COMBINING PROPERTY RIGHTS AND LANDINGS TAXES TO MITIGATE THE ECOLOGICAL IMPACTS OF FISHING

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ABSTRACT

Economists have long promoted fishery rationalization programs, but ITQs may fail to address the ecological consequences of fishing. Of particular concern is that economic incentives to harvest larger fish (due to size-dependent pricing or quota-induced discarding) can destabilize fish populations or lead to evolutionary changes. A substantial theoretical literature in economics has explored incentive problems in ITQ fisheries but has treated highgrading as part of the stock externality. We provide an alternative viewpoint in that the stock externality and the size-based incentives are two distinct externalities and thus require two distinct policy instruments. In this paper, we show that if managers know the price-by-size distribution and the size distribution of the population, total revenues and total catch (in weight) by vessel are sufficient statistics to design a schedule of revenue-neutral individualized landings taxes that eliminate the incentive to highgrade in an ITQ fishery. That is, landings taxes can be used to address the ecological consequences of fishing while using ITQs to address the open access stock externality.

Keywords: Individually Transferable Quotas, landings taxes, fish life history, highgrading, size-selective harvesting, size-based pricing

INTRODUCTION

Economists have long extolled the virtues of fishery rationalization programs. Fisheries economists have particularly argued that Individually Transferable Quotas (ITQs) undo the main causal mechanism for fisheries overexploitation, namely the open access stock externality. However, one of the obstacles to widespread adoption of property rights-based fishery management is a lingering concern that ITQs fail to address the ecological consequences of fishing.

Ecological impacts of fishing can stem from highgrading and discarding. That is, a quota owner has an incentive to fill his or her quota by targeting large, high-value fish and potentially discarding small, low-value fish. Some mortality inevitably results from discarding. Both targeting and discarding can lead to a size distribution of harvested fish that is neither economically optimal nor biologically sustainable. Although the severity of problems is a subject of debate and varies by fishery, the biological and ecological effects of size selective harvesting are extensive and well-documented. Concerns about size selective harvesting include cases in which larger fish are more fecund (Palumbi 2004) or have more viable larvae (Berkeley et al. 2004), the potential for sperm limitation in sequential hermaphrodites (Coleman et al. 1996), and even evolutionary effects (Conover and Munch 2002). Guttormsen et al.

(2008) show in a bioeconomic model how size-selective harvesting of a renewable resource can induce evolutionary changes.

A substantial theoretical literature in economics has explored incentive problems in ITQ fisheries (Anderson 1994,1995; Arnason 1994; Vestergaard 1996; Turner 1996; 1997; Hatcher 2005), but this literature has treated highgrading essentially as part of the stock externality. Our idea is most similar to value-based ITQs introduced by Turner (1996). However, we provide an alternative viewpoint in that the stock externality and the size-based incentives are two distinct externalities and thus require two distinct policy instruments. In this paper, we show that if managers know the price-by-size distribution and the size distribution of the population, total revenues and total catch (in weight) by vessel are sufficient statistics to design a schedule of revenue-neutral individualized landings taxes that eliminate the incentive to highgrade in an ITQ fishery. That is, landings taxes can be used to address the ecological consequences of fishing while using ITQs to address the open access stock externality. The information burden for managing with quotas and individualized taxes appears large at first blush, but all of the required information is already collected by federally managed fisheries in the U.S. and in many other parts of the world. The implication is that a focus on 'prices versus quantities' in instrument choice (Weitzman, 2002) may not be the central issue for fisheries. Instead, even in a deterministic world ecological factors necessitate both price and quantity instruments in some settings.

This paper first discusses evidence of size-based pricing and some of the incentives that it creates. The next section develops a model of individualized landings taxes that is similar to value-based ITQs in Turner (1996). The final section discusses the policy implications and concludes.

