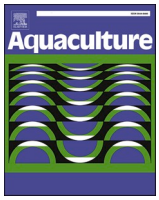
Aquaculture 572 (2023) 739520

Contents lists available at ScienceDirect

Aquaculture

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



Is capture-based aquaculture viable? The case of Atlantic cod in Norway

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ARTICLE INFO

Keywords:
Atlantic cod
Capture based aquaculture
Price premium

ABSTRACT

Capture-based aquaculture (CBA) is an important branch of the aquaculture industry that differs from closed cycle farming in that the stocking material consists of captured wild fish or other aquatic organisms. By skipping the difficult early production stages of fish farming, producers can test whether assumed market advantages such as high quality and consistent supply result in higher prices – and whether these are high enough to incentivize further development of CBA and eventually close the production cycle. CBA-initiatives can also be supported by different policy measures to stimulate the activity. Since these measures involve costs, it is important to know at what level and for how long these measures should be implemented to promote economically sustainable CBA activities. We study CBA of Atlantic cod (*Gadus morhua*) in Norway and find an average price premium of 26% compared to wild harvested cod, but with large interannual variation. However, declining quantities of cod from CBA following reductions in a quota bonus scheme to stimulate activity, indicates that the price premium is not sufficiently large to incentivize further development of the CBA branch of the Norwegian cod industry.

1. Introduction

Aquaculture can be defined as taking control of a part of an aquatic organism's production process to enhance productivity (Klinger et al., 2013). This may occur at any stage of the production process from protecting juveniles, as exemplified by salmon hatcheries in Alaska (Klinger et al., 2013), to harvesting larger individuals for fattening and adaption to market conditions as with bluefin tuna (Shamshak and Anderson, 2009), or by providing protection at later life stages such as oyster farming based on wild seeds (Botta et al., 2020). It is quite common for an aquaculture industry to initially focus on one part of the production process and gradually increase the number of stages in which farmers exercise control until the production cycle is closed. A closed production cycle makes an industry independent of wild resources of the same species and is the mode of operation for most mature aquaculture industries as it provides the greatest scope for innovation and further productivity growth (Asche, 2008).

When a producer tries to take control of a part of the production process, one would expect that such an activity is undertaken only if the producers expect the process to be profitable. Hence, while the revenue potential might be greatest when taking control of the most critical parts of the production process, often associated with early life stages, this may be moderated by the costs associated with taking control of a particular stage. Bluefin tuna is one example of a species where the difficulties associated with early life stages contributed to such high costs that the current aquaculture practices focus on fattening larger fish (Shamshak, 2011). Cod in Norway is another example. In the early 2000s a closed aquaculture sector blossomed with rapid production growth. However, production peaked in 2010 (Puvanendran et al., 2022) as the economic performance of the industry was unsustainable due to excessively high production costs associated with low survival rates and escapees (Treasurer et al., 2011), too early sexual maturity (Skulstad et al., 2013) resulting in reduced growth rate and increased feed conversion ratio before reaching marketable size (Björnsson et al.,

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https://doi.org/10.1016/j.aquaculture.2023.739520
Received 8 December 2022; Received in revised form 21 March 2023; Accepted 24 March 2023
Available online 25 March 2023

2012), and several challenges related to fry quality and diseases (Puvanendran et al., 2022; Nardi et al., 2021).

Cod is the most important fishery in Norway by value and plays an important role in the provision of jobs and value creation in coastal communities (Cojocaru et al., 2019; Iversen et al., 2020; Nielsen et al., 2022). Moreover, it is a species where the regulatory system, due to regional policy considerations, is promoting a small-scale coastal fleet (Standal and Aarset, 2008). This leads to a highly seasonal landing pattern[1] (Birkenbach et al., 2022; Cojocaru et al., 2019) and the use of efficient but quality reducing gear choices and fishing practices (Sogn-Grundvåg et al., 2022) leading to significant exports of unprocessed frozen cod to China (Asche et al., 2022a), despite there being a higher valued market for cod year around (Birkenbach et al., 2020).[2] While the coastal fleet does not appear to respond strongly to quality incentives (Sogn-Grundvåg et al., 2021), there is considerable evidence that there are price premiums for cod of a higher quality at the ex-vessel level (Asche et al., 2015a; Pettersen and Asche, 2020; Sogn-Grundvåg and Hermansen, 2022) as well as the retail level (Asche et al., 2015b; Bronnmann and Asche, 2016; Sogn-Grundvåg et al., 2013, 2014).

