Comprehensive Incentives for Reducing Chinook Salmon Bycatch in the Bering Sea Walleye Pollock Fleet: Individual Tradable Encounter Credits

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Abstract

Concern about recent bycatches of Chinook salmon (*Oncorhynchus tshawytscha*) in the Eastern Bering Sea walleye pollock (*Theragra chalcogramma*) fishery has led to the imposition of a bycatch cap effective 2011—if the cap is exceeded, the fishery will be closed. This hard limit on Chinook salmon bycatch threatens to ignite a race-for-fish in what is currently a highly profitable share-based fishery. A hard cap also has perverse consequences for Chinook salmon by being most restrictive when salmon are relatively abundant and least restrictive when salmon are less abundant and in greatest need of protection. Here we show that a comprehensive incentive plan involving the allocation and trading of a particular form of individual bycatch quota, the Individual Tradable Encounter Credit (ITEC), aligns economic incentives to protect Chinook salmon even when the hard cap is not binding, while concurrently minimizing the cost to industry of avoiding Chinook salmon. Under this plan, incentives for bycatch avoidance are strongest when Chinook salmon encounters are least frequent, and reflect the true cost of bycatch.

Introduction

The BSAI Walleye Pollock Fishery

The Eastern Bering Sea and Aleutian Islands (BSAI) fishery for walleye pollock (*Theragra chalcogramma*) yields gross ex-vessel revenues in excess of $300 million and a first wholesale value over $1 billion (Hiatt et al., 2008); it is, arguably, the premier U.S. fishery. Over time, this fishery has slowly been rationalized, with the last major change occurring in 1998 with the passage of the American Fisheries Act (AFA 1998). This regulation established permanent sector allocations of the total allowable catch (TAC) in addition to placing a moratorium on the entry of new vessels, setting parameters for the formation of cooperatives within sectors, and providing funds to buy out nine of the twenty-nine then active catcher-processors. All sectors quickly organized under inter-cooperative agreements—civil contracts—that created sub-sector allocations to each firm. Sub-sector allocations share many of the characteristics of individual fishing quotas (IFQs): they represent an assured opportunity to harvest a known fraction of the TAC and they can be sold or leased within their sector. Since implementation of the inter-cooperative agreements, the catcher boat and catcher processor fleets have consolidated and become more economically efficient, utilization rates (pounds of finished product per pound of fish caught) have increased, production has shifted towards higher-value product forms, and economic returns have increased (Criddle and Macinko 2000; Anderson 2002; Felthoven 2002; NPFMC 2002; Wilen and Richardson 2008).

Chinook Salmon Bycatch

The walleye pollock fishery uses mid-water trawls to target schools of fish. This fishery has very low bycatch rates (e.g., 1.1% by weight in 2006 and 1.2% by weight in 2007) and even lower discard rates (e.g., 0.28% in 2006 and 0.30% in 2007) (Hiatt et al. 2008). Nevertheless, the magnitude of walleye pollock catches in the Bering Sea is so large that even small bycatch rates represent substantial levels of bycatch mortality. In 2007, for example, bycatch mortality included 264 mt of Pacific halibut (*Hippoglossus stenolepis*), 338 mt of Pacific herring (*Clupea pallasi*), 3.8 thousand crabs (*Paralithodes sp*., *Chionoecetes sp*., and *Lithodes sp*.), 109.1 thousand Chinook salmon (*Oncorhynchus tshawytscha*), and 83.3 thousand other salmon (*O. sp.*) (Hiatt et al. 2008). **Figure 1** depicts the recent history of Chinook salmon bycatch in the BSAI pollock fishery during the A season (January 20-June 10) and B season (June 10-November 1).

Measures to manage Chinook salmon bycatch date back to the early 1980s when an overall cap of 55,250 Chinook salmon was set for foreign and joint-venture trawl fisheries (NPFMC 1982, NPFMC 1983, NPFMC 1984). Fixed portions of the overall cap were allocated to each nation licensed to operate in the fishery; any nation that exceeded its annual cap was prohibited from fishing in large parts of the Bering Sea for the remainder of that year. Rather than extend the fixed cap to the domestic fisheries that subsequently displaced the joint-venture fisheries, the NPFMC explored a variety of fixed and triggered spatial closures (NMFS 1995, NMFS 1999, NPFMC 2005). Failure of these measures to avert the large bycatches observed in 2005, 2006, and 2007 provided the impetus for readoption of an annual hard cap on Chinook salmon bycatch mortality in this fishery (NPFMC 2008).

The PPA

The Preliminary Preferred Alternative (PPA) selected by the NPFMC in April 2009 and submitted for approval by the Secretary of Commerce specifies a framework under which one of two binding caps would apply, how those caps will be apportioned among the sectors, and conditions under which they could be apportioned within sectors (NPFMC 2009). NPFMC recommendations are advisory to the Secretary of Commerce who approves or disapproves the proposed changes to established Fishery Management Plans. It is anticipated that the PPA will be implemented in January 2011.

The PPA apportions 70% of the bycatch cap to the A season and 30% to the B season. During the A season, catcher-processors will be allocated 32.9% of the A season cap, motherships will be allocated 8%, shore-based catcher boats will be allocated 49.8%, and CDQ entities will be allocated 9.3%. During the B season, catcher-processors will be allocated 17.9%, motherships will be allocated 7.3%, shore-based catcher boats will be allocated 69.3% and CDQ entities will be allocated 5.5%. Although these sector allocations are primarily based on sector bycatch history (2002-2006), they also reflect pollock allocations under the AFA; in effect, sectors with “dirty” fishing history received a somewhat smaller bycatch allocation than their proportionate share of historical bycatch. The PPA provides fishery participants with an opportunity to choose between a simple hard cap of 47,591 Chinook salmon (approximately 39,101 adult equivalents) and a less restrictive cap of 60,000 Chinook salmon (approximately 49,296 adult equivalents) accompanied by the adoption of an inter-cooperative agreement (ICA) that creates individual vessel-level incentives to avoid bycatch even when the cap is non-binding. The PPA also stipulates that the average annual bycatch be less than 47,591 in at least 4 of every 7 years and includes a provision under which vessels that opt out of the ICA face an open access bycatch pool equivalent to their share of an overall hard cap of 28,496 Chinook salmon. All unused A season bycatch allowances can rollover into the B season cap.

ICA Requirements

To operate under the ICA hard cap level, sectors or groups of vessels within a sector must prepare a NOAA-Fisheries approved ICA that demonstrates the following attributes: 1) it rewards individual vessels that successfully avoid Chinook salmon or penalizes individual vessels that fail to avoid Chinook salmon; 2) it creates incentives to avoid Chinook salmon bycatch at all levels of abundance[1] in all years; and, 3) it creates incentives that will influence fishing decisions even when bycatch is at levels below the hard cap. These requirements were established to address several unintended negative outcomes that result when restrictive hard caps alone are used for managing fishery bycatch (Boyce 1996, Abbott & Wilen 2009). For example, a fleet-wide hard cap with no individual vessel incentives to avoid bycatch can induce a careless race to fish until the bycatch hard cap is hit, thereby jeopardizing the profitability of the fleet. Strict limits on turtle bycatch forced the early closure of the Hawaiian swordfish fleet in 2006 that resulted in significant revenue loss (Sugihara 2007). Outcomes that are injurious to both the target fishery and bycatch species occur when the prohibited species catch exhibits wide variation in numbers from year to year, such as with Chinook salmon bycatch in the Bering Sea pollock fishery. Insofar as bycatch rates are crude proxies for abundance, a restrictive hard cap will protect Chinook salmon populations exactly when high encounter rates suggest that they are abundant and in least need of protection yet offers no protection when low encounter rates suggest that Chinook salmon populations are low and vulnerable to overexploitation. Ironically, simple hard caps may create a perverse incentive during times of low abundance by encouraging intentional targeting of rare Chinook salmon in order to reduce the future impact of the bycatch hard cap. Clearly, additional mechanisms such as those spelled out in the ICA requirements are needed to protect Chinook salmon and maintain profitability and efficiency within the pollock fishery.

[1] At present, there are no estimates of Chinook salmon abundance in federal waters off Alaska.

A Comprehensive Incentive Plan for Bycatch Avoidance

In this paper, we present a comprehensive bycatch credits allocation and trading plan, the Comprehensive Incentive Plan (CIP), that uses individual (vessel-level) tradable encounter credits (ITEC) and specifically addresses the incentive requirements of the PPA. This approach provides robust vessel-level incentives to reduce Chinook salmon bycatch under all levels of pollock biomass and at any rate[2] of Chinook salmon bycatch. Additionally, the incentives act cumulatively through time to continually reduce overall Chinook salmon encounter rates. The plan is flexible, and can be tuned to meet predetermined performance standards through experimental implementation and monitoring. It shares some elements with well-established pollution credits trading schemes by rewarding vessels with consistently low bycatch rates and penalizing those with chronic high bycatch rates; however, the plan is structured so that the avoidance incentive is greatest during low encounter periods and reflects the actual industry cost of bycatch as determined by lower realizations of pollock catch.

The incentive plan to reduce Chinook salmon bycatch examined here is analogous to regional pollution credit markets in its use of credits trading to create *short-term* individual vessel incentives to reduce Chinook encounter rates. However, stronger individual incentives come from an annual allocation scheme for ITEC that creates *long-term accountability* for bycatch behavior. These allocation incentives promote responsible behavior and operate at all levels of salmon encounter (as required under the PPA). Most significantly, the incentives for bycatch avoidance are strongest at low levels of salmon encounter: times when Chinook populations may be most vulnerable to depletion.

Auxiliary features of the CIP include an industry sponsored research component to monitor and evaluate program efficacy at reducing bycatch as well as to obtain basic information on Chinook salmon population dynamics (e.g., stock assessments) to better understand the impacts of Chinook salmon bycatch on the viability of Chinook salmon populations and aligned fisheries. Current fixed closure areas for fishing, such as the Chinook Conservation Area would remain closed under the CIP. In addition, the CIP includes a two-strikes rule to weed out chronic offenders and a 3% emergency fund saved as a tax by ICA entities to safeguard against genuine bad luck encounters.

[2] The bycatch rate is the number of Chinook salmon caught per metric ton of walleye pollock.

Auxiliary benefits of the CIP include the establishment of an independent certified market place for conducting fishery business transparently. This infrastructural cornerstone would likely find support from outside sources. It would represent a significant step forward towards market efficiency and would be scalable to other bycatch issues and the trading of financial instruments to control risk. In addition, this system will provide natural price signals for the value of bycatch, in terms of the risk and costs of forgone pollock when ITEC become limiting.

This analysis will focus on the inshore catcher-vessel sector using daily data on pollock harvests and Chinook salmon encounters from 2000-2007. These data show that, without behavioral changes, vessels will run out of credits under the simple hard cap even in low salmon encounter years (Figure 2). If ITEC are expensive or unavailable for sale, the cost of unfished pollock due to a shortage of credits can be considerable (Figure 3). The CIP creates incentives for vessel owners to have sufficient ITEC in reserve to avoid the need to buy credits, and to have the option of gaining extra revenue by selling unused credits. These aims can be accomplished through continual bycatch avoidance in order to increase ITEC allocation in future years.

Model Specification: Basic Elements of the Plan

Initial Sector Allocation

Sectors are assumed to receive annual allocations of salmon encounter credits in amounts corresponding to bycatch limits (1 ITEC = 1 Chinook) described in the ICA alternative of the PPA under the industry-wide hard cap of 60,000. For this analysis, the inshore catcher-vessel sector receives 33,390 credits, of which 20,916 are reserved for the A season and 12,474 credits are reserved until the start of the B season.

Legacy Vessel Allocation

Individual vessel allocations of ITEC are made separately for each season and it is assumed that 100% of any unused A season credits are carried forward to the B season. A 100% carry-forward rule creates incentive to avoid bycatch in the A season due to uncertainty of bycatch levels that will occur in the B season. B season Chinook salmon bycatch can be substantial, particularly late in the season (Figure 1, NPFMC 2008). The carryover builds incentive for conservation of ITEC in the A season by providing insurance for maximizing B season pollock harvest.

A key provision of the CIP is the legacy allocation rule, which rewards vessels with low Chinook salmon encounter rates with extra ITEC in future years, and penalizes vessels with high encounter rates by reallocating fewer ITEC in the following years. This rule creates a long-term incentive to lower bycatch, so that vessels will have extra credits as insurance against future moderate to high salmon encounter years. At these times, additional ITEC are likely to be needed to finish harvesting a vessel's pollock allocation and few ITEC will be available for purchase (because other vessels will have similarly large bycatch rates). The cost of unfished pollock due to a shortage of credits can be considerable (Figure 3). The allocation scheme uses these potential costs as incentive for individual vessels to reduce salmon bycatch in order to obtain a maximal reserve of credits.