SIZE-BASED PRICING

Table 1 summarizes size-dependent prices for some ocean fish and shellfish. The fisheries span different places in the world, taxonomic groups, and harvest technologies (including aquaculture). The premiums for large fish vary by species, but they can be substantial. Largely due to a combination of recovery rates and quality, fish processors—and in some cases consumers—are often willing to pay more per weight for larger fish. This sample of fisheries is not a random sample but provides some anecdotal evidence that size-based pricing potentially creates incentives to discard or to target by size.

A recent paper by Kristofersson and Rickertsen (2008) uses fishing micro data to test whether highgrading occurs in the Icelandic cod fishery. They specifically examine two different sources of highgrading: quota price-induced discarding and product price-induced discarding. They find evidence for product price-induced discarding but fail to reject the hypothesis of no quota price-induced discarding. The authors conclude that size-based product pricing leads to discarding because the hold capacity constraint binds. When the hold capacity constraint does not bind, a higher quota price theoretically can induce discarding because the marginal cost of landing fish is higher and vessels must compensate with higher marginal revenue.

Table 1. Examples of size-dependent pricing of fish

Country	Species	Currency/unit	Year	Large	Medium	Small	Premium (Large vs. Small)	Note
Australia	Banana shrimp	AUD/kg	2006	12.69	9.35	7.59	67%	a
Denmark	Euopean Plaice	DKR/kg		20.31	21.46	12.46	63%	b
Denmark	Atlantic Cod	DKR/kg		28.18	25.67	19.59	44%	c
Denmark	Common Sole	DKR/kg		81.82	58.06	47.84	71%	d
Egypt	Tilapia	EGP/kg	2006	8.68	5.87	3.76	131%	e
Iceland	Cod	ISK/kg	1998-2001	151.20	124.90	105.70	43%	f
Iceland	Saithe	ISK/kg	2006	59.67		49.73	20%	g
Norway	Cod	NOK/kg	2006	22.28	20.06	16.89	32%	h
Norway	Salmon	NOK/kg	2006?	32.19	32.17	29.44	9%	i
Spain	Hake	EUR/kg	2005	17.93	13.12	8.47	112%	j
United States	Sablefish	USD/lb	2006	1.82	1.52	1.26	45%	k
United States	Brown shrimp	USD/lb	2005	2.53	2.30	1.07	137%	l

Notes and sources:
a Frank Asche, University of Stravanger (personal communication)
b Niels Vestergaard, University of Southern Denmark (personal communication)
Large is > 0.6 kg/fish, medium is 0.4-0.6 kg/fish, and small is 0.15-0.3 kg/fish.
c Niels Vestergaard, University of Southern Denmark (personal communication)
Large is > 7 kg/fish, medium is 4-7 kg/fish, and small is 1-2 kg/fish.
d Niels Vestergaard, University of Southern Denmark (personal communication)
Large is > 0.5 kg/fish, medium is 0.35-0.5 kg/fish, and small is 0.25-0.35 kg/fish.
e Frank Asche, University of Stravanger (personal communication)
Collected at El Obour market. Tilapia large is 1-5 fish/kg, medium is 6-12 fish/kg, and small is 13-25 fish/kg.
f Large, medium, and small mean prices for longline cod from Kristofersson and Rickertsent (2008).
g Frank Asche, University of Stravanger (personal communication)
h Frank Asche, University of Stravanger (personal communication)
i Frank Asche, University of Stravanger (personal communication)
Aquacultured salmon (exlcludes small sizes that are not normal market categories.
Large is 6-7 kg/fish, medium is 4-5 kg/fish, and small is 2-3 kg/fish.
j Frank Asche, University of Stravanger (personal communication)
Original source Spanish Ministry of Agriculture, Fisheries and Food
k Pacific States Marine Fisheries Commmision.
Sablefish harvest from U.S. west coast (excluding Alaska)
l North Carolina Department of Environment and Resources, Divsiion of Marine Fisheries.
Mean price in August 2005 large (15-20 per pound), medium (36-40 per pound), and small (60-70 per pound).

