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Highgrading in Quota-Regulated Fisheries: Evidence from the Icelandic Cod Fishery

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Abstract

A theoretical model with nonlinear discarding costs is constructed to describe highgrading in a fishery with an Individual Transferable Quota (ITQ) program. The model shows that ITQs provide incentives to discard fish when the hold capacity of the vessel is nonbinding. An empirical model is developed to test for highgrading and to predict the discarded quantities of different grades of fish. This model is applied to the Icelandic ITQ-regulated cod fishery. Net and long-line vessels are involved in highgrading and the quota price induces highgrading for net vessels. The predicted total discarded quantities are 4.7% and 2.7% of total landings for net and long-line vessels, respectively. Long-line and net vessels are predicted to discard 18% and 76% of their small cod catch, suggesting that resource managers should focus on net vessels. These discard rates correspond well with biometric estimates, suggesting that economic modeling is a useful alternative method.

Keywords: cod; discarding; fisheries economics; highgrading; ITQs.

1. Introduction

Different species and sizes of fish usually occupy the same habitat and fishers have only imperfect control over what they catch. A profit-maximizing fisher has incentives to discard less valuable fish at sea, a practice commonly referred to as highgrading. The strength of the incentives depends on the difference in price between high- and low-valued fish, the cost of sorting, and the cost of reharvesting the fish. Highgrading leads to high mortality rates for the discarded fish [8] and results in social costs in the form of the lost market value of the fish, wasted efforts in harvesting the fish, and the wasted reproductive potential of the discarded fish [11].

Discarding may be due to technological reasons, such as a full hold, economic reasons, such as a zero or low market value for the fish, or legal constraints, such as quotas. Anderson [1,2], Arnason [3], and Turner [15] show how Individual Transferable Quota (ITQ) programs can induce highgrading. The cost of the quota is an additional cost item associated with landing the fish. If the quota price is higher than the value of the landed fish, then there is an incentive to discard the less valuable grades.

Regulating authorities can respond to highgrading by banning it as, for example, Iceland and Norway have done. For such a ban to be effective, there must be an enforcement system to catch violators. To evaluate the effectiveness of the enforcement system, regulating authorities need reliable estimates of discarded quantities. Such estimates are currently based on expensive shipboard monitoring. We suggest economic modeling as a complementary approach.

Theoretical models of discarding have been developed by Arnason [3], Vestergaard [16], and Turner [15]. We modify their models in three ways. First, rather than assuming that fishers have no control over what they catch, we assume that they can influence the composition of the catch through their choice of gear. However, once the gear is chosen, the composition cannot be further modified. Second, previous models assumed linear discarding costs, which led to corner solutions, where either all or none of each grade of fish is discarded. However, the empirical evidence from fisheries that have banned discarding contradicts the assumption of such corner solutions [6,9]. In these fisheries, fishers typically choose internal solutions, with some, but not total, discarding of the lower grades of fish. Such behavior is not surprising, given that, usually, greater efforts are made to catch serious offenders and, moreover, increasing penalties are imposed for serious violations. Increasing probabilities of being caught, in combination with progressive penalties, result in increasing marginal discarding costs. Third, instead of using effort as a decision variable, we use a production function to facilitate the construction of our empirical model.

Previous studies of discarding followed a purely theoretical approach and did not include any empirical application. We develop an empirical model using the generalized McFadden profit function to predict the discarded quantities of different sizes of fish. Furthermore, we develop a statistical test for highgrading in the empirical model. Finally, the model is applied to the Icelandic ITQ-regulated cod fishery over the period from September 1998 to June 2001. For validation, the predictions of the model are compared to existing estimates of highgrading in the Icelandic cod fishery obtained from shipboard monitoring.

