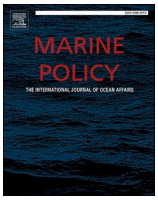
Marine Policy 144 (2022) 105223

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol



Large-scale fisheries during the COVID-19 pandemic: The case of the oceangoing groundfish fleet in Norway

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ARTICLE INFO

Keywords:
COVID-19
Large-scale fishing
Cod
Hedonic price

ABSTRACT

Small-scale fisheries have received most of the attention in the literature investigating negative impacts of the COVID-19 pandemic on seafood production. Larger fishing vessels are often perceived to be more resilient as they are better able to alter harvest patterns in response to supply shocks than smaller, less mobile vessels. In addition, larger fishing vessels often deliver storable frozen products contributing to resiliency. The supply and demand shocks caused by the COVID-19 pandemic provides an opportunity to test this hypothesis and is investigated here on the large-scale groundfish fleet in Norway. The results indicate that during the first two whole years of the pandemic the impact on price was small, but also that there were several secondary effects showing how negative shocks in some supply chains/markets are overcome.

1. Introduction

The seafood sector is exposed to various supply shocks such as stock changes and collapses and changing environmental conditions [1–3], sudden and unanticipated shifts in fisheries management [2,4], demand shocks such as trade wars [5,6], economic downturns [7,8], and exchange rate changes [9,10], affecting trade patterns and prices. Some fisheries have also been affected on the demand side by the rapid increase in aquaculture production [11,12] as exemplified by species such as tilapia and pangasius in the whitefish market [13,14]. However, the crisis caused by the COVID-19 pandemic was more extensive and comprehensive than previous shocks in shifting both supply and demand [15]. On the supply side, lockdowns led to reduced production due to their negative effects on the movement of crews and the hiring of manpower for the processing industry [16,17]. Substantial challenges were also found on the demand side as demand for seafood from the hotel, restaurant and catering sectors more or less disappeared and supply chains were disrupted in many countries when social distancing and lockdowns were adopted to prevent the spread of the virus [14–18].

Most empirical studies of how the pandemic and governmental measures to hinder the spread of the virus affected the seafood sector has focused on small-scale fisheries [4,19–23]. These studies generally show strong negative effects of the pandemic on fishers. For example, Bennett et al. [20] providing a broad review of the impacts of the pandemic on small-scale fisheries around the world found that many small-scale fisheries faced complete shutdowns or strong limitations on fishing activity. In the Northeast United States, the early phases of the pandemic left many fishers tied to the dock due to low prices and disruptions to exports and domestic markets [4]. White et al. [24] examining the US seafood sector, found declines in fresh seafood catches in 2020 of 40 % relative to the previous year. The Newfoundland and Labrador fisheries experienced a drastic reduction in fishing activity and income due to the nationwide and international lockdowns also affecting negatively the income and livelihood of people depending on the sale of seafood for a living [19].

Whereas these studies provide useful insights into the effects of the pandemic on small-scale fisheries, little attention has been given to how large-scale fisheries[1] was affected by and responded to the pandemic. This is a potentially important omission because large-scale fisheries are important for food security in that they supply raw materials for a variety of more shelf-stable products such as salted fish, dried salted fish, and frozen seafood, which are easily stored and are often shipped over

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[1] There are no universally accepted definitions of small- and large-scale fisheries and what may be considered small in one country or setting may be considered large in another [25,26]. In the context of the Norwegian groundfish fisheries focused on here we distinguish between smaller coastal vessels and large oceangoing vessels. The oceangoing fleet consists of trawlers and large conventional vessels fishing with longlines, gillnets and Danish seines.

https://doi.org/10.1016/j.marpol.2022.105223
Received 14 May 2022; Received in revised form 16 July 2022; Accepted 18 July 2022
Available online 20 July 2022
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longer distances. During the COVID-19 pandemic, the grocery retail sector has experienced strong growth in sales of frozen seafood [18]. However, little is known about whether and to what extent large-scale fisheries were able to take advantage of the apparent increase in demand, or if they were hampered by the various supply chain disruptions caused by the pandemic.

Impacts of COVID-19 on the wholesale prices of seafood products [27] and agricultural products [28,29] have been documented. On the one hand, the price changes downstream in general affect prices upstream in the supply chain.[2] On the other hand, suppliers in upstream may adopt various strategies to mitigate the negative impact of demand changes such as substituting which markets and supply chains are being served [30]. This feature is also of more general interest during the pandemic as the shocks associated with COVID-19 provides a strong test of the resilience of large-scale fisheries and thus also their role in food security. This is important because these fisheries have better mobility, provide more storable products and may be more flexible in terms of which markets and supply-chains are being served than smaller coastal vessels typically providing fresh seafood for local markets and restaurants.[3]

This study examines how the Norwegian large-scale oceangoing fleet fishing for Atlantic cod and other groundfish was affected by and adapted to the COVID-19 pandemic. The fleet which in 2020 consisted of 36 large bottom trawlers and 22 large oceangoing longliners,[4] mainly freezes the fish at sea as headed and gutted in 20- or 50-kg bags. The frozen cod is sold for further processing in Norway and worldwide. In 2019, the fleet landed approximately 131,000 tons of cod (in round weight) at an ex-vessel value of approximately NOK 3235 million.