Following the decline of the closed cycle cod farming industry in the late 2000s, an industry developed in Norway in which mature wild-caught cod is stored and fed in pens, strongly supported by regional policy tools (Bertheussen et al., 2020; Dreyer et al., 2008; Sønvisen and Standal, 2019). Compared to closed cycle farming of cod, capture-based aquaculture (CBA) has the advantage that the various biological challenges in the early life-stages of cod farming are skipped. However, both cod farming and CBA have several advantages over the highly seasonal landings of wild cod by the Norwegian coastal fleet,[3] as cod can be sold when fresh landings of wild cod are low and prices high due to the seasonal variations in landings (Bertheussen et al., 2020). CBA of cod helps processors avoid factors that negatively affect fish quality in the wild harvest industry such as fishing practices that reduce quality (Sogn-Grundvåg et al., 2022). In addition, farming and CBA offers processors many opportunities for production planning and, most importantly, more consistent product supply, which is important in serving large retail chains (Asche and Smith, 2018). However, the extent to which these advantages are exploited with CBA produced cod, whether they lead to price premiums and how large they are compared to conventionally harvested cod, has received little attention. This is of interest for the future of the industry as well as the potential to again try closed cycle production of cod and therefore a more advanced cod aquaculture industry. The results will also shed light on the price discount imposed on the wild harvest industry by fishing practices that does not allow the most valuable market segments to be targeted.

This study estimates a hedonic price function that distinguishes cod from CBA from conventionally harvested cod, using a comprehensive dataset provided by the Norwegian Fishermen's Sales Organization (NFSO). Additionally, to gain a better understanding of all aspects of how CBA for cod is practiced, and to what extent the industry tries to exploit the advantages of CBA indicated above, we also elicit expert knowledge through interviews with fishers and fish buyers, all of whom have substantial experience with CBA for cod.

The paper is organized as follows: In the next section a background is provided where the wild fisheries are reviewed together with the development of CBA for cod in Norway. Here, the organization of the ex-vessel market and data are also described. This is followed by a section outlining the econometric models. Finally, empirical results are presented and discussed.

2. Cod production and capture-based aquaculture in Norway

Atlantic cod (*Gadus morhua*) has been one of the most important species in Norwegian fisheries for centuries (Hannesson et al., 2010), and with Norway's limited population, most of the fish is exported (Straume et al., 2020). The Cod fishery is regulated on a single-species basis with a total allowable catch (TAC) for the main species. The fishing fleet participating in the cod fishery is diverse, ranging from small coastal vessels fishing using gillnets and various lines delivering fresh catches to local fish plants daily, to large oceangoing bottom trawlers and long-liners that freeze most of their catch at sea (Cojocaru et al., 2019; Sogn-Grundvåg et al., 2020).

As noted above, the coastal cod fishery has a strong seasonal profile. A consequence is that most of the landings must be preserved before being exported (Straume et al., 2020; Asche et al., 2022a). Common negative effects of the strong seasonality in the cod fisheries in Norway are idle production capacity and laid-off workers outside the main season, and reduced fish quality and lower prices in the high season.

To mitigate the negative market impacts of high seasonality, different schemes have been included in the cod management system. For example, rural community quotas where a share of the TAC is allocated to specific local communities who in turn distribute quotas to selected vessels, provided that the cod is landed fresh in the low season (Hermansen and Dreyer, 2010). The policy's goal is to secure employment in vulnerable areas by improving the raw fish supply during the low season. Another scheme is the quota bonus scheme used to incentivize CBA of cod which is described in more detail below.

