Appendix B1: Paper 1

Marine Policy 58 (2015) 78–87

Contents lists available at ScienceDirect

Marine Policy

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

Is the catch quota management (CQM) mechanism attractive to fishers? A preliminary analysis of the Danish 2011 CQM trial project

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A R T I C L E I N F O

Article history:
Received 25 June 2014
Received in revised form
18 April 2015
Accepted 19 April 2015

Keywords:
Catch quota management (CQM) mechanism
Landing quota (LQ)
Incentive compatibility
Participation constraint
Principal–agent model
Total allowable catch (TAC)

A B S T R A C T

There is a demand for a management mechanism that can reduce the discarding problems of EU fisheries. Catch quota management (CQM) seems to be a promising candidate for such a mechanism. Drawing on a principal–agent model, the objective of this study is to develop and test a method for investigating if the CQM mechanism is efficient in providing fishers with incentives for participating in CQM and complying with the rules. The study uses the 2011 Danish CQM trial project as its empirical basis. The results indicate that CQM fishers have a higher average gross income compared to fishers harvesting according to the conventional rules. Hence, there is an incentive for fishers to participate in the trial. However, with the possibility to cheat, CQM fishers may achieve even higher gross income. It is not obvious that the CQM mechanism's payoff structure (incentives) is attractive enough to ensure that the fishers comply with the rules. The empirical data illustrate that without discarding the CQM fishers achieve a lower average price for their catches. Therefore, to make the CQM mechanism sufficiently attractive to fishers, the participating fishers must be compensated.

1. Introduction

Fisheries in the European Union have shown positive developments during the past couple of decades [1–4], however these are not overall developments [4–7]. While the revision of the Common Fisheries Policy (CFP) in 2002 has contributed to an improvement of the status of many fish stocks [5–7], most of the cod stocks in EU remain in a poor state despite increasingly restrictive fisheries management measures [4,5]. Discarding is a serious and continuing problem, which now involves marketable fish [8–10] and reflects a significant weakness in the CFP [5,11]. Therefore there is a demand for a management mechanism that can help to address the discarding problems experienced in the EU fisheries.

Discards are the part of the catch, which is not retained on-board during fishing operations but is instead returned, often dead or dying, to the sea [12–14]. The practice of returning such dead or dying fish to the sea is called discarding. These discards are often unmarketable species, fish below minimum landing sizes (MLS) and catches of species which fishers are not allowed to land, e.g. due to quota restrictions [8,12]. High-grading is the practice of selectively discarding fish so that only the most valuable fish sizes or species are landed, allowing fishers to attain high prices for their limited catch quotas [13–15]. In commercial fishing, fishers are systematically discarding to maximise the value of the catch [15,16].

Currently the total allowable catch (TAC) is the central measure in EU fisheries management [17]. The landing quota (LQ), where only the landed portion of the catch matters [18,19], is the main mechanism used to operationalise the TAC system [18,20,21]. However the LQ mechanism seems to fail in delivering the desired results [18,20,22,23]. With the LQ mechanism, it is not allowed to land fish smaller than the MLS, catches exceeding the quota, and by-catch for which there is no quota.[2] The LQ's management measures such as mesh-size regulation and limitations set for MLS, automatically determine the discarding of undersized fish [24–27]. The LQ mechanism's regulation [27] also encourages fishers to discard catches exceeding the quota, especially in mixed fisheries [23,29,30]. This discarding practice gives the fishers the opportunity to high-grade catches in order to optimise quota income [15,31–34]. Hence, in EU fisheries discards is still an evident problem despite the heavy emphasis on conservation in the CFP [5]. This is despite the CFP being supported by control measures like

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[2] See the details of LQ mechanism's landing limits in Article 9 "Conditions for landing catches and by-catches", page 7, in the "EU COUNCIL REGULATIONS (EC) No 43/2009 of 16 January 2009 fixing for 2009 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where catch limits are required" [27]. Also see [28].

http://dx.doi.org/10.1016/j.marpol.2015.04.011
0308-597X/

logbooks and control at sea and ashore [23,26]. An alternative to the LQ mechanism, catch quota management (CQM), is currently being adopted in the EU as a mechanism to operationalise the TAC management system [11,35]. Although all LQ fishing regulations are still valid for the CQM fishers, a key feature of CQM that differs from the LQ mechanism is managing the fisheries by controlling what is caught instead of what is landed. The intention is to reduce unregistered fishing mortality, thereby providing better scientific data, and to encourage fishers to fish more selectively, and thus reduce unnecessary fishing mortality [22,28,36–39]. For the purpose of the present paper, unnecessary fishing mortality implies mortality as a result of catches; (1) exceeding the recommended quota, (2) smaller than MLS, (3) unmarketable fish species and (4) any other by-catch which cannot be legally landed. This is important as it can help in reducing discarding and may also prevent the creation of unbalanced predator–prey relations in the environment. By decreasing discarding and therefore reducing unnecessary fishing mortality, the CQM mechanism seeks to optimise the fishers' economic gain as well as achieving ecological sustainability in the fishery [22,39–41]. To achieve this, monitoring and reporting of the total catch are essential management elements in the CQM mechanism. In Danish trials of CQM, registration of catches is monitored centrally, i.e. controlled by the closed-circuit television (CCTV) and remote electronic monitoring (REM) system. For every fishing trip, on average 10% of the fishing events (hauls) per vessel with a minimum of 1 are selected for review of the image data from REM [22,35,44]. Thus, the estimated discards of both cod and other species are recorded. The volume of discards estimated from the video footage is compared with the volume of discards recorded by the fisher in the logbook. This should discourage fishers from discarding and thereby avoid high-grading [42,44,45].

