Risk Attitudes and Individual Transferable Quotas

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Abstract An analysis of ITQ fisheries management is offered in which two different groups of agents facing uncertain harvesting costs take part. The first group, termed as the coastal fleet, is risk averse, while the second group, interpreted as the ocean fleet, is risk neutral. In contradiction to what is seen in deterministic models of quota markets, given strongly decreasing absolute risk aversion amongst the coastal fleet members, it is found that the initial quota allocation affects the equilibrium quota price and the final catch distribution influencing the economic efficiency in the fishing industry.

Key words Transferable quotas, risk attitude, fishery management.

JEL Classification Codes D8, H2, and Q2.

Introduction

In this paper, we discuss impacts of different attitudes towards risk on the equilibrium in a quota market. Our main questions are: How will uncertainty and risk aversion affect the allocation of quotas and price in a competitive quota market? How does a system of individual transferable quotas (ITQs) function when the agents in the fishing industry have different attitudes toward risk? One can also ask whether the government should try to influence the catch distribution and how such policy should be designed under a regime allowing ITQs. The theoretical analysis moves on to discussing Norwegian experiences.

In the textbook competitive quota market model, the quota price in the fishery issued in perpetuity, would be equal to the net expected present value of the flow per quota unit when assuming risk neutrality. In a short-term leasing market, where risk neutral actors buy and sell quotas for a season or a year, the leasing price is shown to be equal to the expected periodical marginal profit in the fishery. Using this theory, we know that the catch volume for each firm under ITQs is independent of the initial allocation of quotas from public authorities. This means, that according to standard results, the government has no control over catch distribution using an ITQ system. Practicing transferable quotas in environmental policy was proposed by Dales (1968). The proposal of introducing ITQs in fisheries management was first formulated by Christy

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Since then, the institution of ITQs has become an important political tool for improving fisheries management. ITQs are primarily an instrument for promoting economic efficiency (e.g., Hannesson 1996). For a more comprehensive review see National Research Council (1999). In theory, it is possible to show that an ITQ system will contribute to the maximization of economic rents from fisheries.

However, the introduction of ITQs may be difficult and controversial (Copes 1986). In spite of these problems, different ITQ programs have been implemented in a number of fisheries in several countries. Grafton (1996) concludes that there is evidence from Australia, Canada, Iceland, and New Zealand that ITQs have improved economic efficiency and increased the returns of fisheries. For experience from the Icelandic fisheries, see Arnason (1993, 1996), Palsson (2000), Eythorsson (2000) and Matthiasson (1997). Similar experience is reported in several studies from the US and Canadian fisheries (Hermann 1996, 2000; Matulich and Clark 2003; Casey et al. 1995; Macinko 1997; National Research Council 1999). These studies discuss a wide range of interesting consequences following the introduction of ITQs.

In contrast to the cases from Iceland and New Zealand, rights-based fisheries regimes in Norway have not involved a high degree of transferability or divisibility of quotas. In Norway, most fisheries are regulated by license limitation and catch quotas. Additionally, annual total allowable catches (TACs) are specified for most fisheries. Fishing authorities distribute rights to harvest shares of the annual TAC either to groups of vessels or to individual vessel operators. A TAC for a group of vessels (“competition quotas”) has been practiced in both herring and cod fisheries, but individual vessel quotas (IQs) have been more common in recent years.1 (For overviews of Norwegian fisheries management, see Bergland, Clark, and Pedersen [2001], Årland and Bjørndal [2002], and Standal and Aarset [2002].) For the cod fishery with conventional gear, IQs were introduced for most of the fleet in 1990. A key feature of these quotas is that quota transfer is not allowed. However, an indirect trade in quotas takes place when vessels with quota rights are sold, and the rights follow the vessel. Furthermore, illegal transfers of quotas between vessels have been observed and prosecuted in court; presumably, other illegal transfers have occurred, but remain undetected.

An interesting question is why Norwegian authorities have not implemented ITQs on a larger scale. One possible explanation might be that they may be unaware of the economic advantage of an ITQ system. However, based on the debate regarding the different kinds of quota systems for fisheries management in practice, this explanation seems implausible. Another explanation might be that although the authorities know that ITQs normally secure economic efficiency, actors who have benefited from the status quo, have the political power to block policy changes that would reduce their advantages.2 Such an explanation might be relevant. The Norwegian government has recently suggested that limited transfer of quotas within the coastal fleet may be permitted (Ministry of Fisheries 2002). Under the new proposal, transfer will only be allowed for vessels within the same length group and geographical area.3 The authorities’ goal is that this change will reduce harvesting capacity and make the coastal fleet more efficient, while precluding a geographical concentration of quota rights or the tran-

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1 Efficiency aspects of these and other quota regimes that have been used or suggested for implementation in Norway are discussed in Bergland and Pedersen (2000).

2 An interesting study by Johnson and Libecap (1982) focuses on contracting problems and regulations in fisheries in the US, where transactions costs become a crucial factor for understanding the actual management decisions. Of course, the appearance of transaction costs might also be relevant in explaining the Norwegian experiences.

3 Note that this is similar to restrictions on transfer in the Alaska halibut/sablefish IQ program (National Research Council [1999]).
sition to a homogenous large vessel fleet. These suggestions are discussed within the fishermen’s organizations and in the coastal communities, and opinions differ. Some fishermen support transfer of quotas because they expect that transfer will allow the industry to become more profitable. However, all in all, there is considerable resistance to programs that permit quota transfers. An argument often heard from the opponents of transferable quotas is that they fear a reduction in the small-scale coastal fleet and concomitant reductions in employment in the coastal regions.

A third plausible explanation for why Norwegian authorities have not implemented ITQs on a larger scale is that the government has objectives other than securing economic efficiency; for instance, maximization of employment in the fishing industry (as seen in Canada [Crowley and Palsson 1992]). Such additional objectives may lead to a policy of controlling the distribution of catch between vessels and groups of vessels. The four main objectives presented by the Ministry of Fisheries (1991–92) are: (i) preserving the pattern of settlement, (ii) protection of fishery resources, (iii) securing employment in coastal areas, and (iv) increasing profitability in the fishing industry. Although the goals are formulated in a general manner, it can easily be seen that these objectives may lead to different policies, depending on the emphasis put on each of the goals. Additionally, there are several reasons for the government to be concerned about the final catch distribution in the fishing industry. First, there may be unique stock externalities associated with the selection of size and age in the catches, depending on the vessels’ gear. Second, there may be variations in the quality of catches and landings that depend on gear type or vessel size. For instance, the traditional production of stockfish requires a certain size and quality of cod, which, in turn, requires a certain type of gear. In general, the authorities want a fleet structure that fits the structure of the land-based processing industry, securing high overall profitability in the fishing industry as well as employment in coastal regions. In an even broader perspective, there may be positive externalities for other industries (e.g., tourism) that are better served by a continuation of the traditional fleet structure, particularly the smaller coastal fleet.