There are many possible implementations of a legacy allocation rule. Indeed, any rule that rewards low bycatch rates with additional credits, penalizes high bycatch rates with fewer credits, and carries forward these rewards and penalties from year to year will suffice. In our plan, we consider the following allocation scheme that distributes credits to individual vessels according to:

$$C_{s,y,i} = P_{s,y,i}\, F_{s,y,i}\, I_s \tag{1}$$

$C_{s,y,i}$ = the number of credits that vessel i receives in season s of year y

$P_{s,y,i}$ = the proportional allocation factor for vessel i in season s of year y

$F_{s,y,i}$ = the AFA cooperative catch share (fraction of the sector's pollock quota) received by vessel i in season s of year y

I_s = the total amount of ITEC for the sector in season s

The proportional allocation factor reflects a vessel's allocation of ITEC relative to its pro rata pollock share. During the first year of implementation, the proportional allocation factor for each vessel is unity ($P_{s,y1,i} = 1$). Thus, all vessels within a cooperative governed by an ICA would receive an ITEC allocation *pro rata* to their pollock allocations. In subsequent years, this proportional allocation factor will change (based on bycatch performance) and individual vessels will receive differing ITEC allocations. For vessels with the same pollock allocation, the relative values of their proportional allocation factors will reflect their relative ITEC allocations: if one vessel's proportional allocation factor is 20% larger than the other vessel, it will receive 20% more credits than the other vessel (assuming both vessels receive the same pollock allocation).

The proportional allocation factor for each vessel is updated according to:

$$P_{s,y,i} = \alpha + \beta P_{s,y\text{-}1,i} + \gamma Q_{s,y\text{-}1,i} \tag{2}$$

$P_{s,y,i}$ = the proportional allocation factor for vessel *i* in season *s* of year *y*

α = the constant weighting parameter

β = the legacy weighting parameter

γ = the incentive weighting parameter

$Q_{s,y,i}$ = the bycatch factor for vessel *i* in season *s* of year *y*

and the constants α, β, and γ are proportional weights that sum to unity (see Appendix A for a more detailed discussion).

The bycatch factor, Q, is computed as a monotonic function of a vessel's bycatch rate with the following properties: vessels with an average bycatch rate (among the other vessels in the same sector) will have $Q = 1$, vessels with higher than average bycatch rate will have $Q < 1$, and vessels with lower than average bycatch rate will have $Q > 1$. The behavior of equation (2) is designed such that the proportional allocation factor for vessels with average bycatch rate ($Q = 1$) approaches 1 over time (i.e., ITEC pro-rata to pollock share). The proportional allocation factor for vessels with lower than average bycatch rates ($Q < 1$) will converge to a value > 1 (with exact value dependent upon bycatch history and parameterization). Similarly, the proportional allocation factor for vessels with higher than average bycatch rates ($Q > 1$) will approach a value < 1. A particularly nice property of this formula is the presence of asymptotic bounds for P that constrain how much ITEC for any vessel can vary (see Appendix A).

The formula in equation (2) is presented in a flexible form to emphasize the fact that with monitoring and feedback, parameters can be tuned to effect different magnitudes of bycatch reduction (i.e., changing the incentive structure) to meet performance standards. We note, however that the actual magnitude of bycatch reduction resulting from any plan involves complex human behavior, which cannot be known *ex ante*, except, perhaps, through experimental implementation. We will return to this issue in the section on "Hypothetical Modeling of Incentives," where we present a heuristic simulation based on plausible estimates of change in bycatch behavior in response to incentives in the CIP.

Example Parameterization

Here we will consider the case where the bycatch function is of the following form:

$$Q_{s,\,y\text{-}1,\,i} = 1 - \delta\, z_{s,\,y\text{-}1,\,i} \qquad (3)$$

$z_{s,\,y,\,i}$ = the canonical *z*-score (clipped to finite values) for vessel *i*'s bycatch rate relative to the other vessels in the sector

δ = a weighting parameter

The weighting parameter, δ, determines the maximum and minimum values for *Q*, and affects the magnitude of fluctuations in proportional allocation factor from year to year as well as determining the asymptotic bounds for the proportional allocation factor (see Appendix A).

We consider the following parameterization scheme (although many others are possible with qualitatively similar behavior but slightly different incentive structures): $\alpha = \beta = \gamma = 1/3$, and where $\delta = 2/3$. That is:

$$P_{s,\,y,\,i} = (1/3) + (1/3)\, P_{s,\,y\text{-}1,\,i} + (1/3)\, Q_{s,\,y\text{-}1,\,i} \qquad (4)$$

and

$$Q_{s,\,y\text{-}1,\,i} = 1 - (2/3)\, z_{s,\,y\text{-}1,\,i} \qquad (5)$$

This weighting scheme produces a lower bound of 2/3 and an upper bound of 4/3 for *P* meaning that vessels can lose no more than 1/3 of its initial allocation and they cannot gain more than 1/3 (assuming its pollock share remains constant). A range of 2/3 in the proportional allocation factor is reckoned to provide sufficient motivation for the incentives to be effective, but can be adjusted as necessary through tuning of the parameters.

Although the analyses presented here are based on the parameters given in equations (4) and (5), different parameterizations are possible that will alter the incentive structure of the plan. In particular, a higher weight given to the legacy component, β is a way to minimize the random effects of sampling error in bycatch rates (bad luck encounters) and emphasize the more consistent intentional behavioral component of variation in bycatch rates among vessels. Because the yearly changes are smaller, vessels must do consistently well in order to obtain the maximum possible increase in ITEC allocation. Similarly, vessels that initially have high bycatch are given more opportunities to improve over time. That is, a larger value for β in equation (1) helps to sort out the behavioral component from the chance component in determining relative ITEC allocations.

Conversely, a larger value for γ creates stronger short-term incentives to reduce bycatch, as the yearly changes in proportional allocation factor will be larger. Because these weights (α, β, and γ) must sum to unity, they should be viewed as tradeoffs between guaranteed ITEC allocation (α), rewarding/punishing consistent bycatch behavior (β), and rewarding/punishing yearly bycatch behavior (γ).

The cumulative nature of this legacy allocation scheme creates continual incentives to reduce bycatch and promotes consistent good behavior. For example, if a vessel is near the top of the pack (i.e., one of the highest proportional allocation factors), then it will remain near the top of the pack only if it consistently continues to perform well relative to the fleet. If such a vessel experiences an average bycatch rate, its proportional allocation factor will decrease in subsequent years. The CIP is designed so that vessels are unable to "slack off" and maintain an augmented ITEC allocation. Because increased allocation ($P > 1$) can only be maintained through continuously low bycatch rates, incentives to reduce bycatch are always present. Furthermore, because vessels with low bycatch rates receive proportionally more credits than vessels with high bycatch rates as a result of reallocation, the cleaner fishing vessels will be able to realize more of their pollock share, causing bycatch rates for the fleet as a whole continuously ameliorate. Conversely, if a vessel is at the bottom of the pack in terms of bycatch avoidance, it will remain there only if it stays at the bottom relative to other vessels in each year. It can dig out of this hole by consistently moving its behavior closer to the mean. This constant competition will stimulate a steady decline in the industry average bycatch rate.

Because of the large variability in Chinook salmon encounter rates, even vessels at the lower limit of ITEC allocation may not be forced to forego a portion of their pollock allocation every year. However, this should not be viewed as a flaw in the legacy plan. These vessels will likely lose a large amount of potential revenue in mid- and high-encounter years. Few credits will be available for trade during these times, so vessels that have exhausted their ITEC will be unable to simply purchase more credits to continue fishing pollock. The only reasonable options for these vessels (to avoid the revenue losses associated with running out of credits) are to improve allocation by reducing bycatch rates or to sell their pollock shares (AFA allocation) and associated ITEC to a cleaner vessel. Due to the nature of the plan, this can be accomplished even with small changes in bycatch rates: such a vessel would not need to reduce bycatch dramatically to see improvements in ITEC allocation (but larger reductions in bycatch would result in larger increases in ITEC allocation). Thus, vessels are incentivized to reduce bycatch in all years, even when their allocations may not be binding.

Scaling for Vessel Size to Place Small Independent Vessels on a level Playing Ground with Large Vessels and Firms

The variance in bycatch rates between vessels can be attributed, in part, to chance encounters with pockets of Chinook salmon, which will result in a sample size effect. That is, smaller vessels will experience greater variance in bycatch rates because they sample a smaller portion of the potential salmon bycatch. This effect is illustrated in Figure 4, where the variance in bycatch rates of smaller vessels in the inshore sector is systematically higher than that for larger vessels. Because small vessels are subject to more sampling error of this kind, they suffer a greater risk of having an overall bycatch rate inflated by the occurrence of an unusually "dirty" tow whereas larger vessels or companies with multiple vessels can average such unusual hauls over a large number of total hauls and total pollock catch. Thus, we used a corrected standard deviation in the allocation calculation to adjust for the effects of random noise due to vessel size (see Appendix A for details). It is a minor but measureable correction on reallocation that removes the disadvantage of increased risk experienced by smaller vessels.

Scaling to Avoid Penalizing Competitive Improvement Through Time

In addition to various forms of sampling variation, the variance in bycatch rates between vessels can also be attributed in part to consistent behaviors shown by vessels that appear to directly influence bycatch rates (e.g., caution in gear deployment, choices of fishing location, tow speed, timing).

One expectation of the CIP is that the variance in the distribution of bycatch rates among vessels will decrease over time as vessels adopt bycatch reducing operational strategies. As this happens, an increased proportion of the variation in bycatch rates will be due to random chance rather than operational choices of individual vessels. Indeed, as shown in Figure 5, there is a clear tendency for lower variance in bycatch rate to accompany a lower sector bycatch rate, reinforcing the idea of a narrower distribution accompanying lowered bycatch rates. This suggests rescaling variances to keep a level playing field (see Appendix A for details).

This scaled variance is intended as a simple correction for the fact that the variance in bycatch rates are expected to decline with time, increasing the effects of equivalent random variation on subsequent allocations will grow. The purpose of this rescaling rule is to keep reallocations of ITEC from increasing artificially as the variance in bycatch distributions falls through time. Without any scaling, as the distribution of bycatch rates within a sector becomes narrower, vessels would see larger changes in ITEC allocation for the same magnitude of changes in bycatch rates. This scaling was implemented to ensure that variance in relative bycatch rate continues to reflect behavioral differences rather than noise as the fleet converges to lower bycatch rates.

Transfer Rules

ITEC Supply and Pricing Considerations

The price of encounter credits will be determined by market perceptions of supply and demand and these in turn will be driven mainly by the perceived risk of running out of ITEC before completing one's pollock harvest. Because this uncertainty is greatest at the beginning of the season (due, in part, to the lack of estimates of Chinook salmon abundance and subsequent encounter rates), the price of ITEC is likely to be highest at that time. Indeed, vessels are likely to offer ITEC for sale only after completing their pollock harvest, when there is no risk of (or cost associated with) running out of credits.

As individual vessel owners become sellers of surplus ITEC towards the ends of the season, the supply of ITEC will increase which will put downward pressure on ITEC. During times of moderate to high Chinook salmon encounters, this rising supply will be met with rising demand and prices could actually increase toward the end of the season. However, during times of low encounters this could result in a glut of ITEC at the end of the season. The potential for an end-of-season glut could cause a severe drop in ITEC prices and a reduction in short-term incentives, paving the way for abuse (i.e., diminished incentives to reduce bycatch). Thus, transfer rules are required to regulate the supply of ITEC.

We examine two types of transfer rules for ITEC: "Buy side" transfer rules and "Sell side" transfer rules (fixed tax on transfers vs. dynamic salmon savings). The best outcome is likely to come from using both kinds of transfer rules together to support incentives for Chinook salmon bycatch avoidance, especially during times of low salmon encounters.

Buy Side Transfer Limits

So that a poorly performing vessel (one at the 2/3 allocation level, $P = 2/3$) can never obtain more than its original allocation through purchase we recommend the following buy side transfer limit: "in each season only an amount less than 1/3 of a vessel's credits allocation for that season may be purchased." This means that the worst performers (with lower allocations) will be able to buy fewer credits, while the better performers, with larger initial allocations, are further rewarded with the ability to potentially buy more if needed. This fixed buy side transfer limit is simple to implement and should not affect the profitability of the sector but is likely to encourage the transfer of pollock catch shares to "clean" boats who experience unfortunate pockets of Chinook salmon rather than transfer of ITEC to vessels with historically high bycatch rates.

The benefits of this simple rule are that:

(i) It addresses *individual vessel* incentives (a requirement of the ICA alternative in the PPA).