2. The Theoretical Model

The model follows the general setup in Arnason [3], Vestergaard [16], and Turner [15], with some modifications regarding the effects of gear choice, the definition of technology, and the nonlinearity of discarding costs. First, we assume that fishers can influence the catch composition through their choice of gear. This assumption is based on the results of Palsson et al. [9], who estimated that long-line vessels discarded 1% of their landings of cod, whereas Danish seine vessels discarded 7.6%. Stratoudakis et al. [12,13] also reported different discarding rates between vessel types. Typically, only a few types of gear are used for fishing cod and considerable investments are required for changing the selected gear.[1] Therefore, the choice of gear is not made at each individual trip, but is a long-run decision. We assume that the gear has been chosen and focus on input use and discard rates for different types of vessels, conditional on the chosen gear.[2]

Second, previous models described the technology using an effort variable. A production function is a more general description that also is convenient for our empirical model. The production function differs between different types of vessels. We assume one input, x, and for each vessel type, V, we define the total catch, y^V, by the production function $y^V(x^V)$. The decision variables are the input usage and the discarded quantities, d, of the different grades of fish, $i = 1,...,I$. Landings, q, of grade i by vessel type V are given as:

$$q_i^V = a_i^V y^V\left(x^V\right) - d_i^V\,, \tag{1}$$

where a_i^V is the fixed proportion of grade i in the total catch for vessel type V and $\sum_i a_i^V \equiv 1$.

For simplicity, we focus on one type of vessel and drop the superscript V denoting the vessel type. The total catch is assumed to be increasing at a decreasing rate in input use, or:

$$\frac{\partial y(x)}{\partial x} = y_x(x) > 0 \quad \text{and} \quad \frac{\partial^2 y(x)}{\partial x^2} = y_{xx}(x) < 0. \tag{2}$$

Third, the fines for discarding are assumed to depend on total discarded quantities, $d \equiv \Sigma_i d_i$. The discarding cost function, $C(d)$, is increasing at an increasing rate in total discards, or:

$$\frac{\partial C(d)}{\partial d} = \frac{\partial C(d)}{\partial d_i} = C_d(d) > 0 \quad \text{and} \quad \frac{\partial^2 C(d)}{\partial d^2} = \frac{\partial^2 C(d)}{\partial d_i \partial d_j} = C_{dd}(d) > 0 \quad \forall i, j. \tag{3}$$

Assume the vessel participates in a single species fishery. The price of fish, p, differs by grade and there are fixed costs, F, as well as four variable cost categories: input costs, quota costs, discard costs, and landing costs. The fishery is managed by an ITQ and there is a quota market with sufficient quantities of quota available for the daily needs of the vessel. The vessel maximizes profits, π, for each fishing trip, or:

$$\max_{x,d_i} \pi(x,d_i) = \sum_{i=1}^{I} [p_i - w_l - w_q] q_i - w_x x - C(d) - F \,, \tag{4}$$

where w_l is the per unit cost of landing, w_q is the per unit price of the landed quota, and w_x is the per unit input price. This model can be adapted easily to other management schemes, such as open access, nontradable quotas, or total allowable catch, and, furthermore, it can be extended to multispecies fisheries. Substitution of the landing function (1) into the profit maximization problem (4) results in:

$$\max_{x,d_i} \pi(x,d_i) = \sum_i \Big[\big(p_i - w_l - w_q \big) \big(a_i y(x) - d_i \big) \Big] - w_x x - C(d) - F \,. \tag{5}$$

In each trip, the fisher cannot land more fish than the hold capacity, *H*, of the vessel, which imposes the following restriction:

$$\sum_i \big(a_i y(x) - d_i \big) \le H. \tag{6}$$

Furthermore, the fisher cannot discard more than the total catch or less than nothing, implying the restrictions:

$$a_i y(x) - d_i \ge 0 \text{ and } d_i \ge 0 \;\forall i. \tag{7}$$

Imposing the restrictions (6) and (7) on the maximization problem (5) results in the Kuhn–Tucker problem:

$$\begin{aligned} \max_{x,d_i,\lambda_{01},\lambda_{1i},\lambda_2} L = & \sum_i \Big[\big(p_i - w_l - w_q \big) \big(a_i y(x) - d_i \big) \Big] - w_x x - C(d) - F \\ & + \sum_i \lambda_{0i} d_i + \sum_i \lambda_{1i} \big(a_i y(x) - d_i \big) + \lambda_2 \Big[H - \sum_i \big(a_i y(x) - d_i \big) \Big]. \end{aligned} \tag{8}$$