In the modeling below, we are interested in the effects of product price on both targeting and discarding behavior. Successful targeting of larger fish does not waste fish in the sense that there is partial mortality of small fish that are thrown back; smaller fish simply are not caught. We would expect that this behavior puts more relative weight on the large portion of the size distribution of fish. Discarding, in contrast, places more weight on the large portion of the size distribution only to the extent that discarded smaller fish survive. If there is 0% mortality of discards, the relative weight on the larger portion of the size distribution is the same for targeting and discarding. As mortality increases, the amount of size selection decreases. However, conditional on the total landings being the same, discarding puts more pressure on the overall stocks relative to targeting. Thus, for concerns about evolutionary effects of size-selective harvesting, intensive selection on size under targeting behavior is arguably the greater concern.

A MODEL OF INDIVIDUALIZED LANDINGS TAXES (ILTS)

Our focus in this paper is on product price-induced behavior. As such, our model describes a fishery with either of two institutional regimes: 1) ITQs in which hold capacity binds or 2) a fishery managed with non-transferable individual fishing quotas. Let t index time and i index individual fishing vessel. Suppose that each fishing vessel chooses overall fishing effort E_{it} and the share of effort devoted to either targeting or discarding (γ_{it}). We lump targeting and discarding together as we are primarily concerned with the effect on the size distribution of the population. For this simple model, one can think of this specification as representing discarding with no mortality. Let s index fish size. The function $x(s)$ represents the size distribution of the population (how many fish at each size converted to biomass units) with L_∞ denoting the terminal (maximum) size as in age-structured models with von Bertallanfy growth.

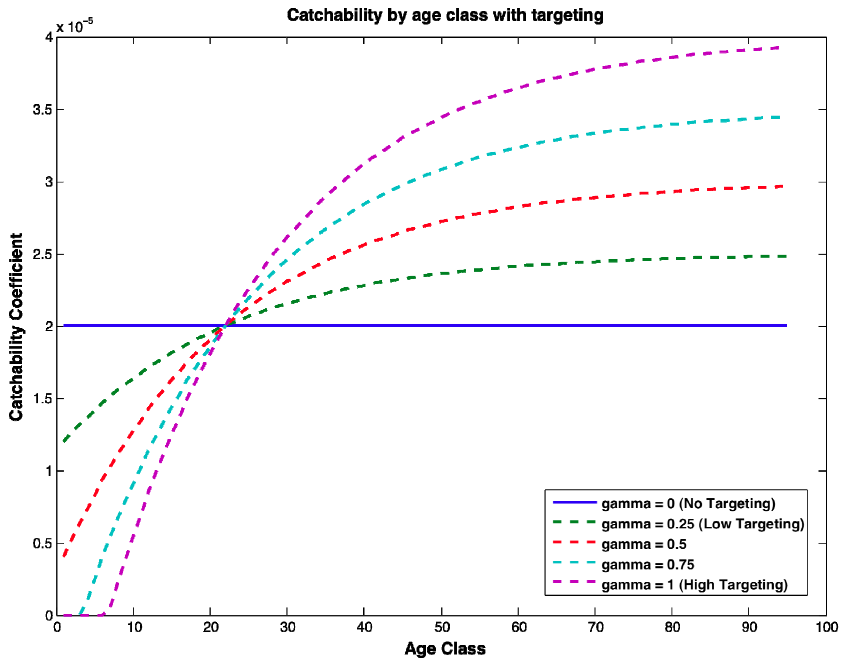

Figure 1. Highgrading effort increases the catchability of big fish and decreases the catchability of smaller fish. As vessels allocate more effort to targeting large fish (increasing γ_{it}), they increase the catchability of bigger fish (fish that are larger than those in age class $\overline{a}$) and alter the size distribution (s). This leads to harvesting more biomass from the upper portion of the biomass distribution $x(s)$.