In British Columbia and elsewhere in North America, a similar approach in monitoring fishing vessels has also been applied. The approach was reported to be successful [46–48], although it was recently questioned [67]. Because the focus was on longline fisheries [47,49,50], the relevance of the success of North American studies to European trawl fisheries was unknown. Therefore Denmark, the United Kingdom, Germany and the Netherlands initiated CQM trial projects to analyse, understand and document the application of CCTV equipment to European trawl vessels, and explore the subsequent use of the information in a CQM system [22,51]. Except for the Netherlands, where the results neither demonstrate a reduction of discards nor a change in fishers' behaviour as a response to CQM mechanism[3] [51], the CQM reported results in general seem to be promising. However, the mechanism is not fully comparable with observed data when it comes to monitoring discards [76,77], but with some further adjustments to improve the accuracy of monitoring catches there is hope that discarding problems in EU can be reduced [76–78]. Among other successful issues, the CQM trials have demonstrated that it is possible to create incentives for the fishers to avoid by-catch and juvenile fish [22,43,44,52,53]. The presence of CCTV and REM systems in the CQM mechanism allows auditing fishing activities, including the verification of the fishers' reported catches. This results in better scientific data [44,45,54,55,76] for the advancement in ecologically sustainable fisheries. Therefore, in 2011, the impact assessment report on the performance of the current CFP conducted by the Director-General for Maritime Affairs and Fisheries (DG MARE) suggested a policy reform that is built on a CQM-like scenario [35]. The assessment suggested that the CQM mechanism should be adopted as a key part of the CFP reform [35]. Following this suggestion, the CQM mechanism has currently been adopted as an integral part of the CFP [11,38,56]. It is adopted as an optional mechanism in managing the EU fisheries. However, a more analytic discussion on how the CQM mechanism can be expected to motivate the fishers to change their fishing behaviour as intended is not discussed in these reports.

The CQM can be seen as a mechanism that attempts to regulate fishers' activities by on the one hand setting rules that must be obeyed (e.g. documentation of all catches) and on the other hand providing benefits (e.g. extra fishing quota and fishing days). To be an efficient mechanism CQM must fulfil two conditions. First, the CQM mechanism must be able to attract the fishers' participation, i.e. it must be attractive for vessels to participate in the CQM trials. Second, when participating, it must be attractive for CQM vessels to commit to the CQM rules. Since the fishers can be expected to respond to management regulations by trading off economic gain against the cost of non-compliance [16], the CQM vessels must earn at least as much as when they operated traditionally. In practice, this means that it must not be attractive for them to mimic the behaviour of traditional vessels [16,57,58], by discarding and not documenting catches honestly.

The aim of this study is to discuss how the CQM mechanism may be formulated in order to attract fishers' participation and make it profitable for them to comply with the rules.

Using the principal–agent model [59–61], the present paper presents crucial properties which have to be present for a CQM mechanism to be both attractive to fishers and motivate compliance. Next, by using data from the 2011 Danish CQM trial project it analyses whether this trial project has the required properties. However, due to lack of vital data the analysis is based on several simplifying assumptions and must be regarded as a theoretical approach more than a realistic assessment of the 2011 Danish CQM trial. Also, only the Skagerrak fishing segment data are used in this study despite the trial project covering the Skagerrak and the North Sea fishing segments. This is because of lack of comparable data for CQM and LQ vessels operating in the North Sea. The study is designed to contribute to help the improvement of the CQM mechanism as a tool for managing the EU fisheries.

2. Description of the CQM mechanism in relation to the LQ rules

The LQ and the CQM mechanism have basically the same fishing rules and regulations. Only catches for which the vessel has a quota may be landed [26,27]. If the vessel does not have a quota for a particular species, it should lease the quota or obtain it from other vessels participating in the quota pool. Otherwise the fishery should be ceased. All catches must be covered by quota holdings [26,27]. The CQM mechanism allows fishers to acquire extra fishing days at sea and extra quotas for the species caught. As cod is the only species accounted for in the CQM trial projects hereto, only the cod quota is increased in the 2011 Danish CQM trial project. It includes a premium of up to 30% of the actual vessel quota, available after the functioning of the documentation system has been approved [22,36]. The additional quota is based on the vessel's track record for the previous annual landings. Cod landed under scientific dispensation schemes and additional quota due to leasing is not included in this track record [22,36,62]. In the event that the initial quota has been partly fished at the time the vessels enters the project, the premium is reduced accordingly, including the discarded undersized cod [22,36]. Participating vessels are not allowed to sell or lease out their cod quota to vessels within or outside the CQM mechanism. If a CQM vessel's cod quota is exhausted, the vessel must stop fishing [22,36]. Although only cod is included in the trial so far, it should be noted that this does not mean that discarding is allowed for other species caught than cod.

In order to allow innovative fishers to develop fishing gear fitted for their purpose, there is a view that some fishing effort regulations should be considered unnecessary for CQM vessels,

[3] We do not have a good explanation to this. However, the results are based on a very low sample size.

Table 1
Special CQM operational rules to follow for the 2011 Danish CQM trial project.[a]

The CQM vessels must have the CCTV linked to the REM system.
Cease fishing with a gear for which cod is recognised as target species when the cod quota is exhausted.
Catches of fish restricted by a quota should not be discarded, if they are above the minimum landing size (MLS).
Cod should not be discarded if caught above the MLS.
Allowed to discard only the cod caught below the MLS, but can only be discarded after weighing and after 30 seconds display in front of the camera.
Discards of fish must only take place via conveyor belt and hatches that can be monitored by a camera.
All cod above and below the MLS must be separated from the catch.
Both the weight of cod above and below the MLS should be registered haul by haul.
All catches under the MLS are counted against the quota.
Haul by haul documentation of all fishing activities and reporting all technical problems to the authority i.e. the Danish Directorate of fisheries.