The fishing industry in Norway can easily be divided into two separate groups (Bergland 1995). The first group consists of agents engaged in the conventional inshore fishery using relatively small vessels where the owner is typically the captain of the boat. In this group, there are usually sole proprietorships or partnerships (self-employed fishermen). We term this group the coastal fleet. The second group is characterized by larger boats operating in the offshore fishery. The owners in this second group are professional owners in the sense that they typically employ all members of the crew, including the captains. This group is normally owned by a limited corporation, and can hereafter be termed the ocean fleet. Members of the two groups may have various attitudes towards risk. It seems reasonable to assume that professional owners, operating vessels belonging to the ocean fleet, have the opportunity to bear risks involved in the industry more easily than vessel owners belonging to the coastal fleet. There may be several reasons for believing in such an assumption. First, professional vessel owners have the opportunity to diversify the risks involved in the fishing industry through investment in other industries in which the profitability increases when it falls in the fishing industry. Such risk diversification can also be done by professional owners through financial investments in various capital markets. Operating owners in the coastal fleet are assumed to have less time and knowledge to engage in such diversifications. Second, owners who

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4 Another existing mechanism may be that small vessel operators diversify their income within the household through employment outside the fishing industry. Furthermore, small vessel operators often form purchasing or selling cooperatives and often negotiate risk pooling relationships with processors to insure against risk.
actively participate in harvesting will have both labor and capital income stemming from the fishing industry, while professional owners only have capital income from the fishery. This makes the risks involved harder to bear for the coastal fleet than for the ocean fleet. Finally, if the income level among professional owners is significantly higher than for operating owners, and the willingness to bear risks increases with income, vessel owners in the ocean fleet will be less risk averse than vessel owners in the coastal fleet.

Inspired by the theoretical and empirical experience mentioned above, we have adopted a simple model emphasizing different attitudes towards risk among the fishing firms to discuss the impacts of uncertainty and risk aversion in a quota market. Making analyses based on such a model can prove interesting for many reasons. First, our model shows that the standard result from the deterministic case; i.e., that the initial distribution of quotas has no influence on the equilibrium in the quota market (catch allocation and price of quotas) does not generally hold in the case of uncertainty and risk aversion. Secondly, risk aversion among fishermen may be one explanation why the smallest operators have been dropping out, as in Iceland5 (Palsson 2000) and New Zealand (Hersoug 2002). Thirdly, the existence of a non-transferable quota system in Norway can partly be explained by the actors’ risk attitudes.

The model on which the analysis is based is introduced in the next section, and the results of the analysis follow. Finally, some concluding remarks are offered.

The Model

In the model, the fishing industry is assumed to consist of relatively small harvesting units. All agents are assumed to be price takers in both output and input markets, as well as in the market for fishing quotas. Moreover, it is assumed that the harvesting units can be segregated into two distinct homogeneous groups. To simplify our model reasoning regarding possible differences in the two groups’ attitude towards risks, we will assume that members of the coastal fleet (agent 1) may be risk averse, while members of the ocean fleet (agent 2) are always risk neutral.6

Before the beginning of a year or other period when operators act (stage 1), the authorities announce a TAC level, \( Y \), and distribute the TAC among the operating units. Fishing units have an ability to buy or sell fishing quotas in a market (stage 2) before actually knowing the fishing conditions they will face in the period. Finally, as the fishing conditions become known, the fishing units catch their yearly quotas (stage 3). No matter which group a vessel belongs to, the harvesting costs on vessel \( i \), \( C_i \), which possibly differ between vessels belonging to the two groups, are assumed to be dependent on the vessel’s catch level, \( y_i \), and stochastic events affecting the fishing conditions for vessel \( i \) are symbolised by the variable \( \theta_i \). In order to

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5 An alternative explanation for reductions in the number of small operators in the Icelandic fisheries is that returns to scale render small vessels uneconomic.

6 In a discussion of fishermen’s attitudes toward risk, Clark (1985), pp. 230-31, proposes that there is “little reason to expect fishermen to be particularly averse to short-term fluctuations in their income; indeed, many fishermen may have a gambler’s taste for the daily ups and downs of their vocation.” Later on he says that “for longer-term decisions, however, risk aversion is much more likely to be significant. Most people who happily gamble with a day’s wages would hesitate to gamble with their annual income.” In our discussion, we have the long-term decisions in mind. In a recent study of a commercial fishery in Sweden, Eggert and Martinsson (2002) found a majority of fishermen to be risk averse, and that the fishermen became more risk averse as the fraction of their income generated from fishing increased.
avoid corner solutions, it is assumed that the harvesting costs increase convexly with regard to the catch level; i.e.,

\[ C_i = C_i(y_i, \theta_i) = \theta_i c_i(y_i), \quad \frac{\partial C_i}{\partial y_i} = \theta_i \frac{dc_i}{dy_i} > 0, \quad \frac{\partial^2 C_i}{\partial (y_i)^2} = \theta_i \left( \frac{d^2 c_i}{d(y_i)^2} \right) > 0, \quad i = 1, 2. \quad (1) \]

A strictly increasing and convex cost function in the harvest volume makes the analyses easier. However interesting cases, situations in which some fishermen leave a portion of their quota unharvested, are impossible to identify as solutions in our model. In a more realistic and complex analysis, which focuses on all effects arising from stochastic production conditions, the distinction between fixed and variable operating costs is reasonable. However, when we restrict our analyses to different risk attitudes, our simplifications regarding the cost function are reasonable.

It can easily be seen from equation (1) that better fishing conditions for vessel \( i \) at sea, making it possible to catch the same quantity for a lower level of inputs and therefore lower costs, here mean a lower value of \( \theta_i \). We have modelled the stochastic influence on costs as a multiplier in the cost function. We consider the \( \theta_i \)'s as normalized variables meaning that \( \text{ex ante, before the actual fishing conditions become known, the fishermen expect the value of the } \theta_i \text{'s to be 1; i.e., } E(\theta_i) = 1, \ i = 1, 2. \) This implies that the expected harvesting costs, \( E(C_i) \), are equal to \( c_i(y_i) \). The stochastic influence on the fishermen’s harvesting costs can be thought of as partly firm specific in the sense that it reflects fortunate or unfortunate events for a particular operator (idiosyncratic shocks), and partly conditions affecting all vessels at the same time (common shocks). An example of an idiosyncratic event might be the actual fish accessible to a particular vessel, while the actual stock size can be an example of a common stochastic shock variable.\(^7\)

It should be noted that the cost function in equation (1) neglects the stock effects present in dynamic analyses; e.g., that high catch levels in one period reduce the size of the fish stock and possibly also the growth rate of the stock. However, given our assumption that the public authorities regulate TAC for each period, taking into account such stock externalities, the short-run cost functions in equation (1) seem to be suitable when focusing on quota and catch distributions in the fishing industry.\(^8\) Furthermore, in a short-term analysis, in which the number of operators and vessel capacity are fixed, it seems reasonable to assume that the higher catch volumes result in higher expected costs, \( (dc_i/dy_i > 0) \), and that costs increase at a growing rate \( (d^2 c_i/dy_i^2 > 0) \).