Using $\Sigma_i a_i \equiv 1$, the Kuhn–Tucker conditions for problem (8) are:

$$\frac{\partial L}{\partial x} = \sum_i \big(p_i - w_l - w_q \big) a_i y_x(x) - w_x + \sum_i \lambda_{1i} a_i y_x(x) - \lambda_2 y_x(x) \le 0 \,, \tag{9}$$

$$\frac{\partial L}{\partial d_i} = -\left(p_i - w_l - w_q\right) - C_d\left(d\right) + \lambda_{0i} - \lambda_{1i} + \lambda_2 \le 0 \quad \forall i, \tag{10}$$

$$\frac{\partial L}{\partial \lambda_{0i}} = d_i \ge 0 \quad \forall i, \tag{11}$$

$$\frac{\partial L}{\partial \lambda_{1i}} = a_i y(x) - d_i \ge 0 \quad \forall i, \tag{12}$$

$$\frac{\partial L}{\partial \lambda_2} = H - \sum_i (a_i y(x) - d_i) \ge 0. \tag{13}$$

In addition, the complementary slackness conditions for problem (8) are:

$$x\frac{\partial L}{\partial x} = d_i \frac{\partial L}{\partial d_i} = \lambda_{0i}\frac{\partial L}{\partial \lambda_{0i}} = \lambda_{1i}\frac{\partial L}{\partial \lambda_{1i}} = \lambda_2 \frac{\partial L}{\partial \lambda_2} = 0 \text{ and } \lambda_{0i} \ge 0,\ \lambda_{1i} \ge 0,\ \lambda_2 \ge 0 \ \ \forall i. \tag{14}$$

2.1. Two Important Solutions

There are many solutions to the Kuhn–Tucker conditions and the complete set of solutions is available from the authors on request.[3] Based on the empirical evidence [9], we focus our discussion on solutions with positive input use such that $x > 0$, some but not total discarding of the less valuable grades $j \in I$ such that $d_j > 0$, and no discarding of the more valuable grades $k \in I$ such that $d_k = 0$. These solutions imply that $\lambda_{0j} = 0, \lambda_{0k} > 0,$ and $\lambda_{1i} = 0,$ and differ with respect to whether the hold constraint (6) is binding or not.

First, let us assume that the vessel is not restricted by the hold constraint (6), or $\lambda_2 = 0$. Equation (9) becomes:

$$\sum_i p_i a_i = \frac{w_x}{y_x(x)} + w_l + w_q. \tag{15}$$

Equation (15) implies that marginal revenue equals marginal cost. Marginal revenue is the average price of the catch. The first cost term is the input price divided by the marginal product, so the marginal cost consists of the input cost of the marginal product plus the per unit landing cost plus the per unit price of the landed quota.

The discarding rules when there is no hold constraint follow from equation (10). For a discarded grade j, we have $d_j > 0$ and:

$$w_q + w_l = p_j + C_d\left(d\right). \tag{16}$$

For a nondiscarded grade k, we have $d_k = 0$ and:

$$\lambda_{0k} \le p_k + C_d\left(d\right) - w_q - w_l. \tag{17}$$

A vessel will discard grade j until the marginal revenue of the discarded fish equals the marginal cost of the discarded fish. Equation (16) states that the marginal revenue of the discarded fish is the quota price plus the nonincurred landing costs of the fish and the marginal cost of the discarded fish is the price plus the marginal discarding costs of the discarded fish. The higher the quota price is, the larger will be the quantity of fish discarded. Furthermore, the lower the price of the discarded fish, the larger will be the quantity of fish discarded. The nonlinearity of the discarding costs prevents a corner solution, where either all or none of the fish is discarded.

The variable λ_{0k} may be interpreted as the change in profits or the marginal revenue from starting to discard grade k. Equation (17) states that grade k will not be discarded as long as the marginal revenue of starting to discard the fish is less than or equal to the marginal cost of discarding the fish. The marginal cost of discarding the fish is the price of the discarded fish plus the marginal discarding cost, minus the quota price and the landing costs of the fish.

Second, let us assume that the vessel is restricted by the hold constraint (6), or $\lambda_2 > 0$. Equation (9) becomes:

$$\lambda_2 = \sum_i p_i a_i - \frac{w_x}{y_x\left(x\right)} - w_l - w_q. \tag{18}$$

For a discarded grade j, we have $d_j > 0$ and equation (10) may be written as:

$$\lambda_2 = p_j - w_l - w_q + C_d\left(d\right). \tag{19}$$

By combining equations (18) and (19), we find the discarding rule for a discarded grade *j* as:

$$\sum_i p_i a_i = p_j + \frac{w_x}{y_x(x)} + C_d(d). \tag{20}$$

As in the first solution, the vessel will discard fish until the marginal revenue equals the marginal cost. However, the composition of the marginal revenue and cost terms has changed in important ways compared with the case without any hold constraint (16). In the case with a hold constraint, one unit of fish is exchanged with another unit and neither the quota price nor the landing costs are relevant. However, the price differences between different grades of fish and the input price are important. In equation (20), the marginal revenue of the discarded fish is the average price of the fish that replaces the discarded fish. The marginal cost of the discarded fish is the price of the discarded fish plus the marginal input cost per unit of fish replacing the discarded fish plus the marginal discarding costs.