(ii) It addresses the possible abuse of abundant ITEC during low salmon abundance years, influencing decisions at levels well below the hard cap.

(iii) It will not affect the completion of pollock harvest (as shown in historical simulations)

(iv) It reinforces the incentives provided by the legacy allocation system because vessel ITEC allocations (P) and buy side limits move in tandem.

Sell Side Transfer Limits

Fixed Transfer Tax

A fixed sell side transfer tax (i.e., a monetary or ITEC-based tax on all transfers) is not desirable to industry as it can potentially limit the pollock harvest that might otherwise occur if ITEC were optimally distributed. Neither is it desirable to Chinook salmon conservation as it is dependent upon transfers taking place. During years of low salmon encounter, very few transfers will take place, reducing the effectiveness of a fixed transfer tax exactly when it is most needed. Conversely, transfers of ITEC occur more frequently and in greater volume during years of moderate to high salmon encounter; at these times, a fixed transfer tax will increase the burden of an already limited ITEC supply. Such times are when credits are most needed by the pollock industry. Thus, fixed transfer taxes are not a good fit to this problem.

Dynamic Salmon Savings (DSS)

We suggest Dynamic Salmon Savings (DSS) as a transfer rule that is adaptive to different levels of salmon encounter and will apply to each vessel after it completes its pollock harvest. This rule is more complicated to implement than a fixed tax, but more desirable to Chinook salmon interests as it represents an adaptive rule that creates more protection during times of low encounters.

DSS imposes a constraint on the "sell" side of transfers. It includes a sector specific "salmon savings rate" (SSR) that is applied to each vessel's surplus ITEC. Surplus ITEC are credits that a vessel did not use to fish its full quota of pollock and includes any credits that it may have sold before completing its pollock harvest. The sector specific SSR calculated near the end of the B season is intended to address the possible abuse of abundant encounter credits during low salmon abundance years while not adversely affecting the completion of pollock harvest. It also provides an indication of Chinook salmon abundance based on current-year encounter rates.

DSS consists of two parts. The first part is a provisional savings rule that applies to vessels that sell credits before the SSR is calculated. The provisional savings rule requires that ITEC savings must be held in reserve to meet the maximum SSR. This promotes salmon savings early in the year. For example, if a cap is set so that the maximum SSR is 50%, then prior to setting the dynamic savings rule (e.g., throughout the A season), vessel owners can only sell up to 50% of their residual ITEC. Thus, if a vessel wishes to sell 50 credits early in the year, it must keep an additional 50 credits *in reserve* until the SSR is calculated. This reserve acts as a conservative salmon savings rule governing transfers until the SSR is computed. It operates like "tax withholding" and protects Chinook salmon from exploitation due to excess ITEC until the SSR is posted.

The second part of DSS is the calculation of the SSR in the B season. Numerical experiments with the Inshore sector daily data over an eight-year period suggest that calculating the SSR when 2/3 of the B season sector pollock quota are caught (2/3 sector TAC) gives the best result for estimating the credits needed to complete the season (see Appendix B for details on calculating the SSR). This is the "estimated total sector bycatch for the B season." This estimate normally occurs between August 29 and Sept 16. This tends to happen later in low salmon encounter years (when fewer transfers are needed) and earlier in moderate to high encounter years (see Table B-1).

In our simulations of the number of credits retired under a fixed transfer tax scheme and DSS, we found that DSS retired significantly (over 4 times) more credits over a span of eight years (2000-2007) for the Inshore catcher-vessel sector (Figure 9A). Not only does DSS save more credits than a fixed transfer tax over this period, it tends to save credits during years of low salmon encounter under this scheme (Figure 9B). Details regarding the implementation of both the fixed transfer tax and dynamic salmon savings can be found in Appendix B, along with more detailed simulation results.

One potential issue related to DSS is the estimation of the number of ITEC needed to complete harvests of pollock. Like all estimates of bycatch, it is subject to error: the large fluctuations in bycatch levels and salmon encounter rates from year-to-year and season-to-season will make individual vessels cautious about running out of ITEC. Furthermore, although some vessels may become less careful in avoiding bycatch if the estimate of bycatch is high, they can be taken advantage of by vessels that are more rigorous in avoiding bycatch. Since vessels are competing with each other for increased allocations, vessels that have lower bycatch relative to other vessels will see increased allocations. The competitive aspect of the legacy plan means that an estimate of bycatch will adversely affect bycatch rates only if *all* vessels are lax about reducing bycatch. Seeing even one vessel outperform the rest will incite the rest of the fleet to catch up. Thus, although estimating the amount of bycatch has the potential to influence fishing behavior, we believe that it will not adversely affect bycatch rates (i.e., elevating bycatch rates above what they would be otherwise).

Worries that the SSR will limit credit availability provide an additional motivating factor for vessels to reduce bycatch, possibly by concentrating effort at the beginning of the B season, when historical bycatch rates have been low. This could have the added feedback effect of increasing the SSR and encouraging other vessels to fish earlier in the B season: by catching more pollock earlier, and at lower bycatch rates, the amount of salmon savings would be set even higher, potentially encouraging more vessels to fish early when bycatch rates are low. One disadvantage to this behavioral change, however, is that it is likely to increase bycatch of chum salmon (*O. keta*), which exhibits higher bycatch rates at the beginning of the B season for pollock. A potential solution to this problem would be to expand the CIP to related fisheries and other bycatch species. Vessels would then be able to trade Chinook salmon ITEC for chum salmon ITEC depending on their intended time of fishing and expectations for bycatch. Additionally, this would give flexibility for individual vessels in the fishery to collectively manage bycatch by leveraging their relative ability to avoid bycatch of one or the other species (i.e., vessels could concentrate effort in fisheries where they are most effective at avoiding bycatch, resulting in an overall decrease in bycatch not possible if each fishery managed bycatch independently).

Incentives/Issues

Industry costs associated with non-transferability of credits

Without a transfer mechanism, some individual vessels will run out of ITEC, and a portion of the walleye pollock TAC could go unfished, resulting in significant revenue losses for the fishery. These losses can happen even during years of low Chinook salmon encounter rates. Figure 2 shows the timing of when vessels would have run out of credits under the proposed Inshore sector performance target cap of 26,484.

In 2000, no vessels would have run out of ITEC. However, in other years with low (2001, 2002, and 2003) and moderate (2004, 2005) Chinook salmon encounter rates, a number of vessels would have run out of ITEC. This suggests that while no trading would have been required in 2000 to complete the walleye pollock harvest, trading would have been required in other years for each vessel to finish harvesting its portion of the walleye pollock TAC.

The revenue loss associated with not being able to trade encounter credits under a hard cap scenario can be considerable. These costs are illustrated in Figure 3, and can exceed $80 million in a single year. The risk of catastrophic losses due to unharvested walleye pollock in any given year should provide strong financial motivation for industry to adopt a plan for transferring ITEC, in addition to incentivizing individual vessels to lower bycatch rates so that they may insure themselves against revenue loss (via increased ITEC allocation and/or reduced need for ITEC).

Trading encounter credits without explicit incentives to avoid bycatch can increase industry revenues and reduce fleet bycatch. Figure 7 illustrates a hypothetical scenario where reallocation (using equation 2) and trading occurs by the following simple rules: ITEC are only traded after a vessel has finished its pollock quota for the season; and ITEC are transferred as soon as they are needed and are made available to the vessel(s) that have run out of ITEC and for whom the intrinsic value (non-market value) is highest–those vessels that are able to offer the highest price for ITEC.

This simulation shows that there can be significant revenue advantages to credits trading for the sector as a whole, despite the fact that individual motivation to avoid bycatch is not explicitly modeled. Although the effect is modest, the natural dynamics of the allocation scheme and the trading model by itself can enhance revenues, and reduce bycatch rates for the fleet as a whole.

Infrastructure for Monitoring and Trading ITEC

Perhaps the greatest long-term benefit of the ITEC trading and allocation plan is the establishment of an independent, certified, and organized marketplace for conducting fishery business. This infrastructural cornerstone would likely find support from outside sources and could be an independent Commodities Futures Trading Commission certified contractor. Having such certification would bring credibility to the fishing industry, represent a significant step forward toward market efficiency and transparency, and be scalable to other bycatch issues (e.g., chum salmon), other fisheries (e.g., Pacific hake *Merluccius productus*) and the trading of financial instruments to control risk.

Handling Transfers Across Sectors

As originally conceived, the CIP would operate throughout the entire walleye pollock fishery. However, implementation of the CIP across sectors is not required. What is required is that trading of ITEC across sectors or subsectors operating under different bycatch incentive programs would be restricted; sectors with Dynamic Salmon Savings can sell credits to any other sector, but may only buy credits from another sector with a Dynamic Salmon Savings rule and the same maximum Salmon Savings Rate. From the point of view of maintaining rational incentives, the following rules should apply to transfers across groups or sectors that may or may not participate in the plan: (1) unless otherwise regulated, sectors with Dynamic Salmon Savings (DSS) may sell credits to any other sector; (2) unless otherwise regulated, sectors without DSS may buy credits from any other sector; and, (3) a sector with DSS cannot buy credits from a sector without DSS.

Incentives and Issues related to the allocation scheme.

A key incentive mechanism for the tradable encounter credits model is the allocation of credits based on current and past (legacy) encounter rate behavior. As we have already seen (Appendix B) the intrinsic fishery value of ITEC can be very high and the cost of forgone walleye pollock under a bycatch hard cap can represent a catastrophic loss. Besides the inherent value in finishing one's walleye pollock allocation, the value of avoiding Chinook salmon bycatch in the current fishing season is increased by the possibility of having surplus ITEC in future years when there may be higher encounter rates for Chinook salmon. This incentive structure (i.e., reallocation) requires forward thinking similar to buying insurance. Having extra credits reduces the risk of forgone walleye pollock and the need to purchase ITEC. The additional revenue per bonus credit in the 2007 A season (assuming the vessel would have otherwise run out of credits) is on the order of $7,000 to $20,000 per ITEC. Of special significance is the fact that this allocation scheme operates more sensitively during years of low salmon encounter (Figure 6). That is, vessels are more strongly rewarded and penalized for fishing behavior during low salmon encounter years.

Incentives related to trading ITEC.

In general, if vessel owners expect to have surplus ITEC in any given year, they can post it for sale on an electronic market site. This could represent significant extra revenue, especially if there is significant variance in bycatch performance among vessels. Alternatively, vessels could enter into the market to lease or buy additional walleye pollock catch shares from vessels that are at risk of running short of ITEC. Similarly, if a vessel owner needs to buy ITEC, he can do so at the market price or offer to lease his walleye pollock catch shares. This incentive structure is similar to that found in markets for trading pollution offset credits; that is, the establishment of a market for both the good (i.e., walleye pollock) and the cost associated with producing that good (i.e., Chinook salmon bycatch) favor the shifting of production to the most efficient actors (i.e., the vessels with the lowest bycatch rates). In the CIP, trading also involves a Dynamic Salmon Savings rule to control possible excess supplies of ITEC in periods of low

Chinook salmon encounter. Simulations suggest that a preliminary SSR of up to 50% can be tolerated without directly harming the walleye pollock harvest, but monitoring and adjustment will be required as the fishery's behavior changes over time.

Legacy Incentives

The second term of the allocation formula (2) is the legacy component that incorporates past behavior into the calculation of ITEC allocation for the current fishing season. This component serves an important function in moderating the long-term effects of bycatch performance on ITEC reallocation to promote consistent bycatch reduction over multiple fishing seasons. One of the problems with any performance-based reward/penalty system is that the measurement of performance is always subject to noise. In this case, random variation in bycatch rates (e.g., sampling error or bad/good luck) can be difficult to separate from variation due to operational choices. The legacy component addresses this problem by causing the reward/penalty for bycatch behavior to decay with time. This has two effects: (1) fluctuations in bycatch rate due to chance events will wash out over time and (2) rewards/penalties compound only as a result of consistently low or high bycatch.

Hypothetical Modeling of Incentives:

The actual year-to-year magnitude of bycatch reduction in any plan cannot be known *ex ante*. However, for heuristic purposes, we illustrate a plausible outcome using a simple behavioral model to simulate the evolution of bycatch patterns. We hypothesized that vessels with high bycatch rates (low Q) would have greater incentive to reduce bycatch rates as a result of the punishment from having ITEC allocation reduced in future years.

Using observed changes in bycatch rates in the inshore sector over the period 2000-2007, we established 25% as an upper bound on the potential change in bycatch rates[3]. This 25% was then scaled by the relative values of Q for each vessel: vessels with a lower value of Q (i.e., relatively high bycatch) were simulated to have greater reductions in bycatch due to a greater incentive to make up for bad performance in the prior year.