The vessels are provided individual vessel quotas (IVQs) for cod and other key species, preventing a race to fish [35]. This means that fishers may try to optimize their cod fishing to seasonal changes in catchability, fish quality, demand, and prices while also considering the opportunity costs of fishing other species [36]. The frozen fish may also be stored in onshore cold storage plants, if for instance the fisher anticipates higher future prices. However, storage costs are incurred and fish quality decline over time, influencing prices negatively [33]. It should also be noted that since 2015 each vessel group have been allowed to transfer up to 10 % of their quotas for cod and haddock from one year to the next. As a response to the COVID-19 this was moved to the vessel level in 2020, and the possible quota transfer was increased to 15 % from 2021. Whereas these options indicate a complex decision environment, it gives fishers some leverage in terms of adapting to demand fluctuations or other disruptions such as those caused by the COVID-19 pandemic.

To examine how the fishery was affected by and responded to the pandemic we apply hedonic price models on a dataset containing details of 26,499 ex-vessel transactions for frozen Atlantic cod covering the last 7 years, including the two first whole years of the pandemic, 2020 and 2021. The frozen cod included in the study was sold through the Norwegian Fishermen's Sales Organization (NFSO), which records all transactions and provided the data for this study. The NFSO is the largest of three sales organizations for frozen cod in Norway, covering all landings in Northern Norway. To examine yearly price changes during the two first whole years of the pandemic (2020 and 2021) while controlling for the effect of factors such as season (month), fish size, lot size and fishing methods, the first hedonic model covers the whole sample period (2015–2021).

Further, to examine whether the apparent surge in demand for frozen seafood from grocery retailing during the pandemic influenced the demand and prices for fish of higher quality, we compare two models with different sample periods, that is, 2015–2019 versus 2020–2021 (17,985 versus 8514 transactions). This is relevant because it seems reasonable to assume that grocery retailers generally – but obviously with some variation – demand higher quality frozen fish than food service outlets such as cantinas in schools, hospitals, other public institutions, and low-end restaurants. In contrast to grocery retailing, many of these outlets were also closed during the first wave of the pandemic. We compare prices before and during the pandemic for key quality attributes such as fish size, storage time, quality grade, and fishing methods, which typically are very important in price formation in fish markets [33,37,38]. Interestingly, the vessel groups differ substantially in the quality of fish landed, with longliners providing fish of higher quality and gaining better prices compared to the more technically efficient trawlers and Danish seiners, but with substantially lower profitability [33].

The remaining part of the paper is organized as follows. Section 2 provide a description of the fishery, its management, and the ex-vessel market for frozen cod. Section 3 provides a preliminary analysis based on descriptive statistics and graphs, and Section 4 describes the hedonic models. The results are presented in Section 5 before conclusions are drawn in Section 6.

2. Background

2.1. The Norwegian groundfish fishery

The groundfish fishery is regulated on a single species basis with a total allowable catch (TAC) for the main groundfish species [35]. In round weight, the total landings of Atlantic cod averaged about 392 thousand tons between 2015 and 2019, which dropped to 331,553 tons in 2020 and rose again to 376,109 tons in 2021. The TAC is allocated to the different vessel groups based on gear type, target species and vessel sizes.[5] The size of individual vessel quotas is restricted and differs among vessel groups, with bottom trawlers holding the largest vessel quotas for cod and haddock. Quotas cannot be transferred between vessel groups but are 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 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 [39] but the number of landing locations has also been reduced [40].

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 or gillnets. 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 our data, 41 bottom trawlers sold frozen cod in 2021, up from 31 in 2019. 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, but some of the trawlers owned by a large vertically integrated company with onshore production, land cod that was caught the last 4–5 days of trips as fresh fish. In addition, the prices for frozen headed and gutted Atlantic cod have generally been higher than those for fresh fish [37]. The trawlers are not allowed to fish within 12 nautical miles of the Norwegian coastline.

The group of oceangoing longliners are allocated about 8 % of the

[2] A number of studies show a high degree of price transmission in seafood supply chains, in particular for products with a limited degree of processing [31].

[3] For instance, Love et al. [32] show how U.S. seafood sale is much more concentrated on a few mostly imported species for processed products, while there is much more diversity in terms of species in fresh sales.

[4] In addition, a fleet of large coastal vessels (> 28 m) using gillnets or Danish seines freezes a share of their catches [33,34].

[5] 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.

yearly Norwegian TAC for Atlantic cod and haddock. In our data, 29 longliners sold frozen cod in 2021, down from 30 in 2019. The longliners are not allowed to fish with trawls, but since 2018, they have been allowed to use Danish seines to fish their quotas for Atlantic cod, haddock, and saithe. In addition, gillnets are used to fish for saithe, as saithe is not a typical bottom feeder, making gillnets more effective than longlines. The 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. The oceangoing longliners freeze their catch on board as headed and gutted fish.