For a nondiscarded grade *k*, we have $d_k = 0$ and equation (10) may be written as:

$$\lambda_2 \le p_k - w_l - w_q + C_d(d) - \lambda_{0k}. \tag{21}$$

By combining equations (18) and (21), we find the discarding rule for a nondiscarded grade *k*, as follows:

$$\lambda_{0k} \le p_k + \frac{w_x}{y_x(x)} + C_d(d) - \sum_i p_i a_i. \tag{22}$$

Grade *k* will not be discarded as long as the marginal revenue of starting to discard that grade of fish is less than or equal to the marginal cost of discarding it. The marginal cost of the discarded fish and marginal revenue are defined as in equation (20).

3. The Empirical Model

Commonly, the translog, the generalized Leontief, and the generalized McFadden functional forms are used to approximate profit functions. We use the generalized McFadden profit function [4] because there are zero observations of the prices in our simulation exercise of discard rates and neither the translog nor the generalized Leontief functions can deal with zero observations. The generalized McFadden function is modified in several ways. First, the legal framework concerning discarding has been constant over the estimation period and the discarding costs become the constant term of the profit function. Second, there are interaction effects between the fish stock and the gear that should be taken into account [9]. We do so by including three seasonal dummy variables, *z*, as discussed in the data section. Third, the input price, denoted by *w*, is measured by the oil price. The per unit landing cost is also measured by this variable. Fourth, the profit function is homogenous of degree one in input and output prices. We impose homogeneity by including price variables in all the first-order terms and dividing all the second-order price terms by the oil price. Our generalized McFadden profit function is:

$$\begin{aligned}\pi = \alpha_0 + \left(\sum_{j=1}^{I} \phi_j p_j + \phi_q w_q + \phi w \right) \sum_{s=1}^{3} \alpha_s z_s + \sum_{i=1}^{I} \alpha_i p_i + \alpha_q w_q + \alpha w + \sum_{i=1}^{I} \sum_{s=1}^{3} \beta_{is} z_s p_i \\ + \sum_{s=1}^{3} \beta_{qs} z_s w_q + \sum_{s=1}^{3} \beta_{xs} z_s w + \frac{1}{2w} \left[\sum_{i=1}^{I} \sum_{j=1}^{I} \gamma_{ij} p_i p_j + \sum_{i=1}^{I} \gamma_{qi} p_i w_q + \gamma_{qq} w_q^2 \right],\end{aligned} \tag{23}$$

where p_i is the price of grade i, w_q is the per unit price of the landed quota, and α, β, and γ are the parameters to be estimated. The ϕ parameters have to be preselected by the researcher [4]. For simplicity, we have set them to zero. Symmetry restrictions, $\gamma_{ij} = \gamma_{ji} \; \forall i, j,$ are imposed on the system.

The output supply and input demand functions are derived by Hotelling's lemma. The output supply functions, q_i, are:

$$\frac{\partial \pi}{\partial p_i} = q_i = \alpha_i + \sum_{s=1}^{3} \beta_{is} z_s + \frac{1}{w} \left[\sum_{j=1}^{I} \gamma_{ij} p_j + \gamma_{iq} w_q \right] \forall i. \tag{24}$$

Icelandic quota regulations take into account factors such as on-board gutting and heading, which affect the measurement of quantity. Consequently, the total quota use is not perfectly correlated with the total catch and we can estimate the input demand function for the quota as:

$$\frac{\partial \pi}{\partial w_q} = -q = \alpha_q + \sum_{s=1}^{3} \beta_{qs} z_s + \frac{1}{w}\left[\sum_{j=1}^{I} \gamma_{qj} p_j + \gamma_{qq} w_q\right]. \tag{25}$$

To estimate equations (24) and (25), an error term is appended to each equation. We assume that the vector of error terms is drawn from a multivariate normal distribution with zero mean and constant variance. The equations are linear in the parameters and the model is estimated by using Zellner's iterative, seemingly unrelated regressions method as implemented by the LSQ procedure in TSP.