Targeting effort γ_{it} influences the catchability of fish according to their age structure, reducing the catchability of young fish (age lower than $\bar{a}$) and increasing the catchability of big fish (age greater than $\bar{a}$):

$$(1) \qquad q_{it}(\gamma_{it}, a) = q^0[1+\gamma_{it}(1-e^{(\frac{\bar{a}-a(s)}{\bar{a}})})]$$

Figure 1 illustrates the effect of targeting effort on the catchability by age class.

We assume a Schaefer production function such that harvest (H_{it}) is proportional to stock and effort with catchability (q_{it}), which depends on the level of share of effort devoted to targeting (γ_{it}):

$$(2) \qquad H_{it} = \int_0^{L_\infty} q_{it}(1-\gamma_{it})E_{it}x(s)ds.$$

Note that if the vessel chooses $\gamma_{it} = 0$, equation (2) reduces to the more familiar qEX, where X is the total stock and the catchability coefficient is constant over the entire size distribution. Applying von Bertallanfy growth and allometric parameters to the age-structured model flattens out the targeting intensity in size space (Figure 2). This tendency suggests that the modeling below will be more relevant for slow-growing fish. Fish that reach terminal length at an early age provide small incentives for targeting on the basis of age. Figure 3 examines the relevance of age-based targeting for different von Bertallanfy growth coefficients when terminal size (L_∞) is held constant.

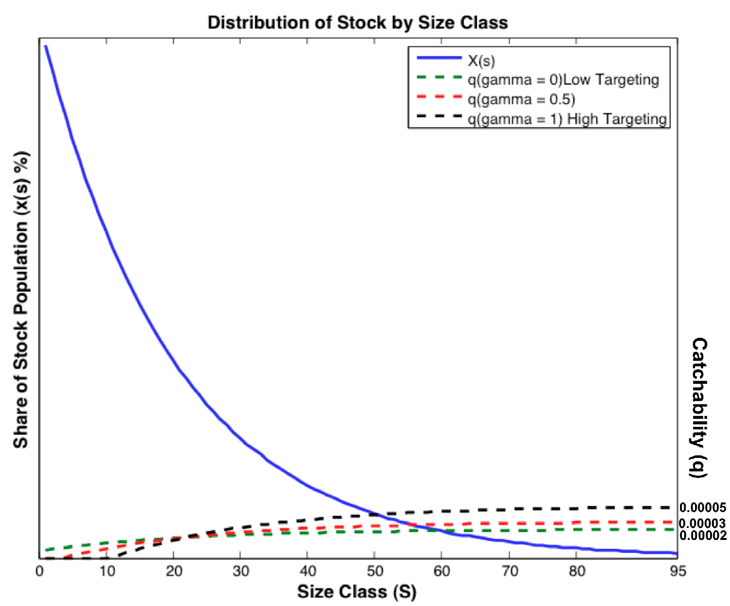

Figure 2. Distribution of Stock and catchability by size class. Applying von Bertallanfy growth and allometric parameters to the age-structured model flattens out the targeting intensity in size space.

When fish have size-dependent prices, revenue is a function of the size distribution of landed fish and not just total biomass. Suppose $p(s)$ is the distribution of price by size. Then total revenues R_{it} are:

$$(3) \qquad R_{it}(E_{it}, \lambda_{it}) = \int_0^{L_\infty} q_{it}(1-\gamma_{it})E_{it}p(s)x(s)ds.$$

Suppose that the cost of effort is a constant c, the individual vessel's quota share is σ_{it}, and the total quota (by weight) in the fishery is Q_t. Note that we could also interpret $\sigma_{it}Q_t$ as hold capacity. The vessel's profit maximization problem can then be written as:

$$(4) \qquad \max \Pi_{it}(E_{it},\gamma_{it}) = \int_0^{L_\infty} q_{it}(\gamma_{it})(1-\gamma_{it})E_{it}p(s)x(s)ds - cE_{it}$$

subject to

$$\begin{array}{ll} \int_0^{L_\infty} q_{it}(\gamma_{it})E_{it}(1-\gamma_{it})x(s)ds \le \sigma_{it}Q_t & [\lambda] \\ E_{it} \ge 0 & [\mu_1] \\ \gamma_{it} \ge 0 & [\mu_2] \\ \gamma_{it} \le 1 & [\mu_3] \end{array}$$