[a] See CQM trial-reports [22,42] for more details, otherwise the CQM vessels have to follow all other traditional fishing regulations applied.

i.e. that there should be a free choice of gear [22,53]. However, the CQM mechanism has so far not been associated with a relaxation of the effort regulations. Thus, until today, the effort regulations for LQ vessels also apply for CQM vessels, except that CQM vessels are granted extra days at sea.

Besides, there is an obligation that CQM vessels must have the CCTV linked to the REM system on board (Table 1), whereas this is not the case under the LQ rules. The REM system enables the authorities to control high-grading if done by CQM vessels [44,45]. Hence, the CQM rules make it more difficult for fishers to discard [44].

Table 1 gives an overview of the operational rules for the vessels that participated in the 2011 Danish CQM trial project.

The interesting question is whether the extra cod quota and extra fishing days at sea granted to CQM vessels compensate for the forgone profits due to the avoided high-grading? If not, it is likely that the CQM fishers will try to copy (mimic) the harvesting behaviour of the LQ fishers in order to maximise their profits regardless of the presence of the REM system [16,57,58].

3. Theoretical model

The main intention of the CQM mechanism is to reduce discarding, which implies a reduction in unnecessary and unregistered fishing mortality [22,36–39]. Although the CQM vessels are required to have CCTV on board, it takes time and surveillance and thus involves costs for the fisheries authorities to check each vessel. An alternative is to formulate the CQM mechanism such that it is not in the interest of the CQM vessels to cheat. A contract, or mechanism, fulfilling this criterion, is said to be incentive compatible [59,61], and how to formulate such a contract can be analysed by using e.g. a simple principal–agent model [59,61].

The game of mechanism design (also called reverse game theory) [59] is a game of asymmetric information in which the principal chooses the payoff structure of the game and the agent decides whether to participate in the game or not [59]. The simple principal–agent model defines a situation where one principal (fisheries authorities) wants one agent (fisher) to behave in a certain manner, and where behaving in the desired manner imposes costs upon the agent [59–61]. The payoff structure is costly for the authorities because it has to allow the fishers a rent in order to secure information revelation [59,61]. The cost of the payoff structure equals the rent required for securing the fishers' participation and truthful information revelation.

The point of departure is that all fishers harvest according to the LQ rules. However, the fishers possess different knowledge about fishing grounds, and where to catch different species. They may also have different knowledge regarding where to get large or small cod. Such information difference may be utilised to reduce unnecessary fishing mortality. Hence it is politically decided to introduce the CQM mechanism, and the challenge to the fisheries authorities (the principal), is to formulate the CQM mechanism, given the LQ rules. The fisheries authorities are assumed to be utilitarian and maximise utility [59,61]. The utility is the aggregate of the expected net income across all fishers. Assuming two groups of homogeneous fishers, the LQ fishers and the CQM fishers, the authorities' challenge is to maximise utility given the total quota to the fishery and that each group of fishers cannot land more than their allotted quota. This is expressed in (1) below:

$$\max \Pi = \beta\{p^{CQM}h_Q^{CQM} - C^{CQM}(h_Q^{CQM}) + p^{LQ}h_Q^{LQ} - C^{LQ}(h_Q^{LQ})\} - K(\beta) \tag{1}$$

$$\text{s.t.} \quad h_Q^{CQM} + h_Q^{LQ} = h_Q \tag{2}$$

where Π is the expected utility to the authorities of the fishing activity. The superscript CQM denotes the CQM fishers and LQ denotes the LQ fishers. When p is a vector of prices per kg for each of the species landed, h_Q^{CQM} and h_Q^{LQ} are vectors of the quota in respect of CQM and LQ fisher for the species landed, $p^{CQM}h_Q^{CQM}$ and $p^{LQ}h_Q^{LQ}$ are the gross revenues of CQM and LQ fishers respectively. Similarly $C^{CQM}(h_Q^{CQM})$ and $C^{LQ}(h_Q^{LQ})$ are the costs incurred by the CQM and LQ vessel respectively. The term h_Q^{CQM} denotes the total quota for CQM fishers, whereas h_Q^{LQ} denotes the total quota for LQ fishers, and h_Q is the total quota for the specific fishery under consideration. Eq. (2) states that the total quota for the fishery is fixed. The challenge is thus for the authorities to divide it between the two groups of fishers. $K(\beta)$ are the costs of surveillance in order to ascertain that the fishers fish according to their specific rules. The parameter β defines the probability for not being caught cheating, and thus it is realistic to assume $K'(\beta) < 0$, i.e. that the first-order derivative of costs with regards to β is decreasing. This implies that when the probability for not being caught cheating increases, the costs decrease, which is reasonable as decreasing costs means lower effort in enforcement of the regulations, which in turn means higher probability for not being caught cheating. Throughout this paper, however, it is assumed that β is politically decided and exogenous to the fisheries authorities. This also fixes the costs term $K(\beta)$.

The idea is that some fishers may be better informed where to get larger sized cod and avoid the small sized cod, and thus will have a competitive advantage in choosing the CQM contract.[4] In

[4] The reason why some fishers may choose the CQM rules instead of the LQ rules may be superior knowledge about groundfish harvesting, which makes them more competent to fish cod and other groundfish and thus reduces their costs in these fisheries. Then, however, mimicking LQ vessels, which do not necessarily specialise in groundfish fisheries, they will lose this cost advantage and there is no reason to believe that CQM fishers have harvest costs that are different from LQ fishers when they mimic the harvest pattern of the LQ fishers.

this endeavour, the authorities must assure that it is not profitable for the fishers who choose the CQM contract to cheat by mimicking the harvest pattern of the LQ fishers, which imply discarding. This is called the incentive compatibility constraint. Also, they must assure that the LQ contract is still profitable for fishers without this superior information. This is called the participation constraint.