[3] We computed the median values of changes in bycatch rates for individual vessels across 8 years of data. The minimum of these median values was around 50%; as a conservative estimate, we set half of that, 25%, as the maximum possible reduction in bycatch attributable to behavior (with the majority of vessels in the simulation reducing bycatch far less).

The incentive to reduce bycatch is modeled as a function of bycatch rates:

$$\text{incentive}_{s,\,y,\,i} = \psi \,/\, (1 + Q_{s,\,y,\,i}),$$

where ψ is the maximum yearly change in bycatch rate and is parameterized as 0.25. Then:

$$\text{incentive multiplier}_{s,\,y,\,i} = 1 - \text{incentive}_{s,\,y,\,i}$$

and the cumulative incentive multiplier (CIM) is simply

$$\text{CIM}_{s,\,y+1,\,i} = \text{CIM}_{s,\,y,\,i}\ (\text{incentive multiplier}_{s,\,y,\,i}),\ \text{and}\ \text{CIM}_{s,\,y1,\,i} = 1$$

and the incentive adjusted bycatch is

$$\text{incentive adjusted bycatch}_{s,\,y,\,i} = \text{CIM}_{s,\,y,\,i}\ (\text{actual bycatch}_{s,\,y,\,i})$$

Thus, the estimated bycatch levels decrease over time depending on the incentive for each vessel in each year. The actual reduction per year varies between 18.75% and 9.375%, depending on the value of Q, where larger reductions occur for smaller values of Q (high bycatch rates) and smaller reductions occur for larger values of Q (low bycatch rates).

These dynamics are then incorporated into the simulation, and run forward to produce the results shown in Figure 8 and Figure 10. The results are similar but more dramatic than the earlier simple allocation and trading results, which do not model any incentives to reduce bycatch.

It is important to note that even though the model was roughly scaled to fit observed variation, these qualitative results are highly dependent on the basic model assumption of self-correction and should be treated only as a plausible scenario to guide expectations. Actual implementation of the plan should allow one to retrospectively construct a more accurate incentive model, and the flexibility of parameters in the CIP allow for adjustments to be made to meet desired performance criteria.

Discussion

The Comprehensive Incentive Plan provides a combination of short-term and long-term incentives to promote bycatch reduction on the level of individual vessels. These incentives come in the form of changes in ITEC allocation based on bycatch performance (long-term incentives) and additional profits or expenses from the trading of ITEC (short-term incentives).

These broad incentives have been mirrored in the Salmon Savings Incentive Plan[4] (SSIP), a simplified version of the suggested CIP for the BSAI pollock fishery that is set to go into place in 2011 (UCBA 2009). While the exact implementation details differ, the SSIP exhibits an incentive structure broadly analogous to the CIP: namely a future increase in the availability of credits for low rates of Chinook salmon bycatch and the inclusion of a market for trading credits. However, one key difference between these plans is the presence in the CIP of direct competition between vessels to encourage ongoing lowering of fleet-wide bycatch rates (Figure 10). Whereas vessels continually compete to lower bycatch regardless of its actual level in the CIP, vessels participating in the SSIP do not directly compete with each other, but create a reserve of Salmon Savings Credits (similar to ITEC) by having bycatch below a fixed performance. Under the SSIP, vessels which have high bycatch rates (relative to the fleet), but which do not exceed their pro-rata allocation of the 47,591 hard cap, are not penalized with a reduced allocation in future years. Vessels are only penalized with a reduced allocation if they purchase credits from another vessel. Although eliminating head-to-head competition between individual vessels reduces the incentive towards cumulative lowering of bycatch rates, the simple accounting for credits under the SSIP may be beneficial and minimize the possibility of any idiosyncratic behaviors arising from competition. Regardless of details, in principle, comprehensive incentive programs that have an allocation component and a trading component represent an effective rational framework for controlling bycatch with simple economic incentives, particularly if the trading leads to transparent organized markets that enhance industry revenues and reduce the costs of regulation and enforcement.

Future Scalability to Multiple Species

The CIP framework for bycatch reduction is both general and scalable. It can be extended to other bycatch species within an individual fishery or across multiple fisheries to further increase industry efficiency. This benefit is analogous to that seen in New Zealand from multispecies trading of fishery quotas (Dewees 1998)[5]. It arises when ITEC for multiple bycatch

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[4] Here, we discuss a draft version of the SSIP, which is publicly available on the website of the NPFMC. The final version that will be implemented in 2011 may contain revisions that address some of the concerns we outline here.

[5] Consider an example where there are two vessels in the same fishery with multiple bycatch species: vessel 1 is better at avoiding bycatch of species A and vessel 2 is better at avoiding bycatch of species B.

species can be traded between vessels that have complementary needs (e.g., excess species B ITEC can be traded for limiting species A ITEC, and this can occur in principle across vessels, sectors, and fisheries where bycatch patterns may be conducive to such optimizations). Such trading can diminish the unfair economic penalties associated with random high encounters in one particular bycatch species at one particular location, and lead to higher overall industry operating efficiency (as well as lower overall bycatch rates). Trading in multiple ITEC species addresses the spatial and temporal patchiness of bycatch and should be attractive to industry. Indeed, the classical theme of increasing economic efficiency through organized trading of substitutable or fungible assets can be further complemented by the implementation of a tradable catch-share market across fisheries where the beneficial permutations only multiply. Analogous to ITEC, trading multispecies catch shares on an organized exchange can address variability in the spatial and temporal distribution of marine fish stocks.

A main concern (GAO 2005) regarding catch share programs is the associated cost and failure of the National Marine Fisheries Service to implement cost-recovery for catch share programs as required by the Magnuson-Stevens Act. Perhaps the greatest future benefit of CIP framework is as a lead-in to the concomitant formation of transparent organized markets that will simplify cost-recovery and decrease costs associated with implementing IFQ programs. With sufficient liquidity for rational price formation, such markets can also reveal the true industry value/cost of bycatch (rather than setting arbitrary targets or fines for bycatch). Moreover, beyond price discovery, markets having centralized exchanges can make scalability to multiple species feasible (for both ITEC and quota shares, leasing or trading). An organized market place for conducting fishery business can provide individual fishermen freedom to balance their ITEC and quota portfolios rationally and mitigate risk. Organized transparent markets can enhance industry rationality, increase efficiency and profits, and reduce the costs of regulation and ease of enforcement. Thus, insofar as they help to catalyze organized markets, fungible assets such as CIP ITEC can be transformative, leading the way to better resource stewardship, lower industry risk, and higher profits.

The vessels can trade respective ITEC allocation with each other to maximize their catch and balance their bycatch obligations.

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Appendix A: Technical Issues Regarding the Allocation Formula

Here we examine several properties of the allocation equation:

$$P_{s,y,i} = \alpha + \beta P_{s,y\text{-}1,i} + \gamma Q_{s,y\text{-}1,i} \tag{2}$$

Scaling:

The proportional allocation factor is transformed into number of credits via equation (1)

$$C_{s,y,i} = P_{s,y,i} F_{s,y,i} I_s \tag{1}$$

$C_{s,y,i}$ = the number of credits that vessel i receives in season s of year y

$P_{s,y,i}$ = the proportional allocation factor for vessel i in season s of year y

$F_{s,y,i}$ = the AFA cooperative catch share (fraction of the sector's pollock quota) received by vessel i in season s of year y

I_s = the total amount of ITEC for the sector in season s

Because different vessels have different shares of the pollock catch, it is possible for the amount of ITEC distributed within a sector to be different from the sector- and season-appropriate fraction of the target bycatch level of 47,591. In other words, if all smaller vessels fish with lower bycatch rates and larger vessels fish with higher bycatch rates, then the subsequent reallocation will increase the allocation for the smaller vessels and decrease the allocation for the larger vessels by a fractional amount. This will result in a net decrease in allocated credits for the sector, since the amount gained by the smaller vessels is lower than the amount lost by the larger vessels. Conversely, a net increase in credit allocation for the sector can occur if the larger vessels tend to fish with lower bycatch rates.

There is a negligible[6], but non-zero possibility that the reallocation would distribute more than a sector's share of the 60,000 hard cap. In such a situation, the amount of ITEC to be distributed can simply be scaled to the 60,000 level. Additionally, sectors may choose to scale the amount of ITEC to the 47,591 level in order to meet the performance criterion of not exceeding the 47,591 target more than three years over any consecutive seven year period.

[6] Note that 60,000 / 47,591 ≈ 1.26. Since the maximum proportional allocation factor (given our parameterization) is 4/3, distributing at the 60,000 level would require the vessels that comprise ~93% of the pollock TAC to be at the upper limit and the remaining ~7% at the lower limit.

Upper and lower bounds for proportional allocations

When the weightings are such that $\alpha = \gamma$ the asymptotic lower and upper bounds on P will depend only on the bounds for Q. Thus, for both equations (3) and (4) the bounds for P are the same (2/3,4/3) when the bounds for Q are [1/3, 5/3] (obtained when $\delta = 1/3$).

Lemma: For $\varepsilon > 0$, Q in $[1\text{-}2\varepsilon, 1+2\varepsilon]$, and $0 \leq \alpha = \gamma \leq 1/2$, the bounds for P are $(1\text{-}\varepsilon, 1+\varepsilon)$.

Proof: We use induction on y.

Base Case:

$$P_{y1} = 1$$

Inductive Step:

$$P_{y+1} = \alpha + (1-2\alpha)\, P_y + \alpha\, Q_y$$

$$\alpha + (1-2\alpha)\, P_y + \alpha\,(1-2\varepsilon) \leq P_{y+1} \leq \alpha + (1-2\alpha)\, P_y + \alpha\,(1+2\varepsilon)$$

$$\alpha + (1-2\alpha)\,(1-\varepsilon) + \alpha\,(1-2\varepsilon) < P_{y+1} < \alpha + (1-2\alpha)\,(1+\varepsilon) + \alpha\,(1+2\varepsilon)$$

$$1-\varepsilon < P_{y+1} < 1+\varepsilon$$

Specific forms for the bycatch function Q

In general, Q can be any monotonic function that rewards low bycatch behavior and that penalizes high bycatch behavior. The performance measure chosen here involves computing a z-score for bycatch rate and converting via linear scaling. Vessels with $z < -2$ receive a $Q = 5/3$, and vessels with $z > 2$ receive a $Q = 1/3$. Vessels with $-2 < z < 2$ have $Q = 1 - 1/3\ z$. Note that this penalty function provides equal incentive for the vast majority ($-2 < z < 2$) of vessels, since the slope of Q is constant for these vessels. Here, the incentive is directly related to the slope of the penalty function: a greater slope indicates a greater change in credit reallocation for the same change in bycatch rate.

An alternative bycatch function was considered that uses each vessel's z-score to compute a cumulative p-value based on a normal distribution. This bycatch function would create the highest incentives for vessels near the mean bycatch rate: these vessels can move up and down in Q value more quickly than vessels at the extremes because of the steepness in the penalty function near the mean. However, this type of bycatch function would provide the least incentive for vessels at the extremes to change behavior, whereas a linear function like the one above would be viewed as being fair to all vessels.

Computation of z-scores

The variance in bycatch rates between vessels can be attributed, in part, to chance encounters with pockets of Chinook salmon, and in part to choices by vessel operators that directly influence bycatch rates (e.g., caution in gear deployment, towing speed, choice of fishing location, timing).

One reasonable expectation of the CIP is for the distribution of bycatch rates among vessels to decrease over time as vessels exploit the same behavioral changes to reduce bycatch rates. A larger proportion of the variation in bycatch rates would then be due to random chance and not intentional behavior on the part of vessels. Since *z*-scores are scaled to the standard deviation of the bycatch rates, large fluctuations in *z*-scores may occur due to random chance. To mitigate this problem, we use an estimated standard deviation based upon a sector-wide bycatch rate (equivalent to a weighted average of individual vessel's bycatch rates). This calculation is based on historical data across the Inshore Catcher-Vessel sector, the Mothership sector, and the Catcher-Processor sector (Figure 5).

Because small vessels are subject to more sampling error (Figure 4), we also use a corrected standard deviation to reduce the effects of random noise due to vessel size. This random noise varies with the inverse square root of $1 + F_{s, y, i}$. ($F_{s, y, i}$ is the AFA cooperative catch share of vessel *i*. Thus, we correct standard deviation using:

$$\sigma_{s, y, i} = \sigma_{s, y} \sqrt{(1+1/n_{s, y})} / \sqrt{(1 + F_{s, y, i})}$$

where $n_{s, y}$ is the number of vessels in the sector for season *s* of year *y*. The adjusted standard deviation, $\sigma_{s, y, i}$, is then used in place of the normal standard deviation, $\sigma_{s, y}$, to calculate the *z*-score for vessel *i*.

