The Efficiency Gains from Coordinating Effort in a Fishery: Evidence from the Chignik Salmon Cooperative

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1. Introduction

A long tradition of theoretical (Gordon 1954; Scott, 1955) and anecdotal (Grafton et al. 2000, Griffith 2007) evidence suggests that rights-based reforms may dramatically enhance the profitability and sustainability of commercial fisheries. A recent report shows that the global collapse of fisheries can be prevented, or even reversed with well-designed catch shares (Costello et al. 2008). Yet <2% of the world's fisheries currently employ catch share systems. This dearth of implementation arises from three main factors. First, ironically, the very constituents who stand to gain the most from rights-based reform (incumbent fishermen) often vocally oppose catch shares on the grounds that they eliminate "free" access to the resource. Second, the initial allocation of rights invites rent-seeking contention. Third, the individual transferable quota (ITQ) model that has achieved some success in Alaska, Iceland, New Zealand, and elsewhere, may still leave significant rents on the table (Costello and Deacon, 2008), and may thus be viewed as a reform hardly worth the effort.

Rather than imposing a rights-based system on all fishery participants, an emerging instrument allocates shares to sub-sectors or groups within the fishery. Coordination among members of a cohesive group can overcome problems of collective action, and may significantly enhance rents by minimizing the race to fish. But how will regulators determine which "groups" receive allocations, and what is the appropriate membership of a group? One promising idea that has been applied in practice is to allow individuals to self-select into an optional cooperative; those opting out simply pursue the status quo model, and those opting in abide by internal rules set by the cooperative. Each group receives a secure allocation from the government regulator; presumably a much simpler negotiating task than allocating unique shares to all individuals (Matulich et al., 2001). We call this governance instrument a "self-selected catch share," a version of which was implemented in an Alaskan salmon fishery from 2002-2004. It merges elements of ITQs, cooperatives, and limited entry fisheries, and may partially overcome the implementation challenges identified above. Managers divvy up a scientifically determined total allowable catch among the sectors, were the share allocated to each sector depends on the size or historic catches of its membership. Fishermen freely elect in, or out, of the catch share system. Both fleets have the option of providing public goods (infrastructure, marketing, technology, science, etc.).

In Alaska, the system involved two sectors: a cooperative sector, which shared profits equally among its participants, and an independent sector. In that case, fishermen chose which sector to associate with, and opted into the cooperative knowing that profits would be shared among all members. This self-selection structure has a number of advantages, and opens a number of questions. First, self-selection allows dissenting fishermen to go it alone with little impact on the cooperative sector. This feature may enhance political viability among those who doubt the ability of the catch share to enhance their personal profitability. Second, allocation occurs to the *sectors* in proportion to their membership, rather than to individuals. This minimizes debate over the catch share allocated to any given individual. Third, the combination of a sector allocation and profit sharing incentivizes the cooperative to internalize cost-increasing behavior, which may enhance the value of the fishery.

Despite these promising attributes, little analysis or empirical evidence exists to guide the implementation of this system of governance. For a resource with heterogeneous permit holders, who will elect into, or out of, the cooperative? Will public goods be efficiently provided? Are inefficient costs internalized by the cooperative? By the independent sector? And ultimately, what are the economic consequences of such a system? We develop a game theoretical model to answer these, and other related questions. The model contains two stages. In the first stage, fishermen decide whether to join the cooperative. In the second stage, the two fleets determine how effort will be deployed to harvest the sector's allocated quota.

The analytics give rise to a number of predictions regarding membership, fishing intensity, efficiency, public goods provision, and profitability in each sector. We test these predictions with a novel data set derived from the Chignik Sockeye Salmon Cooperative which operated from 2002-2004 in Chignik, Alaska. The next section links our analysis to the literature

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on ITQs in fisheries, the economics of cooperatives and the theory of the firm and optimal firm size. Section 3 develops our model of the joining decision and effort allocation in the cooperative and independent fleets. Section 4 presents empirical tests of the model's predictions. Section 5 discusses the findings and offers conclusions.

2. Literature Review

While the dismal economic and ecological consequences of open access fisheries were forecast 50 years ago (Gordon, 1954; Scott, 1955), only recently have those predictions been shown empirically. Today, the collapse of large predatory fisheries, species at all trophic levels, and economically important fisheries in all 64 marine ecosystems in the world are well documented (Halpern et al. 2008; Myers and Worm, 2003; Jackson et al. 2001; Worm et al. 2006). While pollution, climate change, and habitat damage have all been implicated, poor governance structures are widely believed to be the root cause (Beddington et al. 2007; Hilborn et al 2005). Starting with the seminal works of Gordon (1954) and Scott (1955), economists have pointed to the lack of property rights as the underlying mechanism that misaligns the incentives of individual harvesters with profit maximization of the fleet; this misalignment occurs both intra-period (Gordon) and inter-period (Scott). A recent study links fishery collapse to lack of property rights and suggests that the increasing global trend could be halted by appropriate application of catch shares (Costello et al. 2008).

Catch shares have also been empirically shown to enhance profitability of fisheries, though analyses are primarily anecdotal due to the difficulty of obtaining value data before and after catch share implementation. Hannesson (2004) provides an enlightening review of the theory and empirical evidence of fisheries privatization, and builds a substantial case that, when rights are well-defined and appropriately allocated, fisheries profitability can significantly increase. Grafton et al. (2000) studied the economic effects of a 1990 individual transferable quota (ITQ) program for Canadian Halibut. They found large significant increases in producer surplus and a significant lengthening of the fishing season. Leal (2002) surveys several US and Canadian ITQ programs and finds similar effects. Linn et al. (2008) use survey level data to simulate the cost savings from a proposed ITQ on west coast groundfish in the US. They estimate a $18-$20 million annual cost savings, which amounts to a 60% reduction in costs. Newell et al. (2005) examine quota sale and lease prices among New Zealand's many ITQ programs. While they are unable to compare to pre-ITQ conditions, they find that the fisheries secure significant annual rents.

While the ITQ is the most common type of catch share in the industrialized world, it is not the only option, and it may be inappropriate in some contexts. Alternatives, including territorial user right fisheries (TURFs) and cooperatives are also common, and if designed properly, can internalize both intra-period externalities (a la Gordon, 1954) and inter-period externalities (a la Smith, 1955).

However, it is also clear that simple assignment of rights (e.g. shares of an ITQ fishery, stretches of a coastline, or part-ownership in a cooperative) may not fully incentivize profit maximizing behavior (Boyce, 1992; Costello and Deacon, 2007). In many instances, further coordination may be required to realize potential gains. Regulators often try to directly facilitate coordination (e.g. by mandating days-at-sea restrictions), but this approach often fails because fishermen profitably exploit unregulated margins. An alternative is to allow the formation of cooperatives which self-govern, at least along certain margins (e.g. by coordinating who goes fishing and when). An emerging body of evidence examines the efficiency effects of cooperative management, including the contracting problems therein (Johnson and Libecap, 1982; Ostrom, 1990; Wilson, 1990; Knapp and Hill, 2003; Costello and Deacon, 2007)

From 2002-2004, managers of the Sockeye Salmon fishery in Chignik, Alaska experimented with the latter form of governance. They allowed the formation of the Chignik Sockeye Salmon Cooperative, and allowed the cooperative to self-govern, within certain regulatory constraints. But given a large and heterogeneous fleet, forcing all fishermen to join a cooperative is unlikely to achieve efficient coordination. The participation constraint is too onerous and with a high degree of heterogeneity, it is likely to bind, thus threatening the economic viability of the cooperative.