The output supply elasticities are calculated as:

$$\varepsilon_{ij} = \frac{\gamma_{ij}}{\overline{w}} \frac{\overline{p}_j}{\overline{q}_i}, \tag{26}$$

where $\overline{w}$, $\overline{p}_j$, and $\overline{q}_j$ represent the mean values of the variables. The input demand elasticities for the quota are calculated as:

$$\varepsilon_{qj} = \frac{\gamma_{qj}}{\overline{w}} \frac{\overline{p}_j}{\overline{q}}.$$

The output supply and input demand functions are homogenous of degree zero in prices and the input demand elasticities for oil, e_{ix}, are calculated as:

$$\varepsilon_{ix} = -\sum_{j=1}^{I} \varepsilon_{ij} - \varepsilon_{iq}. \tag{27}$$

3.1. Tests for Highgrading

No highgrading implies no discarding, or $d_i = 0$, and the landings equation (1) becomes:

$$q_i = a_i \sum_i q_i = a_i y(x). \tag{28}$$

From equation (28), we have $\partial q_i / \partial p_k = a_i \left(\partial y / \partial p_k \right)$, or $\partial y / \partial p_k = \dfrac{\partial q_i / \partial p_k}{a_i}$. If there is no highgrading, then the composition of landings is not affected by changes in the prices of the different grades of fish. Therefore, a_i is constant and can be estimated by $\overline{q}_i / \overline{y}$. In terms of equations (24), the null hypothesis of no highgrading becomes:

$$\frac{\gamma_{ik}}{a_i} = \frac{\gamma_{jk}}{a_j} \; \forall i, j, k. \tag{29}$$

Correspondingly, from equation (28), $\partial q_i / \partial w_q = a_i \left(\partial y / \partial w_q \right)$. If there is no quota price-induced highgrading, the composition of landings is not affected by changes in the quota price. In terms of equations (24), this null hypothesis becomes:

$$\frac{\gamma_{iq}}{a_i} = \frac{\gamma_{jq}}{a_j} \quad \forall i, j. \tag{30}$$

3.2. Predicted Discarding

Now, we use the model to predict the discarding rates. Assume an initial situation with a free quota and identical prices for all grades of fish. In this situation, denoted with superscript 0, there are no incentives to discard fish and $d_i = 0 \; \forall i$. The total catch of fish is $\sum q_i = y$ and equation (1) can be used to predict the composition of the catch, as follows:

$$y_i^0 = q_i^0 = a_i^0 q^0 = a_i^0 y^0 \rightarrow a_i^0 = y_i^0 / y^0. \tag{31}$$

Under a different set of prices, discarding occurs for the least valuable grades, j, such that $d_j > 0$. For example, this set of prices may be the average prices, denoted with superscript 1. Assuming that the largest and most valuable cod, grade k, is never discarded, we have $d_k = 0$. We can predict the actual catch, y^1, by substituting equation (31) into the landings equation (1) to obtain:

$$q_k^1 = a_k^0 y^1 \rightarrow y^1 = q_k^1 / a_k^0. \tag{32}$$

Equation (32) is used to predict the discarded quantities of each discarded grade *j*, or:

$$q_j^1 = a_j^0 y^1 - d_j^1 \rightarrow d_j^1 = a_j^0 \frac{q_k^1}{a_k^0} - q_j^1. \tag{33}$$

The predicted discarded quantity of each grade is the difference between the predicted catch and the observed landed quantity.[4] Following Palsson et al. [8,9], we report discarding as a percentage of landings.

4. Data

Íslandsmarkaður, the Network of Icelandic fish auctions, provided the price and quantity data. About one third of the annual catch of cod is sold at these auctions and it is possible to classify the transactions by species, fishing method, and size.

Five fishing methods are predominantly used in the Icelandic cod fisheries: trawl, Danish seine, long-line, hand line, and net. The cod sold in the auctions are mainly caught using the last three methods. The hand-line vessels are small and many are not regulated by quotas. Therefore, only data for the long-line and net vessels were used.