Convergence Rates

The legacy weighting parameters, β and γ in equation (2), affect the rate at which a vessel can change its proportional allocation factor, *P*, from year to year. The graphs below (Figure A-3) show the extreme cases realized by two different weighting schemes: (1/3, 1/3, 1/3) and (1/4, 1/2, 1/4).

In the "equal" weighting scheme (1/3, 1/3, 1/3), the legacy component receives less weight than in the "augmented" weighting scheme (1/4, 1/2, 1/4), and incentives are increased (larger yearly changes in allocations). However, fluctuations in allocation due to random noise affecting bycatch rates are also magnified, which decrease the incentives associated with consistent behavior, and should be taken into account when choosing a weighting system.

Appendix B: Technical Issues Regarding the Fixed Transfer Tax and Dynamic Salmon Savings

Fixed Transfer Tax

With a Fixed Transfer Tax (FTT), a fixed percentage of credits are retired for every ITEC transaction. For our simulation, we used a FTT rate of 20%: if a vessel wished to buy 100 credits, 20% or 20 credits would be retired as the “transfer tax”, so that a total of 120 credits would be removed from a seller’s pool of ITEC, but only 100 would be transferred to the buyer.

Dynamic Salmon Savings

Under a Dynamic Salmon Savings rule, a percentage of a vessel’s remaining credits are retired when that vessel finishes fishing its pollock quota: this percentage is the Salmon Savings Rate (SSR). To prevent vessels from selling credits before finishing fishing and avoiding having credits retired, it is additionally required that vessels who sell credits before finishing fishing reserve the appropriate fraction of credits corresponding to the SSR (or the maximum upper bound on SSR if the SSR has not yet been determined). In our simulation, we used 50% as the maximum upper bound on SSR.

Provisional Salmon Savings Rule

Note that prior to the completion of fishing and having credits retired based on the SSR, vessels may still transfer credits if an appropriate number of credits are set aside to cover eventual retirement. For example, if a cap is set so the largest Salmon Savings Rate is 50% (a number that historically will not limit the harvest), then prior to setting the SSR, boats that have finished fishing early can only sell up to 50% of their remainder credits. This means that if a vessel has wishes to sell 50 credits early in the season, it must keep 50 ITEC in reserve until the SSR has been determined.

Alternatively, if the SSR has been determined to be, say, 20%, vessels that wish to sell credits before fishing the entirety of their pollock allocation must retire an additional 25% credits for each transaction. For example, if that vessel sold 80 credits, it would retire an additional 25% or 20 credits. This fraction is equivalent to applying the SSR of 20% on a vessel that finishes fishing pollock with 100 credits remaining: for this hypothetical vessel, 20 credits would be retired, leaving it with 80 credits to sell, exactly the same as in the example.

Calculating a savings rate

Numerical experiments with the Inshore daily data suggest that calculating the savings fraction when 2/3 of the sector pollock quota are caught (2/3 sector TAC) gives the best result, in terms of estimating the credits needed to complete the season. This is the "estimated total sector by-catch for the B season." This estimate normally occurs between August 29 and Sept 16 (see figure and table below). This tends to happen later in low salmon abundance years (when fewer transfers are needed) and occurs earlier in moderate to high abundance years.

The "estimated number of surplus credits" in the table below is the (current number of credits for the sector on the date that the salmon savings rate is calculated) - (estimated total B season bycatch for the sector + buffer). Here the buffer is 5000, to account for error in the estimates of total sector by-catch.

The final "allowable salmon savings rate" would then be (the number of estimated surplus credits) / (current number of credits for the fleet). It is called an" allowable salmon savings rate" in that under this SSR, the pollock harvest for the sector would not be limited by the availability of salmon encounter credits. These numbers are shown in the blue region of the table below. In high abundance years the SSR is 0% and in low salmon abundance years the allowable SSR can be as high as ~30.0%. That is, in year 2000, we would be confident of fishing the entire pollock quota (with margin for error) if the SSR were set at 30.0%. However, such a high rate would put a damper on trading before the rate was posted (albeit, in 2000 no transfers were ultimately necessary).

Simulation results

Annual data for quantities of ITEC retired as a function of annual bycatch (a proxy for salmon abundance) under both the FTT and DSS schemes are shown in Figure 9 and Table B-2. Not only is the total quantity of credits retired through DSS higher for this eight-year period (2000-2007), but the quantity of ITEC retired is high in years of low salmon abundance: precisely when the potential for abusing extra ITEC is the highest! Conversely, the quantity of credits retired through FTT is highest in years of intermediate abundance: when the most transactions take place (due to a balance of availability and demand). Increasing the FTT rate to recover more ITEC has the potential of reducing credit transfers in mid-abundance years. The subsequent revenue loss can be extreme if a high FTT rate is chosen.

Appendix C: Afterthoughts

It may be desirable to allow cooperatives to impose a small 3% tax on all vessel credits allocations to create an Emergency Fund for extreme bad luck cases. This small "emergency fund" could be used to help bail out any vessel that the coop determines had genuine bad luck. Any remainder credits could be put on the market by the coop toward the end of the year to raise revenue. The bad luck event (as deemed by a coop, or better yet a sector) could be incorporated into the legacy system (or not) by adjusting the bycatch rate to not fully reflect this event (say cut the number in half for that tow). This allowance should only happen occasionally per vessel (e.g., once per vessel in seven years).

Chronic bad players, those with consistently above average bycatch rates can place a drag on the overall performance of the fleet and harm its standing with regard to the Chinook salmon problem. They may be content with the minimal 2/3 allocation and be willing to wait until later in the season when credits could become more available as individual pollock quotas are filled and/or vessels are more comfortable with selling surplus ITEC at low prices. They may not care about the risk that next year may be a moderate to high abundance year, when ITEC will not be readily available, and may be willing to put their businesses at risk. Moreover as discussed, the credits may be uneconomic for the worst players, because they are worth less in terms of expected return on pollock.

One possible way to handle this is to implement a two-Strikes Rule that suspends credits trading privileges from such repeat offenders in all seasons until they can demonstrate that they can move out of the worst category in any one season. It is ultimately up to the industry to decide the details of this rule and what defines this worst category (e.g., three standard deviations below the mean for two years running, or near the bottom of the list for two years running). Such a rule could quickly weed out the few worst players, and would likely only need to be in effect for some initial period. It has not been implemented in the simulations in the current study.

To summarize, being a chronic offender is risky and uneconomic for several reasons: chronic offenders will tend to run out of credits quickly because of their lower allocation; they will need to buy credits at a price that may not be economic given their high bycatch rates; and, they risk losing trading privileges.

Tables

Table B 1. Calculation of SSR for the Inshore Catcher-Vessel sector for years 2000-2007

	Dynamic Salmon Savings Rate (at end of B season)						Unknown
year	A	B	C	D	E	F	G
2000	16-Sep	9859	254	7286	2573	26.1%	711
2001	11-Sep	9812	277	7493	2319	23.6%	2743
2002	5-Sep	10236	1655	19895	(9659)	0.0%	9622
2003	2-Sep	10801	256	7304	3497	32.4%	7144
2004	31-Aug	9716	1890	22010	(12294)	0.0%	20924
2005	29-Aug	9668	4142	42278	(32610)	0.0%	33734
2006	10-Sep	9703	3591	37319	(27616)	0.0%	21179
2007	2-Sep	9826	1465	18185	(8359)	0.0%	33813

A = date when 2/3 walleye pollock caught

B = sector credits remaining (includes 100% carry-forward from A season)

C = bycatch caught (up to the date in A)

D = predicted total bycatch with buffer (for season) (computed as D = 9 C + 5000)

E = estimated surplus credits (computed as E = B – D)

F = allowable salmon savings rate (computed as F = E / B)

G = actual total bycatch (for season)

Table B-2. Number of ITEC recovered vs. yearly bycatch (proxy for salmon abundance) for two different sell side transfer rules.

	RETIRED CREDITS	
Total Bycatch	Fixed Transfer Tax	Dynamic Salmon Savings
1454	0	12483
8866	91	8776
19923	910	0
20471	735	3258
31136	1563	0
46354	1010	0
55782	437	0
70148	343	0

Figure Captions

Figure 1. Chinook salmon bycatch in the BSAI pollock mid-water trawl fishery, 1991-2010. (www.fakr.noaa.gov/sustainablefisheries/inseason/chinook_salmon_mortality.pdf)

Figure 2. Historical simulation of the timing and cumulative numbers of vessels (Inshore sector) in each season that would have run out of ITEC under the PPA performance-target cap of 47,591 fish with no trading and without behavioral changes. Note that some vessels would have run out of credits even in low encounter years (e.g., 2002, 2003).

Figure 3. Annual revenue losses for the inshore sector that would have occurred under the performance-target cap of 47,591 fish. This calculation is based on daily catch data from Sea State Inc. and assuming an ex-vessel value of $0.20/lb for the A season and $0.12/lb for the B season.

Figure 4. Smaller vessels show higher variability in bycatch rates. (based on annual data from 2003-2007)

Figure 5. Standard deviation of bycatch rates as a function of sector total bycatch rate. (Annual data from multiple sectors provided by Sea State, Inc.)

Figure 6. (A) Surplus ITEC achievable with 10 fewer Chinook salmon caught using the "equal weight" Legacy Allocation Formula (equation 2) with a linear penalty function. **(B)** Credit penalties (reduced ITEC) as a result of 10 more Chinook salmon caught.

Figure 7. Potential revenue recovered (for the Inshore sector) from trading ITEC under the PPA performance-target cap. Even without explicit incentives to avoid bycatch, trading by itself can help to maximize industry revenues.

Figure 8. Potential revenue recovered (for the Inshore sector) from trading ITEC and modeled incentives to avoid bycatch under the PPA performance-target cap.

Figure 9. (A) Number of retired credits over eight years (2000-2007) under two different transfer rules: a Fixed Transfer Tax and Dynamic Salmon Savings. **(B)** Number of ITEC recovered vs. yearly bycatch (proxy for salmon abundance). More ITEC is recovered during low salmon abundance years using Dynamic Salmon Savings.

Figure 10. Effects for the Inshore sector of cumulative market incentives for reducing Chinook salmon bycatch.

Figure A-1. A linear penalty function capped at *z*-scores of +2 and -2. Because the slope of the penalty function is equal for $-2 < z < 2$, most vessels have equal incentive to reduce bycatch.

Figure A-2. A penalty function based on the cumulative distribution function for a Gaussian distribution. The slope is highest in the middle; therefore, the incentives are largest for vessels with average bycatch rates.

Figure A-3 (A) Comparison of two weightings of the legacy component, with $Q = 1/3$. **(B)** Comparison of two weightings of the legacy component, with $Q = 5/3$. In both **(A)** and **(B)**, convergence to the bounds is slower under the "augmented" weighting scheme (1/4, 1/2, 1/4).

Figure B-1. Cumulative bycatch as a function of pollock harvested during the B season.

Figure 1

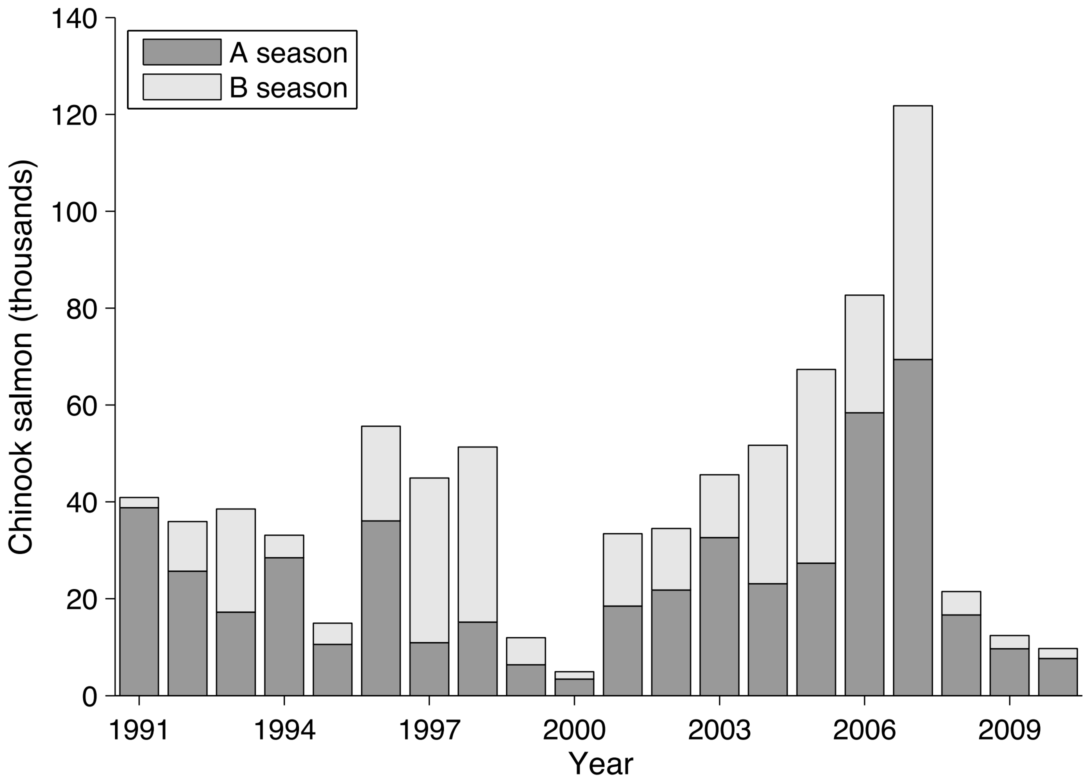

A season
B season
Chinook salmon (thousands)
0
20
40
60
80
100
120
140
1991
1994
1997
2000
2003
2006
2009
Year