This intuitive observation raises the possibility of a split-sector fishery: a cooperative fleet and an independent fleet both receive secure allocations, raising questions regarding the size and membership of the cooperative. These issues are isomorphic to questions raised by the theory of the firm: When would we expect a firm to emerge out of the decentralized actions of a large number of agents? How large will the firm be? With which "agents" will the firm contract? A subset of these questions is addressed more generally in a literature on the nature of the firm, spawned by Coase (1937). Essentially, firms emerge when production can be arranged internally to avoid the costs from competitive transactions (transactions costs, information costs, monitoring and enforcement, etc.). In Chignik, Alaska, unregulated (i.e. "independent") fishermen were allowed to self-select into the cooperative, and thus the size of the cooperative was endogenous.

This cooperative "firm" contracted internally to harvest a given allocation of fish at a significantly reduced cost. Just as a firm's size and degree of vertical integration dictate its profits, the membership of the cooperative affects is cost savings.

In this analysis we derive and test theoretical predictions about the performance and efficiency of the self-selected catch share system. In the next section we present a model which derives the membership, size, and efficiency of the self-selected cooperative.

3. Model

Our model of within season fishing activities includes three features that are present in many actual fisheries: (1) heterogeneity in the skill levels and alternative employment opportunities of individual fishermen; (2) heterogeneity over time and/or space in the unit value of the stock; and (3) the potential for fishermen to gain, collectively, by sharing information, infrastructure or other public inputs. These features allow us to examine three important aspects of the allocation of fishing effort: (1) avoiding redundant capacity and assigning fishing activity to the most efficient fishing units, sometimes referred to as 'rationalization' of effort; (2) coordinating effort over time and space to avoid races for the 'best' fish; (3) providing efficient levels of public inputs.

Fishing skill is parameterized by the term γ, which we interpret as the rate at with a fisherman can apply effort, e.g., the number of purse seine sets he/she can make per day. Fisherman h's total effort is the product of γ_h and the time h spends fishing, T_h. We parameterize a fisherman's opportunity cost of time with ϕ. If h has an attractive opportunity in another fishery that operates at the same time, or in an entirely different occupation, ϕ_h will be large.

The unit value of the stock varies over space because it migrates toward a port where fishing vessels and processing facilities are based and the cost per unit effort falls as the stock comes nearer.[1] We parameterize this by dividing the fishing grounds into two zones and regarding the distance to each as a single value, 0 or $\bar{d}$. These zones are called 'inside' and 'outside', respectively, and distance is normalized so that fishing at an additional unit of distance increases the cost per unit effort by 1 unit. We assume the stock spends $\bar{T}$ periods in each zone.

The cost per unit effort can be reduced by the availability of a public good input, G. Examples of G include shared information on stock locations and shared infrastructure. Individual contributions to the public good, denoted x_h, are costly to contributors and total provision of G is determined by the aggregate amount contributed.

Combining these components and including a common cost per unit effort parameter α, fisherman h's total cost is

$$c_h = \left\{\alpha + d_h - G\left(\sum x_h\right)\right\}\gamma_h T_h + \phi_h T_h + x_h \,. \qquad (1)$$

The expression in brackets includes all cost components that are proportional to h's effort. We assume $G(0) = 0$, $G' > 0$, $G'' < 0$ and $\alpha + d_h - G(\cdot) > 0\,\forall h$.

Total catch, Q, is assumed to be a linearly homogeneous function of aggregate effort, E, and the stock, Z. The fishing technology is represented by

$$Q = ZF(E/Z) \qquad (2)$$

where $F' > 0$, $F'' < 0$, $F(0) = 0$ and $F(E/Z) < 1$. Catch per unit effort is assumed to be identical for all who fish at a given distance. Because the stock migrates toward port, those who fish outside are the first to apply effort and they encounter a larger stock than those who fish inside. The concavity of F guarantees that catch per unit effort is greater for those fishing outside than for those fishing inside.[2]

The regulator's goal is an escapement target of $(1-\beta)Z$, implying that the TAC equals βZ. Given (2) this implies that total effort must satisfy $E \le ZF^{-1}(\beta)$. The regulator limits effort to meet the TAC by constraining fishing times to satisfy

$$\sum_h \gamma_h T_h \le ZF^{-1}(\beta) \equiv \kappa \,. \qquad (3)$$

Before fishing starts harvesters are allowed to join a co-op that will coordinate its members' effort to maximize total co-op profit; those not joining choose distance, time spent fishing and public input contributions individually, taking as given the decisions of the regulator and other independents. The sets of independent harvesters and co-op joiners are denoted I (independent) and J (joiners) and their respective numbers are $n(I)$ and $n(J)$. The regulator

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[1] Because the stock migrates along a route, this variability could be characterized as occurring over time.

[2] See Costello and Deacon (2007) for a discussion that extends this reasoning to non-migratory species.

assigns portions of the stock to each group in proportion to these numbers and in such a way that one group's harvest opportunities are unaffected by the actions of the other group.[3] The separate stock assignments are denoted Z_I and Z_J, the separate TAC assignments are βZ_I and βZ_J , and the regulator constrains each group's fishing times according to (3) to meet these TAC assignments. We assume each firm is capable of earning positive profit by fishing independently, regardless of the composition of the independent and co-op fleets.[4] The initial joining decision and subsequent decisions on effort deployment are modeled as a two-stage entry game. Subgame perfect Nash equilibria are identified by backward induction.[5]

Stage 2 choices by the co-op

The co-op's manager is motivated to maximize total co-op profit and the co-op's total catch is fixed by the regulator. Consequently, the co-op's optimal policy solves the following cost minimization problem:

$$\min_{d_i, T_i \ i \in J;\ x_J} \sum_{i \in J} \left(\alpha + d_i - G(x_J)\right)\gamma_i T_i + \sum_{i \in J} \phi_i T_i + x_J \,, \tag{4}$$

subject to $d_i \in \{0, \bar{d}\}, T_i \in [0, \bar{T}]$ for all $i \in J$,and a regulatory constraint on members' fishing times set according to (3). x_J is the co-op's expenditure on the public input.

The co-op's optimal policy is straightforward.[6] First, it sets $d_i = 0$ for each member. This is obvious because (4) is non-decreasing in the d_i for each member and strictly increasing in d_i for any member who spends positive time fishing. Second, the co-op's policy assigns positive harvest times to a subset of members who have low values of the ratio ϕ_i / γ_i and limits the number who actually fish so that the co-op's season lasts the entire time fish are available, $\bar{T}$.[7] Other co-op members do not fish at all. Since ϕ_i and γ_i are *i*'s cost per unit time and effort per unit time, respectively, the ratio ϕ_i / γ_i is *i*'s cost per unit effort, so it is sensible to concentrate effort among low ϕ_i / γ_i members. By slowing the rate of fishing and making its season last as long as possible, the co-op concentrates effort among these efficient members to the greatest extent possible. Third, the co-op's public input provision satisfies

$$G'(x_J) F^{-1}(\beta) Z_J \le 1, \tag{5}$$

where $x_J \ge 0$ and (5) holds with equality if $x_J > 0$ .This is a Samuelson condition for optimal provision of a public good.

These results are summarized as

Proposition 1 The co-op's policy requires that:

(i) All active co-op members fish as close to port as possible;

(ii) Only members with low cost per unit effort (ϕ_i / γ_i) apply effort, these efficient members fish the entire time the season is open, and the season is open for $\bar{T}$ periods, the entire time the stock is available;

(iii) Provision of the public input equates the co-op's aggregate marginal benefit from provision to marginal cost, satisfying a Samuelson efficiency condition.