Assuming a positive level of effort ($E_{it} > 0, \mu_1 = 0$) and positive harvest of fish (not all effort is devoted to highgrading ($\gamma_{it} < 0, \mu_3 = 0$), the associated necessary conditions are:

$$(5) \qquad \int_0^{L_\infty} q_{it}(\gamma_{it})(1-\gamma_{it})p(s)x(s)ds - c - \lambda\int_0^{L_\infty} q_{it}(\gamma_{it})(1-\gamma_{it})x(s)ds = 0$$

$$(6) \qquad \begin{array}{l} -\int_0^{L_\infty} q^0 \exp(\frac{\bar{a}-a}{\bar{a}})E_{it}p(s)x(s)ds - 2\gamma_{it}\int_0^{L_\infty} q^0(1-\exp(\frac{\bar{a}-a(s)}{\bar{a}})E_{it}p(s)x(s)ds \\ +\lambda\left[\int_0^{L_\infty} q^0 \exp(\frac{\bar{a}-a}{\bar{a}})E_{it}x(s)ds + 2\gamma_{it}\int_0^{L_\infty} q^0(1-\exp(\frac{\bar{a}-a(s)}{\bar{a}})E_{it}x(s)ds\right] \le 0 \end{array}$$

$$(7) \qquad \gamma_{it}\mu_2 = 0$$

The vessel will choose not to highgrade if the revenues from not highgrading exceed the opportunity cost of the quota:

$$(8) \qquad \int_0^{L_\infty} q^0 E_{it}p(s)x(s)ds > \lambda\int_0^{L_\infty} q^0 E_{it}x(s)ds$$

Otherwise, the vessel will devote positive effort to highgrading.