CBA of cod has a long history, dating back to the 1880s when Norwegian and foreign sailing vessels stored the fish alive onboard when nearing the end of trips (Hermansen, 2018). The fish was landed live in Grimsby in England and achieved high prices compared to the salted cod produced to preserve the fish during the long trips (Hermansen, 2018). However, until recently, live storage of cod has not reached any significant quantities. But after the turn of the millennium, improved fishing practices and innovative technology in storage facilities led to better survival rates. To increase CBA, a quota bonus scheme acting as a subsidy was introduced in 2008. Vessels landing cod for CBA would only be deducted 80% of the weight of the fish from the vessel's cod quota with up to 200 tons allocated from the TAC for this scheme, implying a bonus of 20% additional cod quota. As this did not have the desired effect, the bonus was increased to 50% with up to 4000 tons allocated from the TAC in 2013. This led to a strong increase in live storage. However, the bonus was not popular among fishers not engaged in CBA as their quotas was reduced with increasing CBA activity. In 2019 the bonus was reduced to 40% and further to 30% in 2020, with reduced allocations from the TAC. Live storage of cod peaked in 2018 with about 6980 tons of cod from CBA and with a declining trend after that, coinciding with the reduced quota bonus.

The regulatory framework for CBA is linked to both traditional fisheries and aquaculture.[4] In terms of live storage, the CBA regulations require that the cod is stored live for at least one week for the quota bonus to kick in. In addition, the fish must be fed after four weeks. If the fish is to be stored live for >12 weeks, the CBA operators must comply with the regulations of the Aquaculture Act and obtain an aquaculture

[1] During the first quarter of the year, mature cod migrate from the Barents Sea to the coast of northern Norway on its yearly spawning run. In this period the fish is available for the coastal fleet which land approximately 75% of their yearly catches in February, March and April (Hermansen and Dreyer, 2010).

[2] These are consequences that can be avoided with a different management system and fleet structure (Knútsson et al., 2016).

[3] Approximately 75% of the fresh wild cod is landed in the first quarter of the year (Hermansen and Dreyer, 2010).

[4] For a detailed review of how these legislations impose restrictions for CBA operations, see Sønvisen and Standal (2019).

license.[5] Generally, this is more demanding and costly compared with the CBA regulations due to additional requirements. For example, the Aquaculture Act has stricter requirements regarding slaughtering, and slaughter must take place in a plant licensed for aquaculture rather than a wild harvest processing plant (Dreyer et al., 2008).

The main fishing gear used for CBA of cod in Norway is demersal seine.[6] When fishing for live-storage, small hauls are required to limit gear damage to the fish (Humborstad et al., 2016). The fish is pumped onboard the vessel and into large storage tanks with circulating seawater.[7] An important reason for the success in using seines for CBA of cod is that cod has a mechanism for healing swim bladder ruptures caused by positive buoyancy during hauling (Humborstad et al., 2016; Midling et al., 2012). Experimental trials indicate that after about 24 h, cod with punctured swim bladders has recovered (Humborstad and Mangor-Jensen, 2013). Thus, vessels may let the cod rest for about 24 h in the onboard holding tanks before they set the sein again, which means that 4–5 days may be needed to fill the vessel's storage capacity for live cod, contributing to high harvesting costs.

After the fish is transferred to storage pens, which are usually owned by buyers, there is large variation in the time before the buyer purchases the fish. For example, one large buyer usually purchases the fish on the 1st of June every year, which means that fishers may have owned the fish for up to the 12-weeks. For the fisher this implies slow cash flow, and they risk that some fish will die, escape the pens, or feed poorly during storage reducing the total weight of the initial catch and the quota bonus. On the other hand, the fish buyer covers the storage and feeding costs.

Despite being a versatile raw material of high quality that can be used in a range of products, the cod from CBA is, with some exceptions,[8] exported as fresh whole fish and mainly used to fulfill delivery contracts with supermarket chains when the supply of fresh wild cod drops from May and onwards. Key markets for the CBA cod are France and Spain. Fig. 1 shows average monthly prices of wild harvested cod and CBA cod for the period 2015–2020. The figure clearly indicate that the average CBA prices are higher than for wild caught cod. An interesting feature with CBA practices is that fishers and fish buyers typically sign delivery contracts with fixed prices for the entire season, in contrast to wild harvest where prices are negotiated for each landing.