Proof: See text and the Appendix.

Stage 2 choices by independents

The independent fleet's catch per unit effort at any location *d* depends on the effort levels and locations of all independents. We denote catch per unit effort by $H\left(d;\, d_i, \gamma_i, T_i,\, i \in I, Z_I\right)$ and assume each independent takes it as given.[8] Independent *h*'s profit when the set *I* fishes independently is

$$\pi_h = H\left(d_h;\, d_i, \gamma_i, T_i,\, i \in I, Z_I\right)\gamma_h T_h - \left(\alpha - G\left(\textstyle\sum_{i \in I} x_i\right) + d_h\right)\gamma_h T_h - \phi_h T_h - x_h \,. \tag{6}$$

Independent *h*'s profit is linear in T_h and, by assumption, maximal profit is positive. Firm *h*'s maximal profit is therefore increasing in T_h, which implies $T_h = T_I$ for all $h \in I$.

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[3] The possibility of partitioning a stock in this fashion depends on the behavior of the target species. Assigning different season openings and closures may work for a migrating species; a spatial division may be appropriate for a sedentary species.

[4] This should be an assumption on the model's primitives.

[5] We assume all licensed fishermen could earn positive profit by fishing independently if no co-op were allowed. This is consistent with the presence of positive license values under purely independent fishing in the fishery we examine empirically.

[6] The assumption that any co-op member could have earned positive profit from fishing as an independent implies that the co-op's maximal profit is necessarily positive. By joining the co-op, each member avoids any cost associated with fishing outside and benefits from the public input.

[7] See the Appendix.

[8] The number of independents is assumed sufficiently large that each individual ignores the effect of his/her effort level on the group's catch per unit effort.

Independent h's optimal public input contribution satisfies

$$G'\left(\textstyle\sum_{i\in I} x_i\right)\gamma_h T_I \le 1, \qquad (7)$$

where $x_h \ge 0$ and (7) holds with strict equality if $x_h > 0$. The left-hand and right-hand sides of (7) are h's private marginal benefit and marginal cost for contributing. Let i^* be the independent with the highest γ among all independents; the private marginal benefit of contributing is greatest for this independent. Assuming individual fishermen's effort rates are distinct, if $G'(0)\gamma_{i^*}T_I > 1$ then this harvester and only this harvester will make a contribution; i^*'s contribution in this case will satisfy (7) with equality.[9] Alternatively, if $G'(0)\gamma_{i^*}T_I \le 1$ then each independent fisherman's optimal contribution is zero. In either case, it is clear (and unsurprising) that independents under-provide the public input.

The choice of fishing distance can be examined using the marginal and average catch-effort functions, $M(E,Z) \equiv \partial Q/\partial E = F'(E/Z)$ and $A(E,Z) \equiv Q/E = F(E/Z)/(E/Z)$. The shapes of theses functions, shown in Fig. 1, are determined by the monotonicity and concavity of $F(\cdot)$. To meet the catch target, the regulator fixes total independent effort according to (3), at a level denoted κ_I. If all independents fish at the same distance, all obtain the same *average* catch per unit effort, $A(\kappa_I)$, regardless of whether all fish inside or outside. Suppose independent h chooses to fish inside while all other independents fish outside. In this case h encounters the stock after other independents have fished and obtains the marginal (rather than average) catch per unit effort from κ_I units of effort, $M(\kappa_I)$. Alternatively, if h fished outside while all other independents fish inside, h's catch per unit effort would be $M(1)$ in Fig. 1, the marginal catch from the first unit of effort.[10]

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[9] Given that (9) is satisfied with equality for independent i^*, the inequality must be strict for all other independents, implying that their optimal contribution is zero. This is a standard free-rider equilibrium.

[10] Fisherman h's catch equals h's catch per unit effort times the effort h applies, $\gamma_h T_I$. Catches from the same location will therefore differ among fishermen in proportion to their γ parameters.

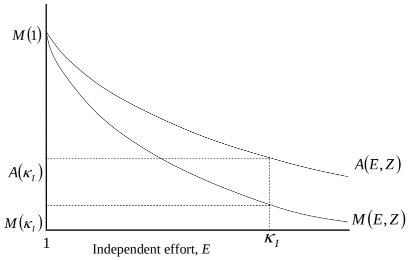

Fig. 1 Independent fisherman h's catch per unit effort, depending on where other independents fish

If all independents are fishing outside, any individual that deviates to the inside would find that cost per unit effort falls by $\bar{d}$, but catch per unit effort falls by $A(\kappa_I) - M(\kappa_I)$. If $A(\kappa_I) - M(\kappa_I) > \bar{d}$, which we refer to as Condition (i), then no independent will find it profitable to deviate inside.[11] If Condition (i) holds, which is more likely when $\bar{d}$ is small, a Nash equilibrium strategy profile in this subgame necessarily has all κ_I units of effort fishing outside. Suppose, instead, that all independents are fishing inside. In this case any individual who deviates outside will find that cost per unit effort increases by $\bar{d}$, but catch per unit effort increases by $M(1) - A(\kappa_I)$. If $M(1) - A(\kappa_I) < \bar{d}$, which we refer to as Condition (ii), then no independent will find it profitable to deviate outside. If Condition (ii) holds, which is more likely when $\bar{d}$ is larger, a Nash equilibrium strategy profile in this subgame necessarily has all κ_I units of effort fishing inside.

Finally, suppose $A(\kappa_I) - M(\kappa_I) \le \bar{d} \le M(1) - A(\kappa_I)$ so neither condition holds. The first inequality implies that if all independents fish outside a deviation inside is profitable, and the second inequality implies that if all independents fish inside a deviation outside is profitable. We illustrate this case in Fig. 2, with outside effort measured left to right on the horizontal axis. If all independents fished inside their profit per unit effort would be $A(\kappa_I)$, shown by point *a*; a deviation outside would increase profit per unit effort to $M(1) - \bar{d}$, which exceeds $A(\kappa_I)$. Alternatively, if all independents fished outside profit per unit effort would be $A(\kappa_I) - \bar{d}$, shown

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[11] The common cost term $\phi_h T_I$, which appears in both profit comparisons, has been ignored.

by point *b*; a deviation inside yield profit $M(\kappa_I)$, shown by point *c*, which is greater. Consequently, a Nash equilibrium strategy profile for the second stage subgame cannot have all effort fishing either inside or outside in this case. To characterize Nash equilibrium choices of distance, suppose all independent effort was initially fishing outside and successive units were transferred inside. This would cause profit per unit effort from fishing inside to increase from point *c* toward point *a*. One possible function that traces out the resulting profit to insiders is the dot-dash line labeled 'insider profit'.[12] If $\hat{E}$ units of effort fish outside and all others fish inside so all earn equal profit, no one has an incentive to deviate.[13] Accordingly, a Nash equilibrium strategy profile in this case is described by this division of inside and outside fishing.

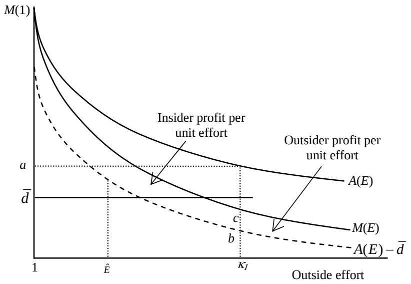

Fig. 2. Case 1: A strategy profile in which some independents fish outside while others fish inside is a NE.