Fishing takes place during stage 3. At this stage, the value of the stochastic variables are known and each firm maximizes its profits with a given vessel quota. At stage 2, the operators decide whether to buy or sell quotas, and at stage 1, the fishery managers distribute an exogenously given TAC to the firms. In order to analyze the behaviour of operators and the operation of the quota market, we solve the model by backward induction starting with the vessels’ choices of catch level at stage 3. Firm \( i \)'s profit at stage 3 is given by:

\(^7\) Danielsson (2002) analyses the efficiency of catch and effort quotas in the presence of risk. His model includes environmental stochastic variations in the growth of the fish stock and in the catch per unit of effort. Both of these stochastic variations may be involved in our random variable, \( \theta_i \).

\(^8\) This simplification is used in other studies focusing on different agents in the quota market; e.g., Grafton (1992); Matulich, Mittelhammer, and Roberte (1996); and Matulich and Sever (1999). Another example of a paper abstracting from the stock-growth relationship is Hannesson (2000). All these papers assume risk-neutral agents.
where \( p \) is the dockside exogenous price of unprocessed fish. The problem facing firm \( i \) at stage 3 is to maximize its profit given the quota constraint that actual catchers cannot exceed the individual vessel quota:

\[
y_i \leq \tilde{y}_i,
\]

where \( \tilde{y}_i \) is the individual vessel quota that agent \( i \) owns in the period. It is assumed that the authorities monitor the operators effectively, preventing the vessels from exceeding their quotas. The first-order condition for maximum profit at stage 3 is:

\[
p - \theta_i \frac{dc_i}{dy_i} = \lambda_i,
\]

where \( \lambda_i \) is the increase in firm \( i \)'s profit from a small increase in its IQ. In cases where quota regulation represents an effective constraint on the activity of firm \( i \), it will be the case that \( \lambda_i > 0 \). We assume this to be the case so that equation (3) holds as an equality. This means that even for high levels of \( \theta \)'s, where the fishing conditions are poor, the vessel owner will find it advantageous to catch the whole quota. Furthermore, it follows from equations (2), (3), and (4), that the profit and catch volume for each vessel are functions of the quota level and the stochastic variable; i.e.,

\[
R_i = R_i(\tilde{y}_i, \theta_i) \quad \text{where} \quad \frac{\partial R_i}{\partial \tilde{y}_i} = \lambda_i(\tilde{y}_i, \theta_i), \quad \frac{\partial^2 R_i}{\partial \tilde{y}_i^2} = \frac{\partial \lambda_i}{\partial \tilde{y}_i} = -\theta_i \frac{d^2 c_i}{d(\tilde{y}_i)^2} < 0, \quad (5)
\]

\[
\frac{\partial R_i}{\partial \theta_i} = -c_i(\tilde{y}_i) < 0, \quad \frac{\partial^2 R_i}{\partial \tilde{y}_i \partial \theta_i} = \frac{\partial \lambda_i}{\partial \theta_i} = \frac{dc_i}{dy_i} < 0 \quad \text{and} \quad \frac{\partial^2 R_i}{\partial (\theta_i)^2} = 0
\]

\[
y_i = y_i(\tilde{y}_i, \theta_i) \quad \text{where} \quad \frac{\partial y_i}{\partial \tilde{y}_i} = 1 \quad \text{and} \quad \frac{\partial y_i}{\partial \theta_i} = 0. \quad (6)
\]

At stage 2, the agents buy and sell quotas before they actually know the realization of the stochastic variable. This reflects an assumption of slowness and inflexibility in the transferable quota market due to problems for the agents to buy and sell quotas at the same time as they are conducting fishing operations at sea. The public authorities, having the responsibility of ensuring that vessels do not exceed their quotas, might also close the transferable quota market before the fishing season starts in order to have correct information of the quota distribution. Anticipated profits for the vessel owners can be defined by:

\[
\text{A more general assumption would be to introduce the ex vessel price of unprocessed fish as a stochastic variable. This assumption will be discussed at greater length in the conclusion.}
\]

\[
\text{Clark (1985 pp. 231–35), amongst others, considers the case in which a vessel owner in some nations would not find it advantageous or possible to catch the whole quota, meaning that the expected catch becomes lower than the quota a vessel owns. Applying this reasoning at stage 2 in the model (see below), it can easily be seen that even risk-neutral actors would reduce their net demand for quotas giving a lower quota price compared to the situation in which the actors are facing a value of } \theta = 1, \text{ being profitable.}
\]
\[ \pi_i = R(\tilde{y}_i, \theta_i) + k(\tilde{y}_i - \bar{y}_i), \]  

(7)

where \( k \) is the price per unit of quota, assumed to be exogenous for each of the operators, and \( \bar{y}_i \) is the original quota the public authorities distribute to actor \( i \).\(^{11}\)

Then, following the traditional decision-theoretical approach when uncertainty appears (Clark 1985, p. 238), the vessel owners’ goal, \( \text{ex ante} \), is to maximize the expected utility from profit with regard to disposable IQ \( \text{ex post} \), \( \tilde{y}_i \). The expected utility from profit is defined by:

\[ E[U_i(\pi_i)] \text{ where } \frac{dU_i}{d\pi_i} > 0 \text{ and } \frac{d^2U_i}{d(\pi_i)^2} \leq 0, \ i = 1, 2, \]  

(8)

where \( U(\pi_i) \) is a traditional von Neumann-Morgenstern’s (1947) utility function.\(^{12}\)

In this model, operators in the ocean fleet are assumed to be risk neutral; \( i.e. \), \( \frac{d^2U_i}{d(\pi_i)^2} = 0 \), while it is assumed that operators in the coastal fleet may be risk averse; \( i.e. \), \( \frac{d^2U_i}{d(\pi_i)^2} \leq 0 \).

The first-order condition for agent \( i \)’s optimal choice of an \( \text{ex post} \) quota is given by:

\[ \frac{dE[U_i]}{d\tilde{y}_i} = E\left\{ U_i'(\pi_i) \left( \frac{\partial R}{\partial \tilde{y}_i} - k \right) \right\} = 0, \ i = 1, 2, \]  

(9)

which can be rewritten as:

\[ E\left\{ U_i'(\pi_i) \left[ \lambda_i(\tilde{y}_i, \theta_i) - k \right] \right\} = 0, \ i = 1, 2. \]  

(10)

A further interpretation of this condition is given in connection with equation (15). The second-order condition is:

\[ \frac{d^2E[U_i]}{d(\tilde{y}_i)^2} = E\left\{ U_i''(\pi_i) \left[ \lambda_i(\tilde{y}_i, \theta_i) - k \right]^2 + U_i'(\pi_i) \frac{\partial \lambda_i}{\partial \tilde{y}_i} \right\} = A_i < 0, \ i = 1, 2. \]  

(11)

The second-order condition (11) is satisfied because \( U_i''(\cdot) \leq 0 \) and \( \frac{\partial \lambda_i}{\partial \tilde{y}_i} < 0 \). Equilibrium at stage 2 is determined by the two equations in (10), and a market clearing condition that requires that the sum of initial quota allocations equal the sum of \( \text{ex post} \) quotas; \( i.e. \),

\[ \tilde{y}_1 + \tilde{y}_2 = \bar{y}_1 + \bar{y}_2. \]  

(12)

Equations (10) and (12) implicitly define the endogenous variables \( k, \bar{y}_1, \) and \( \bar{y}_2 \) as functions of the initial allocations; \( i.e. \),

\(^{11}\) Grafton (1996) states that in all ITQ programs (to that date), fishers received a quota allocation free of charge.