3. Data and empirical specification

For the econometric analyses, we use transaction data for ex-vessel sales of Atlantic cod. Only fresh cod from Finmark in the northeast to Lofoten in the south was used for the analysis, as virtually all the CBA cod is produced in this area. The data consist of 983,569 transactions over a six-year period (2015–2020), covering all landings of wild-caught cod and cod from CBA. The data includes detailed information regarding each transaction such as the date, the weight of each lot, the average size of fish, the payment for the lot in NOK, a quality index, and whether the cod was landed directly or stored live. For each transaction, the price was calculated by dividing the real value of sales by the live weight. The price was deflated using the monthly Producer Price Index (PPI) from the Central Bank of Norway. Information about the fishing gear applied, an important quality indicator usually affecting prices (Asche et al., 2015a; Pettersen and Asche, 2020; Sogn-Grundvåg et al., 2020; McConnell and Strand, 2000), is also included in the data. Table 1. shows descriptive statistics for the variables included in the analyses. The statistics are calculated with the average real price in NOK per kg.

We examine the impact of the different product attributes by estimating a hedonic price function (Rosen, 1974). The approach has been frequently applied when investigating the influence of various product attributes on the seafood price at different stages of the seafood supply chain, in particular at the landing level (Asche et al., 2015a; Blomquist et al., 2015; Carroll et al., 2001; Fernández Sánchez et al., 2020; Gobillon et al., 2017; Lee, 2014; McConnell and Strand, 2000; Wolff and Asche, 2022) and the retail level (Ankamah-Yeboah et al., 2016; Asche et al., 2015b, 2021; Bronnmann and Asche, 2016; Roheim et al., 2011; Sogn-Grundvåg et al., 2014, 2013).

For finding the appropriate functional form, we applied the Box-Cox test (Box and Cox, 1964). Specifically, we fit the model with the transformed dependent variable to test if a level or log-linear specification fits the model better. The test indicates that a linear specification is the most appropriate. Thus, we follow Bronnmann and Asche (2016) and estimate a linear specification. The level specification can be written as (Model 1):

$$P_{it} = a + \sum_{j=2}^{J} b_j quota_{jit} + \sum_{k=2}^{K} \gamma_k quality_{kit} + \sum_{l=2}^{L} \delta_l gear_{lit} + \sum\nolimits_{P=2}^{P} \vartheta_p quarter_{pit} + \sum_{r=2}^{R} \tau_r year_{rit} + e_{it}, \quad (1)$$

where P_{it} is the deflated price of product i at time t, b_j is a vector of quota that influence the price, γ_k is the vector of different cod qualities, δ_l is the vector of different gears and ϑ_p and τ_r are vectors for the quarters and years. e_{it} is a stochastic error term. In this analysis, the attributes are dummy variables as shown in Table 1. Expressing the attributes as dummy variables follows established practice in the literature (Asche et al., 2021; Bronnmann and Asche, 2016; Carroll et al., 2001; McConnell and Strand, 2000; Roheim et al., 2011, 2007). In addition, we include yearly and monthly dummy-variables to account for time patterns.

Interaction effects can be used to model relationships that vary over time (Asche et al., 2015b). As we are interested in the development of the live quota bonus over the years, we also estimate the model including live quota year interactions (Model 2).

$$P_{it} = a + \sum_{j=2}^{J} b_j quota_{jit} + \sum_{k=2}^{K} \gamma_k quality_{kit} + \sum_{l=2}^{L} \delta_l gear_{lit} + \sum\nolimits_{P=2}^{P} \vartheta_p quarter_{pit} + \sum_{r=2}^{R} \tau_r year_{rit} + \sum_{s=2}^{S} \rho_s year_{sit} * live\ bonus\ quota_{it} + e_{it}, \quad (2)$$

In both models, the Breusch-Pagan and White test for heteroscedasticity results in a rejection of the null hypothesis of no heteroscedasticity, indicating that the variance of the errors cannot be assumed to be constant. Consequently, robust standard errors are reported. Maximum variance inflation factor shows that multicollinearity is not present. We estimate the models with clustering for all the main categories (quota, quality, gear) of attributes, as there is no obvious criterion to select the unit of clustering.