We used three size categories for cod: small (< 2.0 kg), medium (2.0–3.5 kg), and large (> 3.5 kg). The price was defined as the average weekly price of all cod caught by a particular gear type and belonging to a particular size category. Not all grades are sold on all days, so weekly data were used to eliminate missing values. The final dataset covers 141 weeks and is based on 116,159 transactions with a total quantity of 77,000 tons and a market value of 10.5 billion ISK, or about US$140 million.

The quota prices are provided by the Directorate of Fisheries, which enforces laws and regulations regarding fisheries management, monitors fishing activities, and imposes penalties for illegal catches. A central quota market existed from 1 September 1998 to 31 May 2001 and we used data for this period.

As this is a short-run model, there are few variable input factors. Capital is fixed on a week-to-week basis. In addition, Icelandic labor regulations imply that the number of fishers on each vessel is fixed. Furthermore, the fishers are usually paid catch value shares and labor cost becomes a function of output value. The major input that the fisher can control in the short run is fuel. The price of oil for fishing vessels was provided by the oil retailer Oliufelagid ESSO, which is the largest provider of fuel and oil-based products to the Icelandic business sector.

Table 1 shows that the mean price increases with the size of the cod. There are only small differences in the prices of cod from long-line and net vessels. The price of small cod is only slightly above the quota price, indicating an incentive to discard this size category. The composition of landings from the two vessel types is quite different, showing the potential importance of separating discarding behavior by vessel type. Long-line vessels land a catch composed of 11% small, 67% medium, and 22% large cod, whereas net vessels land a catch composed of 1% small, 18% medium, and 80% large cod.

Three seasonal dummy variables are added to the estimated model. The first variable covers the net season, which also is the second half of the long-line season, lasting from February through April. The second variable covers the first half of the long-line season, lasting from November through January. The third variable covers the first off-season in May and the fall months August, September, and October. The constant term covers the season with the smallest catches in June and July. These three seasons approximate the reported quantity landed by each vessel type for each month as reported by, for example, Helgason [5].

5. Empirical Results

The fishers deliver their catch prior to the actual auction, so they do not know the prices that they will obtain. We assume that the fishers are rational, that they make efficient use of relevant information in their optimizing behavior, and that they have quasi-rational price expectations [7]. Quasi-rational expectations imply that the best-fitting time-series model can describe expectations of future prices. An ARIMA model is estimated for the price of each size category and for each vessel type, using all available historical data from the auctions over the period from January 1995 through August 1998. Stationarity was tested by a Dickey–Fuller test, with a lag length chosen by the method described by Pantula [10]. The Extended Sample Autocorrelation Function method of Tsay and Tiao [14] was used to identify the orders of the ARIMA models. The selected orders are shown in Table 1. The first number refers to the order of the AR process, the second number to the order of integration, and the third number to the order of the MA process. The parameters of the model were updated for each prediction of the week ahead by reestimating the model with all available observations.

5.1. Elasticity Estimates

The elasticities are easier to interpret than the parameter estimates. The estimated parameters are not presented, but they are available from the authors upon request. The estimated elasticities, calculated at mean values, are reported in Tables 2 and 3 for the net and long-line vessels, respectively. The associated t values are reported in parentheses and the adjusted R^2 values are shown in the last column of each table. A t value that is higher than or equal to 1.96 is significant at the 5% level of significance.

Several elasticities are quite different in the two models. First, the own-price supply elasticities are positive and the own-price demand elasticity for the quota is negative in both models, with one exception. The own-price supply elasticity for large cod caught by long-line vessels is negative. However, it is significantly different from zero. Second, in the absence of highgrading, one would expect all size classes to be complements. This is not the case for any vessel type. In the net model, large cod is a substitute for small and medium-sized cod, whereas, rather surprisingly, small and medium-sized cod appear to be substitutes for large cod. In the long-line model, small and medium-sized cod are substitutes. Third, the quota elasticities are not significantly different from zero, with two notable exceptions in the long-line model. In this model, an increased quota price will reduce the supply of small cod, whereas an increase in the price of small cod will increase the quota price. Fourth, in the net model, the oil price elasticity is significant and positive for small cod, suggesting that an increased oil price increases the supply of small cod; that is, it reduces discarding. This effect is consistent with the predictions of equation (20). In the long-line model, the oil price elasticity is negative and significant for the supply of medium-sized cod and for the demand for the quota, suggesting that an increased oil price reduces the demand for the quota.