\(^{12}\) The term stems from von Neumann and Morgenstern (1947) who first formulated the axiomatic foundation.
These functions are further expounded in the following analysis.

Prior to the actors’ decisions regarding transactions on the quota market, the authorities distribute the TAC, \( Y \), to the operators; i.e.,

\[ Y = \tilde{y}_1 + \tilde{y}_2. \]  

(14)

Given this model, two interesting questions arise. First, how does the possibility that members of the coastal fleet might be risk averse affect the quota market price and the \textit{ex post} distribution of quotas and catches? Second, how do changes in the \textit{ex ante} quota distribution and the original level of TAC affect the quota market price and the \textit{ex post} distribution of quotas and catches when actors belonging to the coastal fleet might be risk averse? These two questions are analyzed below.

**Risk Attitudes and Quota and Catch Distribution**

In order to reveal what happens in the quota market when an agent is risk averse compared to the case in which all agents are risk neutral, equation (10) can be rewritten as:

\[
E\{U'(\cdot)[\lambda, k - k]\} = E[U'(\cdot)|E[\lambda, \cdot] + \text{cov}[U', \lambda, \cdot] - E[U'(\cdot)]k = 0
\]

(15)

or

\[
E[\lambda, \cdot] = k - \gamma,
\]

where:

\[
\gamma_1 = \frac{\text{cov}[U'(\cdot), \lambda_1(\cdot)]}{E[U'(\cdot)]} \leq 0 \quad \text{and} \quad \gamma_2 = \frac{\text{cov}[U'(\cdot), \lambda_2(\cdot)]}{E[U'(\cdot)]} = 0,
\]

because \( U_{1''} \leq 0 \) and \( U_{2''} = 0 \). From equation (15), it follows that a risk-neutral agent chooses his or her optimal \textit{ex post} quota such that the expected marginal gain in profit for an extra unit, \( E[\lambda, \cdot] \), is equal to the quota price, \( k \), while risk-averse agents choose a level of \textit{ex post} quotas such that the last unit gives a higher marginal gain in expected profit than the quota price; i.e., \( E[\lambda, \cdot] > k \). Given the same levels of the IQs \textit{ex ante}, this means that going from a situation in which the coastal fleet is originally risk neutral to a situation in which the coastal fleet becomes risk averse, would result in changes to the \textit{ex post} quotas and the quota price approximately equal to:

\[
\Delta\tilde{y}_1 = \Delta y_1 = -\Delta\tilde{y}_2 = -\Delta y_2 = \frac{-\gamma_1}{E\left[\frac{\partial \lambda_1}{\partial \tilde{y}_1}(\cdot) + \frac{\partial \lambda_2}{\partial \tilde{y}_2}(\cdot)\right]} < 0
\]

(16)

and

\[
\Delta k = \frac{E\left[\frac{\partial \lambda_2}{\partial \tilde{y}_2}(\cdot)\right]}{E\left[\frac{\partial \lambda_1}{\partial \tilde{y}_1}(\cdot) + \frac{\partial \lambda_2}{\partial \tilde{y}_2}(\cdot)\right]} \gamma_1 < 0,
\]
where the signs of the expressions directly follow from the assumptions. From the assumption regarding the solution at stage 3, that equation (3) holds as an equality, it follows that ex post quota volume and the final catch volume are identical (equation [6]). This means that risk-averse members of the coastal fleet will hold a lower level of quotas than they would hold if they were risk neutral. Correspondingly, the risk-neutral ocean fleet increases their level of quota holdings. In order to make such transfers possible, the quota price must fall. For the ocean fleet, the quota price reflects their expected marginal gain in profit by the last kilo caught, while the coastal fleet has higher expected marginal gain in profit for their final unit caught. Finally, it should be noted that the results in equation (16) generally hold for all movements from risk neutrality to risk aversion, no matter how strong the aversion towards risks becomes.

**Result 1.** Members of the coastal fleet will hold a lower ex post quota (they will sell more or buy less), when they are risk averse as opposed to risk neutral. The equilibrium price in the quota market will be lower when members of the coastal fleet are risk averse as opposed to risk neutral.

Let us now turn to the question of how changes in original quotas affect the ex post quotas, the final catch distribution, and the market clearing quota price. In order to do so, let us first take a look at how marginal exogenous changes in the initial quota allocation and quota price affect behaviour. By differentiating the first-order condition in equation (10), we obtain:

\[
E \left[ U_i'(\pi_i) (\lambda_i - k) + U_i''(\pi_i) \frac{\partial \lambda_i}{\partial \tilde{y}_i} \right] d\tilde{y}_i + E \left[ U_i'(\pi_i) (\lambda_i - k) (\tilde{y}_i - \bar{y}_i) - U_i'(\pi_i) \right] dk
\]

\[= -E \left[ U_i'(\pi_i) k (\lambda_i - k) \right] d\tilde{y}_i,
\]

which gives us the following changes in the ex post quota and catch level:

\[
\frac{\partial \tilde{y}_i}{\partial \tilde{y}_i} = \frac{\partial \tilde{y}_i}{\partial y_i} = \frac{D_i}{A_i} \quad \text{and} \quad \frac{\partial \tilde{y}_i}{\partial k} = \frac{\partial \tilde{y}_i}{\partial y_i} = \frac{-B_i}{A_i},
\]

where \( D_i = -E \left[ U_i''(\pi_i) (\lambda_i - k) k \right] \), \( B_i = E \left[ U_i''(\pi_i) (\lambda_i - k) (\tilde{y}_i - \bar{y}_i) - U_i'(\pi_i) \right] \) and \( A_i \) is defined in equation (11). According to our assumptions, the signs of the expressions in equation (17) are ambiguous. In order to reveal additional information, let us first take a further look at the effect caused by a partial increase in the ex ante quota.