Figure 2

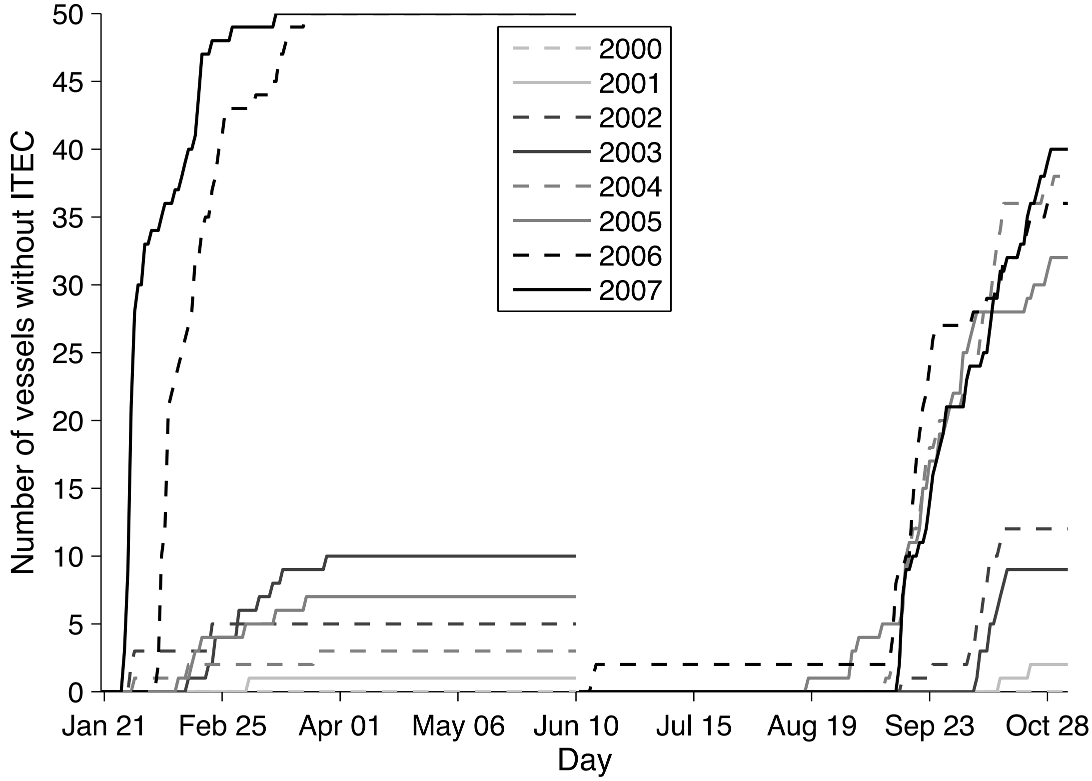

2000
2001
2002
2003
2004
2005
2006
2007
Number of vessels without ITEC
0
5
10
15
20
25
30
35
40
45
50
Jan 21
Feb 25
Apr 01
May 06
Jun 10
Jul 15
Aug 19
Sep 23
Oct 28
Day

Figure 3

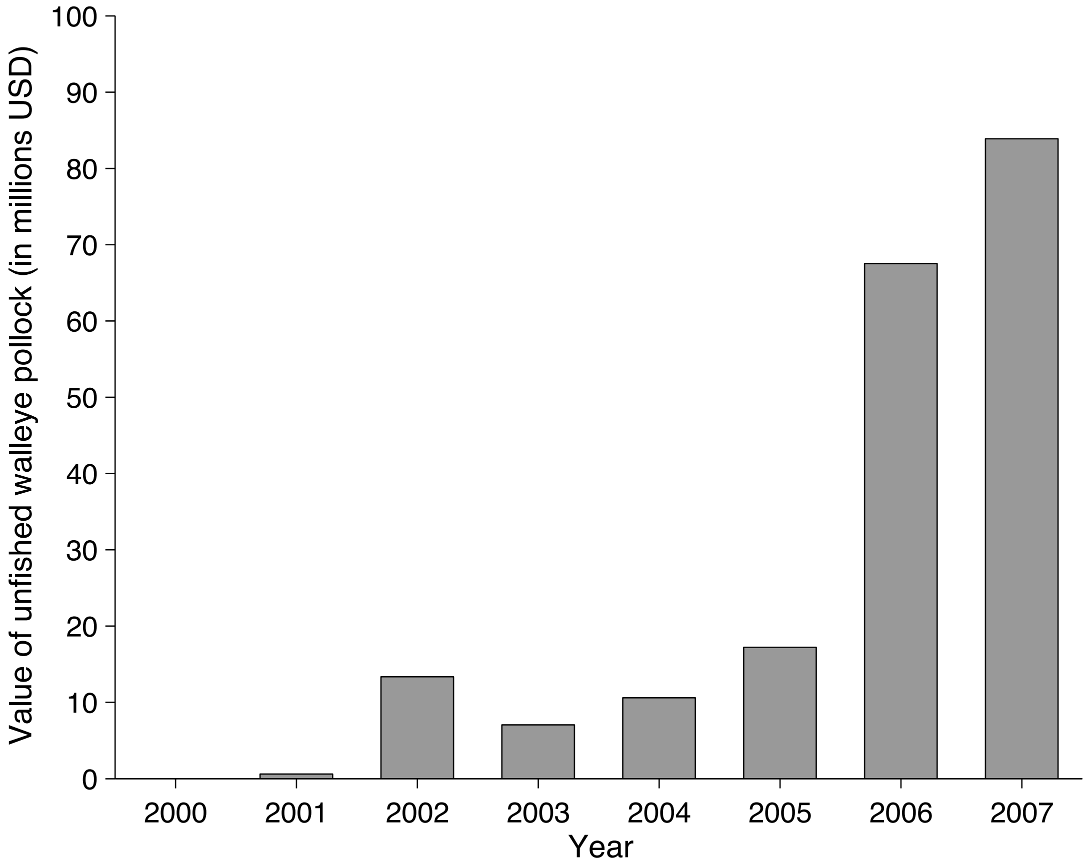

Value of unfished walleye pollock (in millions USD)
100
90
80
70
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
Year

Figure 4

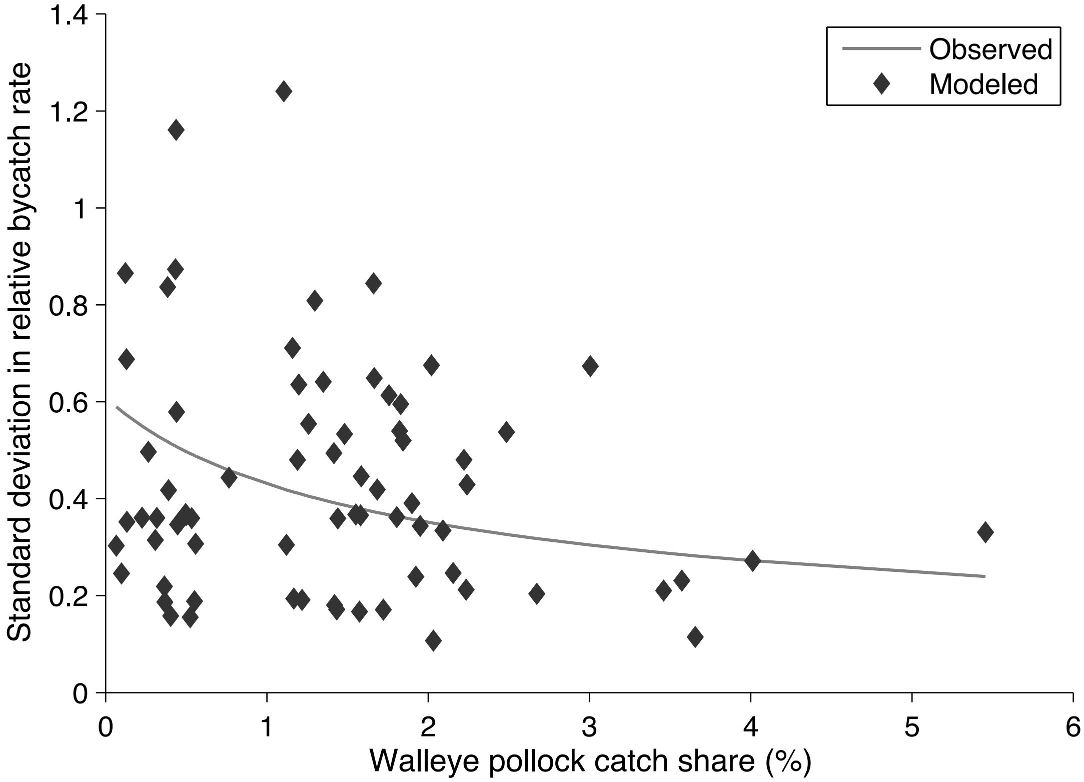

Observed
Modeled
Standard deviation in relative bycatch rate
Walleye pollock catch share (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6

Figure 5

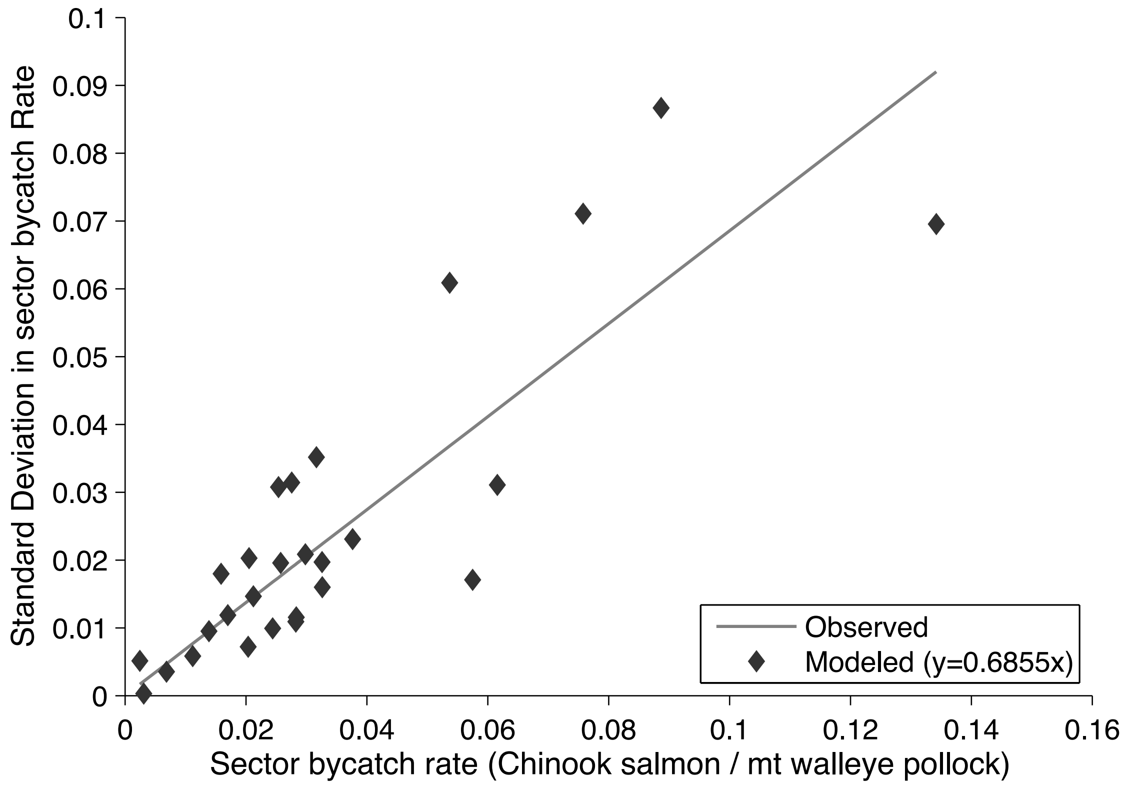

0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Standard Deviation in sector bycatch Rate
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Sector bycatch rate (Chinook salmon / mt walleye pollock)
Observed
Modeled (y=0.6855x)