[5] The 12-week limit for CBA without an aquaculture license was a compromise between precautionary considerations regarding fish welfare and CBA operators wanting to store the fish for as long as possible without entering the more demanding and costly aquaculture legislation (Dreyer et al., 2008). From 2019, CBA operators could apply to extend the 12-week period to 20 weeks without an aquaculture license.

[6] Experimental fishing trials shows that using longlines and pots for CBA of cod is feasible, but with a high incidence of floaters, which if left untreated resulted in high mortality (Humborstad et al., 2016). Trials with trawl show that fishing depth, haul sizes and duration influence survival rates and gear damages to the fish (Digre et al., 2017; Olsen et al., 2013).

[7] Some vessels use nets to lift the fish onboard, but this may cause pressure damage on some of the fish.

[8] At least one buyer uses the CBA cod to make stockfish. Because the quality of the product is highly dependent on the weather, CBA allows the producer to time production with favorable weather conditions.

Fig. 1. Average monthly live weight prices of wild harvested cod and cod from CBA, 2015–2020. Source: NFSO.

Table 1
Descriptive statistics.

	Frequency in %	Mean price	Min price	Max price	SD
Quota					
Regular quota	95.97	15.85	1.24	86.55	4.54
Other	3.66	15.91	4.48	39.11	4.58
Live bonus quota	0.37	19.96	8.14	40.76	6.06
Quality					
A	96.89	16.06	1.22	86.55	4.40
Downgraded	3.1	9.67	3.79	54.63	4.79
Extra	0.01	21.77	13.35	29.73	2.90
Gear					
Net	41.86	15.38	3.90	54.63	4.64
Jig	28.81	15.91	4.13	86.55	4.41
Line	16.63	16.10	1.24	63.29	4.28
Demersal Seine	10.63	17.22	2.34	40.76	4.60
Autoline	1.72	16.71	4.96	41.96	3.86
Other	0.07	15.48	3.81	26.76	4.42
Trawl	0.07	16.13	3.99	29.12	4.21
Quarter					
q1	51.98	15.81	1.24	55.45	4.34
q2	29.24	15.97	3.81	63.29	5.07
q3	7.94	16.18	5.12	86.55	4.66
q4	10.83	15.69	2.34	53.51	3.72
Year					
2015	19.8	10.32	3.79	54.63	1.96
2016	17.67	16.65	1.24	86.5	2.20
2017	17.44	14.78	5.73	36.79	1.71
2018	16.59	14.53	5.76	47.58	1.71
2019	13.92	17.75	6.94	52.81	2.06
2020	14.59	23.43	7.93	63.29	3.45
Total		**15.89**	**0.13**	**86.55**	**4.55**

4. Empirical results

Table 2 reports the estimated coefficients of the linear hedonic regressions and implicit price premiums. The base product is a quality A cod, caught with net in the first quarter of 2015. The base quota type is the regular quota. With one exception for model 2, all parameter estimates in the two empirical models are statistically significant. Moreover, the models perform well in terms of goodness of fit and explain 81% in the variation in the dependent variable.

The results are largely in line with what has been reported earlier when investigating only the wild fisheries (Asche et al., 2015a; Pettersen and Asche, 2020). There is a discount for downgraded quality,[9] and trawl is the gear that gives the highest price. The seasonal effects indicate that the cod is highest prices in the first quarter from January to March. For the fourth quarter we estimated the largest price discount of 7% compared to the first quarter. Compared to the base year 2015, we found price increase for all other years under study. In the years 2019 (69%) and 2020 (124%) cod generates the highest prices.