When it comes to the fishers in both vessel groups, the assumption is that they maximise net income, given by

$$\Pi^k = \beta\{p^k h^k - C^k\left(h^k\right)\},\quad \text{where}\quad k = \text{CQM, LQ} \tag{3}$$

$$h^{CQM} \le h_Q^{CQM} \tag{4}$$

$$h^{LQ} \le h_Q^{LQ} \tag{5}$$

where Π^k is the net income to fisher in group k, and h^k is a vector of the amount in kg for the species landed for fishers in group k. For LQ fishers, $\beta = 1$, as they are not assumed to be able to cheat, and thus are not caught cheating. As there are well-functioning control rules in place for fish landings in Denmark it is realistic to assume that no fisher can cheat by landing more than their allotted quota, which is indicated by restrictions (4) and (5). For LQ fishers the assumption is that both gross income and harvesting costs are well known variables to the fisheries authorities. Hence, it is possible to normalise the net income to LQ fishers to 0.[5] Then, as CQM fishers can always choose to cheat and fish according to the LQ rules, the net income of a CQM fisher must be at least as high as 0. The participation constraints thus are

$$p^{LQ} h_Q^{LQ} - C^{LQ}(h_Q^{LQ}) = 0 \tag{6}$$

$$p^{CQM} h_Q^{CQM} - C^{CQM}(h_Q^{CQM}) \ge 0 \tag{7}$$

For the CQM fishers not to be tempted to cheat, the CQM contract must fulfil the following condition:

$$p^{CQM} h_Q^{CQM} - C^{CQM}(h_Q^{CQM}) \ge \beta\left\{p_{LQ}^{CQM} h_{LQ}^{CQM} - C_{LQ}^{CQM}(h_{LQ}^{CQM})\right\} \tag{8}$$

where $p_{LQ}^{CQM} h_{LQ}^{CQM}$ and $C_{LQ}^{CQM} h_{LQ}^{CQM}$ are the revenue and costs respectively of CQM fishers when fishing according to the LQ rules and discarding, but with a higher cod quota and assuming that (4) is fulfilled with equality. The left-hand side of (8) expresses the net income of CQM fishers harvesting according to the CQM rules whereas the right-hand side expresses the net income of CQM fishers harvesting according to the LQ rules, but with an additional cod quota. Hence, (8) says that the net income of CQM fishers when operating according to the CQM rules must be at least as high as the net income of CQM fishers when harvesting according to the LQ rules, but with the extra cod quota, and when there is a possibility for being caught cheating.

If the assumption is that the costs of LQ fishers harvesting according to the LQ rules equal the costs of CQM fishers harvesting according to the LQ rules, i.e. $C^{LQ}\left(h_Q^{LQ}\right) = C_{LQ}^{CQM}\left(h_{LQ}^{CQM}\right)$, then (8) can be expressed as follows:

$$p^{CQM} h_Q^{CQM} - C^{CQM}\left(h_Q^{CQM}\right) \ge \beta\{p_{LQ}^{CQM} h_{LQ}^{CQM} - p^{LQ}\left(h_Q^{LQ}\right)\} \tag{8'}$$

The right-hand side of (8′) is the expected difference between the gross income of CQM fishers harvesting according to the LQ rules, but with the extra cod quota, and the gross income of LQ fishers harvesting according to the LQ rules. As the CQM fishers can always harvest more cod than the LQ fishers, the right-hand side of (8′) will always be positive, implying that the CQM fishers must be allowed a rent beyond that of the LQ fishers when harvesting according to the CQM contract. The right-hand side of (8′) gives the limit for the rent to the CQM fishers necessary to make the set of contracts incentive compatible.[6] This indicates the minimum costs to the authorities of the regulation. A crucial assumption for (8′) is that eventual cost advantages are lost when CQM fishers mimic the harvest pattern of LQ fishers.

Some qualitative incentives may not be taken care of in the model presented above. Due to such restrictions of the model, variables that matter, but not taken care of in the model, will be discussed based on empirical data.

4. Data

In order to be able to apply the model above to the Danish 2011 CQM trial project in Skagerrak, data had to be compiled from various sources. These are: (1) data on total landings per species, value per species and number of vessels for the vessel category demersal trawlers and demersal seiners' 18–24 m total length for both CQM and LQ vessels obtained from the Danish National Institute of Aquatic Resources [63], (2) data on prices per kg of size-grade cod extracted from the DG MARE report [35], and (3) data from the 2011 Danish CQM trial-project report which are used to calculate the proportions of cod as divided on each of the five size-grades [22]. None of the mentioned sources could provide data on harvest costs. Although general data on harvest costs per vessel group exist for all Danish vessels [64], it does not exist separately for the CQM and LQ vessels.

The catch data is restricted to 8 specific species, which, according to the 2011 Danish CQM trial-project report [22], are the most important common commercial species landed for the relevant métier vessels. All other species landed are included in the category "Other Species".

Based on the above sources, the average landings (in 1000K) and price per kg is calculated in Danish kroner for the 8 most important common commercial species harvested by CQM and LQ fishers. The formulas applied to calculate the numbers presented in Table 2 are given in Appendix A (A1)–(A3). The CQM and LQ vessel included in the analysis are métier vessels, i.e. vessels of the same size (18–24 m total length), fishing in the same areas prior to the CQM trial project, and with the same gear type [22]. Prior to the CQM trial, the landings made by the CQM and LQ vessels were reported to be the same [22]. Hence, similar fishing behaviour and landing patterns are presumed for the two vessel groups prior to the CQM trial project. Thus the results in Table 2 suggest that the two vessel groups have chosen different harvesting behaviour and landing strategies due to the implementation of the CQM mechanism.

5. Results

5.1. Gross income per fish species

The data show that whereas the LQ fishers get a major share of their gross income from Norway lobster, the CQM fishers' main income source is shared between European plaice and Atlantic cod. This is shown in Fig. 1 as well as in Table 2.