We summarize these results as

Proposition 2 In the subgame involving the independent sector's choice of time spent fishing, public input contributions, and fishing locations, a Nash equilibrium strategy profile requires that:

(i) Each independent harvester fishes the entire time the regulator leaves the independents' season open;

(ii) The independent sector under-provides the public input relative to what is efficient;

(iii) All independents fish outside if $A(\kappa_I) - M(\kappa_I) > \bar{d}$, fish inside if $M(1) - A(\kappa_I) < \bar{d}$ and are split between fishing inside and fishing outside if $A(\kappa_I) - M(\kappa_I) \le \bar{d} \le M(1) - A(\kappa_I)$.

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[12] The properties of the dot-dash line need to be determined.

[13] Fig. 2 is drawn so these curves only cross once; we have not excluded the possibility that they cross more than once.

Proof: See Figs. 1, 2 and the preceding discussion.

We also note that the TAC constraint (3) and the regulator's stock assignment, $Z_I = Z\,n(I)/n(K)$, imply that the independent sector's season length equals

$$T_I = \frac{ZF^{-1}(\beta)/\,n(K)}{\sum_{i\in I}\gamma_i\,/\,n(I)} \qquad (8)$$

and is therefore inversely proportional to the group's average skill.

The Stage 1 decision of whether or not to join

We adopt the convention that fishermen are indexed in increasing order of their γ terms, so high skill fishermen have high index numbers. To obtain a clear identification on the attributes of co-op joiners, we assume that the ratio ϕ/γ and γ are inversely ordered. This will be true if the ϕ terms are constant, if ϕ and γ are inversely ordered, or the ϕ terms do not increase more than proportionately as γ increases.

We start by examining the second stage profit shares of successive co-ops in which new members are added in order of their γ parameters and demonstrate that larger co-ops (formed in this fashion) necessarily have higher profit per member. Writing out the co-op's profit share equation and incorporating its optimal policy choices and the regulator's TAC assignment yields

$$\pi_J(J) = \frac{Z}{n(K)}\left(\beta - \alpha F^{-1}(\beta)\right) + \frac{1}{n(J)}\left\{G(x_J^*)F^{-1}(\beta)\frac{Zn(J)}{n(K)} - x_J^*\right\} - \frac{1}{n(J)}\sum_{i\in J_{\min}}\phi_i\bar{T} \qquad (9)$$

where $J_{\min}$ indicates the set of co-op members selected to fish and x_J^* is the co-op's optimal public input level. The first term on the rhs is catch per member which, given the TAC allocation formula, does not depend on co-op size. The second term is the co-op's maximal net public good benefit per member. As shown in the Appendix, it necessarily is increasing in $n(J)$. The third term is the opportunity cost of time spent fishing divided by the number of co-op members; it decreases with co-op size for the following reason. If a new member is added the TAC allocation rule causes a proportionate increase in the co-op's effort, so effort per member remains unchanged. Consequently, the effect of a new member on the third term in (9) coincides with the new member's effect on the co-op's *average* time cost per unit effort. The new member's time cost per unit effort (ϕ/γ) is necessarily less than that of existing members. Therefore, the new member will be designated to fish and the co-op's average time cost per unit effort falls.

Taken together these results imply that co-op profit per member increases with co-op size, as illustrated by the upward sloping line $\pi_C(\gamma)$ in Fig. 3.[14] The positive co-op profit shown for the lowest skill level follows from the assumption that all fishermen could earn positive profit by fishing independently, plus the fact that (i) a one member co-op would receive its own TAC allocation and thereby avoid fishing outside and (ii) its allocation exceeds what the least skilled harvester would catch as an independent. This reasoning also implies that a 1 member co-op's profit exceeds what the same fisherman could earn by fishing independently with all other harvesters.

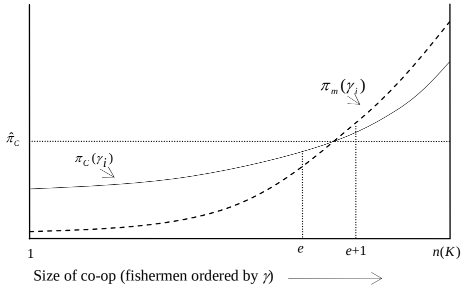

Fig. 3. Equilibrium co-op size

Next, we examine the profit of the marginal (least profitable) member in a sequence of independent fleets formed by successively adding lower skilled harvesters and demonstrate that the marginal independent's profit necessarily falls as the size of the independent fleet grows. To simplify, we assume the independent fleet's equilibrium public input provision is 0. We also make use of the convention $G(0)=0$ and the fact that catch per unit effort equals $\beta / F^{-1}(\beta)$ due to the TAC constraint. Incorporating these simplifications, independent harvester *h*'s profit in the case where all independents fish outside is

$$\pi_h(I)=\left\{\left(\frac{\beta}{F^{-1}(\beta)}-\alpha-\bar{d}\right)\gamma_h-\phi_h\right\}T_I,$$

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[14] This line is a smooth curve connecting a set of discrete points indicating the profit shares of co-ops of different sizes; another similar line follows shortly.

which can be written
$$\pi_h(I)=\left\{\left(\frac{\beta}{F^{-1}(\beta)}-\alpha-\bar{d}\right)-\frac{\phi_h}{\gamma_h}\right\}\gamma_h T_I. \tag{10}$$

Our earlier assumption implies that ϕ/γ falls as γ increases, so independents with higher skill parameters have higher profits. The marginal (least profitable) independent in any group is therefore the one with the lowest γ and forming a sequence of independent fleets by successively adding lower skill fishermen causes marginal profit to decline. The same conclusion applies in the case where all independents fish inside because *h*'s profit in this instance is found by replacing the constant $\bar{d}$ in (10) by zero. This result also extends to the case where some independents fish inside and others fish outside because equilibrium in the second stage requires that each independent earns the same profit per unit effort at either location. This implies that the inside vs. outside differential in catch per unit effort exactly matches the differential in cost per unit effort, $\bar{d}$, so once again independents with higher skill parameters have higher profits.[15]

The dashed line $\pi_m(\gamma_i)$ in Fig. 3 illustrates the marginal profit in a group of independent fishermen who have efficiency parameters greater than or equal to a given level γ_I. The left vertical intercept of $\pi_m(\gamma_i)$ lies below the $\pi_C(\gamma_i)$ intercept because, as explained earlier, a 1 member co-op's profit exceeds what the same fisherman could earn by fishing independently with all other harvesters. The right vertical intercept of $\pi_m(\gamma_i)$ is shown to lie above the corresponding intercept for the co-op, indicating that the highest skilled fisherman could earn more by fishing as a lone independent than by joining an all-inclusive co-op, but this is not the only possibility. If both conditions on intercepts are met then $\pi_m(\gamma_i)$ must cross $\pi_C(\gamma_i)$ from below at least once.

Such a crossing point identifies a threshold skill level that separates co-op joiners from independents. In Fig. 3 the threshold is index value *e*, referring to a fisherman with skill level γ_e. Since $\pi_m(\gamma_i)>\pi_C(\gamma_i)\forall i>e$, all those with skill greater than γ_e will fish independently; since $\pi_C(\gamma_i)\geq\pi_m(\gamma_i)\forall i\leq e$, all those with skill less than or equal to γ_e will join the co-op.[16] Since both conditions are satisfied, these choices are best responses at stage 1. This allocation of fishermen to groups, together with Nash equilibrium strategy profiles in stage 2, is therefore a

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[15] The $\beta/F^{-1}(\beta)-\alpha-\bar{d}$ term is replaced by one of two expressions in this case, depending on whether the individual involved fishes inside or outside, but these two expressions take on the same value.