The group of large coastal vessels (above 28 ms in length) can use several types of gear, including longline, gillnets, Danish seine and purse seine but not trawl. The size of the quotas depends on the length of the vessel. Some of the vessels in this group freeze the fish on board, and these are mainly the newest and largest vessels. In our data, 8 vessels fishing with gillnets sold frozen cod in 2021, the same number as in 2019. For Danish seine fishing, 13 vessels sold frozen cod in 2021, up from 8 in 2019. Of the three vessel groups in focus here, this group has the greatest flexibility in terms of the choice of fishing method and few restrictions in terms of fishing areas.

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. 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 [41]. Longliners, however, are less technically efficient than bottom trawlers and Danish seiners. In addition, longlining has substantial costs of bait, which is not incurred by trawlers and seiners, implying higher costs of fishing.

2.2. The ex-vessel market

Catches from the larger vessels are landed at one of 14 independent cold storage plants spread along the coastline, from which buyers ship the lots by cargo vessels to processing plants in Norway or abroad [42] with China as the largest direct market with processing for re-exports as the main activity [43]. Given Norway's limited population, most of the landed fish is exported [44]. The fisher pays a weekly storage fee and the NFSO charges a service fee of 0.69 % of the sales value of frozen headed and gutted cod independent of sales mode. The fisher is free to choose between auction and direct sales [45]. The auction is conducted online on the NFSO's auction website, implying that physical inspection of the fish is not possible at the time of bidding. The auction is an English type of auction where the bidder with the highest bid at the closing time wins. The auction website is open for registered buyers and sellers, and entry is easy [46].

3. Data and preliminary analysis

The transaction data used in this study include all sales (auction or direct sales) of on-board frozen Atlantic cod between 2015 and 2021. Each transaction includes information such as the total weight of lots in kilograms, the type of vessel, average sizes of the fish, vessel name, buyer name, price, quality (regular or downgraded), storage time (days), and product form (H&G – headed and gutted – and others). The main types of vessels are oceangoing bottom trawlers and longliners as well as large coastal vessels using Danish seines. The rest is composed of small vessels fishing with different methods, such as gillnets, traps, and pots. In the sample, the total annual ex-vessel value of frozen Atlantic cod was between NOK 1.4 billion in 2015 and 2.4 billion in 2021.[6]

The annual transaction quantity during the sample period was about 57,737 tons in 2015 and 69,979 tons in 2021. The smallest annual transaction quantity was about 46,000 tones in 2019 and 2020, and the largest transaction quantity was in 2021. Fig. 1 illustrates the intra-annual variation in transaction quantities and prices for frozen cod for the period covered by the study by indexing the price and quantity to 100 in January 2015, and shows strong seasonality. The figure shows that a strong increasing trend in the price turned down in the first half of 2020 and that toward the end of 2021 prices were at the same level as before the pandemic. At the end of 2021, a strong increase in quantity can be observed. This is probably due to the increasing number of trawlers (up from 31 in 2019 to 41 in 2021) selling their catches through NFSO. In addition, large coastal vessels fishing with Danish seines increased their landings of frozen cod.

Usually, the trawlers spread their fishing for cod out over the year in contrast to the coastal fleet, but with the highest landing when the prices are the highest in the fall. Longliners usually concentrate their cod fishing during winter due to higher fish availability.

Because the fish is mainly frozen at sea,[7] it can be stored in onshore cold storage plants to adapt to market opportunities. Fig. 2 shows the average storage time by days. Prior to the pandemic, the average storage time for frozen cod was only 12 days [46]. This increased substantially from March 2020 but was reduced to normal levels in 2021. Longer storage time is associated with reduced fish quality, resulting in lower prices [46]. This indicates supply chain challenges or low demand during the early phase of the pandemic, and it shows that at least some fishers do use cold storage plants to adapt to market shocks.

Table 1 reports transaction characteristics by the type of vessels for the whole sample periods and subsamples of 2015–2019 and 2020–2021. For all the three types of vessels, the average prices increase substantially from the early subsample to the later subsample, due mainly to the price increase in 2021. Bottom trawlers have the most remarkable price growth, which can be explained by an increased share of fish sold through auctions (10.6 % increase for bottom trawlers) as well as the fact that the average fish size increased from 3.84 kg to 4.31 kg for bottom trawlers. The price premium in the auction market for all types of vessels and the positive impact of increased fish size on prices for bottom trawlers may also offset the negative impact of longer storage time, the small increase in downgraded fish, and smaller transaction quantities on average prices.

4. Hedonic price modeling

Hedonic price models are the most common approach to model the price effect of fine scale product attributes, and have been used in several seafood markets [38,47–50]. We apply three hedonic price regression models with different sample periods to examine how the COVID-19 pandemic affected prices in the largest ex-vessel market for frozen Atlantic cod in Norway. Model A includes transactions from 2015 to 2021 to examine yearly price changes during the two first whole years of the pandemic (2020 and 2021), while controlling for the effect of factors such as season (month), fish size, lot size, and fishing methods. To examine directly whether the pandemic influenced prices, we estimate models B and C with different sample periods; that is, 2015–2019 (B) and 2020–2021 (C) (17,985 versus 8514 transactions) to facilitate comparisons.