Figure 6

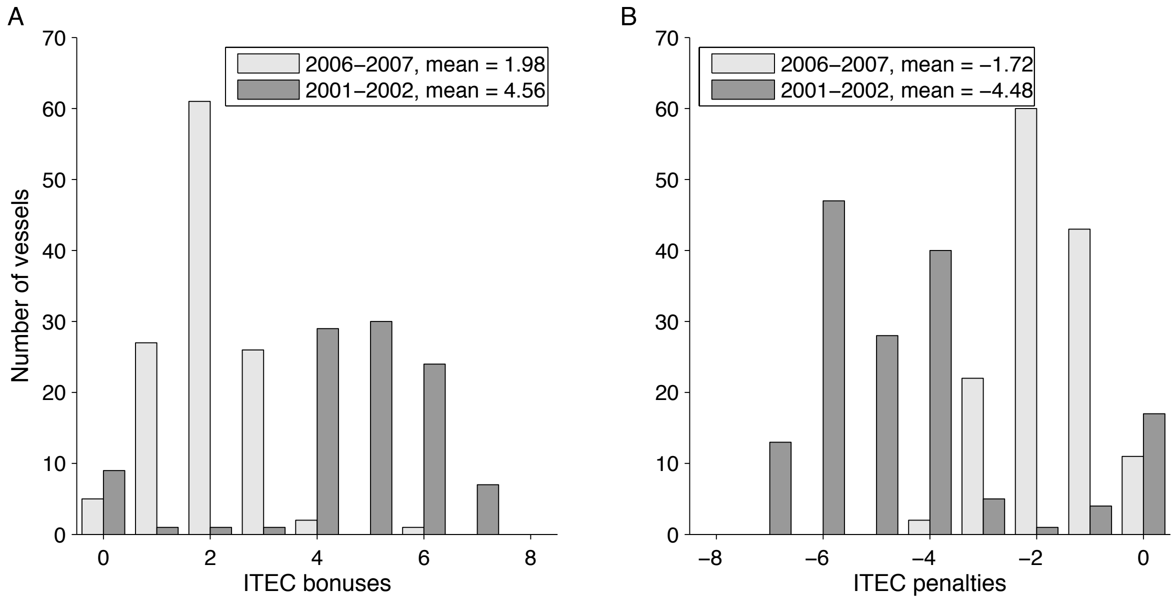

A
2006–2007, mean = 1.98
2001–2002, mean = 4.56
Number of vessels
ITEC bonuses
B
2006–2007, mean = −1.72
2001–2002, mean = −4.48
ITEC penalties

Figure 7

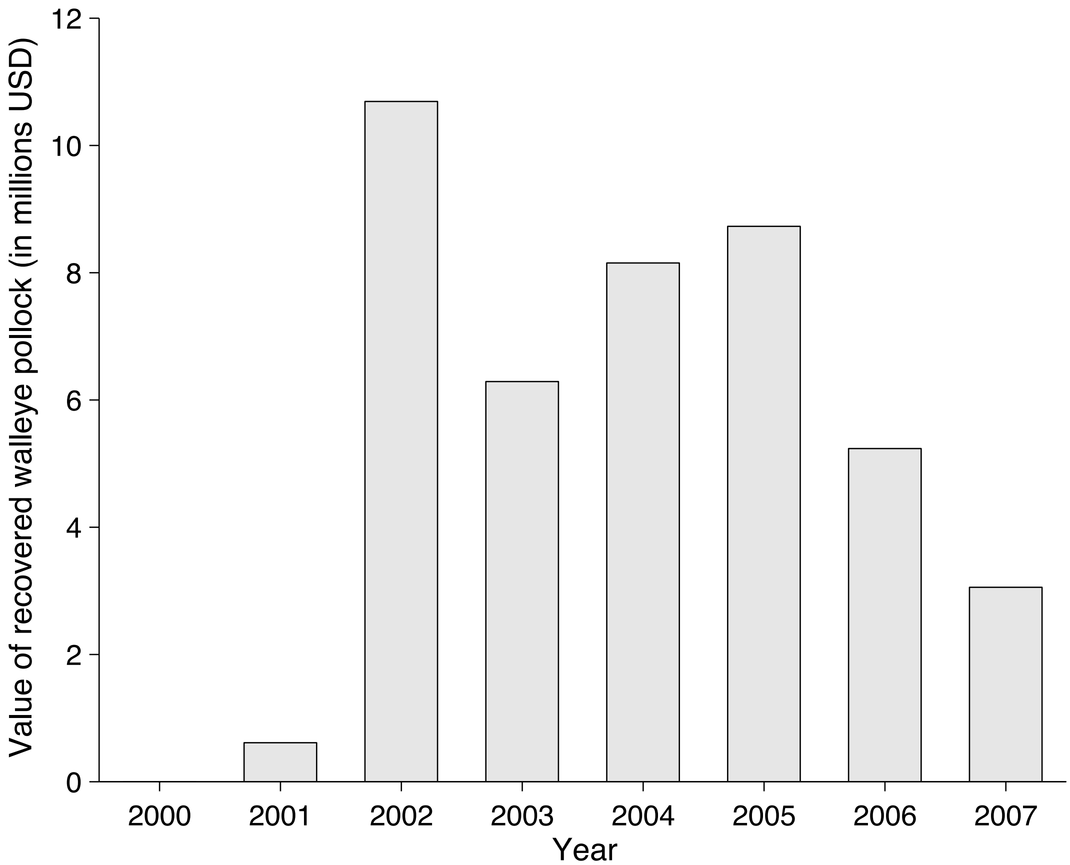

Value of recovered walleye pollock (in millions USD)
0
2
4
6
8
10
12
2000
2001
2002
2003
2004
2005
2006
2007
Year

Figure 8

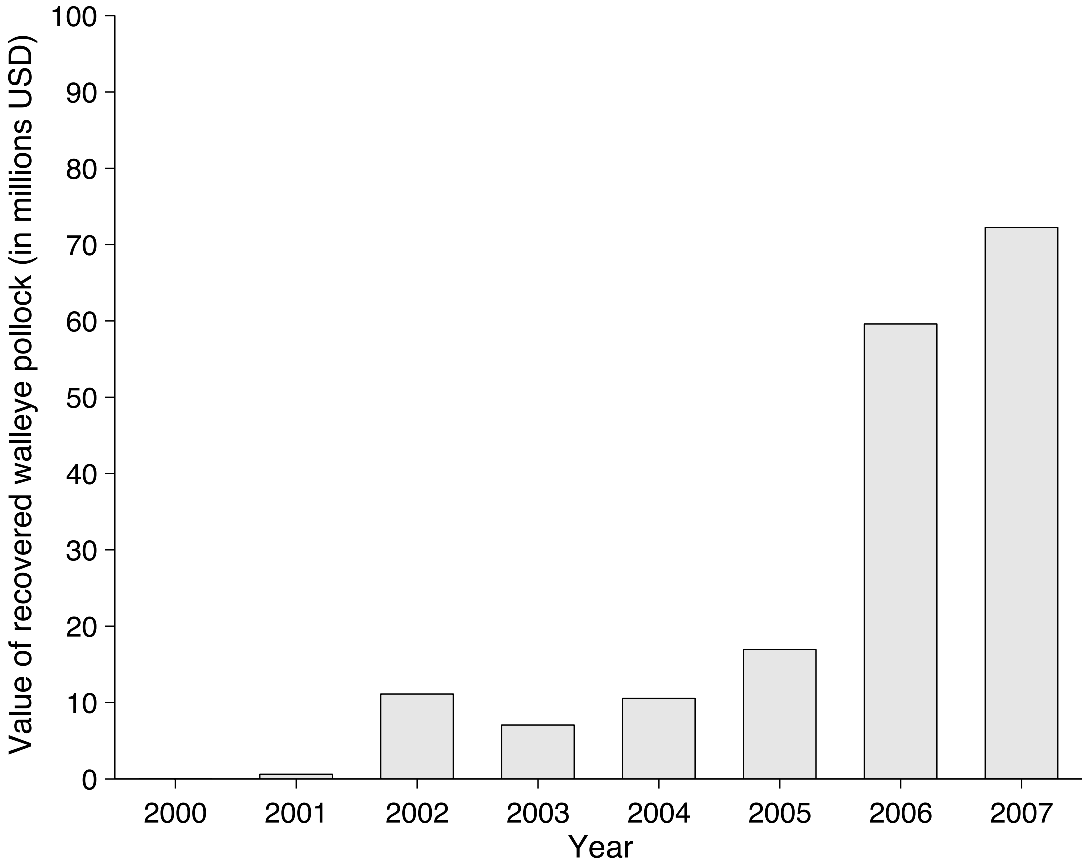

Value of recovered walleye pollock (in millions USD)
0
10
20
30
40
50
60
70
80
90
100
2000
2001
2002
2003
2004
2005
2006
2007
Year

Figure 9

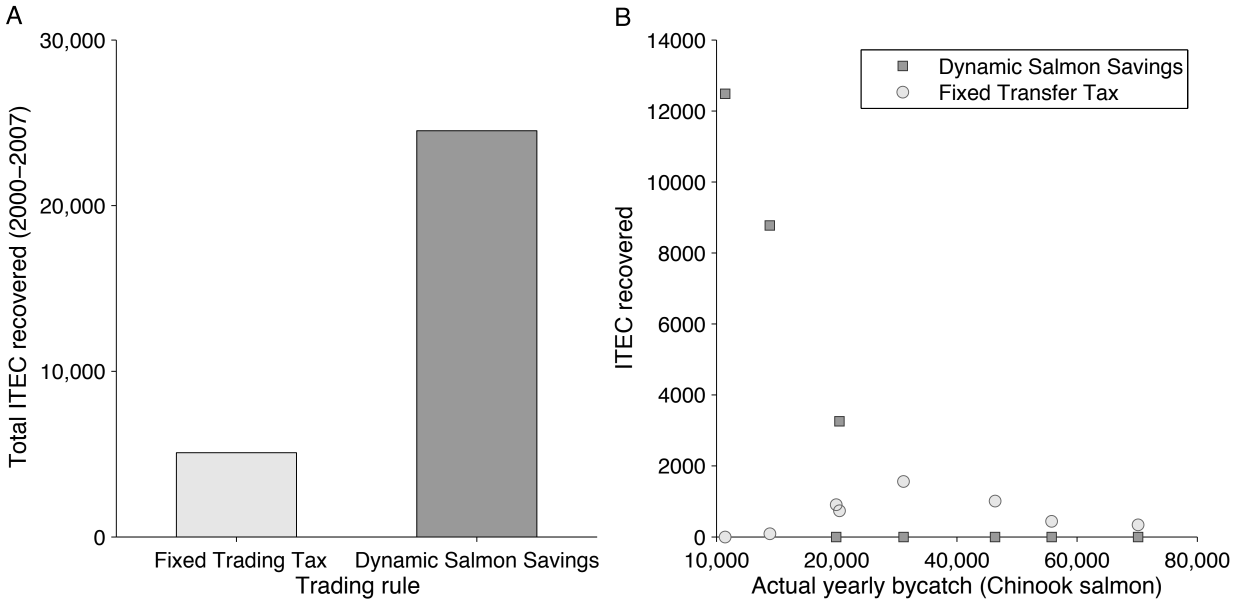

A
B
Total ITEC recovered (2000–2007)
30,000
20,000
10,000
0
Fixed Trading Tax
Dynamic Salmon Savings
Trading rule
ITEC recovered
14000
12000
10000
8000
6000
4000
2000
0
10,000
20,000
40,000
60,000
80,000
Actual yearly bycatch (Chinook salmon)
Dynamic Salmon Savings
Fixed Transfer Tax