[16] We assume a fisherman joins the co-op if profits from the two choices are equal.

subgame perfect Nash equilibrium. If $\pi_m(\gamma_i)$ lies entirely below $\pi_C(\gamma_i)$ the Nash equilibrium strategy profile calls for all fishermen to join the co-op. If the two curves cross more than once, there will be an equilibrium for each occasion where $\pi_m(\gamma_i)$ crosses $\pi_C(\gamma_i)$ from below. The generic Stage 1 prediction that high γ fishermen choose to fish independently is not surprising since, by definition, highliners compete most successfully in the race to fish and joining the co-op would necessitate sharing their catch proceeds with less skilled fishermen.[17]

Key results on the joining decision are summarized as

Proposition 3 Under our assumption on the relationship between effort rate and time cost parameters, a subgame perfect Nash equilibrium strategy profile has the following properties:

(i) The group choosing to fish independently consists of highliners; more precisely, all independents have skill levels greater than any co-op member;

(ii) The choices of distance, fishing time and public input contributions are described by Propositions 1 and 2.

4. Empirical Evidence

The preceding analysis develops several theoretical predictions regarding membership, efficiency, fishing location, and public goods provision in a self-selected cooperative and its independent counterpart fleet. The theoretical setup was motivated by a generally increasing trend toward allocation to sectors in many fisheries world-wide. As noted in the introduction, there is one commercially important fishery for which our theoretical model is nearly a perfect match.

From 2002-2004 the commercial sockeye salmon fishery in Chignik, Alaska, operated with a self-selected cooperative. This is one of Alaska's oldest limited entry fisheries, dating back to the 1880s. Typically about 100 purse seine permit holders had competed for a share of the fishery-wide catch limit prior to 2002.[18] In 2002 the Alaska Board of Fisheries approved a request by some permit holders to form annual cooperatives for voluntary joiners and this arrangement continued through 2004. In 2005, the Alaska Supreme Court shut down the co-op ruling that it violated an Alaska law prohibiting permit holders who did not actively fish from accruing profits.

The number of fishermen who joined ranged from 77 in 2002 and 2003 to 87 in 2004. Joiners were allocated a collective share of the total allowable catch for each year, and the co-op was free to choose as a collective how to harvest that share. The remaining share of the TAC was allocated to the independent sector for traditional, competitive harvest. Importantly, the co-op and independent fleets were usually assigned separate days for fishing and the season for each fleet ended when that sector's TAC expired.

Before proceeding to our empirical tests, three critical facts about the Chignik sockeye salmon fishery are worth highlighting:

Fact 1: Sockeye salmon migrate towards only one river in the Chignik system (Chignik R.), and are "funneled" toward that river as the migration extends from open ocean, through Chignik Bay, into Chignik Lagoon, and finally into Chignik River.

Fact 2: Fish processors have tremendous monopsony power in Chignik under traditional, non-cooperative fishing – with 100 fishermen, and only one or two processors; it is widely believed that processors extract most of the rents from negotiation. However, there is evidence of a potential premium for higher quality product.

Fact 3: There exists a significant variation in fishermens' skill levels (measured by share of catch history in recent years).

Fact 1 suggests that the incentives for a spatial race to fish "outside", rather than waiting until fish migrate to the more profitable location ("inside"), may be strong. Fact 2 implies that a coordinated body could possibly wield its own market power, and may be able to agree on standards to enhance quality – both of which may raise the co-op's output prices. Fact 3 indicates that there is potential for an interior solution where some individuals may select into the cooperative, while others might find it profitable to remain independent operators.

We have collected data from several sources to create a novel dataset on fishing behavior in Chignik and adjacent fisheries. We use these data to test our theoretical predictions, and to provide evidence of the magnitude of the effects. We begin with an assessment of the co-op's effect on the value of the fishery and proceed with more detailed tests of the theoretical model.

Value of the Fishery

The theory describes several mechanisms through which costs are reduced by cooperative fishing. This implies that cooperative fishing should have a positive effect on the bottom-line profitability of the Chignik fishery. Although we lack data on profits, we do have data on the value of fishing permits, which should capitalize expectations of increased profits.

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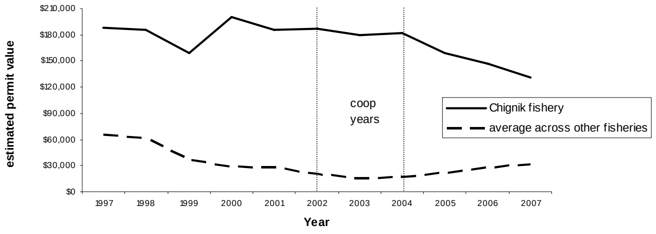
[17] We have not demonstrated that $\pi_m(\gamma_i)$ increases monotonically. As the independent fleet's average skill level increases the season length falls, which works against the profit increase resulting from higher skill.

[18] Purse seines are essentially large nets that cinch from the bottom to prevent schools of fish from escaping. The Appendix shows maps of the Chignik fishing area.

Figure 4 provides visual evidence suggesting the coop had a positive effect on Chignik permit values. We see that the average permit value across five adjacent purse seine salmon fisheries hit a low during the coop years but remained near their peak at Chignik.[19] Once the coop was shut down in 2005, permit values fell sharply at Chignik (from $182,000 in 2004 to $131,500 in 2007) despite increases in the average permit value across adjacent fisheries (from $16,640 in 2004 to $31,840 in 2007).

Figure 4
Permit Value in Alaska's Limited Entry Purse Seine Fisheries



The panel regression results in Column 1 of Table 1 indicate that the visual evidence in Figure 4 is robust to several controls. The panel regression employs 66 fishery-year observations – there are 11 years (1997-2007) and 6 fisheries. The regression controls for year and fishery fixed effects, and for the pounds of fish available for harvest for each observation. The result indicates that the co-op policy increased the value of a permit by $33,303. This is a 19.6 percent increase relative to $169,500, which was the mean value of a Chignik permit over 1997 to 2007 excluding the coop years. We now turn to more detailed tests of specifically how these efficiency gains were realized.

Table 1:
Panel Regression of the Proportion of Active Permits

Independent Variables	***(1)*** *Y = permit value*	***(2)*** *Y = proportion of permits fished*
Constant	74,902*	0.808*
Co-op Years	33,303*	-0.345*
t-statistic	(2.07)	(5.77)
robust t-statistic	(3.60)	(6.28)
lbs harvested (000s)	-0.012	-4.10e-07
	(0.10)	(0.11)
	(0.18)	(0.11)
Fixed Effects		
Year dummies	Included	Included
Fishery dummies	Included	Included
Observations	66	66
F-statistic	26.36	21.17
Adjusted R^2	0.903	0.882

Notes: (1) * Significant at 0.05 level for a one-tailed t-test (using uncorrected standard errors). (2) uncorrected t-stats are presented along with standard errors corrected for heteroskedasticity because the 'robust' standard errors may be biased in small samples. (3) Year dummies span 1997-2007. (4) Fishery dummies are included for Alaska Peninsula, Chignik, Cook Inlet, Kodiak, Prince William Sound, and Southeast. (5) Data are available at: http://www.cfec.state.ak.us/research/salmon/salpmt97_06.pdf and http://www.cfec.state.ak.us/research/salmon/salpmt98_07.pdf.

Allocation of Fishing Effort

Perhaps the most compelling reason for forming a cooperative in Chignik is to coordinate on harvest, and thus execute the cooperative's allocation much more efficiently. Our model indicates that this would naturally imply a consolidation (and reduction) in fishing effort, even though it requires no reduction in yield (Prop.1.ii). Thus, we would expect to observe a decline in the proportion of active (i.e. fished) permits during the cooperative years.

