AJAE appendix for '*Highgrading in Quota-Regulated Fisheries: Evidence from the Icelandic Cod Fishery*'

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Complete Set of Kuhn–Tucker Solutions

The solutions below represent different combinations of binding constraints in the Kuhn-Tucker conditions specified by equations (9) to (13) in the article. Solutions without fishing is of limited interest with respect to discarding and we only consider solutions with a positive input use such that $x > 0$.

Solutions without Discards

Solution 1a ($\lambda_{0i} > 0 \; \forall i$ and $\lambda_{1i} = \lambda_2 = 0 \; \forall i$)

In equation (15) in the article, we allowed for discarding of less valuable grades j. If we assume no discarding of any grade such that $d_i = 0 \;\; \forall i$, equation (15) and its interpretation remain as in the article. However, the discarding rule (17) has to hold with equality such that:

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

When the right hand side is positive, the no-discard constraint is binding and we have no discarding. This implies that no discarding will occur as long as the price of grade k plus the marginal discard costs exceed the quota price plus landing costs. The equation shows that the quota price gives incentives for discarding by adding to landing costs and that monitoring and punishment will increase the marginal discard costs and, thereby, prevent discarding.

Solution 1b ($\lambda_{0i} > 0 \; \forall i$, $\lambda_{1i} = 0 \; \forall i$, and $\lambda_2 > 0$)

In equation (18) in the article, we allowed for discarding of less valuable grades j. If we assume no discarding of any grade such that $d_i = 0 \;\; \forall i$, equation (18) remains as in the article. The no-discarding rule, in equation (22), holds with equality

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

In this case, the no-discard rule changes substantially. Grade *i* will not be discarded as long as the marginal cost of discarding it, now comprised of the price of the fish, the marginal discard cost and the marginal input cost per unit output (the cost of fishing a new unit to replace the discarded unit) exceeds the average price of the next unit caught. Note that neither the landing costs nor the quota price affects the results since the same amount of fish is landed.

Solutions with Discards

Here we are primarily interested in discarding and assume that discarding occurs for some grades but not for other grades. This situation is typical according to existing empirical evidence. Assume that *I* is the set of all grades, *J* is the set of grades with positive discards and *K* is the set of non-discarded grades such that $i \in I$, $j \in J$, $k \in K$, $I = J \cup K$, and $J \cap K = \varnothing$.

Solution 2 ($\lambda_{0j} = 0, \lambda_{0k} > 0, \lambda_{1i} = 0 \; \forall i$, and $\lambda_2 = 0$)

This is the first solution discussed in the article, with a non-binding hold constraint and internal solution for discarding. We refer to equations (15) to (17) and the associated text in the article for further information.

Solution 3 ($\lambda_{0j} = 0, \lambda_{0k} > 0, \lambda_{1i} = 0,$ and $\lambda_2 > 0$)

This is the second solution discussed in the paper, with a binding hold constraint and internal solution for discarding. We refer to equations (18) to (22) and the text in the paper for further information.

Solution 4 ($\lambda_{0j} = 0, \lambda_{0k} > 0, \lambda_{1j} > 0, \lambda_{1k} = 0,$ and $\lambda_2 = 0$)

Total discarding of grade *j*, no discarding of grade *k*, and hold constraint is not binding. Equations (15) and (16) for grade *j* become

$$\sum_i p_i a_i = \frac{w_x}{y_x(x)} + w_l + w_q - \sum_j \lambda_{1j} a_j$$

$$w_q + w_l = p_j + C_d(d) + \lambda_{1j}$$

such that

$$\lambda_{1j} = w_q + w_l - \left(p_j + C_d(d)\right).$$

If the quota price plus the landing costs exceed the forgone fish price plus the marginal discard cost, then discard all of grade *j*. Neither the discarding rule for grade *k* nor its interpretation change and are given by equation (17) in the article as

$$\lambda_{0k} = p_k + C_d(d) - w_q - w_l.$$

Do not discard as long as the price plus marginal discarding costs exceed the landing costs.