In the case where agent \( i \) is risk neutral, a partial increase in the initial quota, \( \bar{y}_i \), has no effect on the ex post quota; i.e., \( \frac{\partial \tilde{y}_i}{\partial \bar{y}_i} = 0 \) because \( D_i = 0 \). In the case of risk aversion, however, the sign of \( D_i \) is generally ambiguous. Following the traditional assumption that an agent is likely to have decreasing absolute risk aversion, it is shown in appendix A that \( D_i \leq 0 \), where the equality holds when the absolute risk aversion is constant (Pratt 1964; Arrow 1965; and Sandmo 1971). Strongly decreasing absolute risk aversion means that the money an agent is willing to give up in order to escape from uncertainty, the absolute risk premium, is a decreasing function of income. If the agent has strongly decreasing absolute risk aversion, increased initial individual quota would increase the agent’s ex post quota and catch level, while constant absolute risk aversion, such as risk neutrality, would mean that the initial quota has no effect on the catch level. The case of strongly decreasing absolute risk aversion seems reasonable. Higher initial quota allocation increases wealth. In-
creased wealth increases the ability to bear risks, implying that wealthier individuals will hold higher levels of quota \textit{ex post}. Moreover, whether a risk-averse vessel owner satisfying the assumption of strongly decreasing absolute risk aversion would plan to catch exactly the additional \textit{ex ante} quota units himself, buy additional quotas in the market, or sell some of the increased \textit{ex ante} quota is an interesting question. Taking a look at the first expression in equation (17) and remembering the negative signs of the variables \( A_i \) and \( D_i \) (under conditions of strongly decreasing absolute risk aversion), it can be seen that the outcome will depend on whether \( D_i = A_i \), \( D_i < A_i \) or \( D_i > A_i \). Using the definitions above, it follows that: \( D_i - A_i = -E[U_i''(\cdot)(\lambda_i - k)\lambda_i] - \frac{\partial E[U_i''(\cdot)]}{\partial y_i} \). In appendix A, given strongly decreasing absolute risk aversion, the first term, \( -E[U_i''(\cdot)(\lambda_i - k)\lambda_i] \), is shown to be negative, while the second term, \( -\frac{\partial E[U_i''(\cdot)]}{\partial y_i} \), is unambiguously positive due to the assumption of increasing expected marginal costs in harvesting. This means that decreasing absolute risk aversion will lead the coastal fleet to buy additional quota beyond their increased \textit{ex ante} quota holdings. The coastal fleet, as a consequence of having more quota units initially, has become richer and is, therefore, willing to bear the increased risk of buying additional quotas \textit{ex post}. However, the coastal fleet must also take into account that additional fishing activity will increase costs, which increases their incentive to sell some of the increase in the \textit{ex ante} quota units. Consequently, we do not know whether the change in the coastal fleet’s attitude towards risks, measured by the first term, dominates, is equal to, or is dominated by the change in harvesting costs, measured by the second term. When the change in attitude towards risks dominates; \( i.e., D_i - A_i < 0 \) or, equivalently, \( |D_i| > |A_i| \), the coastal fleet will buy additional quotas. If the cost effects dominate; \( i.e., D_i - A_i > 0 \) or, equivalently, \( |D_i| < |A_i| \), the coastal fleet will sell some of the increase in initial quotas.

The sign of \( B_i \) will be unambiguously negative in the risk neutral case; \( i.e., B_i = -E[U_i''(\pi_i)] \), meaning that the effect on the \textit{ex ante} quota caused by a partial increase in the quota price will be unambiguously negative, most easily written as \( \frac{\partial \pi_i}{\partial y_i} = 1/E[\partial \pi_i / \partial y_i(\cdot)] < 0 \). The results in the risk-neutral case are well known. When making a decision whether to buy or sell original quotas, the only thing that matters is the expected marginal profit in harvesting, reflected in the difference between the fish price and expected marginal costs, and the price of quotas, no matter what the original quota level might be. The higher the price level on quotas, the more quotas will be sold or fewer bought.

In the case of risk aversion, however, the level of quotas \textit{ex ante} may influence the final catch distribution, and the individual effect from increased quota price on \textit{ex post} quota holdings and catches is ambiguous. A necessary condition for increased quota price to reduce an agent’s level of \textit{ex post} quota is that \( B_i < 0 \). It is shown in appendix B that a sufficient condition for having this intuitively reasonable result is that the risk-averse actor has a low level of proportional risk aversion,\(^13\) meaning that the agent is willing to give up a fraction of a low income (when experiencing a high level of \( \theta \)) if they receive the same fraction of a higher income (when experiencing a low level of \( \theta \)).\(^14\)

\(^{13}\) In a situation in which the initial wealth is 0, the proportional risk aversion is defined as the absolute risk aversion function (see appendix A) multiplied with the income; \( i.e., -U''(U'')\pi_i = r\pi_i \), (Lindley 1985, pp. 178). Having a low proportional risk aversion means in this case of no initial wealth that \( r\pi_i < 1 \).

\(^{14}\) Thon and Thorlund-Petersen (1993) define such relative gambles and call the actor in a situation with low proportional risk aversion a relative risk-loving actor.
RESULT 2. (a) If a member of the coastal fleet has strongly decreasing absolute risk aversion, an increased initial individual quota would increase the agent’s ex post quota and catch level, while constant absolute risk aversion would mean that the initial quota has no effect on the catch level. (b) A sufficient condition for the result that increased quota price will reduce an agent’s level of ex post quota is that the agent has a low level of proportional risk aversion. If the agent is risk neutral, as in the case of constant absolute risk aversion, increased quota price will reduce an agent’s level of ex post quota holdings.

Now, let us take a look at how changes in initial quotas affect the behaviour of the agents as well as the quota price. Differentiating equation (10) for \( i = 1, 2 \) and equation (12) gives:

\[
\begin{align*}
A_i d\tilde{y}_i + B_i dk & = D_i d\tilde{y}_i \\
A_2 d\tilde{y}_2 + B_2 dk & = 0 \\
d\tilde{y}_1 + d\tilde{y}_2 & = d\tilde{y}_1 + d\tilde{y}_2.
\end{align*}
\]

First consider a redistribution of quotas from the risk neutral to the risk-averse agent; i.e., from firm 2 to firm 1. We assume that \( d\tilde{y}_1 = -d\tilde{y}_2 > 0 \). By using Cramer’s rule in equation (18), we derive the following solutions:

\[
\frac{d\tilde{y}_1}{d\tilde{y}_1} = \frac{dy_1}{dy_1} = -\frac{dy_2}{dy_1} = -\frac{D_2 B_1}{A_1 B_2 + A_2 B_1} \geq 0
\]

and

\[
\frac{dk}{d\tilde{y}_1} = \frac{D_1 A_2}{A_1 B_2 + A_2 B_1} \geq 0.
\]

Following our initial assumptions regarding the agents’ attitude towards risks, the denominators in the expressions will be positive. Moreover, both numerators will also be positive. If the risk-averse agent has strong decreasing absolute risk aversion, a redistribution of quota from the risk-neutral agent to the risk-averse agent leads to a higher catch volume for the risk-averse agent and a correspondingly reduced catch volume for the risk-neutral agent and a higher quota price. It should also be noted that if the absolute risk aversion is constant, the redistribution of initial quotas will have no influence on the final catch distribution or the quota price.

RESULT 3. A reallocation of initial quotas from the risk-neutral ocean fleet to the risk-averse coastal fleet results in higher catches in the coastal fleet (and correspondingly lower catches in the ocean fleet) and an increase in the quota price. There is no effect on the equilibrium of reallocations in cases where both actors are risk neutral or when the coastal fleet has constant absolute risk aversion.

Now, let us take a look at the case in which the TAC increases, and the increase is given to the ocean fleet; i.e., \( dY = d\tilde{y}_2 > 0 \) and \( d\tilde{y}_1 = 0 \). The results, derived from equation (18), when restricting ourselves to situations with low proportional risk aversion are:
This suggests that an increase in the total quota will reduce the quota price, regardless of risk preferences. The decrease in the quota price would lead both members of the ocean fleet and members of the coastal fleet to catch more. This means that the initial increase in the \textit{ex ante} quota, originally given to the ocean fleet, will be distributed among both groups (because $d\tilde{y}_1/d\tilde{y}_2 < 1$), meaning that the ocean fleet will tend to increase its supply of (or reduce its demand for) quotas, and members of the coastal fleet will tend to increase their demand for (or reduce their supply of) quotas.