5 Note, that this is a normalisation, which may allow for a positive rent to the LQ fishers.

6 Note that the smaller the β is, the smaller the required rent. This is because a low β means very high probability of getting caught cheating, which makes this option unprofitable for the CQM fishers.

Table 2
Landings in 1000K and price in DKK per species for CQM and LQ vessels, 2011.

Species	CQM vessels		LQ vessels	
	Landings per vessel (kg 1000)	Price per kg (DKK)	Landings per vessel (kg 1000)	Price per kg (DKK)
Norway lobster	1.709	71.18	13.372	72.48
Haddock	34.700	10.72	5.306	8.71
Saithe	6.922	10.65	11.279	9.91
European Plaice	78.579	10.28	24.536	10.17
Lemon Sole	1.172	37.72	1.105	39.42
Witch flounder	1.144	29.73	3.168	22.23
Atlantic cod	26.359	21.68	10.780	23.61
Common sole	0.016	118.70	0.281	111.68
Other Species[a]	8.626	16.18	17.631	10.47

[a] See Appendix B: Table B1, for details on specific species included in the category "Other Species".

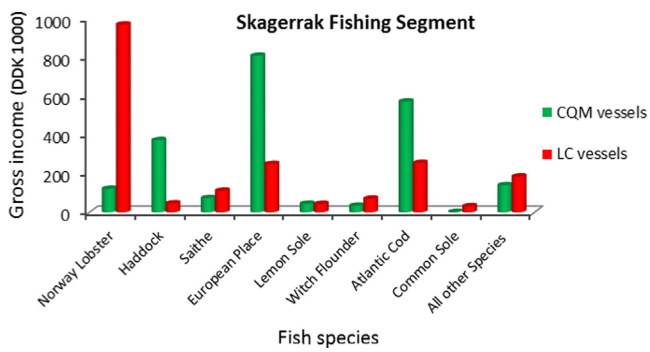

Fig. 1. Comparison of Gross Income per fish species (DDK 1000).

Table 3
Price indices in Danish kroner (DKK) per kg fish for cod and all species excluding cod for CQM and LQ vessels.

Vessel group	Cod	All species excluding cod
CQM vessels	21.68	10.02
LQ vessels	23.61	19.51

5.2. *Price index for cod and other species caught*

A price index for cod, and a price index for all species landed except cod for both CQM and LQ vessels were calculated. The price indices are given in Table 3, and were calculated using (C1) and (D1) in Appendices C and D respectively.

The price indices in Table 3 confirm that the CQM vessels have higher percentage of lower-value species within the category "All species excluding cod" than the LQ vessels. The domination of the high-value species for LQ vessels contributes to the high price index. Also, the price index for cod indicates that the CQM mechanism may work in order to reduce high-grading, as the average price per kg cod landed is lower for CQM vessels compared to LQ vessels. This indicates that the CQM vessels have higher shares of lower grade (smaller) cod.

5.3. *Is the CQM mechanism incentive compatible?*

For the CQM mechanism, as applied in the 2011 Danish CQM trial project in Skagerrak, to be an efficient mechanism to reduce unnecessary fishing mortality, it must be the case that the CQM fishers cannot profit on mimicking the harvesting pattern of the LQ fishers. At the same time both groups of fishers must have an incentive to participate in the fishery under their respective rules. Since cod is currently the only fish species accounted for in the CQM trials, the participating vessels in the 2011 Danish CQM trial were allocated extra quota only for cod.

Table 4 provides the summary of the results concerning the total gross income realised per vessel by CQM and LQ fishers, when harvesting according to their respective rules and when CQM fishers mimic the behaviour of the LQ fishers. Ideally, following the theoretical model and Eq. (8′) in Section 3, it is in the interest of the current study to compare the economic rent of CQM fishers when harvesting honestly and when mimicking LQ fishers. However, due to lack of separate cost data for CQM and LQ fishers, gross income was used. The simplifying assumption that the costs for both groups of vessels are the same, i.e. $C^{CQM}\left(h^{CQM}\right) = C^{LQ}\left(h^{LQ}\right)$, was also used. Note that this simplification disregards possible cost advantages for the CQM fishers. With cost advantages for CQM fishers, the rent required by CQM fishers in order not to mimic LQ fishers will be lower.

In Table 4, "True" CQM or LQ vessels means that fishers behave according to the required rules. "Mimicking LQ vessels" means that the CQM fishers do not operate according to the CQM rules, but instead mimic the behaviour of the LQ fishers when it comes to harvesting and landing patterns. These are model entities based on theoretical assumptions and given the CQM and LQ mechanism rules. It should be noted that it is assumed that when CQM fishers mimic the LQ fishers, they maintain their extra cod quota. There are three alternatives for how the CQM fishers may mimic the LQ fishers.

Alternative 1: The assumption here is that the fishers follow the CQM harvesting rules, except that they discard small-sized cod to achieve the cod price index of the LQ vessels. This means that the CQM fishers (1) retain their extra cod quota, 2) land the extra cod quota, but discard small-sized cod, and (3) do not discard other species caught to high-grade, and hence the price index of "all species excluding cod" is the same as when the CQM fishers are fishing honestly.

Alternative 2: The assumption here is the same as above, except that the mimicking fishers are not discarding cod, but instead discard "all other species excluding cod", in order to achieve the higher price index for this harvest category. This implies that for "all other species caught excluding cod", the fishing behaviour and landing pattern of the CQM fishers is the same as that of the LQ fishers. The CQM fishers now obey the rules for cod, implying a lower price index for cod.

Alternative 3: The assumption here is that the fishers follow the fishing behaviour and landing patterns of the LQ fishers to achieve the higher price index of both cod and "all other species" caught.

In all 3 alternatives above, the CQM fishers retain and land their extra cod quota and maintain their extra fishing days.