Figure 10

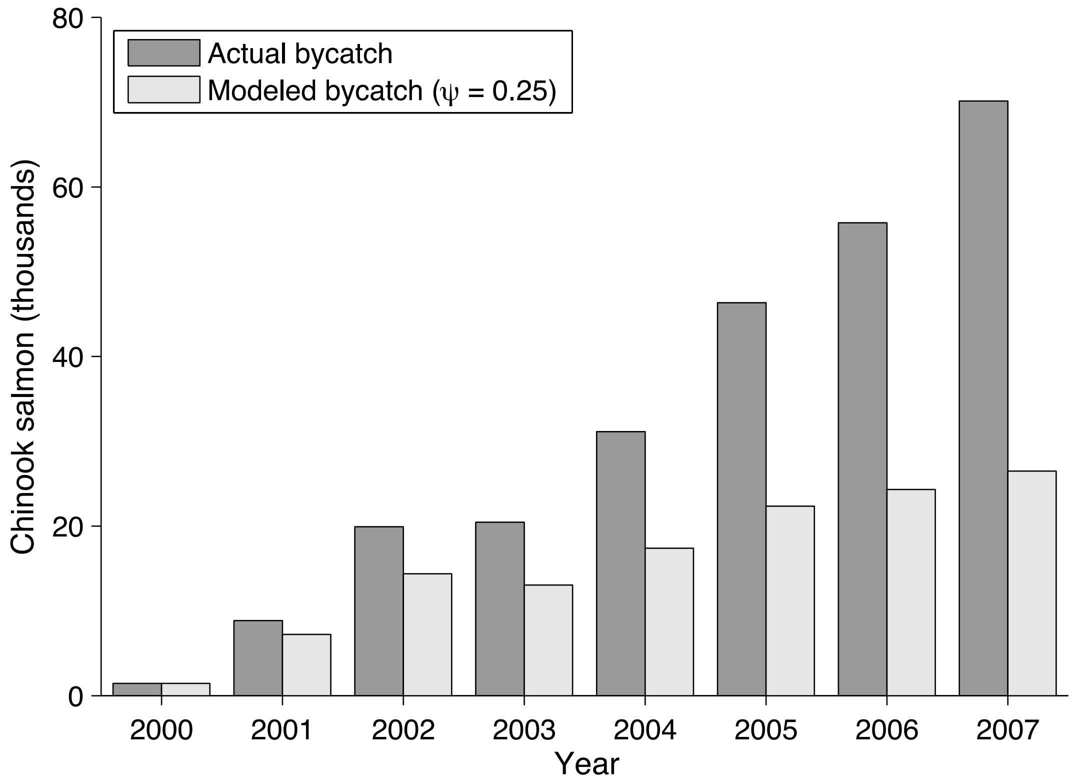

Actual bycatch
Modeled bycatch (ψ = 0.25)
Chinook salmon (thousands)
0
20
40
60
80
2000
2001
2002
2003
2004
2005
2006
2007
Year

Figure A-1

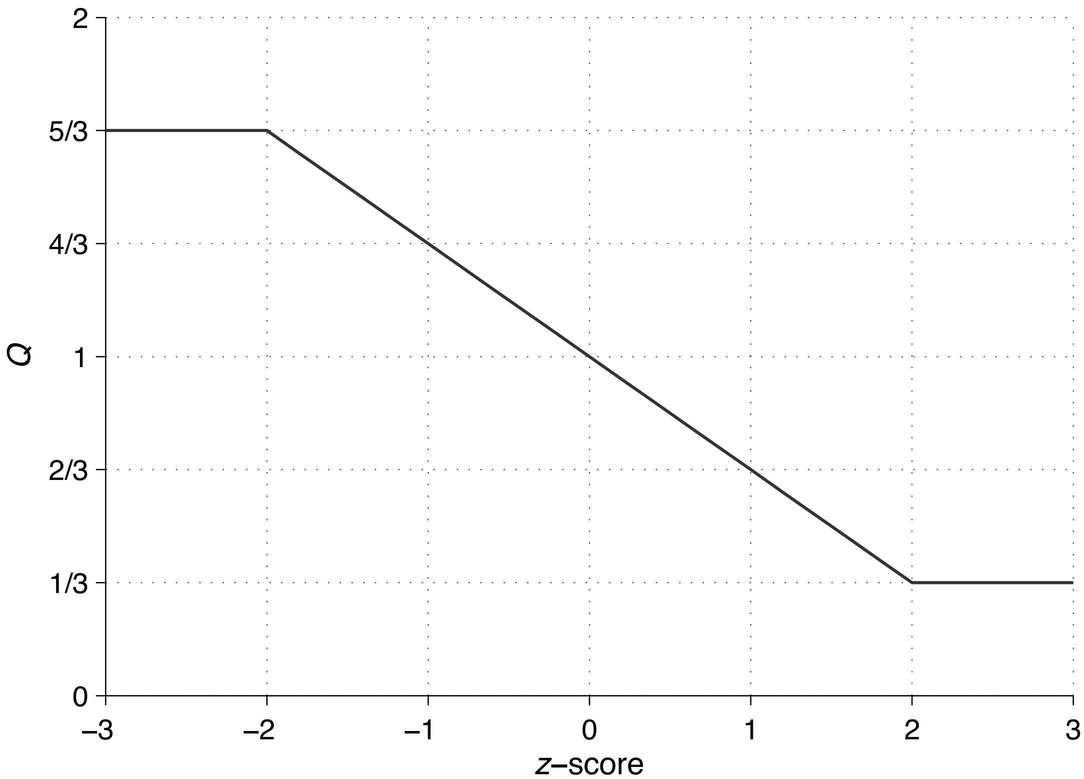


Figure A-2

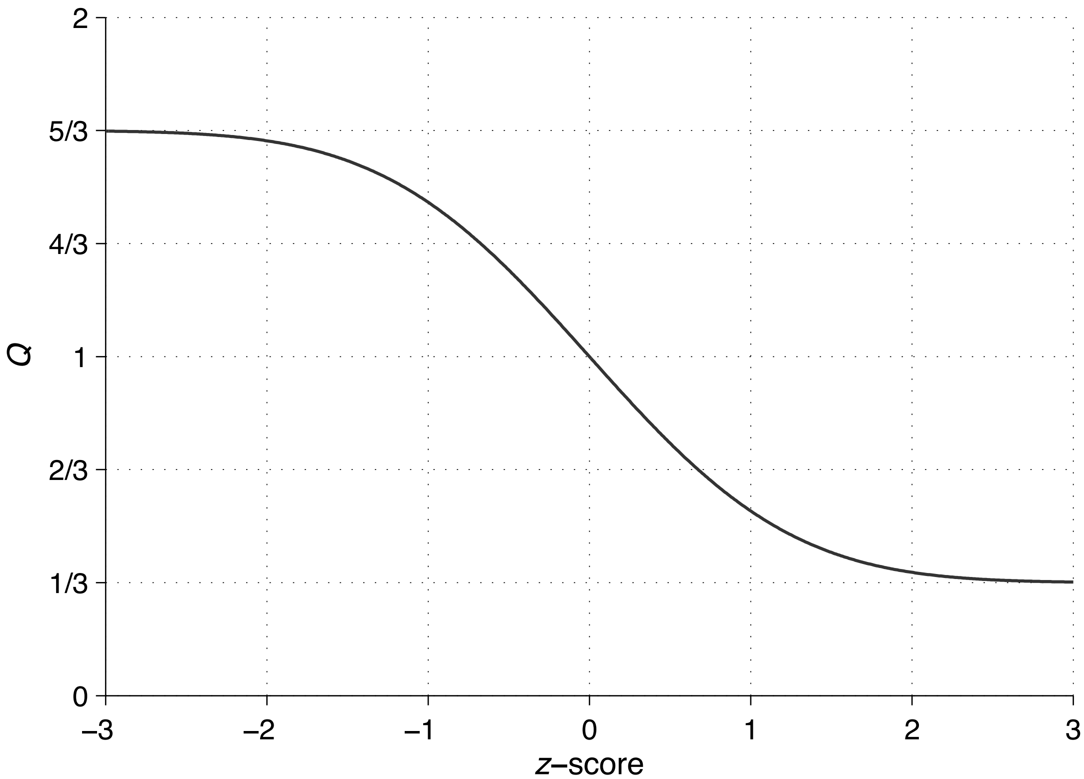
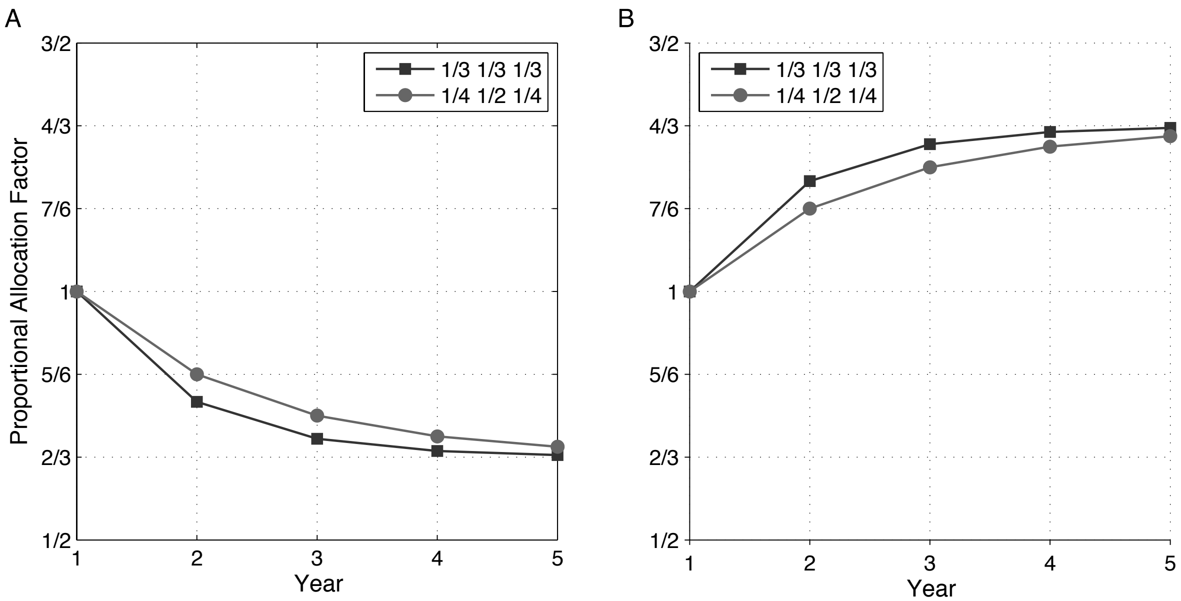
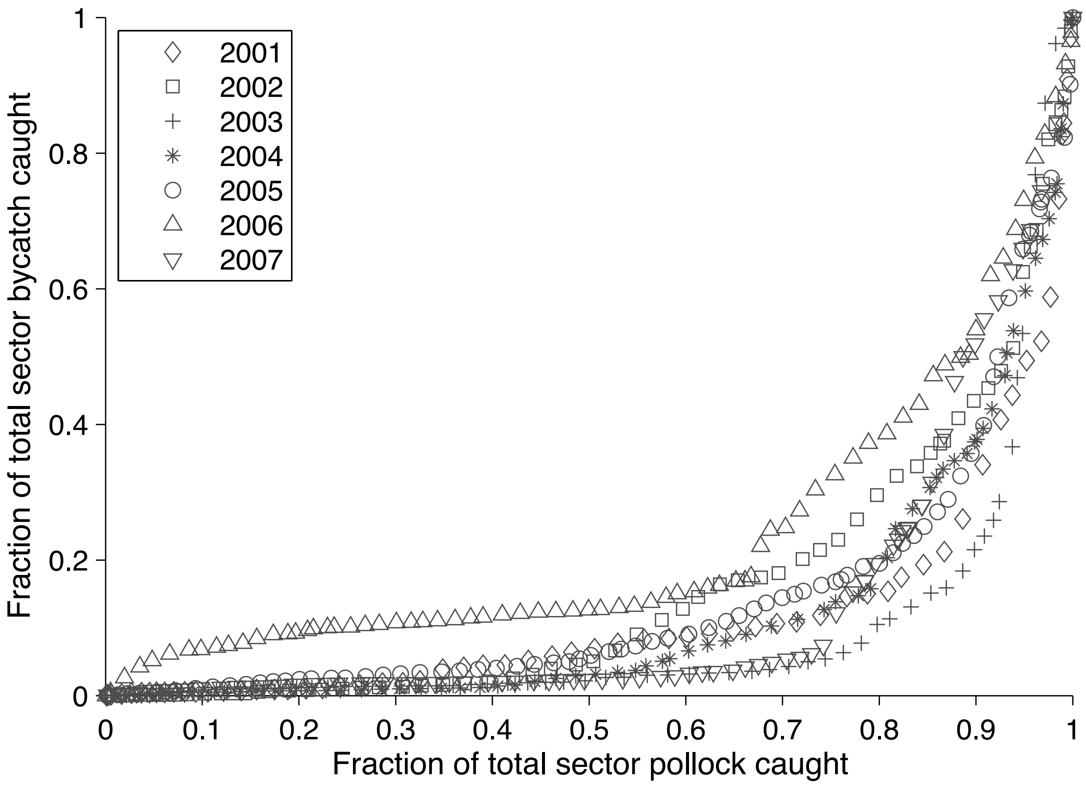


Figure A-3


A
B
3/2
4/3
7/6
1
5/6
2/3
1/2
Proportional Allocation Factor
Year
1/3 1/3 1/3
1/4 1/2 1/4
1
2
3
4
5

1030 **Figure B-1**



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