\textbf{Result 4.} \textit{Given a low proportional risk aversion amongst the members of the coastal fleet, an increase in the initial quota for the ocean fleet, due to an increase in the TAC, leads to increased harvesting for both groups and a decrease in the quota price.}

Let us now consider the case of an increased total quota and that the increase is given to the coastal fleet; \textit{i.e.}, $dY = d\tilde{y}_1 > 0$ and $d\tilde{y}_2 = 0$. By restricting the discussion to situations in which the coastal fleet has low proportional risk aversion, which implicitly means decreasing absolute risk aversion, it is seen from equation (18) that:

\begin{equation}
0 < \frac{dy_1}{d\tilde{y}_1} = \frac{B_1A_2}{A_1B_2 + A_2B_1} \leq (>)0, \quad \frac{dy_2}{d\tilde{y}_2} = \frac{(A_1 - D_1)B_2}{A_1B_2 + A_2B_1} \geq (>)0
\end{equation}

and

\begin{equation}
\frac{dk}{d\tilde{y}_2} = \frac{-A_1A_2}{A_1B_2 + A_2B_1} < 0.
\end{equation}

That is to say an increase in the \textit{ex ante} quota allocation to the risk-averse coastal fleet for a given level of initial quota to the ocean fleet will increase the harvest in the coastal fleet. As long as the catch increase for the coastal fleet is assumed to be lower than the increase in the total quota; \textit{i.e.}, $|D_1| < |A_1|$, catches in the ocean fleet will also increase and the quota price will decrease. As noted above, this will hold if the increase in expected marginal costs for higher catches in the coastal fleet dominates the effect measuring lower absolute risk aversion as a consequence of being wealthier. In the opposite case, in which the effect of reduced risk aversion dominates the cost effect; \textit{i.e.}, $|D_1| > |A_1|$, the coastal fleet will buy more (sell fewer) quotas from the ocean fleet and the quota price will increase.

\textbf{Result 5.} \textit{Given low proportional risk aversion among the agents in the coastal fleet and implicit decreasing absolute risk aversion, the allocation of additional initial quotas to the coastal fleet will result in an increased harvest for the coastal fleet at a given level of ex ante quotas for the ocean fleet. If the cost effect dominates (is dominated by) the risk aversion effect for the coastal fleet, the harvest level by the ocean fleet increases (decreases) and the quota price falls (rises).}
Risk Attitudes and ITQs

In our model, economic efficiency in the fishing industry can be defined by catch levels that maximize the total expected profit for the two groups of fishermen. This is equivalent to minimizing the total expected costs in the fishing industry, and is, therefore, a necessary condition for economic efficiency. Alternatively, one may consider the catch levels that maximize the sum of the expected utilities for fishing firms to be an efficiency goal. Here we have chosen the first one, because the total expected costs of harvesting for this alternative are lowest. Maximizing the total expected profit for the fishing industry can be seen as a partial economic efficiency goal for the public authorities. Finally, let us take a look at how changes in initial quotas may affect the total expected profit for the two groups of fishermen. It is well known that economic efficiency based on this objective is secured when the expected marginal profits for the two groups are equal and, moreover, that the efficiency in the industry increases as the difference between the expected marginal profits decreases. Let the difference between the expected marginal profits be defined by

$$Z = E\lambda_1 - E\lambda_2 > 0,$$

where the inequality holds when the agents belonging to the coastal fleet are risk averse, see equation (15). Then, by using equation (19) and remembering that $$E\lambda_2 = k$$ [from equation (15)], a redistribution of quotas from the ocean fleet to the coastal fleet leads to:

$$\frac{\partial Z}{\partial y_1} = E\left[\frac{\partial \lambda_1}{\partial y_1}\right] \frac{D_1 B_2}{A_1 B_2 + A_2 B_1} - \frac{D_1 A_2}{A_1 B_2 + A_2 B_1} \leq 0,$$

where:

$$d\lambda_1 = -d\lambda_2 > 0.$$

The first term in equation (22) is non-positive because $\frac{\partial \lambda_1}{\partial y_1} < 0$ and $D_1 B_2/(A_1 B_2 + A_2 B_1) \geq 0$, and the second term is shown as: $-[D_1 A_2/(A_1 B_2 + A_2 B_1)] \leq 0$, given decreasing absolute risk aversion among coastal fleet members. This means that a redistribution of quotas from the ocean fleet to the coastal fleet, given strongly decreasing absolute risk aversion among coastal fleet members, reduces the difference between expected marginal profits and, therefore, increases economic efficiency in the industry. The intuition is that the risk-averse coastal fleet members become wealthier when their levels of initial quotas are increased, leading to less risk-averse behaviour and a better functioning quota market. Similarly, based on equations (20) and (21), increasing the TAC level and distributing the increase to the ocean fleet and the coastal fleet, respectively, leads to changes in $Z$ equal to:

$$\frac{\partial Z}{\partial y_2} = E\left[\frac{\partial \lambda_1}{\partial y_1}\right] \frac{B_1 A_2}{A_1 B_2 + A_2 B_1} + \frac{A_1 A_2}{A_1 B_2 + A_2 B_1},$$

where:

$$d\lambda_2 = dY > 0, d\lambda_1 = 0,$$

and

$$\frac{\partial Z}{\partial y_1} = E\left[\frac{\partial \lambda_1}{\partial y_1}\right] \frac{B_2 A_1}{A_1 B_2 + A_2 B_1} + \frac{A_1 A_2}{A_1 B_2 + A_2 B_1} + E\left[\frac{\partial \lambda_1}{\partial y_1}\right] \frac{B_1 D_1}{A_1 B_2 + A_2 B_1} - \frac{D_1 A_2}{A_1 B_2 + A_2 B_1} \leq \frac{\partial Z}{\partial y_2},$$

where: $d\lambda_1 = dY > 0, d\lambda_2 = 0$. 
In equation (23), the effect on $Z$ of giving the ocean fleet a higher initial quota is found. Given $B_1 < 0$, the first term is unambiguously negative, while the second term is unambiguously positive, implying that the difference between the expected marginal profits may be higher or lower, depending on whether the first or second term dominates. However, as seen in equation (24) where the effect on the ocean fleet is compared to the effect on expected marginal profits following from an increased initial quota for the coastal fleet, the effect is shown to be higher for the coastal fleet than for the ocean fleet. This means that if one wishes to increase the TAC level, the increase in the difference between the marginal profits becomes less (or the reduction between the marginal profits becomes higher) if one gives the coastal fleet additional quotas compared to a situation in which the ocean fleet is given the increased TAC, given that the coastal fleet members have strongly decreasing absolute risk aversion. The economic reason is that, as a consequence of having additional quotas, the risk-averse coastal fleet becomes more willing to bear risks involved in harvesting.

**Result 6.** A redistribution of initial quotas from the ocean fleet to the coastal fleet leads to higher economic efficiency in the case of strongly decreasing absolute risk aversion in the fishing industry. Under the same assumption, an increase in the TAC level will lead to the highest total expected profit in the fishing industry, if the additional quota units are distributed to the coastal fleet.