The results in Table 4 indicates that CQM fishers harvesting in Skagerrak do have higher average gross income (DDK 2 166 480) compared to fishers harvesting according to the LQ rules (DKK 1 961 050). Hence, there is an incentive for fishers to participate in the trial and harvest according to the CQM rules. However, rows 2–4 of Table 4 also show that with the possibility to cheat and mimic the harvesting behaviour of the LQ fishers, CQM fishers may achieve an even higher gross income. This means they may have an incentive to cheat and harvest according to the LQ rules. However, the increase in their gross income decreases with increasing probability of getting caught, and when β becomes sufficiently low, implying that the probability of getting caught is higher, expected gross income of the

Table 4
Gross Income in DKK per vessel per year for CQM fishers when harvesting according to CQM rules and when mimicking LQ vessels, and for LQ fishers harvesting according to LQ rules.

Vessel group	Total Gross Income (DKK 1000) when $\beta=1$	Range of β values (probability range)	Range of total gross income (DKK 1000) when: $\beta=0.5$, $\beta=0.99$	Description of the scenario
True CQM vessels	2166.48	NA	NA	Fishing according to their rules
Alternative 1: Mimicking LQ vessels for cod and not for other species	2328.93	0.5–0.99	1164.47–2305.64	Mimicking LQ vessels
Alternative 2: Mimicking LQ vessels for other species but not for cod	2217.34	0.5–0.99	1108.67–2195.17	Mimicking LQ vessels
Alternative 3: Mimicking LQ vessels for both cod and other species	2278.07	0.5–0.99	1139.04–2255.29	Mimicking LQ vessels
True LQ vessels	1961.05	NA	NA	Fishing according to their rules

NA=not applicable.

CQM fishers when fishing honestly is higher compared to when they mimic LQ fishers. When $\beta=0.5$, i.e. with a 50% chance of not being caught cheating, the results indicate that the fishers will be better off harvesting honestly. In this case, if the CQM fishers harvest according to the rules, they earn almost double the income they earn when they mimic the LQ fishers. But with a sufficiently high β, the CQM mechanism, as it materialised in the Skagerrak demersal trawl fisheries, is not incentive compatible (IC). This is because CQM vessels may cheat and earn a higher gross income by mimicking LQ vessels.

Having shown that the CQM mechanism, as it materialised in the Skagerrak demersal trawl fisheries, is not IC for sufficiently high β, a relevant question is; how much extra gross income do the CQM fishers need for the CQM mechanism to become IC? Assuming $\beta=0.99$ (Table 4), the answer is the difference between the corresponding gross income for CQM fishers when mimicking LQ vessels and the gross income of the "True LQ vessels". So, applying Eq. (8′) in Section 3, the results show that for the CQM mechanism to be IC, the CQM fishers must earn DKK 344 590 (Alternative 1), 234 120 (Alternative 2) or 294 240 (Alternative 3) more than the LQ fishers, given no cost advantage for any of the groups of the fishers. Note that these amounts are too high if CQM fishers have a cost advantage when mimicking LQ fishers' behaviour. When CQM fishers do not cheat, they "only" earn DKK 205 430 (DKK 2 166 480–1 961 050) more per vessel per year compared to LQ fishers. This implies that the CQM fishers, although catching more cod and other valuable groundfish species as European plaice and haddock, will still be better off if they mimic the LQ vessels' harvest and landing patterns.

6. Discussion

The current study illustrates that the CQM vessels' catch composition leads to lower price indices compared to the LQ vessels, but a larger volume of total landings. This may be taken as an indication that the CQM mechanism does work when it comes to avoid high-grading of both cod and all other fish species caught. However, just as the fishers have expressed their concerns [65], the CQM mechanism's operational rules seem to encourage the entry of vessels with particular characteristics. As mentioned in Section 2, the operational rules of the CQM mechanism increase the cod quota for the CQM vessels, while the quotas for other species are unchanged. The extra cod quota is granted as a percentage (currently 30%) of the quota the vessel already holds. Vessels with a high cod quota face high rewards from participating in the CQM trial and may therefore be more likely to participate in the CQM trial than vessels with a smaller cod quota [65]. On one hand, this is positive as it implies that those accounting for the largest cod catches are also those who agree to reduce their discards of cod. On the other hand, since the additional quota premium of up to 30% of the normal vessel quota is based on catches after subtracting incurred discards, it is probably those vessels with already relatively low discards who gain most from adopting the CQM rules. Consequently, the mechanism does not attract those who are the largest discarders.

Looking at the difference in harvesting pattern between the two vessel groups, the CQM vessels harvest more cod than LQ vessels (Table 2), and they seem to practice groundfish fishery. This may explain why the CQM vessels also harvest more European plaice and haddock than LQ vessels. Cod, European plaice and haddock are all groundfish stocks. In typical cod fisheries, European plaice and haddock are the most common valuable by-catch species as they often share similar water depths and seabed areas [66]. The extra fishing days granted allows the CQM vessels to spend more time in groundfish fisheries, whereas the LQ vessels, with restricted fishing days, switch gear and engage in *Nephrops norvegicus* fisheries, and land a lot more Norway lobster compared to the CQM vessels. Usually *Nephrops norvegicus* fisheries take incidental catches of small gadoids and flatfish [68]. This may explain why LQ fishers practice high-grading (discarding e.g. small gadoids and flatfish) and concentrate on only returning high-value species like Norway lobster [69]. Thus, the catch composition between the CQM and LQ vessel group is different despite being vessel groups originally targeting the same species. This indicates that the implementation of the CQM mechanism has triggered different harvesting patterns across the two vessel groups.