[6] The average exchange rate was NOK 1 = USD 0.1209/EUR 0.1071 in 2015 and NOK 1 = USD 0.1163/EUR 0.0856 in 2021.

[7] Some of the trawlers land cod that was caught the last 4–5 days of trips as fresh fish.

The hedonic price model is specified as:

$$\log(Price_i) = a_0 + a_1 Auction_i + a_2 \log(Transaction\_Quantity_i) + a_3 \log(Fish\_Size_i) + a_4 Quality_i + a_5 \log(Storage\_Time_i) + a_6 H\&G + f_1 Bottom\_Trawl_i + f_2 Longline_i + f_3 Danish\_Seine_i + \sum_{o=1}^{3} g_o Seller\_Quantile\_o_i + \sum_{o=1}^{3} h_o Buyer\_Quantile\_o_i + \sum_{o=1}^{k} y_o Year_o + \sum_{o=1}^{n} m_o Month_o + Residual_i$$

where *i* represents the transactions during the sample period; log is the logarithm function. *Price* is in NOK per kg. *Auction* is a dummy for sales by auction, with direct sales as the base. *Transaction-Quantity* is the transaction quantity in kilograms. *Fish-Size* is the average size of the fish in each lot. *Quality* is a dummy for cod with regular quality, with downgraded fish as the base. *Storage-Time* is the storage time in days. H&G is a dummy for headed and gutted cod, with other product forms as the base. *Bottom-Trawl*, *Longline*, and *Danish-Seine* are dummies for the three main fishing methods, with the other fishing methods as the base. The error term, *Residual,* captures other unobserved factors that affect prices.

In the model specifications, we also control for buyer and seller heterogeneity following previous literature [45,46,48] by grouping buyers and sellers into quantiles on the basis of transaction quantity. For either buyers or sellers, dummies for the 1st, 2nd, and 3rd quantiles are included in the model, with the 4th quantile (the largest buyers or sellers) being the base. The Appendix show summary statistics for variables by seller and buyer quantiles.

Table 2 reports summary statistics of the variables used in the three models. An interesting observation from the table is that the gear type Danish seine increased their share of the total sales quantity from 7.1 % before the pandemic to 11.3 %, as Danish seine is a gear often associated with poorer fish quality [33]. Table 2 also shows that the average price for cod was NOK 34.09 per kg during 2020–2021, 14.5 % higher than the average price during 2015–2019. As shown in Fig. 1, prices were lowest in the first few years of the whole sample period, and while peaking in 2019, they are still higher during the pandemic than early in our sample. Regarding fish quality indicators, the quality index (*Quality*), fishing methods, and fish size did not change much between the two periods. However, fish sizes increased substantially for bottom trawlers between the two sample periods, as discussed above. Similarly, the longer average storage time in the later period compared to the former period (11.5 versus 9.6 days) is mainly attributed to the increased storage time of cod supplied by bottom trawlers.

5. Empirical results

The regression results are reported in Table 3. The adjusted R^2 values range between 0.65 (Model C) and 0.85 (Model B), indicating a great goodness of fit with the data. Model A in Table 3 shows that the estimates of the year dummies increase until 2019. This means, after controlling for fish size, fishing methods, monthly seasonality, and so on, prices rose steadily until 2019 when prices are almost 42 % higher than in 2015 (the base). In 2020 prices dropped by about 17 % compared to 2019 and dropped further with about 3 % from 2020 to 2021 when controlling for other product attributes. Hence, while the upward price trend was broken in 2020, most likely due to the increased landings in Norway as well as among other harvesting nations, the prices during the