In order to approve economic efficiency, an alternative strategy could be that TAC should only be given to risk-neutral actors (in the ocean fleet). However, implementing such a strategy would increase the total expected harvesting costs because of the convex cost function, even though the need for insurance due to risk aversion would disappear.

**Concluding Remarks**

In order to draw some political implications from our analysis, let us apply our main results to the structure of the Norwegian fishing fleet. First, we consider Result 3 concerning a redistribution of the initial quota from the risk-neutral ocean fleet to the risk-averse coastal fleet. The public authorities have preferences for preserving the pattern of settlement and securing employment in coastal areas. Result 3 suggests that a redistribution of quotas in favour of the coastal fleet results in higher ex post quotas and higher catches in the coastal fleet, making it easier to satisfy the social goals of stable settlement patterns and employment in coastal areas. The economic mechanism behind this conclusion is that the coastal fleet becomes more able to bear the risks involved in fishing as a consequence of being wealthier when their initial quota share is increased (while leaving in mind the assumption of strongly decreasing absolute risk aversion). Taking a look at the expected marginal profit from harvesting for the two groups, the expected value for the coastal fleet approaches more closely to the expected marginal profit for the ocean fleet. A higher ex post quota level for the coastal fleet means reduced expected marginal profit for this part of the fleet, while lower ex post quotas for the ocean fleet imply higher marginal profits. This means that the proposed redistribution of initial quotas not only affects income distribution, but also increases economic efficiency, measured in aggregated expected profit stemming from the fishing industry. However, it

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15 This was proposed by a colleague at a research seminar.
should be remarked that actually implementing redistributions of initial quotas might be difficult, due to the historical fishing rights the actors may have established.

Many traditional fisheries in Norway, as well as many fisheries all over the world, have in recent years been faced with a need to reduce TAC levels due to past overfishing. Now, applying our Results 4, 5, and 6, let us consider what happens when a reduction in TAC is implemented. As seen from our analysis, the effect of reducing TAC depends upon the group taking the burden. When the coastal fleet bears the total reduction, the members of the fleet, as a consequence of being poorer, want to reduce the risks. This leads them to reduce their ex post quotas (sell more/buy less). This does not occur in the risk-neutral ocean fleet. Consequently, when the coastal fleet bears the total TAC reduction, economic efficiency in the fishing industry, as measured by the expected aggregated profit, decreases. Therefore, from a political point of view, a reduction in TAC, if needed, should be implemented by making cuts in the initial quotas given to the ocean fleet.

Our conclusions, and possible policy implications mentioned above, are based on an analysis of a model in which we have made several simplifying assumptions. First, we have divided the fishing fleet into two homogeneous groups, a risk-neutral ocean fleet and a risk-averse coastal fleet, whose risk aversion declines as profits increase. The basic assumption in our reasoning is that where one group of owners is significantly more risk averse than the other, differences in attitude towards risk among vessel owners affect the functioning of the quota market. The final catch distribution not only reflects the expected marginal costs for the different groups, but also the most risk-averse actors’ needs to insure themselves against unfortunate events in the future. The central hub of our reasoning is that the more the quota market behaves as an instrument for the agents to diversify risks, the less the final catch distribution will reflect the expected marginal profit for the actors. If we change the assumption about risk attitudes for the two groups; i.e., assuming that the coastal fleet is risk neutral and the ocean fleet is risk averse, our conclusions will be reversed. Second, our model includes a rigid separation between three sequential decision-making stages. The quota market is considered to be a leasing market for quotas, in which it is practically or legally difficult to trade in quotas during the season (year). The opposite case would be that it is a perfect possibility to transfer quotas after all aspects of harvest costs are known with certainty. Our model is unsuitable for discussing impacts of different attitudes towards risk in the case of perfect information. However, no matter how flexible the quota market functions, there will always be some aspects affecting costs that are unknown before fishing begins, such as weather conditions and stock accessibility. The coastal fleet is more vulnerable to adverse weather conditions and reduced stock accessibility because it includes smaller vessels with reduced range and hold capacity. This is an argument for analyzing quota markets in which agents may have different risk preferences.

Third, we have ignored stock dynamics. In some fisheries where ITQs have been introduced (e.g., Iceland and New Zealand), there are both markets for quotas issued in perpetuity and short-run leasing markets (for a year or a season). To study the market for perpetual quotas, we believe that it would be necessary to account for stock-growth relationships. However, modelling stochastic environmental variables, stock dynamics, and different risk preferences would involve a complex analysis that might not necessarily provide additional qualitative insight regarding the functioning of quota markets. Fourth, we have treated stochastic events in our model as cost uncertainty. In practice, agents will often have imperfect information concerning a wide range of variables; for instance, the price of raw fish ($p$). However, modelling additional stochastic variables may not change our main results. Finally, the cost function in our model is simple. We ignore the distinction between fixed
and variable costs and other possible decompositions of costs in the fishing industry. Altogether, our analysis is based on several simplifying assumptions. We believe that this paper points to an important issue, namely the functioning of quota markets when actors have differing risk preferences. However, further empirical and theoretical research will be necessary to determine the relevance and robustness of the results drawn from our analysis.

References


Appendix A

The degree of risk aversion is measured by the absolute risk aversion function, defined by:

\[ r_i = - \frac{U''(\pi_i)}{U'(\pi_i)} = r_i(\pi_i), \quad r_i(\pi_i) \leq 0, \quad (A1) \]

which is assumed to be decreasing in profit, \( r_i'(\pi_i) = -U'''(\pi_i)/U'(\pi_i) + [r_i(\pi_i)]^2 \leq 0. \) It is seen that a necessary condition for decreasing absolute risk aversion is that \( U''''(\pi_i) > 0. \) The following reasoning is analogous to that found in Arrow (1965) and Sandmo (1971). Let \( \lambda_i = k \) now define a particular value of profit, \( \pi_i^0. \) Then \( \lambda_i < k \) would mean a profit below \( \pi_i^0; i.e., \pi < \pi_i^0, \) and \( \lambda_i \geq k \) would mean \( \pi \geq \pi_i^0. \) According to equation (A1) it follows that:

\[ r_i^0 = - \frac{U'(\pi_i^0)}{U''(\pi_i^0)} \geq - \frac{U'(\pi_i)}{U''(\pi_i)} \quad \text{when} \quad \pi_i \geq \pi_i^0(\lambda_i \geq k), \quad (A2) \]

and

\[ r_i^0 = - \frac{U'(\pi_i^0)}{U''(\pi_i^0)} \leq - \frac{U'(\pi_i)}{U''(\pi_i)} \quad \text{when} \quad \pi_i < \pi_i^0(\lambda_i < k). \]

From equation (A2) it then follows that:

\[ -U'(\pi_i)(\lambda_i - k)r_i^0 \leq U'(\pi_i)(\lambda_i - k) \quad \text{for all possible values of} \ \pi_i. \quad (A3) \]

