	0.0325	***	0.0234	***	0.0294	***	0.0300	***	3.05 %
	[0.002]		[0.0021]		[0.0023]		[0.0024]		[0.0024]		
With time dummies	Yes		Yes		Yes		Yes		Yes		
With seller dummies	No		Yes		No		Yes		Yes		
With buyer dummies	No		No		Yes		Yes		Yes		
With seller-buyer dummies	No		No		No		No		Yes		
R^2	0.7079		0.7125		0.7246		0.7292		0.7325		
Adj. R^2	0.7076		0.7117		0.7238		0.7279		0.7302		

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error.

3.2. Estimation results of the cod model

For Atlantic cod, Model E in Table 2 shows that *Daily Quantity* is significant and negative (-0.0032), which implies that a 10 % increase in the daily transaction quantity would lead to a 0.032 % reduction in price. On the other hand, *Transaction Quantity* is significant and positive, suggesting that a 10 % increase in the transaction quantity would lead to a 0.016 % increase in price. These estimates are small and indicate that Atlantic cod prices are hardly affected by the daily traded quantity and the size of deals. *Fish Size* is measured in kilograms, and thus the estimate of 0.0203 indicates that the price of Atlantic cod would increase by 2.03 % if the fish size increased by 1 kg. Buyers' willingness to pay for Atlantic cod of regular quality is reflected in the estimate for *Quality-2*, which indicates a price premium of about 44.1 % compared with downgraded Atlantic cod.

The dummies for longline and Danish seine are significant.

Table 4
Econometric results from estimating the hedonic price models for haddock.

Variable	Model A		Model B		Model C		Model D		Model E		Impact of dummies in Model E
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.	
Intercept	1.9480	***	1.9115	***	1.8728	***	1.8513	***	1.8586	***	
	[0.0296]		[0.0326]		[0.0305]		[0.0349]		[0.0355]		
log (Daily-Quantity)	−0.0033	**	−0.0033		−0.0027	*	−0.0027	*	−0.0029	**	
	[0.0015]		[0.0015]		[0.0015]		[0.0015]		[0.0015]		
log (Transaction-Quantity)	0.0078	***	0.0082	***	0.0054	***	0.0055	***	0.0058	***	
	[0.0013]		[0.0013]		[0.0011]		[0.0011]		[0.0011]		
Fish-Size	0.0039		0.0054		0.0039		0.0063		0.0060		
	[0.0042]		[0.0042]		[0.004]		[0.004]		[0.004]		
Quality-1	0.6936	***	0.6893	***	0.5652	***	0.5614	***	0.5575	***	74.6 %
	[0.0167]		[0.0167]		[0.0197]		[0.0201]		[0.0201]		
Quality-2	0.5528	***	0.5521	***	0.4289	***	0.4286	***	0.4269	***	53.2 %
	[0.0146]		[0.0146]		[0.0182]		[0.0186]		[0.0187]		
Longline	0.1570	***	0.1671	***	0.1507	***	0.1493	***	0.1402	***	15.0 %
	[0.0059]		[0.0117]		[0.0075]		[0.0133]		[0.0144]		
Danish-Seine	−0.0650	***	−0.0319	**	−0.0571	***	−0.0336	**	−0.0301	**	−3.0 %
	[0.0079]		[0.0135]		[0.009]		[0.0138]		[0.0146]		
Other fishing methods	0.0049		0.0348		0.0175		0.0356		0.0301		
	[0.0251]		[0.0266]		[0.0224]		[0.0242]		[0.0243]		
Auction	0.0052		0.0122		0.0296	***	0.0360	***	0.0354	***	3.60 %
	[0.0043]		[0.0046]		[0.0047]		[0.0051]		[0.0053]		
With time dummies	Yes		Yes		Yes		Yes		Yes		
With seller dummies	No		Yes		No		Yes		Yes		
With buyer dummies	No		No		Yes		Yes		Yes		
With seller-buyer dummies	No		No		No		No		Yes		
R^2	0.7190		0.7237		0.7455		0.7491		0.7546		
Adj. R^2	0.7183		0.7216		0.7436		0.7460		0.7492		

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error.