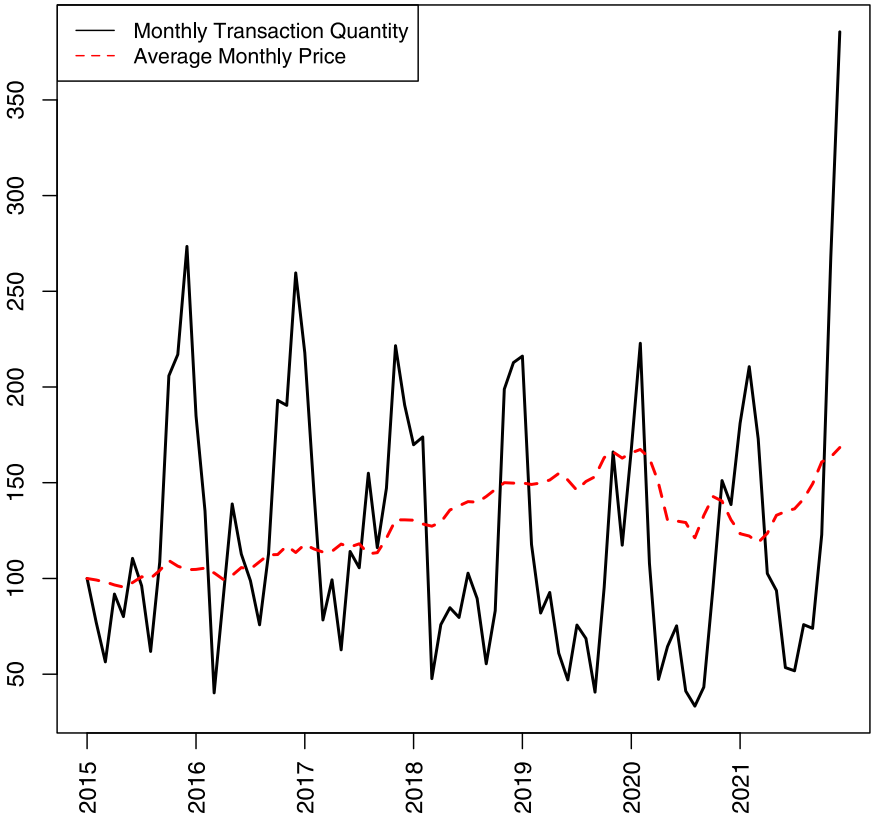

Fig. 1. Indexes of average monthly prices and monthly transaction quantity (Jan/2015 = 100).

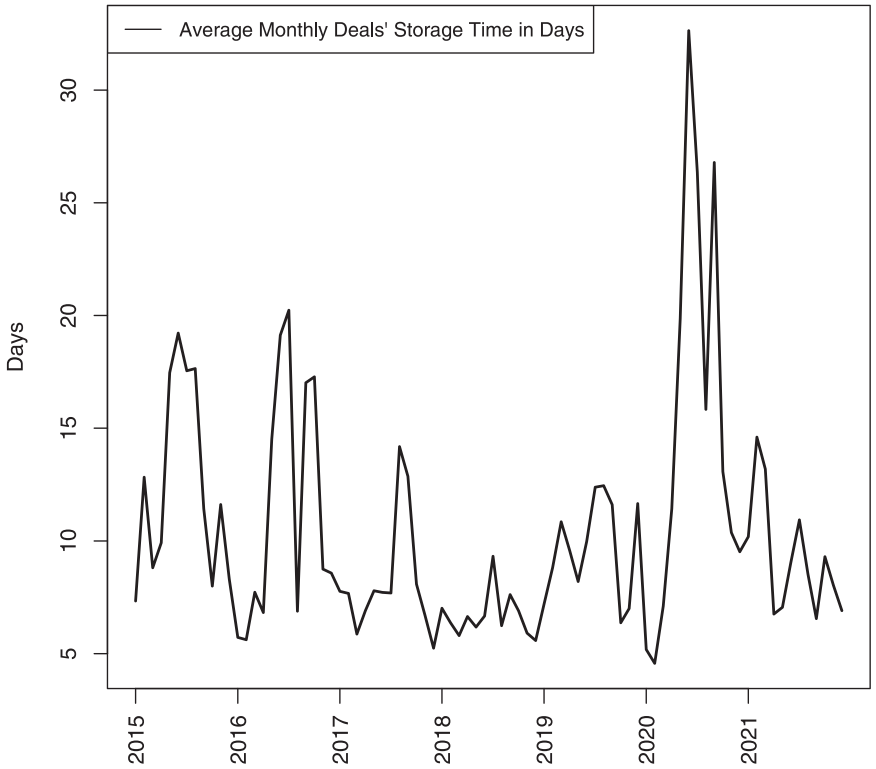

Fig. 2. Average storage time of cod in days.

Table 1
Transaction characteristics by fishing methods.

Variable	Bottom-trawlers	Longliners	Danish-Seiners
2015–2021			
Price (NOK/kg)	30.40	34.01	29.29
Share of auction (%)	36.6	43.9	57.8
Transaction quantity (kg)	16,311	15,096	6205
Fish size (kg)	3.50	3.93	2.99
Share of cod of regular quality (%)	87.9	99.8	94.7
Storage time (in days)	10.93	6.02	15.94
Share of H&G (%)	99.7	99.9	96.3
Landing quantity (tons)	40,613	40,360	41,246
2015–2019			
Price (NOK/kg)	26.97	29.11	32.22
Share of auction (%)	56.6	36.3	42.3
Transaction quantity (kg)	16,609	16,793	15,924
Fish size (kg)	3.84	3.50	3.95
Share of cod of regular quality (%)	98.7	88.8	99.9
Storage time (in days)	5.90	10.57	5.73
Share of H&G (%)	100.0	99.7	99.9
Landing quantity (tons)	13,123	13,372	12,502
2020–2021			
Price (NOK/kg)	33.54	33.27	38.00
Share of auction (%)	67.2	37.4	47.3
Transaction quantity (kg)	15,397	15,241	13,253
Fish size (kg)	4.31	3.49	3.89
Share of cod of regular quality (%)	93.2	85.8	99.7
Storage time (in days)	19.98	11.73	6.67
Share of H&G (%)	100.0	99.7	99.9
Landing quantity (tons)	1985	1781	2495

Table 2
Summary statistics.