5.2. Discarding

The *p* values of the tests for the cases of no highgrading (29) and no quota price-induced highgrading (30) are reported in Table 4. In addition, the predicted discard rates for cod and the split in discard rates between small and medium-sized cod, as calculated by equation (33), are reported.

No highgrading is clearly rejected for both vessel types, whereas no quota price-induced highgrading is rejected for net vessels at the 5% level of significance. According to our theoretical model, the effects of the quota price on highgrading depend on whether the hold constraint is binding. The quota price is expected to have an effect only when the hold constraint is nonbinding. If the hold constraint is nonbinding, then a higher quota price is expected to increase discarding. The hold constraint for the net vessels appears to be less binding and quota price-induced discarding cannot be rejected for this vessel type.

The discarded quantities are reported as percentages of the total landings of cod. The predicted total discarded quantities for net and long-line vessels are 4.7% and 2.7%, respectively. As expected, most of the discarded fish is small cod and the discarded quantity of medium-sized cod is less than 1% of the total landings.

The discard rates suggest that discarding is more common in the net than in the long-line fisheries. Taking into account the average landings shown in Table 1, the difference in discard rates between the two vessel types is substantial. About 1% of the average landings of net vessels consist of small cod, compared with 11% for long-line vessels. Consequently, the long-line vessels discard about 18% of their catch of small cod, whereas the net vessels discard about 76% of their catch of small cod.

The Icelandic Marine Research Institute estimated discard rates based on a comparison of the length distribution of landings and catch samples in 2001. Our predicted discard rates correspond well with the estimates reported by this Institute [9]. Their reported discard rates of 3% for net vessels and 1% for long-line vessels are somewhat lower than the predictions of our model. However, they are of the same approximate size.

6. Conclusions

Our theoretical model shows that a profit-maximizing fisher has incentives to discard small cod. Different vessel types may have different discard rates and ITQs provide incentives for discarding as long as the hold capacity of the vessel is nonbinding. If the hold capacity is binding, then the quota price will not induce discarding.

In our empirical model of the Icelandic cod fisheries, a no highgrading hypothesis is clearly rejected both for net and long-line vessels, whereas no quota price-induced highgrading is rejected only for net vessels. The predicted total discarded quantities are 4.7% and 2.7% for net and long-line vessels.

Our predicted discard rates correspond well with biological estimates obtained by shipboard monitoring, suggesting that the proposed method is reasonably accurate. Furthermore, the availability of the required data is increasing as fish markets start to use electronic sales systems. The costs of economic modeling are relatively low compared with expensive shipboard monitoring. Thus, economic models can help regulating authorities to choose the optimal level of shipboard monitoring.

The results suggest that the ban is inefficient in stopping discards in the Icelandic cod fishery. It is predicted that long-line and net vessels will discard about 18% and 76% of the catch of small cod, respectively. The test results indicate that the lower discard rates of the long-line vessels may be due, at least partly, to better capacity use and less quota-induced discarding. These results have some policy implications. First, discarding of small cod is a problem and monitoring should be increased. Second, resource managers should focus their monitoring attention on net rather than long-line vessels or, generally, on seasonal fisheries where the hold capacity is limited during short periods. Third, the economic incentives generated by full capacity use and the interaction between gear and capacity use suggest capacity or gear regulation as a possible method of reducing the highgrading problems in ITQ-regulated fisheries.

Endnotes

1. Many commercial fisheries are characterized by few distinct gear types. As an example, the major gear types used in the Icelandic cod fishery are trawl, Danish seine, long-line, hand line, and nets. The required equipment for these types of gear varies considerably.
2. In our data on Icelandic net and long-line vessels, less than 10% of the vessels changed gear type, including permanent changes. Therefore, the assumption of fixed gear is plausible.

3. Some of the solutions, such as no discarding of any grades or full discarding of all grades, are of no interest. Other solutions, such as full discarding of some grades, may be of some interest. However, the empirical evidence suggests that the two solutions presented are the most relevant.

4. Note that the interpretation of the simulation results relies on no output flexibility. If there is some output flexibility, then the results will predict the upper level of discards rather than the actual discards.