Figure 5 provides strong visual evidence that the proportion of active permits in Chignik declined dramatically during the co-op years relative to the mean proportion of permits fished across five adjacent purse seine fisheries. As the figure shows, the proportion of the 100 permits that were actively fished in Chignik fell from 0.94 in 2001 to 0.41 in 2002 when the co-op was first allowed to form. The proportion of permits fished increased again after the co-op was effectively dissolved in 2005.

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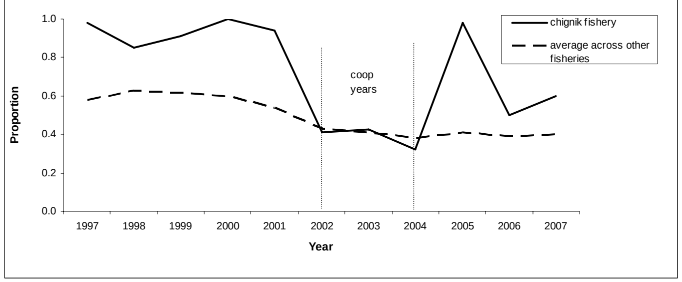
[19] The adjacent fisheries are Alaska Peninsula, Cook Inlet, Kodiak, Prince William Sound, and Southeast Alaska.

Figure 5
Proportion of Permits Fished in Alaska's Purse Seine Fisheries



The panel regression results in Column 2 of Table 1 indicate that the visual evidence is Figure 5 is robust to several controls. The result indicates that the co-op policy reduced the proportion of permits fished by nearly 0.35. This economically and statistically significant finding is consistent with the proposition that the co-op will consolidate effort among a subset of its members.

Moreover, annual Chignik Area management reports indicate that the fishery-wide drop in the proportion of permits fished was almost entirely caused by consolidation within the co-op. These reports show that the proportion of co-op permits that were actively fished during 2002-2004 ranged from approximately 0.25 to 0.28. In contrast, the proportion of independent permits that were actively fished ranged from 0.92 to 1.0 during 2002-2004.

Our theoretical model suggests that the co-op can significantly reduce costs by coordinating on the *location* of harvest. Because the co-op secures a guaranteed allocation of catch, our theory predicts that member fishermen will agree to wait until fish swim "inside," at which time harvest will be more efficiently executed (Prop. 1.i). In contrast, some or all of the independent sector's harvest may take place 'outside' (Prop. 2.iii).

We use data on the spatial location of catch to test these propositions in two different ways. Ideally we would have data on the exact distance from harbor where harvest took place. These data are not available but we are able to identify the proportion of catch caught in Chignik Lagoon, which is a coarse measure of 'inside' catch (see Fig. A2). We use fishery-wide annual time-series data to see how the proportion of sockeye caught 'inside' deviated during 2002-2004 from longer annual time trends. We use within-fishery cross-section data to assess how the proportion of 'inside' catch differed between the co-op and the independent fleet during 2002-2004.

The time-series regression model in Column 1 of Table 2 uses annual data for 1970-2007. It accounts for the cyclical nature of the time-series data by including a high-order polynomial time trend (a 4th order polynomial). The model also controls for a 4th order polynomial in annual variation in harvest. As the results indicate, a policy of allowing the self-selected cooperative appears to have increased the proportion caught inside by 0.27, which may imply significant savings in transportation costs. Note that this is a lower-bound estimate of the effect of the co-op on fishing location because some fishermen remained independent during 2002-2004.

Table 2:
Time-Series Regression Analysis of Inside Catch and Season Length

Independent variables	***(1)*** ***Y = proportion of catch from inside***	***(2)*** ***Y = number of days fished***
Constant	0.773*	471.13
Co-op Years	0.267*	32.16*
t-statistic	(3.48)	(3.66)
robust t-statistic	(5.04)	(3.52)
lbs harvested	4.63e-07	0.0004
lbs harvested^2	-1.66e-07	-3.14e-10
lbs harvested^3	-4.69e-20	1.02e-16
lbs harvested^4	-2.07e-07	-1.17e-23
Year	0.039	-106.93*
Year^2	-0.004	7.107*
Year^3	0.0008	0.021*
Year^4	-2.07e-07	0.0004
Observations	38	26
F-statistic	6.14	1.987
Adjusted R^2	0.664	0.528

Notes: (1) * Significant at 0.05 level for a one-tailed t-test (using uncorrected standard errors). (2) uncorrected t-stats are presented along with standard errors corrected for heteroskedasticity because the 'robust' standard errors may be biased in small samples. (3) The data used here come from Chignik area annual management reports. Column 1uses available data for 1970-2007. Column 2 uses available data for 1980-2006. We lack data on season length prior to 1980 and the 2007 data are not yet published.

Table 3 presents additional evidence of the co-op's effect on inside catch by contrasting the co-op and independent fleet's behavior within 2002-2004. As the table indicates, the co-op harvested its entire allocation inside Chignik Lagoon as predicted by the theoretical model. By comparison, the independent fleet harvested from both inside and outside in 2002 and 2003, which is consistent with the theoretical possibility of a mixed equilibrium. During 2004, when there were only 13 independents, all harvest took place inside the lagoon.

Table 3
Proportion of Sockeye Caught Inside by Co-op and Independent Fleets
(on days reserved exclusively for one of the two fleets)

	Cooperative fleet	Independent fleet
2002		
Number of sockeye harvested	576,757	162,979
Proportion caught inside	1.00	0.82
2003		
Number of sockeye harvested	757,974	334,330
Proportion caught inside	1.00	0.79
2004		
Number of sockeye harvested	541,400	61,446
Proportion caught inside	1.00	1.00

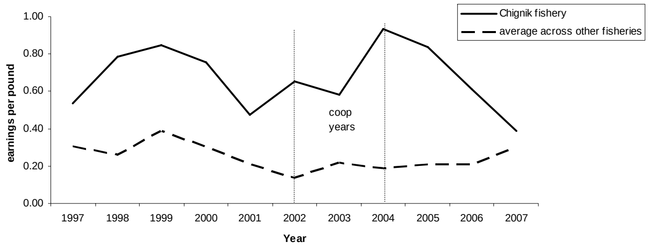
The theoretical model also provides predictions about the season duration. Prop.1.ii indicates that the cooperative's allocation will be harvested by a subset of the most efficient harvesters within the coop. The *number* of co-op members who actually fish is chosen with the goal of slowing the rate of fishing, thereby lengthening the season until it extends for the entire time the fish are available to be caught. This strategy allows the co-op to make maximal use of its most efficient members. By contrast, independent harvesters are predicted to fish aggressively, causing the regulator to shorten the season in order to meet the TAC (or escapement) target.

As before, we test the theoretical implications for season length against time-series data. Column 2 of Table 2 employs annual data from 1980-2006 on the total number of days spent fishing at Chignik. The regression estimates indicate that the average effect of the co-op policy was to lengthen the season at Chignik by 32 days.

To summarize, the available data are consistent with theoretical predictions concerning how behavior will change when a voluntary co-op is formed. Panel data indicate that the co-op policy caused a nearly 20 percent increase in the value of permits and a sharp decline in the number of permits fished. Time-series and cross-section data indicate that the co-op kept its fleet closer to port and that it extended fishing season length.