	Model A (2015–2021)		Model B (2015–2019)		Model C (2020–2021)	
Variable	Mean	SD	Mean	SD	Mean	SD
Price (NOK/kg, in log)	3.414	0.217	3.371	0.201	3.505	0.223
Auction	0.407	0.491	0.399	0.490	0.425	0.494
Transaction-Quantity (kg, in log)	8.098	2.080	8.188	2.048	7.907	2.135
Fish-Size in log	1.014	0.766	1.020	0.760	1.001	0.779
Quality	0.914	0.280	0.920	0.271	0.902	0.297
Storage-Time (days in log)	1.705	1.020	1.684	0.992	1.748	1.077
H&G	0.995	0.073	0.994	0.074	0.995	0.071
Bottom-Trawl	0.659	0.474	0.669	0.471	0.637	0.481
Longline	0.230	0.421	0.234	0.423	0.222	0.416
Danish-Seine	0.085	0.278	0.071	0.257	0.113	0.317
Price	31.102	6.598	29.686	5.734	34.094	7.270
Transaction-Quantity	15,174	28,013	15,889	29,076	13,665	25,558
Fish-Size	3.567	2.352	3.576	2.345	3.550	2.366
Storage-Time	10.212	18.943	9.623	17.797	11.457	21.108

Table 3
Regression results.

	Model A (2015–2021)			Model B (2015–2019)			Model C (2020–2021)		
Variable	Estimate	SE		Estimate	SE		Estimate	SE	
Intercept	2.8920	0.0125	***	2.9162	0.012	***	3.1710	0.0190	***
Auction	0.0208	0.0015	***	0.0051	0.0014	***	0.0416	0.0032	***
Transaction-Quantity	0.0060	0.0003	***	0.0056	0.0003	***	0.0083	0.0007	***
Fish-Size	0.1080	0.001	***	0.0811	0.0008	***	0.1662	0.0021	***
Quality	0.2160	0.0042	***	0.2168	0.0051	***	0.1983	0.0075	***
Storage-Time	-0.0140	0.0007	***	-0.0075	0.0008	***	-0.0266	0.0014	***
H&G	-0.0194	0.0102		-0.0285	0.0094	***	0.0170	0.0121	
Bottom-Trawl	0.0195	0.0042	***	0.0093	0.0034	***	0.0378	0.0095	***
Longline	0.0796	0.0041	***	0.0686	0.0034	***	0.0953	0.0095	***
Danish-Seine	-0.0275	0.0047	***	-0.0308	0.004	***	-0.021	0.0109	**
Buyers: 1st quantile	-0.1126	0.0148	***	-0.0395	0.0109	***	-0.1898	0.0241	***
Buyers: 2nd quantile	-0.0579	0.0058	***	-0.0285	0.0049	***	-0.0725	0.0069	***
Buyers: 3rd quantile	-0.0234	0.0025	***	-0.0048	0.0022	**	-0.0258	0.0040	***
Sellers: 1st quantile	-0.0124	0.0041	***	-0.0006	0.0027		0.0079	0.0075	
Sellers: 2nd quantile	0.0008	0.0025		0.0013	0.0022		0.0240	0.0061	***
Sellers: 3rd quantile	0.0052	0.0020	***	0.0048	0.0015	***	0.0390	0.0039	***
January	-0.0993	0.0031	***	-0.0998	0.003	***	-0.0876	0.0067	***
February	-0.1061	0.0032	***	-0.1065	0.0024	***	-0.1138	0.007	***
March	-0.1194	0.0037	***	-0.0998	0.0027	***	-0.1534	0.0075	***
April	-0.1107	0.0033	***	-0.0862	0.0029	***	-0.1690	0.0076	***
May	-0.0859	0.0030	***	-0.0707	0.0028	***	-0.1130	0.0063	***
June	-0.0716	0.0030	***	-0.0453	0.0029	***	-0.1212	0.0063	***
July	-0.0578	0.0029	***	-0.0352	0.0025	***	-0.1211	0.0071	
August	-0.0477	0.0031	***	-0.0298	0.0025	***	-0.0885	0.0073	
September	-0.0373	0.0031	***	-0.0212	0.0025	***	-0.0709	0.0070	
October	-0.0077	0.0029	***	0.0003	0.0026		-0.0259	0.0065	***
November	0.0016	0.0027		0.0088	0.0021	***	-0.0190	0.0058	***
Year-2016	0.0586	0.0020	***	0.0614	0.0019	***			
Year-2017	0.1484	0.0020	***	0.1531	0.0019	***			
Year-2018	0.3090	0.0023	***	0.3156	0.002	***			
Year-2019	0.4246	0.0020	***	0.4293	0.0018	***			
Year-2020	0.3519	0.0030	***						
Year-2021	0.3200	0.0025	***				-0.0427	0.0033	***
Adj.R^2	0.7649			0.8532			0.6462		

Notes: ***, **, and * indicate significance at the 0.01, 0.05 and 0.10 level, respectively. Robust standard errors are in parentheses.

two pandemic years are higher than all the previous years but 2019.[8] The lower average price when controlling for other attributes in 2021 compared to the price in 2020 is a strong indication of significant shifts in landing patterns given that the nominal average price is higher in 2021.