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Table 1. Variable Definitions and Descriptive Statistics for Quantity and Price Variables

Vessel Type	Output/ Input	Variable Type[1]	Variable Name[2]	Descriptive Statistics Mean[3]	SD[4]	Min	Max	ARIMA Model[5]
Long-line	Small cod	Exp. price	p_1^l	105.7	59.3	84.7	122.9	1,0,1
Long-line	Medium cod	Exp. price	p_2^l	124.9	102.6	104.6	149.2	0,1,1
Long-line	Large cod	Exp. price	p_3^l	151.2	320.4	122.6	188.7	2,1,1
Net	Small cod	Exp. price	p_1^n	106.1	49.9	87.6	122.4	1,0,3
Net	Medium cod	Exp. price	p_2^n	124.9	102.3	104.7	149.1	0,1,1
Net	Large cod	Exp. price	p_3^n	151.1	318.2	123.5	189.0	0,1,1
Both	Quota cod	Price	w_q	104.8	74.4	85.2	126.0	
Both	Oil	Price	w	19.7	37.2	12.3	30.6	
Long-line	Small cod	Quantity	q_1^l	36.1	23.6	2.8	120.9	
Long-line	Medium cod	Quantity	q_2^l	210.7	146.8	24.0	707.8	
Long-line	Large cod	Quantity	q_3^l	68.6	63.7	5.0	380.1	
Long-line	Quota	Quantity	q^l	264.6	182.8	43.1	962.0	
Net	Small cod	Quantity	q_1^n	2.8	4.3	0.0	22.3	
Net	Medium cod	Quantity	q_2^n	43.0	50.2	0.3	302.5	
Net	Large cod	Quantity	q_3^n	188.1	202.4	3.0	1130.4	
Net	Quota	Quantity	q^n	224.7	236.6	8.9	1287.0	

[1] Exp. price is the expected price as predicted by the ARIMA model defined in the last column.

[2] The superscript in a variable name refers to the vessel type (l = long-line and n = net). The subscript refers to the size category (1 = small, 2 = medium, and 3 = large).

[3] Prices are reported in ISK per kg and quantities in tons per week.

[4] SD refers to the standard deviation of the variable.

[5] The first number refers to the AR component, the second to the order of integration, and the third to the MA component.

Table 2. Elasticities Calculated at Mean Values and Adjusted R^2 Values for the Net Model with t Values in Parentheses

	Small	Medium	Large	Quota	Oil	Adjusted R^2
Small cod	3.39	2.40	–7.00	–0.75	1.96	0.41
	(2.76)	(0.95)	(2.83)	(0.74)	(3.45)	
Medium cod	0.13	1.94	–3.26	0.58	0.61	0.35
	(0.95)	(1.46)	(2.21)	(0.90)	(1.73)	
Large cod	–0.07	–0.62	1.24	–0.30	–0.24	0.51
	(2.83)	(2.21)	(2.13)	(0.70)	(1.29)	
Quota	0.01	–0.13	0.35	–0.20	–0.03	0.50
	(0.74)	(0.90)	(0.70)	(0.47)	(0.18)	

Table 3. Elasticities Calculated at Mean Values and Adjusted R^2 Values for the Long-Line Model with t Values in Parentheses

	Small	Medium	Large	Quota	Oil	Adjusted R^2
Small cod	1.53	–2.28	1.64	–1.06	0.17	0.38
	(2.39)	(2.52)	(2.09)	(2.96)	(0.92)	
Medium cod	–0.33	0.92	0.26	–0.50	–0.34	0.33
	(2.52)	(2.34)	(0.90)	(1.77)	(2.46)	
Large cod	0.62	0.66	–0.68	–0.41	–0.18	0.31
	(2.09)	(0.90)	(0.94)	(1.01)	(0.81)	
Quota	0.15	0.48	0.15	–0.50	–0.27	0.35
	(2.96)	(1.77)	(1.01)	(1.82)	(2.10)	

Table 4. P Values for Tests of Highgrading and Predicted Discard Rates

	Hypothesis		Predicted Discard Rates			
Model	Highgrading	Quota Price	Small	Medium	Total	Discards[1]
Net	0.000	0.041	3.90%	0.79%	4.70%	3.00%
Long-line	0.008	0.336	2.44%	0.27%	2.71%	1.00%

[1] Estimates reported by the Icelandic Marine Research Institute in Palsson et al. [9].