Although the theory indicates the co-op policy will increase economic profits by lowering harvest costs, the policy could also generate an output price premium through higher-quality fish due to better handling by the co-op. Figure 6 provides some visual evidence that 2002-2004 output prices at Chignik increased relative to the average price received at five adjacent fisheries. Table 4 complements the visual evidence with a panel-regression model using the same controls as Table 1. The results here suggest that the co-op policy caused an increase of 0.17 per pound at the Chignik fishery. Note that this price effect could result from either improved product quality, or from increased bargaining power with processors. In either case, the $0.17 effect is a lower-bound estimate because nearly one-third of the sockeye caught at Chignik were harvested by the independent sector during 2002-2004.[20]

Figure 6
Gross Earnings per Pound for Alaska's Limited Entry Purse Seine Fisheries



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[20] We lack cross-section data during 2002-2004 that would allow us to compare output prices between the co-op and independent sector.

Table 4:
Panel Regression of Gross Earnings Per Pound

Independent Variables	*Y = gross earnings per pound*
Constant	0.424*
Co-op Years	0.167*
t-statistic	(2.32)
robust t-statistic	(1.57)
lbs harvested (000s)	-1.01e-06
	(2.36)*
Fixed Effects	
Year dummies	Included
Fishery dummies	Included
Observations	66
F-statistic	13.05
Adjusted R^2	0.846

Notes: (1) * Significant at 0.05 level for a one-tailed t-test (using uncorrected standard errors). (2) uncorrected t-stats are presented along with standard errors corrected for heteroskedasticity because the 'robust' standard errors may be biased in small samples. (3) Year dummies span 1997-2007. (4) Fishery dummies are included for Alaska Peninsula, Chignik, Cook Inlet, Kodiak, Prince William Sound, and Southeast. (5). The data are available at: http://www.cfec.state.ak.us/research/salmon/salpmt97_06.pdf and http://www.cfec.state.ak.us/research/salmon/salpmt98_07.pdf.

Who Joins and Who Fishes for the Co-op?

We now turn to two questions central to our analysis. Who joins the self-selected cooperative? Who fishes on behalf of the Co-op? The theoretical model predicts that highliners will remain independent while less-skilled fishermen will opt into the co-op (Prop.3.i). The model also predicts that the co-op will deploy its highest skilled members to fish on behalf of the entire enterprise (Prop.1.ii).

Our model suggests that historic catch is a good proxy for the critical skill parameter, γ, so we test these predictions with data on past catch. Ideally we would like to have data on the past sockeye catch share of each individual Chignik permit holder for some time period prior to 2002 so that we could assess how prior relative success affected the choice to join and the co-op's choice of who to deploy on behalf of the enterprise. Unfortunately, the catch shares of individual harvesters are not disclosed due Alaska confidentiality laws.

We proceed with our analysis of who joins and who fishes for the co-op using summary data on catch share that were ranked and clustered for us in the following way by the Alaska Commercial Fisheries Entry Commission (ACFEC). First, ACFEC separated fishermen into co-op joiners who fished, joiners who did not fish, and independents for each year during 2002-2004. Second, the fishermen within each category were ranked by average sockeye catch share over the 1995-2001 period.[21] Third, the ranked fishermen were clustered into groups of three fishermen in order to meet Alaska disclosure laws.[22] Fourth, the average catch share within each cluster was reported to us.

Table 5 uses the clustered data to provide initial evidence in support of our theoretical propositions. Here we see the mean 1995-2001 catch share for fishermen who remained independents exceeded that of co-op joiners (1.29 percent compared to 1.00 percent). The table also indicates that the mean catch share of those who fished for the co-op exceeded the mean for 'inactive' co-op members (1.11 percent compared to 0.90 percent).

Table 5:
Comparison of Mean Catch Histories for Ranked and Sorted Clusters of Fishermen

	# of Obs.	*Mean Catch Share*	*t-stat for diff. (abs. value)*
Independents v. All Joiners			
Independents	18	1.29	2.90*
All Co-op Members	78	1.00	
Coop Fishermen vs. non-Fishermen			
Co-op Members who Fished	18	1.11	1.83*
Co-op Members who did not Fish	59	0.90	

Notes: * statistically significant at 0.05 level for a one-tailed test. The data used here are pooled for 2002-2004.

A more robust statistical approach is to test for first-order stochastic dominance. We do so here by (a) comparing the distribution of independents' catch share against that of the co-ops, and (b) comparing the distribution of the active co-op members' catch share against that of the non-active co-op members. Figures 7a and 7b plot the harvest share cumulative density functions for joiners and independents, using the ranked and clustered data just described. Visually, the empirical distributions of catch shares for both comparisons conform to our hypothesis of stochastic dominance with a minor exception near the peak of the CDF in Figure 7b. Moreover,

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[21] We do not consider more distant catch histories because vessel attributes and skill levels can change over time; we do not consider other salmon species because the co-op fished exclusively for sockeye.

[22] Occasionally the clusters contain four fishermen when the number of fishermen in a group is not divisible by three.

Kolmogorov-Smirnov tests confirm that the differences in the CDFs are statistically significant by conventional standards.[23]

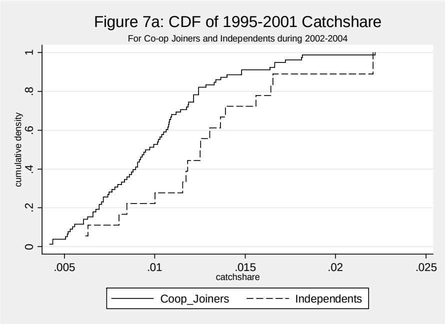
Figure 7a: CDF of 1995-2001 Catchshare

For Co-op Joiners and Independents during 2002-2004

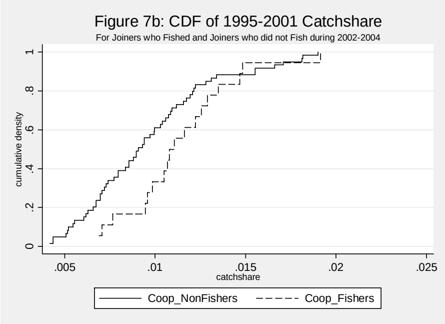
Figure 7b: CDF of 1995-2001 Catchshare

For Joiners who Fished and Joiners who did not Fish during 2002-2004

To summarize, two pieces of evidence from the available data are consistent with some central hypotheses of our theoretical model. First, we find that the highest-skilled fishermen, as measured by 1995-2001 catch shares, tended to remain independent. Second, we find that, within the group of co-op joiners, the highest-skilled fishermen tended to harvest on behalf of the enterprise.

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[23] The test results are available from the authors.

Public Good Provision

Our evidence on public good provision by the co-op is anecdotal. As described in the annual management report (Stichert, 2007), the co-op enhanced harvest efficiency by installing fixed leads, stationary nets placed along the major migration route that funneled the migrating stock toward a point where purse seiners were waiting. This sort of shared infrastructure was not employed by the independent fleet.

Other types of public good provision generally took the form of very precise coordination of members' actions. According to the annual management report (Stichert, 2007), the co-op managed the temporal allocation of its members effort at a very fine scale. During low tides Chignik Lagoon, the area in which the co-op carried out its harvests, shrinks to a fraction of its size at high water. The co-op often timed its harvest activities to coincide with low tides, thereby concentrating the fish to much greater extent than would occur naturally. In order to concentrate its allowed catch during low tides, the co-op allowed fish to escape up river on high tides during periods the co-op was allowed to fish. There is no evidence that the independent fleet engaged in this type of coordination. To improve product quality the co-op received permits to hold live fish in net pens for up to three days to better match deliveries to processing capacity. On occasion, the co-op even released live fish from capture when processing capacity was insufficient.[24] Independent harvesters have no incentive to engage in such practices and we are aware of no evidence indicating that they did.[25]

Finally, the co-op coordinated information on stock locations from all of its active members and used this information to dispatch vessels and crews to the most advantageous locations. We are aware of no evidence that the independent fleet followed this practice; indeed, fishermen are notorious for hiding such information from their competitors.