Table 5
F-test results for the econometric models.

Model	Against	Degrees of freedom	Statistic value	p-value
Atlantic cod model:				
Model B	Model A	50	8.62	< 0.01
Model C	Model A	50	32.4	< 0.01
Model D	Model B	50	32.7	< 0.01
Model D	Model C	50	9.01	< 0.01
Model E	Model D	99	3.27	< 0.01
Haddock model:				
Model B	Model A	50	3.52	< 0.01
Model C	Model A	50	21.7	< 0.01
Model D	Model B	50	21.0	< 0.01
Model D	Model C	50	2.95	< 0.01
Model E	Model D	99	2.33	< 0.01

However, there is no price difference for fish caught by other fishing methods and bottom trawl (the base). Compared with bottom trawl, Atlantic cod from longliners obtains a price premium of 7.73 %, and Atlantic cod caught using Danish seine is 6.58 % cheaper than the base. The lower prices for Danish seiners than bottom trawlers (and longliners) are probably a reflection of the lower quality.

3.3. Estimation results of the haddock model

For haddock, Model E in Table 3 indicates that the daily quantity and the transaction quantity have a weak effect on the price of haddock (-0.0029 and 0.0058), which is not surprising given that there is a global market for cod (Asche et al., 2002). *Fish Size* is not statistically significant for haddock, which may be due to the use of a dichotomous dummy variable (above or below 0.8 kg)—a rather coarse representation of the fish size. However, the price premium for large line-caught haddock (*Quality-1*) sold under the specific minimum price is 74.6 % compared with downgraded haddock. The dummy for regular quality (*Quality-2*) shows that buyers pay a 53.2 % premium for regular quality compared with downgraded haddock, holding other variables constant. This indicates that downgraded haddock is of substantially lower quality than haddock of regular quality.

For haddock caught with the longline method, the price premium is 15.0 %, and the estimate for Danish seine fishing implies a discount of 3.0 % compared with the base. The estimate for other fishing methods is insignificant.

3.4. Simulation analysis

For the fishing methods, the price premiums for Atlantic cod and haddock are further compared. For longline, the price premium in percentage terms for Atlantic cod is smaller than that for haddock (7.73 % versus 15.04 %). However, the price premiums in NOKs depend on the respective price for the base product and may provide different comparison results. Using the estimated coefficients, we obtained the average fitted price for fish caught by trawl. Setting the dummy variables for the fishing method to 0 and taking the means of the numeric variables in the models yielded the expected price for the base product, which is about NOK 20.85 and 16.68 per kilogram for Atlantic cod and haddock, respectively. We derived the expected price from the expected price in the logarithm scale by taking the variance of residuals into account, following Duan (1983). This yields price premiums for the longline method of about NOK 1.61 and 2.51 per kilogram for Atlantic cod and haddock, respectively. Since the estimated premiums for the longline and Danish seine are relative to the same base, we can derive the price premium for longline relative to Danish seine. For Atlantic cod, longline obtains a 13.3 % premium over the Danish seine method. For haddock, longline obtains a 18.6 % premium over Danish seine fishing.

To illustrate the effect of the different fishing methods on the value generated at the ex-vessel level of the value chain, we calculate the potential gains in value if the Atlantic cod and haddock caught with bottom trawl and Danish seine had been caught with longline, which has the highest prices. If the quantity of fish caught using Danish seines in the nine-year period covered by the study had been caught with longline, the value of the fish would have increased by about NOK 50 million and NOK 31 million for Atlantic cod and haddock, respectively. Similarly, if the quantity of fish caught with bottom trawling had been caught with longlines, the value of the fish would have increased by NOK 509 million for Atlantic cod and NOK 330 million for haddock. Thus, the additional value gained if all the cod and haddock quotas had been moved from bottom trawlers and Danish seiners to longliners is about NOK 920 million. However, as illustrated in Fig. 1, the cost of fishing is substantially higher for longlining than for bottom trawling and Danish seining. A simple back-of-the-envelope calculation using the additional costs of fishing with longline for the same extra quantity of fish landed by trawlers and Danish seiners indicates an increase in costs of about NOK 1637 million.