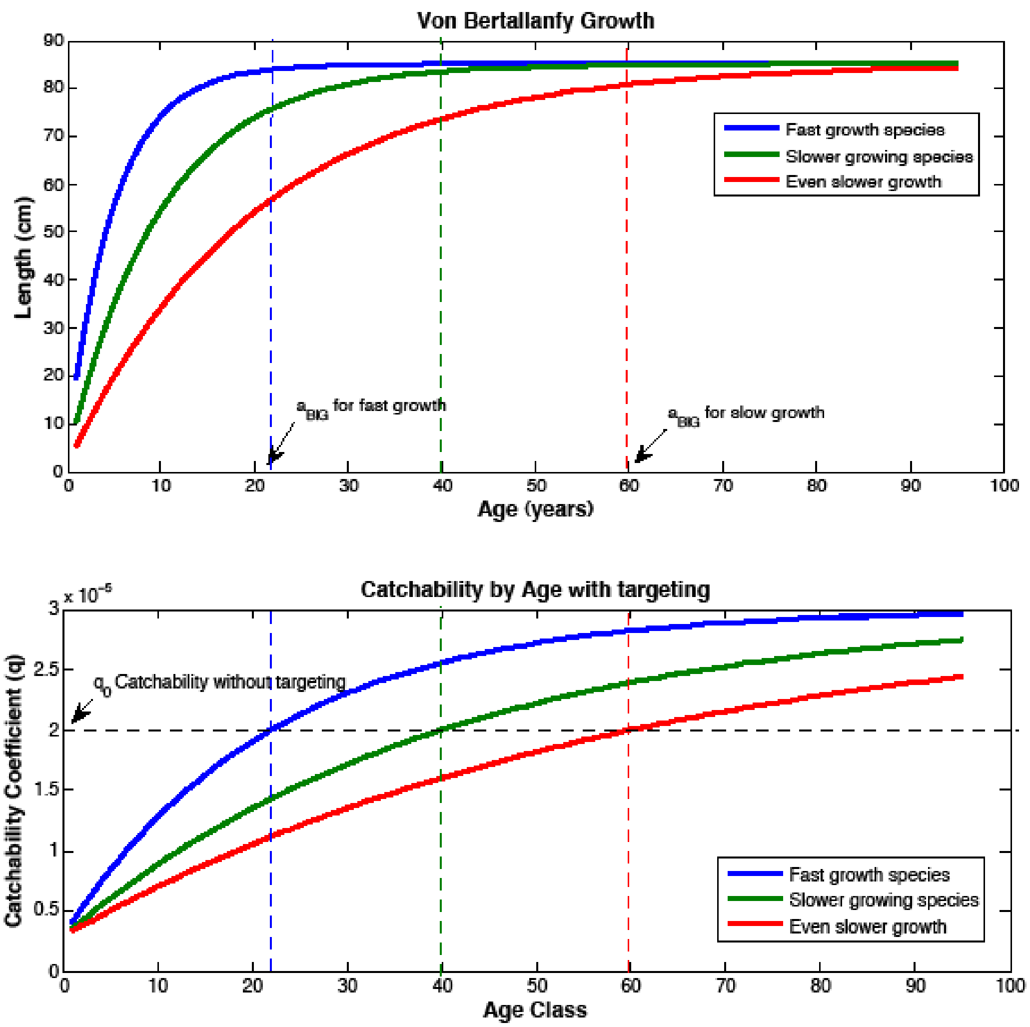

Figure 3. Growth and targeting in the age-based model. The effective targeting in an age-based model depends on the von-Bertallanfy growth curve. For slower growing species, rotating the catchability distribution is more relevant for older fish.

Suppose that the regulator wishes to eliminate highgrading such that fisheries draw from the entire size distribution of fish. Let $\overline{p}$ denote a target fleet-wide average price, where

$$\text{(9)} \qquad \overline{p} = \frac{\int_0^{L_\infty} p(s)\, x(s) ds}{\int_0^{L_\infty} x(s) ds}.$$

Figure 4 illustrates this fleet-wide price. The regulator can undo the incentive to highgrade in this setting

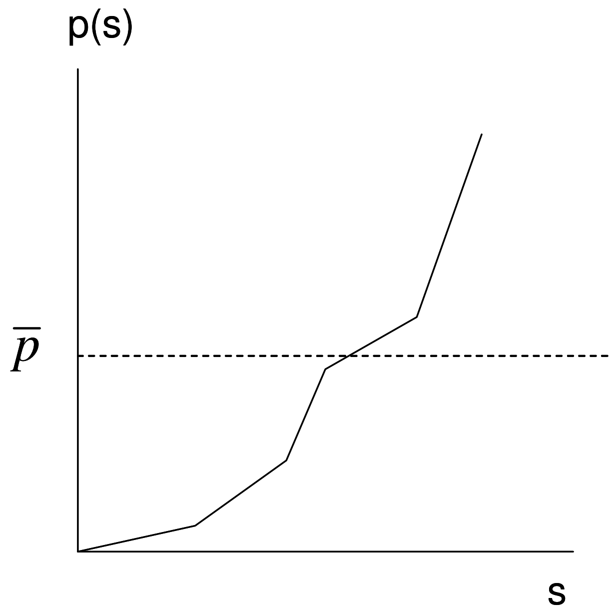

Figure 4. Fleet-wide target price. When prices are size-dependent, fleet-wide target price is the weighted average of the price distribution.

by imposing an individualized landings tax (ILT):

(10) $\tau_{it} = \hat{p}_{it} - \overline{p}$, where

(11) $$\hat{p}_{it} = \frac{R_{it}}{H_{it}} = \frac{\int_0^{L_\infty} q_{it} E_{it} (1-\gamma_{it}) p(s) x(s) ds}{\int_0^{L_\infty} q_{it} E_{it} (1-\gamma_{it}) x(s) ds}$$

At first blush, the ILT might seem burdensome for the regulator. However, it is easily calculated from data that are already collected through landings tickets in federally regulated fisheries in the U.S. and in many other parts of the world. The regulator need only know the total quantity of fish landed and the total revenue. Knowledge of the price distribution is necessary to set $\overline{p}$ at the right level and can be obtained with a random sample of landings.