Then, taking the expectation on both sides of the inequality in equation (A3) and using the first-order condition in equation (10), it follows that:

\[ E[U'(\pi_i)(\lambda_i - k)] \geq -r_i^0E[U'(\pi_i)(\lambda_i - k)] = 0, \quad (A4) \]

where the equality holds when the absolute risk aversion is constant. This means that:

\[ D_i = -kE[U'(\pi_i)(\lambda_i - k)] \leq 0, \quad (A5) \]

where the equality holds for constant absolute risk aversion. Now, taking a look at the difference between the term \( D_i \) and \( A_i, \) it follows that:

\[ D_i - A_i = -E[U'(\lambda_i - k)\lambda_i] - E\left[U'(\cdot)\frac{\partial \lambda_i}{\partial y_i}\right] = -E[U'(\cdot)(\lambda_i - k)]E[\lambda_i] \quad (A6) \]

\[ - \text{cov}\{U'(\cdot)\lambda_i(\cdot) - k, \lambda_i(\cdot)\} - E\left[U'(\cdot)\frac{\partial \lambda_i}{\partial y_i}\right] \]

According to equation (A4), the first term on the right-hand side of equation (A6) is negative when the absolute risk aversion decreases strongly. The second term is also
negative because the correlation between $\lambda_i$ and $U_i''(\cdot)\lambda_i$ must be positive when absolute risk aversion decreases (implying that $U_i'''(\cdot) > 0$, see the comments on equation A1). The sum of these first two terms on the right-hand side of (A6), being unambiguously negative, can be thought of as measuring the actor’s less averse attitude towards risks when being richer, while the third term, being unambiguously positive, reflects that the expected marginal cost increase when harvesting more, see the discussion regarding the size of $D_i - A_i$ in the text.

Appendix B

Using the definition of $B_i$ in the text, $B_i$ can be reformulated as:

$$B_i = E[U_i'(\pi_i)(\lambda_i - k)](\tilde{y}_i - \tilde{y}_i) - E[U_i'(\pi_i)].$$

(A7)

The second term in equation (A7) is always negative, while the sign of the first term will depend on the sign of $E[U_i'(\pi_i)(\lambda_i - k)]$ and $(\tilde{y}_i - \tilde{y}_i)$. This means that given the case of constant absolute risk aversion, this first term is 0, meaning that $B_i$ is negative. Moreover, in the case where an actor plans to harvest exactly the amount of fish given by the ex ante quota, the first term is 0, meaning that $B_i$ is still negative, no matter what the actor’s attitude towards risks may be. However, in the case of strongly decreasing absolute risk aversion, implying that (A4) holds strictly, the sign of the first term will be negative when the actor buys additional quota units, $\tilde{y}_i < \tilde{y}_i$. It will be positive when the actor sells some of the initial quotas, i.e., $\tilde{y}_i > \tilde{y}_i$. This means that we know for sure that an actor, who buys quotas and has strongly decreasing absolute risk aversion, will always want to reduce her catch (by buying less quotas) when the quota price increases. However, whether an actor, who initially sells quotas and who has strongly decreasing absolute risk aversion, would reduce her catch (by selling more quotas) when the quota price increases, relies on the assumption that the absolute value of the positive first term is dominated by the absolute value of the negative second term. The intuition behind the positive first term in this case is that the actor, originally selling quotas, becomes richer when the quota price increases, making it easier to bear the risks involved in harvesting, partially leading to a wish for increasing ex post quotas. Given strongly decreasing absolute risk aversion, we know that when this positive “indirect income effect,” caused by an increase in the quota price, is dominated by the “direct substitution effect,” an actor, initially selling quotas, just like an actor originally buying quotas, wants to reduce the level of ex post quotas when the quota price increases.

However, in order to consider the sign of $B_i$ more generally in the case of risk aversion, no matter whether the actor initially buys or sells quotas, let us use a definition found in Thon and Thorlund-Petersen (1993). Consider a situation in which an actor, $i$, is facing a fear gamble; he or she could obtain a low income $n_1$ with probability $\frac{1}{2}$ and a high income $n_2$ with probability $\frac{1}{2}$. The expected utility of the income is then:

$$E[U_i(W_i + n)] = \frac{1}{2} U_i(W_i + n_1) + \frac{1}{2} U_i(W_i + n_2),$$

where $W_i$ is the actor’s initial income.

According to the definition in Thon and Thorlund-Petersen (1993), an actor, facing a fear gamble, is relatively risk loving, or, as we choose to say, has a low level
of proportional risk aversion when she will be willing to give up a share, \( e \), of the lowest income given that this state of the world is realised, if she additionally receives the same share, \( e \), of the highest income when this is realised. The expected utility of such a relative fear gamble must then be higher than the initial situation; i.e.,

\[
\frac{1}{2} U_i \left[ W_i + (1 - e)n^1 \right] + \frac{1}{2} U_i \left[ W_i + (1 + e)n^2 \right] > E \left[ U_i (W_i + n) \right] \quad (A8)
\]

or

\[
U_i \left[ W_i + (1 - e)n^1 \right] + U_i \left[ W_i + (1 + e)n^2 \right] > U_i (W_i + n^1) + U_i (W_i + n^2).
\]

Now, using a first-order Taylor approximation on the two terms on the left side of the inequality, implying that

\[
U_i \left[ W_i + (1 - e)n^1 \right] \approx U_i (W_i + n^1) - e n^1 U_i' (W_i + n^1)
\]

and

\[
U_i \left[ W_i + (1 - e)n^2 \right] \approx U_i (W_i + n^2) - e n^2 U_i' (W_i + n^2),
\]

then gives:

\[
-en^1 U_i' (W_i + n^1) + en^2 U_i' (W_i + n^2) > 0 \quad \text{or} \quad n^1 U_i' (W_i + n^1) < n^2 U_i' (W_i + n^2). \quad (A9)
\]

Remembering that \( n^1 < n^2 \) implies that equation (A9) is equivalent to the statement that \( n U_i' (W_i + n) \) increases in \( n \); i.e.,

\[
\frac{d \left[ n U_i' (W_i + n) \right]}{dn} = U_i'' (W_i + n) + n U_i''' (W_i + n) > 0. \quad (A10)
\]

By using the following definitions \( n = (\lambda_i - k)(\bar{y}_i - \bar{y}_i) \) and \( W_i = R_i (\cdot) - \lambda_i (\bar{y}_i - \bar{y}_i) \), meaning that \( W_i + n = \pi_i \), it can be seen that (A10) is analogous to:

\[
U_i' (\pi_i) + (\lambda_i - k)(\bar{y}_i - \bar{y}_i) U_i''' (\pi_i) > 0.
\]

When equation (A10) holds for every realisation of \( \theta_i \), it must hold for the expected value; i.e.,

\[
E \left[ U_i' (\pi_i) + (\lambda_i - k)(\bar{y}_i - \bar{y}_i) U_i''' (\pi_i) \right] > 0. \quad (A11)
\]

The inequality in equation (A11) then implies \( B_i < 0 \). In a situation in which the initial income is 0, this means that the proportional risk aversion, defined in footnote 11, is below 1; i.e., \(-[U_i''' (\cdot)/U_i'' (\cdot)] \pi_i < 1 \). A utility function giving a constant proportional risk aversion, \( 1 - \beta \), is given by \( U = \alpha (\pi_i)^\beta, \alpha > 0, 0 < \beta < 1 \). It can be easily seen that this utility function gives decreasing absolute risk aversion, implying that low constant proportional risk aversion necessarily leads to decreasing absolute risk aversion.