3.5. Robustness checks

We further performed the Box-Cox test by setting a grid from –2 to 2. The optimized transformation parameters indicate the test results are inconclusive. Accordingly, we estimated Models A, B, C and E for cod and haddock. For the two sets of models, the F-test indicates that Model E is the “best model”. The estimation results are reported in Appendixes A and B.

For the estimated coefficients of the fishing methods (and the other dummy variables), the logarithm functional form reports the percentage price premium, while the linear functional form reports the price premium in NOK. We further compared the estimated coefficients of fishing methods from the two functional forms. As we discussed before, the price premium in percentage terms is 7.73 % for Atlantic cod and 15.04 % for haddock, relative to their respective base, fish caught by trawl. By taking the fitted price for the base, we obtained a price premium for the longline fishing method of about NOK 1.61 and 2.51 per kilogram for Atlantic cod and haddock, respectively, which are close to their counterparts in the model with the linear functional form (NOK 1.87 and 2.66 per kilogram).

Since Model E fits data better than the other models, we use the Frisch-Waugh theorem to estimate this model and control for the whole match effect. All variables except for the dummies for seller-buyer pairs are centered with respect to their mean at the level of seller-buyer pairs. Model E is estimated with the centered variables and without the dummies for seller-buyer pairs. In our dataset, there are about 3.6 % of pairs with only one transaction in the 9-year period for cod and 4.4 % for haddock. We aggregate these seller-buyer pairs with only one transaction as one pair to avoid zeros in the data. We then estimated the level and logarithm functional forms. Tables 6 and 7 report the estimation results for cod and haddock.

In Tables 6 and 7, besides the Newey-West standard error (NW SE), we also reported the Driscoll and Kraay standard error (DK SE) (Driscoll and Kraay, 1998) to control for correlation between day-to-day unobservables. As shown in Tables 6 and 7, the two types of standard errors generally do not affect the significance level for each variable. For either cod or haddock, the logarithm functional form generates a higher (adjusted) R^2 value than the linear functional form. Compared to the original Model E, the new logarithm model has a higher R^2 value, and the new linear model has a lower R^2 value for either cod or haddock. This may indicate that the logarithm functional form fits the data better than the linear functional form. For the logarithm functional form, the new model with the (almost) complete match effect increases the R^2 value by 10.2 % for cod, and 12.2 % for haddock. The coefficient of *Longline* in the new logarithm model is 0.0655 for cod, which is smaller than the counterpart in Model E (0.0854); the inverse is true for haddock (0.1639 versus 0.157), which may marginally affect the

Table 6
Econometric results from estimating the hedonic price models for cod, with complete match effect.

Variable	Dependent variable: log(Price)					Dependent variable: Price				
	Est.	NW S.E		DK S.E.		Est.	NW S.E		DK S.E.	
log (Daily-Quantity)	−0.0038	0.0008	***	0.001	***	−0.0879	0.0145	***	0.0145	***
log (Transaction-Quantity)	0.0019	0.0005	***	0.0006	***	0.0246	0.009	***	0.009	***
Fish-Size	0.0208	0.0005	***	0.0007	***	0.4793	0.0104	***	0.0104	***
Quality-2	0.3599	0.0087	***	0.0143	***	5.8867	0.1036	***	0.1036	***
Longline	0.0655	0.0071	***	0.0113	***	1.8577	0.1209	***	0.1209	***
Danish-Seine	−0.0716	0.0065	***	0.0101	***	−1.1254	0.1219	***	0.1219	***
Other fishing methods	0.0005	0.0111		0.0178		0.3872	0.2091		0.2091	*
Auction	0.0395	0.0027	***	0.0036	***	0.6532	0.046	***	0.046	***
With time dummies	Yes					Yes				
With seller dummies	Yes					Yes				
With buyer dummies	Yes					Yes				
Complete match effect	Yes					Yes				
R^2	0.8069					0.6882				
Adj. R^2	0.8052					0.6867				

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error, and DK S.E. Driscoll and Kraay standard error.

simulation results in the previous section.