The changes in price over time are confirmed when comparing Models B and C. While Model B confirms a steadily upward price trend during 2015–2019, Model C shows a price reduction of 4.27 % from 2020 to 2021, holding other variables constant. This confirms that the price increase from 2020 to 2021 shown in Fig. 2, is explained by changes in the variables included in Model C. Thus, a likely explanation for this is that demand for high quality fish increased leading to higher prices, but also that fishers adapted their fishing and timing of sales to changes in demand and prices – particularly by avoiding sales during the first phase of the pandemic.

For monthly seasonality, most of the coefficients of the month dummies in the three models are negative, indicating that prices were highest in December (the base), in line with earlier studies [37,55]. Different from Models A and B, the estimates of dummies for July–September in Model C are insignificant, indicating some impact of COVID-19 on the price seasonal pattern.

For all the three models, the estimates of the 1st, 2nd, and 3rd quantile dummies for buyers are negative and decline monotonically in absolute terms, indicating that the smaller the buyer, the larger the price discount. Each of the estimates in absolute values in Model B is smaller than the counterpart in Model A; the opposite is true for Model C. This implies a huge increase in price discounts for the smaller buyers from the period before the pandemic (Model B) to the two first whole years of the pandemic (Model C), i.e., 18.98 % versus 3.95 % for the smallest buyers in the 1st quantile, 7.25 % versus 2.85 % for the buyers in the 2nd quantile, and 2.58 % versus 0.48 % for the buyers in the 3rd quantile.

For the quantile dummies for sellers, the estimates are different in the three models. The 1st quantile dummy for the smallest sellers is significant and negative in Model A but not significant in the other two models. The 2nd quantile dummy for sellers is only significant and positive in Model C. However, the 3rd quantile dummy for sellers is significant and positive in all the three models. The significant estimates are much larger in Model C than in Models A and B. For Model C, the group with the smallest sellers (1st quantile) does not differ from the largest sellers (4th quantile, the base). However, the average price, ceteris paribus, is 2.4 % higher for the 2nd quantile seller group and 3.9 % higher for the 3rd quantile seller group, both relative to the largest sellers in the 4th quantile (the base).

Comparing Model B for the sample preceding the pandemic and Model C for 2020 and 2021 shows several interesting findings. The price premium for auction sales is only 0.51 % compared to direct sales in Model B. But this premium increases to 4.16 % in Model C, indicating increased buyer participation in auctions [46]. The estimated coefficient for *Fish-Size* increases 105 % from Model B (0.0811) to Model C (0.1662), indicating an increase in demand for larger fish during the pandemic.

Storage time has a significant and negative effect on prices, which may be explained by the fact that storage time influences the quality of cod negatively [45]. The negative effect of storage time on price increased during the pandemic (− 0.0075 in Model B versus − 0.0266 in Model C). The estimates for dummies for the types of vessels, signaling fish quality, changed in favor of the three primary methods. Compared with other fishing methods,[9] the price premium for longliner, which usually provides the best quality fish [33,41,56], increased from 6.86 % in Model B to 9.53 % in Model C, an growth rate of about 38.9 %. Although the price premium for bottom trawl increases to 3.78 % from a negligible value before the pandemic, it is still much lower than price premium for cod caught by longline. The discount for cod caught with Danish seines dropped from − 3.08 % in Model B to − 2.1 % in Model C.

The estimate for the quality dummy (*Quality*) decreases marginally from 0.217 in Model B to 0.198 in Model C, indicating a similar price premium for cod of regular quality for the two subsample periods.

6. Conclusions

Larger fishing vessels are often perceived to be more resilient as they are better able to alter harvest patterns in response to supply shocks than smaller, less mobile vessels. The supply and demand shocks caused by COVID-19 provide an opportunity to test this hypothesis as several studies have reported significant negative effects for small-scale fisheries. In this paper we investigate the impacts of COVID-19 using a hedonic price equation as well as supporting descriptive data analysis for large-scale Norwegian cod fisheries.

The results largely support the resilience hypothesis. There are no significant negative impacts of COVID-19 on the cod price. In fact, the price was higher in 2020 and 2021 than in all years of the dataset but 2019. The moderate price decline from 2019 is attributable to the increased landings. This suggest that in aggregate, demand for Norwegian cod has held up well during the pandemic, and as such, to the extent there has been supply chain challenges these have been addressed by shifting the fish to alternative supply chains.

However, there are several smaller impacts of COVID-19 that shows how the industry is resilient by adopting to negative shocks. Initially, there is a strong increase in the time the cod spend in storage, suggesting that it takes time to find new market opportunities to replace those exposed to negative shocks. The changed market conditions also appear to have made supplying higher quality more profitable suggesting that there are incentives within the Norwegian system for supplying quality at least under some circumstances [33]. Finally, while not studied directly here, the increased landings of frozen cod by the large coastal vessels suggest that the frozen market contributes to resilience also for the smaller vessels by shifting quantities away from the fresh market which is the main market for smaller coastal vessels.

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.