Our results indicate that the live bonus quota leads to an average price premium of 25.71% for the period under study (2015–2020), compared to the regular cod. Hence, there is a significant price incentive for the live storage of cod, indicating that there clearly is a market that pays a premium for higher quality fish. In Model 2 the interaction effects allow the premium to vary between years and, the live quota bonus is now associated with the base year 2015. This indicates a premium of 30.59%. The interaction effects show how the premium changes relatively to the premium in the base year. The results indicate that there were statistically significant but varying price premiums for all years, except for the year 2017. We found a statistically significant premium of 25.41% for the live quota bonus in 2016, which decreased to 4.62% in 2018. The premium was 17.73% in 2019. This indicates that the premium disappears at moderate quantities, which has also been found to be the case for new species (Asche et al., 2022c). In 2020, when less fish was landed as CBA, our result shows a hefty premium of 67.50% for the live quota bonus, again signaling the strong market demand for the higher quality fish.

5. Discussion and conclusions

CBA is a branch of the aquaculture industry that differs from closed cycle farming in that the stocking material consists of captured wild fish or other aquatic organisms. Despite having accounted for as much as an estimated 20% share of the world's total aquaculture production (FAO, 2004), CBA has received little attention in literature. By skipping

[9] The category "A quality" is the regular quality. "Extra quality" is a superior quality. Downgraded quality cod is cod that is not sufficiently fresh or with other flaws.

Table 2
Parameter estimates and computed average price premiums.

VARIABLES	Coefficients (Model 1)	Price premium (%)	Coefficients (Model 2)	Price premium (%)
Quota type base: regular				
Other quota	−0.748**	−7.11	−0.747**	−7.10
	(0.316)		(0.316)	
Live bonus quota	2.707***	25.71	3.220***	30.59
	(0.451)		(0.160)	
Quality base: A				
Downgraded quality	−5.390***	−51.19	−5.386***	−51.16
	(0.502)		(0.500)	
Extra quality	2.458***	23.34	2.626***	24.95
	(0.761)		(0.631)	
Gear base: Net				
Autoline	0.705***	6.70	0.706***	6.71
	(0.095)		(0.095)	
Hand line	0.348***	3.31	0.348***	3.31
	(0.052)		(0.052)	
Line	0.769***	7.30	0.769***	7.31
	(0.054)		(0.054)	
Demersal Seine	1.148***	10.90	1.148***	10.91
	(0.139)		(0.139)	
Trawler	1.542***	14.64	1.543***	14.65
	(0.161)		(0.160)	
other	−0.822***	−7.81	−0.821***	−7.80
	(0.104)		(0.105)	
Quarter base: q1 (January–March)				
q2 (April–June)	−0.493***	−4.68	−0.490***	−4.66
	(0.052)		(0.051)	
q3 (July–September)	−0.577***	−5.48	−0.582***	−5.53
	(0.195)		(0.194)	
q4 (October–December)	−0.765***	−7.26	−0.765***	−7.27
	(0.248)		(0.248)	
years base: 2015				
2016	6.177***	58.67	6.178***	58.69
	(0.124)		(0.124)	
2017	4.270***	40.55	4.274***	40.60
	(0.080)		(0.078)	
2018	4.063***	38.59	4.072***	38.68
	(0.152)		(0.150)	
2019	7.275***	69.10	7.281***	69.17
	(0.127)		(0.126)	
2020	13.052***	123.97	13.038***	123.85
	(0.228)		(0.232)	
Year live bonus quota interactions				
2016 live quota			−0.545***	25.41
			(0.173)	
2017 live quota			−1.205	19.14
			(1.215)	
2018 live quota			−2.734***	4.62
			(0.546)	
2019 live quota			−1.354***	17.73
			(0.255)	
2020 live quota			3.885***	67.50
			(0.237)	
Constant	10.529***		10.527***	
	(0.122)		(0.121)	
Observations	983,569		983,569	
R^2	0.81		0.82	
Robust standard errors in parentheses				
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$				

challenging production phases such as the difficult juvenile and on-growth stages of cod farming, producers engaged in CBA can test whether market advantages such as high quality and a more consistent supply leads to market prices that cover the costs involved in CBA. Prices achieved should also be of interest for closed cycle farming for new and emerging aquaculture species such as cod as they indicate the price premium for consistent supply of high-quality fish. The prices also provide a benchmark of the value of better practices for wild harvest in settings where fishing practices may compromise fish quality (Bertheussen and Dreyer, 2019; Sogn-Grundvåg et al., 2022).