We replace for λ_{1j} into the equation above and obtain

$$\sum_i p_i a_i - \frac{w_x}{y_x(x)} - w_l - w_q + w_q \sum_j a_j + w_l \sum_j a_j - \sum_j p_j a_j - C_d(d) \sum_j a_j = 0.$$

Note that

$$\sum_i a_i = 1$$

$$\sum_j a_j + \sum_k a_k = 1$$

$$\sum_k a_k = 1 - \sum_j a_j.$$

Using these equalities, we get

$$\sum_k p_k a_k = \frac{w_x}{y_x(x)} + \sum_k a_k \left(w_l + w_q\right) + C_d(d) \sum_j a_j.$$

At optimal effort, the value of the non-discarded fish equals its quota and landing costs plus marginal input cost per unit output plus the marginal discard cost of the discarded fish.

Solution 5 ($\lambda_{0j} = 0, \lambda_{0k} > 0, \lambda_{1j} > 0, \lambda_{1k} = 0,$ and $\lambda_2 > 0$)

Total discarding of grade *j*, no discarding of grade *k*, and binding hold constraint. Equations (15) and (16) for grade *j* become

$$\sum_i p_i a_i = \frac{w_x}{y_x(x)} + w_l + w_q - \sum_j \lambda_{1j} a_j - \lambda_2$$

$$-\left(p_j - w_l - w_q\right) - C_d(d) - \lambda_{1j} + \lambda_2 = 0$$

such that

$$\lambda_{1j} = w_q + w_l - p_j - C_d(d) + \lambda_2.$$

Replace for λ_{1j} into the equation and solve for λ_2

$$\sum_i p_i a_i - w_l - w_q - \frac{w_x}{y_x(x)} - \lambda_2 - \sum_j p_j a_j + w_l \sum_j a_j + w_q \sum_j a_j - C_d(d) \sum_j a_j + \lambda_2 \sum_j a_j = 0$$

$$\sum_k p_k a_k - \sum_k a_k \left(w_l + w_q\right) - \frac{w_x}{y_x(x)} - C_d(d) \sum_j a_j - \lambda_2 \sum_k a_k = 0$$

$$\lambda_2 = \frac{\sum_k p_k a_k}{\sum_k a_k} - \left(w_l + w_q\right) - \frac{1}{\sum_k a_k}\left[\frac{w_x}{y_x(x)}\right] - \frac{\sum_j a_j}{\sum_k a_k} C_d(d)$$

$$\lambda_2 = \frac{1}{\sum_k a_k}\left[\sum_k p_k a_k - \frac{w_x}{y_x(x)} - \sum_j a_j C_d(d) - \sum_k a_k \left(w_l + w_q\right)\right].$$

The hold constraint is binding if the net marginal revenue of non-discarded grades of fish is positive. The revenue is the average price of non-discarded fish. The costs are the marginal input cost per unit output plus the marginal discarding cost of the discarded grades plus the landing and quota costs of the non-discarded grades.

Replace for λ_2 into the expression above to obtain

$$\lambda_{1j} = w_q + w_l - p_j - C_d\left(d\right) + \frac{1}{\sum_k a_k}\left[\sum_k p_k a_k - \frac{w_x}{y_x\left(x\right)} - \sum_j a_j C_d\left(d\right) - \sum_k a_k\left(w_l + w_q\right)\right]$$

$$\lambda_{1j} = \frac{1}{\sum_k a_k}\left[\sum_k p_k a_k - \frac{w_x}{y_x\left(x\right)} - C_d\left(d\right)\right] - p_j.$$

Discard all of grade *j* if the net marginal revenue per unit non-discarded fish is larger than the forgone price of the discarded fish.