Given the prevalent management regulations, the CQM and LQ fishers adjust their fishing behaviour by reallocating effort to groundfish and shellfish fishery respectively, in order to maximise their gross income [57,58]. It is therefore expected that groundfish fishery is more profitable for CQM fishers, due to factors such as superior knowledge about the groundfish fishing grounds, which may provide a competitive advantage, and the opposite is true for LQ fishers [16,20]. Due to the flexibility of the CQM mechanism, it is possible that the CQM fishers are able to utilise their knowledge, by harvesting on fishing grounds where they can catch cod, the species for which they already are allocated a larger quota. If the CQM vessels' harvesting costs for cod are lower than if they mimic the LQ vessels and fish high-value species like Norway lobster, then it is less likely that the CQM fishers will mimic the LQ vessels.

The results in Section 5.3 are based on the simplifying assumption that $C^{LQ}\left(h^{LQ}\right)=C_{LQ}^{CQM}\left(h_{LQ}^{CQM}\right)$ implying that the costs per fishing day of a CQM vessel harvesting according to the LQ rules equal the costs of an LQ vessel. This means that if the CQM fishers have cost advantages when cheating, implying $C_{LQ}^{CQM}\left(h_{LQ}^{CQM}\right)<C^{LQ}\left(h^{LQ}\right)$, then

the necessary compensation to CQM vessels for not discarding will be higher than those amounts presented under the results in Section 5.3. Due to these simplifying assumptions and the fact that cost data per vessel group is lacking, the estimated compensation results in Section 5.3 do not necessarily correspond to the actual data of the 2011 Danish CQM trial-project's participating vessels in Skagerrak. However, the methods of the present study will in general be applicable in providing insights about how the CQM mechanism may be formulated in order to attract fishers' participation and make it profitable for them to comply with the rules. The model used is generic, implying that even if the simplifying assumptions used may be unrealistic, the model framework can still be used to grasp important aspects of the CQM mechanism. With sufficient data, the model can easily be adjusted and made operational for use in other EU fisheries. As mentioned above, details of the operating costs at vessel group level are required to enable the provision of concrete recommendations for questions on how to make the CQM mechanism incentive compatible. This is the expectation because like many other studies on fisher's behaviour, the current study has postulated that fishers are entirely driven by economic interests [16,20,57,70]. Nevertheless, it could be important to take into considerations the relevance of tradition, past experience and information exchange on fisheries' behaviour [16,71–73].

7. Conclusion

The CQM mechanism is supposed to reduce unnecessary fishing mortality, and thereby reduce discarding. To achieve this, all fishing activities are constantly monitored by the CCTV with REM the system. However, since no system is fool-proof there nevertheless may be a possibility for CQM vessels to cheat by discarding small-sized fish or unwanted by-catches and get away with it. An interesting question is then; can it be trusted that the vessels

Table B1
Species Included in the Category "Other Species" per vessel.

Skagerrak fishing segment					
CQM vessels			**LQ vessel**		
Species name	**% of total landings**	**Price per kg (DKK)**	**Species name**	**% of total landings**	**Price per kg (DKK)**
Common dab	2.0862	7.06	Sprat	8.0847	1.45
European hake	1.8261	14.35	Atlantic herring	3.1510	1.45
Monk	0.4234	33.01	European hake	2.4321	12.61
Pollack	0.3694	23.94	Common dab	1.8150	7.09
Catfish	0.1240	37.90	Monk	1.7444	35.43
Turbot	0.1093	63.90	Ling	0.4516	13.11
Cuttlefish	0.0984	38.11	Pollack	0.4087	20.49
Ling	0.0977	14.94	Turbot	0.3389	76.65
Whiting	0.0708	7.83	Whiting	0.2534	5.58
Tub gurnard	0.0595	19.82	Cuttlefish	0.2310	30.77
Brill	0.0371	50.28	Brill	0.2103	50.70
Unknown Species	0.280	16.30	Rays + Skates	0.1451	10.81
European flounder	0.0246	5.71	North deep-water prawn	0.1234	39.44
Atlantic halibut	0.0221	90.81	Atlantic halibut	0.0843	94.27
Lumpfish	0.0155	17.17	Catfish	0.0801	45.69
Edible crab	0.0100	18.95	Tub Gurnard	0.0800	9.51
Marine crabs	0.0062	26.10	Lumpfish	0.0729	69.76
Rays + Skates	0.0035	18.36	Atlantic Mackerel	0.0672	6.10
Tusk	0.0014	20.28	European flounder	0.0515	3.87
Picked dogfish	0.0010	19.04	Roundnose grenadier	0.0432	5.01
Atlantic Mackerel	0.0009	16.17	Picked dogfish	0.0400	19.69
Grey gurnard	0.0008	9.92	Unknown species	0.0375	7.58
Lumpfish	0.0005	2.45	Lumpfish	0.0364	5.97
European lobster	0.0002	117.63	Edible crab	0.0293	19.43
Greater weever	0.0002	15.50	Marine crabs	0.0268	18.53
Skate (Raja batis)	0.0002	37.54	Golden redfish	0.0209	8.52
Breaked redfish	0.0002	28.73	Sandeel	0.0181	1.45
Atlantic herring	0.0001	2.00	Grey gurnard	0.0178	2.51
Long-Rough dab	0.0001	14.00	Rabbitfish	0.0175	1.59
Megrim	0.0001	8.82	Skate (Raja batis)	0.0115	27.87
Mullet	0.0001	39.45	Tusk	0.0100	14.52
Tope	0.00001	8.71	Blue ling	0.0082	15.74
			Greater weever	0.0074	12.95
			Tope	0.0035	10.19
			Beaked redfish	0.0023	8.70
			Long-Rough dab	0.0015	1.48
			Atlantic Horsemackerel	0.0008	6.22
			Spinous spider Cr.	0.0006	3.67
			European lobster	0.0005	101.13
			Mullets	0.0002	42.41
			European eel	0.0001	24.01
			Freshwater bream	0.0001	22.74
			Sea trout	0.00002	22.39
			Greenland halibut	0.00002	45.00
			Megrim	0.00001	8.80
			Bass	0.00001	30.00
			Garfish	0.00001	8.13