4. Discussion

The empirical findings in this study clearly show that fishing methods influence the price of frozen Atlantic cod and haddock after controlling for the influence of other variables, such as the size of fish and seasonality. The study also controls for the likely influence on price of market imperfections caused by heterogeneity among sellers, buyers and buyer-seller relationships (Gobillon et al., 2017). More specifically, the results show that frozen Atlantic cod from longliners obtains price premiums on average of 12.6 % and 15.0 % compared with that caught by bottom trawlers and Danish seiners, respectively. For frozen haddock, longliners obtain an average price premium of 13.3 % over bottom trawlers and 20.0 % over Danish seiners.

These results indicate that the quality and value of the limited Atlantic cod and haddock resources can be enhanced by allocating larger quotas to longliners at the expense of bottom trawlers and Danish seiners. The better fish quality and environmental sustainability and reputation of line-caught Atlantic cod and haddock compared with other fishing methods also provide good opportunities for enhanced value-adding in secondary processing and marketing. This should lead to improved value creation from the limited Atlantic cod and haddock stocks, much in line with the FAO's request to take better care of the scarce marine resources (Food and Agriculture Organization (FAO, 2018).

However, the costs of fishing are substantially higher for longliners than for bottom trawlers and Danish seiners, which largely explains the differences in profitability favoring the more technically efficient bottom trawlers and Danish seiners. This also explains why longliners through political pressure are now allowed to use Danish seines for groundfish, including cod and haddock. The lower costs of fishing with Danish seines are likely to improve the profitability of longliners adopting this fishing method, but the quality of fish is likely to be reduced, with implications for value-adding and marketing.

Thus, policymakers face the following dilemma: should more quotas be allocated to longliners at the expense of bottom trawlers and Danish seiners to gain higher total value from the limited Atlantic cod and haddock resources, or should bottom trawlers and Danish seiners, the most technically efficient and profitable fishing methods, be favored at the expense of the less efficient and profitable longliners? And should longliners be allowed to fish with Danish seines?

In trying to solve these dilemmas, policymakers must consider several complicating issues. First, the current fleet of longliners utilizes its fishing capacity to the maximum. Thus, allocating additional quotas to this group will imply new investments in vessels to enhance the

Table 7
Econometric results from estimating the hedonic price models for haddock, with complete match effect.

Variable	Dependent variable: log(Price)					Dependent variable: Price				
	Est.	NW S.E.		DK S.E.		Est.	NW S.E		DK S.E.	
log (Daily-Quantity)	−0.0036	0.0015	**	0.0017	**	−0.0766	0.0195	***	0.0222	***
log (Transaction-Quantity)	0.0051	0.0011	***	0.0012	***	0.0519	0.0154	***	0.0161	***
Fish-Size	0.0086	0.004	**	0.004	**	−0.016	0.0603		0.0588	
Quality-1	0.5495	0.0209	***	0.0265	***	7.7769	0.2277	***	0.2754	***
Quality-2	0.4228	0.0193	***	0.0253	***	5.1965	0.194	***	0.2593	***
Longline	0.1639	0.0202	***	0.0285	***	3.0584	0.2412	***	0.3216	***
Danish-Seine	−0.002	0.0174		0.0223		0.0449	0.2341		0.3107	
Other fishing methods	−0.0016	0.0331		0.039		0.9226	0.4636	**	0.5562	*
Auction	0.0408	0.0057	***	0.0072	***	0.3873	0.0783	***	0.105	***
With time dummies	Yes					Yes				
With seller dummies	Yes					Yes				
With buyer dummies	Yes					Yes				
Complete match effect	Yes					Yes				
R^2	0.807					0.694				
Adj. R^2	0.805					0.690				