In this solution, equation (17) in the article for non-discarded grade *k* becomes

$$\lambda_{0k} = p_k + C_d\left(d\right) - w_q - w_l - \lambda_2.$$

$$\lambda_{0k} = p_k + C_d\left(d\right) - w_q - w_l - \frac{1}{\sum_k a_k}\left[\sum_k p_k a_k - \frac{w_x}{y_x\left(x\right)} - \sum_j a_j C_d\left(d\right) - \sum_k a_k\left(w_l + w_q\right)\right]$$

$$\lambda_{0k} = p_k - \frac{1}{\sum_k a_k}\left[\sum_k p_k a_k - \frac{w_x}{y_x\left(x\right)} - C_d\left(d\right)\right].$$

Discard nothing if the price of the fish is larger than the net marginal revenue of non-discarded fish.

Parameter Estimates

Table A1. Parameter Estimates for the Gillnet Model with *t*-values in Parentheses

	α_i	β_{i1}	β_{i2}	β_{i3}	γ_{i1}	γ_{i2}	γ_{i3}	γ_{iq}
Small cod	5.4	6.6	2.0	1.2	1.6	1.0	–2.3	–0.4
	(3.1)	(6.6)	(2.0)	(1.1)	(2.8)	(1.0)	(2.8)	(0.7)
Medium cod	34.5	77.5	31.4	11.7		12.0	–17.0	4.3
	(2.1)	(6.5)	(2.6)	(0.9)		(1.5)	(2.2)	(0.9)
Large cod	–10.2	382.9	54.9	109.8			28.4	–9.6
	(0.2)	(9.1)	(1.3)	(2.4)			(2.1)	(0.7)
Quota	–37.8	–446.8	–84.0	–112.7				7.7
	(0.8)	(9.0)	(1.7)	(2.1)				(0.5)

Table A2. Parameter Estimates for the Longline Model with *t*-values in Parentheses

	α_i	β_{i1}	β_{i2}	β_{i3}	γ_{i1}	γ_{i2}	γ_{i3}	γ_{iq}
Small cod	22.3	21.8	12.7	35.2	9.4	–11.9	7.2	–6.6
	(2.9)	(3.9)	(2.3)	(5.8)	(2.4)	(2.5)	(2.1)	(3.0)
Medium cod	34.0	185.9	28.2	158.7		28.1	6.6	–18.2
	(0.9)	(5.3)	(0.8)	(4.2)		(2.3)	(0.9)	(1.8)
Large cod	16.9	72.2	6.2	63.1			–5.7	–4.9
	(1.0)	(4.6)	(0.4)	(3.7)			(0.9)	(1.0)
Quota	–55.6	–234.4	–39.1	–212.6				22.7
	(1.3)	(5.4)	(0.9)	(4.6)				(1.8)

Some Comments on the Empirical Model and the Parameter Estimates

The theoretical model assumes that penalty costs are increasing in discarded quantity. However, without observed variation in penalty costs, it is impossible to distinguish the effect of penalty costs from the effects of a constant term. As an example, let us assume that equation (4) in the article

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

can be written as

$$\max_{x,d_i} \pi\left(x, d_i\right) = \sum_{i=1}^{I} [p_i - w_l - w_q] q_i - w_x x - \gamma d^2 - F$$

where C(d)= γd^2 is the nonlinear discard cost function and γ is a discard cost parameter. This parameter is determined exogenously by the government and captures the expected fine. The profit function is derived by applying standard duality theory and will be a function of the exogenous variables, i.e., prices of inputs and outputs and the discard cost parameter $\pi^*\left(p_i, w_l, w_q, w_x, \gamma\right)$.

We want to estimate this profit function using data but do not know its true functional form. Therefore, we approximate it by a McFadden profit function. Regardless of the shape of the discard cost function, we need variation in γ to be able to estimate its effect. Since no changes were made in the legal framework or monitoring schemes during our sample period, there is no empirical variation in γ so the effects in the output supply and input demand functions are indistinguishable from those of the constant terms and, therefore, included in the constant terms. The effect of increased penalty on discards should be negative. However, it is impossible to predict the total effect of the constant term and this effect. Therefore, the composite constant terms have no clear interpretation or a priori expected signs. Also note that we only estimate the share equations and not the actual profit function. Therefore, we do not have an estimate of the constant term of the profit function.