following the CQM rules are not discarding? Unless the CQM mechanism offers incentives that make fishers earn more than within the LQ mechanism, the fishers will probably still be discarding in order to increase the income from their fishing operation. In this paper, the principal–agent model is used to discuss whether a Danish CQM trial project fulfils the criteria to be an efficient mechanism in order to reduce unnecessary fishing mortality in a mixed demersal fishery in Skagerrak. The model uses the empirical data from the 2011 Danish CQM trial for vessels harvesting in Skagerrak. The results show that the CQM mechanism, as formulated in this trial and for this specific fishing segment, is not incentive compatible. The reason is that with a low probability of being caught cheating, it is profitable for CQM fishers to cheat by mimicking the behaviour (harvesting pattern) of the LQ fishers. However, because of the inability to get sufficient data to draw robust conclusions, the results are very preliminary, and highly theoretical. The greatest weakness is that due to cost data limitations, the two vessel groups are assumed to have similar costs. The post-trial empirical data suggest a sort of specialisation in fishing methods between CQM and LQ vessels, as the LQ fishers get most of their income from high-value species such as Norway lobster, whereas CQM fishers get the main share of their income from European plaice and Atlantic cod. Hence, one may question whether the two vessel groups were distinctively different with regard to their harvesting patterns prior to the trial. Or rather, is it the case that the CQM rules allow fishers to specialise in different fisheries according to the rules they choose to follow? This is an important management concern [20,74]. Due to the possibility that there may be adaptive fishing behaviour, i.e. specialisation in different fishing methods between the fishers following CQM and LQ mechanism, it would be important for future research to study the incentives leading to such responses (reallocation of effort to different species), and link them to the models used in analyses of fishing behaviour [16,20,72,75]. Unveiling such incentives will contribute to clarify whether or not CQM is an efficient management mechanism for reducing discarding in the EU fisheries.

Comprehensive studies of incentive compatibility, require the availability of data on cost, effort and harvest on the vessel level. The future CQM studies are encouraged to make such data available whenever possible as this would enable the development of an empirical basis for improving CQM as a mechanism to reduce discard problems in EU fisheries.

$$*\text{Adjusting factor} = \frac{\text{Price per kg cod from the provided raw data of the 2011 Danish CQM} - \text{trial Project}}{\text{Price index per kg cod based on the price per size} - \text{grade cod from the DG MARE report}}$$

Acknowledgement

We acknowledge EcoFishMan Project for their provision of funds. We also extend our acknowledgement to the Technical University of Denmark, Danish National Institute of Aquatic Resources (DTU Aqua data) for the provision of the primary raw data used in the study. Special thanks to Mogens Schou for his endless help in advising how to access the CQM data, Jørgen Dalskov for giving the permission to access the data provided, and Hans Jakob Olesen for providing us the actual data. We also thank Kirsten Birch Håkansson for her willingness and endless support in answering questions in relation to clarifications and availability of the data required. Thank you to Roger B. Larsen and Kåre Nolde Nielsen for the comments and suggestions in writing this paper. We sincerely thank Søren Qvist Eliasen and Petter Holm for the constructive comments, suggestions and clarifications about the CQM rules, which have significantly strengthened our paper.

Appendix A. The variables in Table 2 above were calculated as given in (A1)–(A3) below.

Harvest (kg) per vessel per species for CQM and LQ vessels was calculated as indicated in (A1) and (A2) respectively.

$$\text{Harvest}_i^{CQM} = \frac{\text{Total kg for species } i \text{ landed by the CQM vessels}}{\text{Number of vessels involved}} \quad (A1)$$

$$\text{Harvest}_i^{LQ} = \frac{\text{Total kg of species } i \text{ landed by the LQ vessels}}{\text{Number of vessels involved}} \quad (A2)$$

where the subscript i refers to species, and the superscripts LQ and CQM refer to harvesting according to the LQ and CQM rules respectively.

The price per kg fish species landed was calculated using the DTU Aqua fish data provided [63], i.e. based on landing (in kg) and value (in DKK) per species landed from vessels harvesting in the Skagerrak. Thus the price per kg fish for either CQM or LQ vessel was calculated as given by (A3).

$$\text{Price}_i = \frac{\text{Value of total kg landed for species } i \text{ (DKK)}}{\text{Total kg landed for species } i} \quad (A3)$$

where i is the type of species as indicated in column one of Table 2.

Appendix B

See Table B1.

Appendix C. The price index per kg cod

$$P_k^{Cod} = \sum_{f=1}^{5} \rightarrow_k^{cod(f)} \cdot h_k^{cod(f)}, \quad \text{where} \quad k = \text{CQM, LQ} \quad (C1)$$

where P_k^{Cod} is the Price Index per kg cod landed, $p_k^{cod(f)}$ is the price per kg size-grade f cod landed adjusting factor*, and $h_k^{cod(f)}$ is the proportion (%) of size-grade f cod landed.

There are 5 cod sorting grades (kg).

Appendix D. The Price Index per kg of all species excluding cod

$$P_k^{All\ SP} = \sum_{i=1}^{8} \rightarrow_k^{Species(i)} \cdot h_k^{Species(i)}, \quad \text{where} \quad k = \text{CQM, LQ} \quad (D1)$$

where $P_k^{All\ SP}$ is the Price Index per kg for all species landed, excluding cod, $p_k^{Species(i)}$ is the price per kg species i landed, and $h_k^{Species(i)}$ is the proportion (%) of species i landed.

There are 8 species categories excluding cod. Refer Table 2 (first column) for details of the 8 category species included in "*All SP*".

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