To the best of our knowledge there are no studies that have quantified the price premiums for any seafood produced by CBA compared to wild harvest, while controlling for other relevant factors such as fishing gear and seasonality. We estimate a price premium for cod from CBA in Norway and compare this with wild harvested cod. We found that cod from CBA achieves an average price premium of 26% at the ex-vessel level compared to wild harvested cod over the six-year period studied. We also found that the average price premium of 26% for CBA cod hides

substantial variation over time. By introducing interaction terms between the CBA dummy and years, we found that the price premiums vary significantly between years. Somewhat surprisingly, we found no significant price premiums for CBA cod in 2017. Large quantities of live cod landed, and a limited number of good storage facilities owned by buyers, may have led fishers to accept prices like those achieved in the wild harvest fishery. The subsidy provided in the form of a generous quota bonus (50%) may also have contributed to this as one has observed in other markets that quality premiums can disappear when supply becomes sufficiently large (Asche and Smith, 2018).

At a first glance, the huge price premium (67.5%) for CBA cod in 2020 is surprising given that the social distancing and lockdown measures adopted to prevent the spread of the COVID-19 virus caused demand for seafood from the hotel, restaurant, and catering sectors to disappear more or less (Love et al., 2021, 2022). However, the hefty price premium is probably explained by the fact that fishers and buyers agree on contracts for CBA cod in January with fixed prices for the entire season, as opposed to the prices for wild harvested cod negotiated daily, as well as a reduction in the quota-bonus and therefore supply. According to exporters, the high-quality CBA cod was mostly sold to the retail sector which experienced sales growth for seafood during the COVID pandemic (Love et al., 2021). In Spain, one of the most important markets for fresh high-quality cod from Norway, de la Iglesia et al. (2022) found that for the period March to June, fresh seafood sales increased by 161% from 2019 to 2020. Thus, the high quality and consistent supply of CBA cod – and the ability of Norwegian exporter firms to direct supply to markets and customers less affected by the pandemic, as was also found for frozen cod from Norway (Asche et al., 2022b), indicate that cod from CBA contributed to a more resilient Norwegian cod industry during the substantial market shock caused by the COVID pandemic.

Our results clearly indicate that buyers are willing to pay extra for live-stored cod compared to wild harvested cod. However, the price premiums alone may not be sufficient for fishers to engage in CBA. Our study only shows the revenue side, but there is also a cost side that we do not have data for. CBA in Norway faces several challenges and limitations due to its complex institutional framework, regulations from different sectors that do not harmonize, and the high opportunity costs perceived by fish processors and farmers. In fact, even in 2020 when the price premium was very high, production declined significantly in line with the reduction in the subsidy provided in the form of the quota bonus. Hence, the observed price premiums do not appear to be sufficient to cover the additional costs associated with CBA practices compared to the harvesting cost in the traditional fishery. As such, the current CBA system relies heavily on economic incentives in the form of the quota-bonus, which has come under scrutiny for its legitimacy and effectiveness with stakeholders having differing views on the success and objectives of the CBA. The continued operation of CBA in Norway accordingly appears to be more dependent on the subsidy than the price premium.

Funding

This work was supported by the Norwegian Seafood Research Fund (CT #901764) and the Norwegian Research Council (CT# 301951, 302197 and 320612).

CRediT authorship contribution statement

Ingrid Kristine Pettersen: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Frank Asche:** Conceptualization, Investigation, Validation, Writing – original draft, Writing – review & editing. **Julia Bronnmann:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Geir Sogn-Grundvåg:** Conceptualization, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Hans-Martin Straume:** Conceptualization, Validation, Investigation, Writing – review & editing.

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.

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