With the ILT imposed, the vessel's objective is now:

(12) $$\begin{aligned} \max \Pi_{it}(E_{it}, \gamma_{it}) = \int_0^{L_\infty} q_{it}(\gamma_{it}) E_{it} [1-\gamma_{it}] p(s) x(s) ds - cE_{it} \\ - \tau_{it} \int_0^{L_\infty} q_{it}(\gamma_{it}) E_{it} [1-\gamma_{it}] x(s) ds \end{aligned}$$

$$
\begin{aligned}
&\textit{subject to} \\
&\int_0^{L_\infty} q_{it} E_{it} (1-\gamma_{it}) x(s) ds \le \sigma_{it} Q_t && [\lambda] \\
&E_{it} \ge 0 && [\mu_1] \\
&\gamma_{it} \ge 0 && [\mu_2] \\
&\gamma_{it} \le 1 && [\mu_3]
\end{aligned}
$$

Substituting in the tax, we see that profits can be rewritten as:

$$
\begin{aligned}
\Pi_{it}\left(E_{it}, \gamma_{it}\right) &= \int_0^{L_\infty} q_{it}(\gamma_{it})[1-\gamma_{it}] E_{it} p(s) x(s) ds - cE_{it} \\
&\quad - \left(\frac{\int_0^{L_\infty} q_{it}(\gamma_{it})[1-\gamma_{it}] E_{it} p(s) x(s) ds}{\int_0^{L_\infty} q_{it}(\gamma_{it})[1-\gamma_{it}] E_{it} x(s) ds} - \overline{p} \right) \int_0^{L_\infty} q_{it}(\gamma_{it})[1-\gamma_{it}] E_{it} x(s) ds \qquad (13) \\
&= \overline{p} \int_0^{L_\infty} q_{it}(\gamma_{it})[1-\gamma_{it}] E_{it} x(s) ds - cE_{it}
\end{aligned}
$$

By inspection of equation (13), we can see that effort devoted to highgrading can only decrease profits. Formally, assuming a positive level of effort ($E_{it} > 0, \mu_1 = 0$) and positive harvest of fish (not all effort is devoted to highgrading ($\gamma_{it} < 0, \mu_3 = 0$), the associated necessary conditions are:

(14) $$\overline{p} \int_0^{L_\infty} q_{it}[1-\gamma_{it}] x(s) ds - c - \lambda \int_0^{L_\infty} q_{it}[1-\gamma_{it}] x(s) ds = 0$$

(15) $$\left(\lambda - \overline{p}\right) \left[\int_0^{L_\infty} q^0 \exp\left(\frac{\overline{a}-a}{\overline{a}}\right) E_{it} x(s) ds + 2\gamma_{it} \int_0^{L_\infty} q^0 \left(1 - \exp\left(\frac{\overline{a}-a}{\overline{a}}\right)\right) E_{it} x(s) ds \right] + \mu_2 = 0$$

(16) $$\gamma_{it} \mu_2 = 0 .$$

Equation (14) can only hold if $\overline{p} > \lambda$, which implies that the term before the braces in (15) is negative, and thus $\mu_2 > 0$. By equation (16), $\gamma_{it} = 0$. There is no effort devoted to highgrading.

DISCUSSION

The setup and basic conclusion of our model are similar to Turner (1996), and the cancellation that removes the incentive to highgrade in our model is analytically similar to his. The main differences are 1) that we allow for a continuous distribution of fish size, 2) we focus on product price-induced selectivity (rather than quota price-induced discarding), and 3) the ITQ in our model is a weight-based quota with an individual-level taxation scheme attached to it. In Turner, the two instruments are rolled into one as a value-based ITQ. Managers with a value-based quota need to set a value-based TAC. With our combined ILT/ITQ instrument, the traditional role of stock assessment is preserved. Weight-based quotas can still be used with adjustments based on the total revenues landed. Whereas in Turner (1996), quota needs to be allocated either in dollar units or in weight-based units tied to relative prices. Neither of these follows clearly from standard stock assessment. Moreover, neither is particularly feasible when products are highly differentiated by size; the data requirements at the level of individual vessels are prohibitively high.