Data Availability

The authors do not have permission to share data.

Acknowledgements

Funding from the Research Council of Norway (#302197 and #324685) is acknowledged.

[8] There is a global market for cod [51–54], and as such Norway's landing cannot in itself explain larger price movements. However, as there is a common quota setting process in the northeast Atlantic, the quota movements for other important harvesting nations like Russia will be highly correlated with the Norwegian quota.

[9] Several other fishing methods were used, such as traps and pots. These are treated as one group and used as a base category for comparisons with bottom trawl, longline, and Danish seine.

Appendix. Summary statistics of variables by seller or buyer quantiles

Buyer/Seller group	Price in log	Auction	Transaction Quantity in log	Fish-size in log	Quality-A	Storage-time in log	H&G	Bottom-Trawl	Longline	Danish-Seine	Price (NOK/kg)	Transaction-quantity (kg)	Fish-size (kg)	Storage-time (days)
Model A (2015–2021)														
Buyers: 1st quantile	3.18	0.55	6.13	0.94	0.46	2.13	1	0.64	0.23	0.12	25.6	2259.57	3.23	19.99
Buyers: 2nd quantile	3.35	0.68	7.27	1.24	0.89	1.95	0.99	0.57	0.26	0.15	29.35	8004.38	4.38	14.79
Buyers: 3rd quantile	3.34	0.54	7.72	1.11	0.83	1.79	1	0.65	0.2	0.1	29.16	11,006.08	3.94	10.82
Buyers: 4th quantile	3.43	0.38	8.19	1	0.93	1.68	0.99	0.66	0.23	0.08	31.47	16,052.21	3.5	9.92
Sellers: 1st quantile	3.38	0.52	7.22	0.99	0.96	2.08	0.99	0.35	0.32	0.32	30.13	6529.78	3.43	17.45
Sellers: 2nd quantile	3.42	0.49	7.93	1	0.98	1.74	0.99	0.27	0.48	0.2	31.19	11,252.09	3.48	11.24
Sellers: 3rd quantile	3.4	0.49	8	0.99	0.94	1.74	0.99	0.31	0.32	0.29	30.8	13,724.86	3.46	11
Sellers: 4th quantile	3.42	0.37	8.2	1.02	0.9	1.67	1	0.82	0.17	0	31.24	16,574.34	3.61	9.42
Model B (2015–2019)														
Buyers: 1st quantile	3.35	0.66	6.46	1.33	0.74	1.81	1	0.53	0.33	0.13	29.95	2872.18	4.6	11.15
Buyers: 2nd quantile	3.3	0.6	7.76	1.08	0.93	1.92	0.99	0.69	0.19	0.09	27.58	10,307.58	3.89	12.45
Buyers: 3rd quantile	3.32	0.66	7.49	1.08	0.69	1.83	1	0.71	0.16	0.1	28.52	9972.57	3.68	10.86
Buyers: 4th quantile	3.38	0.33	8.38	1	0.97	1.64	0.99	0.66	0.25	0.06	30	17,533.29	3.53	9.25
Sellers: 1st quantile	3.34	0.5	7.6	1.02	0.95	2.14	0.96	0.43	0.32	0.24	28.83	8362.41	3.58	17.8
Sellers: 2nd quantile	3.39	0.5	8.02	1	0.97	1.72	0.99	0.2	0.48	0.29	30.13	12,079.8	3.46	11.16
Sellers: 3rd quantile	3.38	0.49	8.15	1.01	0.94	1.68	1	0.33	0.37	0.18	29.94	14,808.78	3.5	10.12
Sellers: 4th quantile	3.37	0.35	8.26	1.03	0.91	1.65	1	0.84	0.16	0	29.62	17238	3.61	8.69
Model C (2020–2021)														
Buyers: 1st quantile	3.22	0.4	5.89	1	0.58	2.4	1	0.51	0.23	0.25	26.83	975.59	3.5	32.1
Buyers: 2nd quantile	3.48	0.66	7.35	1.21	0.83	1.86	1	0.39	0.47	0.11	33.45	6172.75	4.47	13.8
Buyers: 3rd quantile	3.47	0.62	7.14	1.12	0.72	1.83	1	0.62	0.14	0.18	33.02	6759.4	3.97	11.12
Buyers: 4th quantile	3.52	0.34	8.24	0.95	0.97	1.7	0.99	0.66	0.23	0.09	34.63	16,713.38	3.35	11.04
Sellers: 1st quantile	3.51	0.53	7.32	0.99	0.96	1.91	1	0.34	0.45	0.16	34.54	6081.81	3.44	17.9
Sellers: 2nd quantile	3.48	0.49	7.4	0.96	0.94	1.86	0.98	0.14	0.25	0.58	33.37	8821.91	3.32	13.05
Sellers: 3rd quantile	3.57	0.45	7.95	1	0.93	1.65	1	0.41	0.47	0.05	36.23	14,051.68	3.56	9.49
Sellers: 4th quantile	3.49	0.39	8.08	1.01	0.88	1.74	1	0.87	0.11	0.01	33.53	15,449.94	3.61	11.12

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