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error, and DK S.E. Driscoll and Kraay standard error.

fishing capacity—which opposes the longstanding policy of reducing the fishing capacity. At the same time as new longliners will have to carry substantial financial costs, influencing their profitability negatively, the technical efficiency and revenue of bottom trawlers and Danish seiners will be reduced. However, longliners might benefit if they were allocated larger quotas of the valuable Atlantic cod at the expense of the less valuable haddock, as this may lead to a more profitable mix of quotas for this vessel group. This implies that bottom trawlers and Danish seiners would receive smaller quotas for Atlantic cod and larger quotas for haddock, which would reduce their revenues at the same time as the costs of fishing would probably be similar, thus implying reduced profits.

Reducing fuel consumption and greenhouse gas emissions is also an important issue. As shown in Table 1, the cost of fuel varies substantially among the vessel groups. The new scheme for fuel surcharges introduced in 2020 is likely to increase the cost of fuel, particularly for vessels with high fuel consumption, such as bottom trawlers. This may reduce the gap in profitability between the bottom trawlers and longliners.

The recent liberalization of fishing methods, i.e., letting longliners use Danish seine to catch their quotas of Atlantic cod and other groundfish, must also be considered given that the additional quotas for Atlantic cod may be caught with the highly effective Danish seine, albeit with lower quality and sold at lower prices, as indicated above. It should also be noted that the rather rigid fishery management system in Norway, with vessel quotas owned by fishers, would make it very difficult for regulators to move quotas among vessel groups, as this may lead to lawsuits with claims for compensation for lost quotas.

Policymakers should also consider recent research and development into quality-enhancing technology for both Danish seiners and bottom trawlers, such as live on-board storage and slaughtering (Olsen et al., 2013; Digre et al., 2017; Sønvisen and Standal, 2019). Incentives, such as a quota bonuses, are one way to enhance the adoption of such new technology, which may lead to enhanced quality and higher prices for bottom trawlers and Danish seiners alike. In order to improve fish quality, the Norwegian Food Safety Authority should implement and enforce stricter legislation to ensure faster on-board slaughtering and bleeding of fish. Finally, the environmental sustainability of and marketing opportunities for the different fishing methods should also be considered.

CRediT authorship contribution statement

Geir Sogn-Grundvåg: Conceptualization, Investigation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Dengjun Zhang:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **Bent Dreyer:** Conceptualization, Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Econometric results from estimating the hedonic price models for Atlantic cod, dependent variable: Price