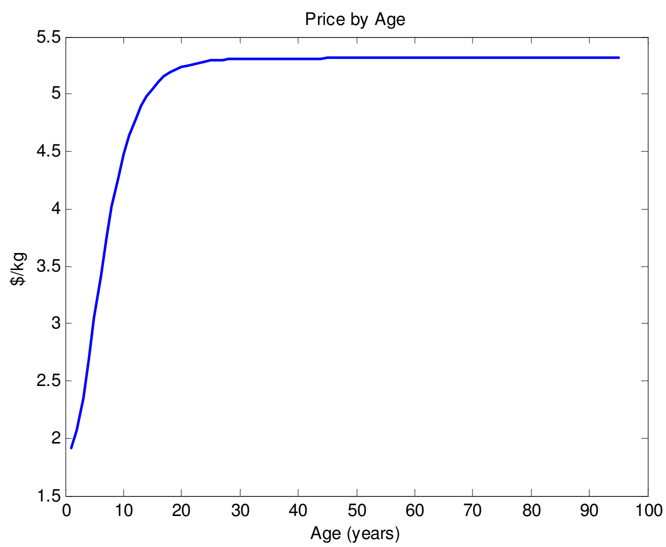

Figure 5. Price of sablefish as a function of age. Uses OLS estimates of size-dependent pricing and converts to age-dependent pricing using von Bertallanfy growth and allometric parameters specific to sablefish.

ITQs have become more politically palatable in recent years perhaps because they have been renamed “catch shares,” but landings taxes present far greater political challenges. Is it worth attempting to put an ILT in place for a real-world fishery? The empirical evidence from Kristofersson and Rickertsen (2008) suggests that highgrading in Icelandic cod is present and results from size-dependent product pricing. This finding suggests that ILTs could be relevant for non-ITQ as well as ITQ fisheries. Nevertheless, the discarding in Kristofersson and Rickertsen (2008) is not large and may not justify policy action. In contrast, some experimental literature suggests that evolutionary impacts are sizable and a definite concern for fisheries managers (Conover and Much 2002). Guttormsen et al. (2008) show that the costs of regulation to combat size selection determine whether it is worth avoiding selection-induced evolutionary changes. The costs of implementing our proposed regulation within existing regulatory structures may be small, but the political costs almost certainly will be high.

To further motivate our model, we use twelve observations of size-dependent sablefish price in 2006 to fit a linear price equation. Sablefish are managed with ITQs in Alaska and are being considered for ITQ-based management in the U.S. Pacific Northwest. The data come from the PACFIN database and represent sample means at three locations with between three and five size classes in each sample. Specifically, we use OLS to estimate price per kg (P) as a function of fish weight in kg (w): $P = 1.87\ (0.56) + 0.50\ (0.14) * w$. Standard errors are in parentheses, and the R^2 is 0.58. We can convert our size-dependent pricing into age-dependent pricing using von Bertallanfy growth and allometric parameters for sablefish. The results are in Figure 5, which provides a clue that the selection pressure on sablefish from targeting or discarding is probably present but not likely to be strong. The price premiums for larger fish are substantial. However, compared to many other long-lived fish, sablefish grow to near full size in a relatively short amount of time. There is an incentive to avoid fish below 10 years of age, but there is little incentive to target fish over, for instance, 40 years of age when the same premium would apply to a fish of age 20. This example illustrates that size selection may not always be significant enough to warrant an ILT even when size-dependent pricing is pronounced. An important next step in this research is to explore other possible applications of an ILT in which selection pressure appears stronger and model the consequences of ILT-based management using an age-structured model.

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