	Model A		Model B		Model C		Model D		Model E	
Variable	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.
Intercept	13.1909	***	13.2922	***	13.3244	***	13.2462	***	13.2038	***
	[0.2522]		[0.2584]		[0.2482]		[0.253]		[0.253]	
log (Daily-Quantity)	−0.0651	***	−0.0619	***	−0.0798	***	−0.0758	***	−0.0757	***
	[0.0152]		[0.0151]		[0.0147]		[0.0146]		[0.0146]	
log (Transaction-Quantity)	0.0024		0.0033		0.0208	**	0.0186	**	0.0192	**
	[0.0093]		[0.0095]		[0.0091]		[0.0092]		[0.0092]	
Fish-Size	0.5832	***	0.5818	***	0.4738	***	0.4710	***	0.4711	***
	[0.0089]		[0.0088]		[0.0103]		[0.0103]		[0.0103]	
Quality-2	6.0748	***	6.0854	***	5.9177	***	5.9127	***	5.9004	***
	[0.0922]		[0.0915]		[0.0987]		[0.0986]		[0.0986]	
Longline	1.9564	***	1.6379	***	1.9398	***	1.8775	***	1.8709	***
	[0.0468]		[0.0887]		[0.0539]		[0.0896]		[0.0908]	
Danish-Seine	−1.1021	***	−1.3216	***	−1.1478		−1.1794	***	−1.1361	***
	[0.059]		[0.0937]		[0.062]		[0.0946]		[0.0966]	
Other fishing methods	−0.2070	**	0.1353	0.0000	−0.6869	***	−0.0243		0.0366	
	[0.103]		[0.1493]		[0.1149]		[0.1563]		[0.1613]	
Auction	0.4623	***	0.5468	***	0.3308	***	0.4480	***	0.4564	***
	[0.0369]		[0.0381]		[0.0403]		[0.0413]		[0.042]	
With time dummies	Yes		Yes		Yes		Yes		Yes	
With seller dummies	No		Yes		No		Yes		Yes	
With buyer dummies	No		No		Yes		Yes		Yes	
With seller-buyer dummies	No		No		No		No		Yes	
R^2	0.7332		0.7374		0.7527		0.7568		0.7602	
Adj. R^2	0.7330		0.7366		0.7520		0.7557		0.7582	

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error.

Appendix B. Econometric results from estimating the hedonic price models for haddock, dependent variable: Price

	Model A		Model B		Model C		Model D		Model E	
Variable	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.	Est.	NW S.E.
Intercept	6.2271	***	5.5668	***	5.5522	***	5.0342	***	5.1874	***
	[0.3303]		[0.354]		[0.3367]		[0.3727]		[0.3726]	
log (Daily-Quantity)	−0.0735	***	−0.0727		−0.0709	***	−0.0679	***	−0.0688	***
	[0.0196]		[0.0199]		[0.0191]		[0.0194]		[0.0194]	
log (Transaction-Quantity)	0.0927	***	0.0904	***	0.0637	***	0.0596	***	0.0621	***
	[0.0165]		[0.0168]		[0.0152]		[0.0155]		[0.0154]	
Fish-Size	−0.1578	**	−0.0992	*	−0.1424	**	−0.0821		−0.0723	
	[0.062]		[0.0614]		[0.0611]		[0.0606]		[0.0601]	
Quality-1	9.6969	***	9.6094	***	8.061	***	8.0146	***	7.9016	***
	[0.1966]		[0.1967]		[0.2196]		[0.2223]		[0.2198]	
Quality-2	6.7945	***	6.7977	***	5.2489	***	5.2939	***	5.2528	***
	[0.1525]		[0.1545]		[0.186]		[0.1913]		[0.1874]	
Longline	2.6369	***	2.9710	***	2.5938	***	2.7467	***	2.6585	***
	[0.0935]		[0.1676]		[0.1094]		[0.1818]		[0.1912]	
Danish-Seine	−0.9763	***	−0.5188	***	−0.8507	***	−0.4780	**	−0.3885	**
	[0.1127]		[0.1997]		[0.1245]		[0.1979]		[0.2063]	
Other fishing methods	0.9401	**	1.5587	***	1.0421	***	1.5095	***	1.4226	***
	[0.379]		[0.3981]		[0.3425]		[0.3658]		[0.3658]	
Auction	−0.0409		0.0437		0.2653	***	0.3323	***	0.3046	***
	[0.0664]		[0.0683]		[0.0702]		[0.0722]		[0.0743]	
With time dummies	Yes		Yes		Yes		Yes		Yes	
With seller dummies	No		Yes		No		Yes		Yes	
With buyer dummies	No		No		Yes		Yes		Yes	
With seller-buyer dummies	No		No		No		No		Yes	
R^2	0.7453		0.7510		0.7634		0.7682		0.7746	
Adj. R^2	0.7446		0.7492		0.7616		0.7654		0.7696	

Notes: ***, ** and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. NW S.E. represents Newey West standard error.

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