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[24] The preceding two examples are from: Mark A. Stichert, *2004 Chignik Management Area Annual Management Report*. Alaska Department of Fish and Game, at: http://www.sf.adfg.state.ak.us/FedAidPDFs/fmr07-15.pdf. (2007)

[25] An additional coordination benefit was realized by fishery managers. an ability to precisely control a day's catch in a way that cannot be accomplished with independent fishing. With independent fishing the fishery manager must forecast the rate of catch and announce a closing time calculated to meet the escapement target, an imprecise process at best. On days the co-op fished, the manager could hit the escapement target precisely, simply by requesting that the co-op cease fishing when the desired number of fish was caught (Pappas and Clark, 2003).

5. Discussion and Conclusions

Our model indicates that an association of harvesters that can coordinate the activities of its members can achieve significant gains, relative to what a traditional policy of licenses and season closures can achieve. These gains arise from elimination of redundant fishing units, better spatial allocation of effort, and provision of public inputs including shared infrastructure, shared information and precise coordination of effort across time and space. Our evidence from the Chignik salmon cooperative provides empirical verification that a profit maximizing association will indeed carry out such actions and indicates the magnitudes of the gains. An ITQ policy, though clearly superior to licenses and season closures, does not obviously instill incentives to capture all of these gains, particularly those arising from coordination. An ITQ regime does not assign rights to harvest fish at precise times and places. If the stock varies in unit value depending on its location and the time of the season, the individual quota holder will deploy gear at a time and place that gives an advantage over other quota holders in the competition to capture the best fish. Defining spatially and temporally delineated harvest rights could in principle solve this problem, but there are obvious practical obstacles to doing so. Moreover, spatially and temporally delineated ITQ rights would not encourage cooperation in the provision of shared inputs.

We focused on a cooperative association that shares profits, but other organizational forms clearly are possible. Non-voluntary associations, mandated by government may have advantages in that they avoid the self-selection of membership. However, any attempt to force individual fishermen to deploy gear at specific times and places, under the direction of government, would surely be fought politically or in the courts. For this reason, voluntary associations are of practical interest. Fortunately, it appears from the Chignik case that voluntary associations can achieve significant gains.

While our analysis indicates that allowing a voluntary co-op to form can lead to overall cost reductions, we make no claim that all individuals in the fishery will be made better off in the process. Some of the highliners who would opt to fish independently when a co-op is allowed may reason that their catch shares would be higher if the relatively low skilled co-op joiners were not assigned a dedicated share of the allowed catch. In the Chignik case, the filing and eventual success of a legal claim opposing the new institution suggests that this can happen.

Michael Grunert and Dean Anderson, two of the higher skilled Chignik fishermen, opted into the independent fleet and filed a court complaint against the state challenging the validity of the new management regime. The plaintiffs initially lost the case but appealed the ruling, arguing, among other things, that the Board of Fisheries exceeded its statutory mandate in promulgating the co-op for the purpose of increased economic efficiency. While the Supreme Court affirmed that efficiency is a legitimate management goal, it found that implementation of the new policy contradicted aspects of the Limited Entry Act (of 1974), because the Act requires “present active participation” by all who gain economically from holding a permit. The co-op’s practice of assigning active fishing responsibilities to only a fraction of its membership violated this condition. Because this practice was a major source of efficiency gains for the co-op, this prohibition eliminated the co-op’s viability. Accordingly, our analysis and the eventual fate of the co-op vividly demonstrate an obvious point—that the ultimate success of allowing voluntary associations can hinge on the way TAC shares are assigned.

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Appendix

A.1 Co-op's optimal policy

The co-op's optimal allocation minimizes

$$\min_{d_i, T_i\ i \in J;\ x_J} F^{-1}(\beta) Z_J \alpha + F^{-1}(\beta) Z_J \sum_{i \in J} d_i - \left\{ F^{-1}(\beta) Z_J G(x_J) - x_J \right\} + \sum_{i \in J} \phi_i T_i \qquad \text{(A.1)}$$

subject to $\sum_{i \in J} \gamma_i T_i = F^{-1}(\beta) Z_J$, $d_i \in \left\{0, \bar{d}\right\}$, $T_i \in \left[0, T_J\right]$ for all *i*, and $T_J \leq \bar{T}$. Since (A.1) is strictly increasing in d_i the optimal policy sets $d_i = 0$ for each member. The term in brackets is the net benefit that the public input provides. Given assumed properties of $G(x_J)$ the following first-order condition is necessary and sufficient for minimizing (A.1) with respect to x_J :

$$F^{-1}(\beta) Z_J G'(x_J) - 1 = 0 \,. \qquad \text{(A.2)}$$

This is the Samuelson condition for efficient public input provision.

It remains to find an assignment of member fishing times that minimizes the fourth term in (A.1), subject to the catch constraint. Index co-op members in increasing order of the ratio $\frac{\phi_i}{\gamma_i}$. Since ϕ_i and γ_i are *i*'s cost per unit time and effort per unit time respectively, this ratio is *i*'s cost per unit effort. Consider a policy that assigns fishing time $\bar{T}$ to successive co-op members, in order of their index, until the constraint (6) is violated or satisfied with equality. If (6) is violated, let $\hat{i}$ indicate the highest indexed member in this low indexed subset and assign this member a fishing time that satisfies (6) exactly; all higher indexed members are assigned zero fishing time. This assignment satisfies the catch constraint by construction. To see that this assignment is cost minimizing, write the fourth term in (A.1) as $\sum_{i \in J} \frac{\phi_i}{\gamma_i} \gamma_i T_i$. The term $\gamma_i T_i$ is the fishing effort assigned to *i* and the ratio is *i*'s cost per unit effort. Any alternative assignment would require reducing $\gamma_i T_i$ by a lower indexed member and increasing $\gamma_i T_i$ in the same amount by a higher indexed member. Since the index orders members in terms of the ratio, this alternative assignment would necessarily result in higher total cost. Therefore this assignment of fishing times is optimal.

A.2 Public input benefit per member increases with co-op size

The public input confers a net benefit, per co-op member, of

$$NB\big(n(J)\big) = \frac{1}{n(J)} \left\{ F^{-1}(\beta) Z \frac{n(J)}{n(K)} G(x_J) - x_J \right\}. \qquad \text{(A.3)}$$

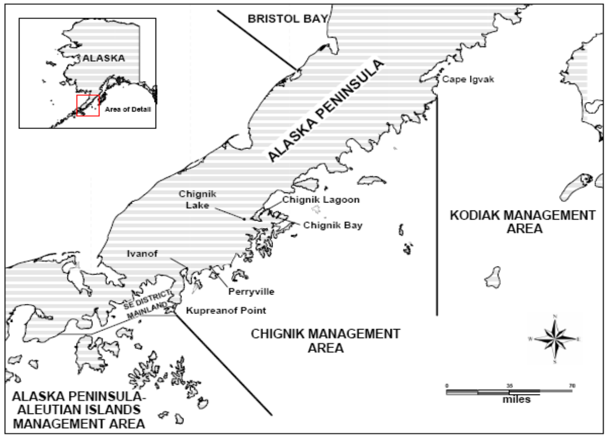
Differentiating this with respect to $n(J)$ yields

$$\begin{aligned} \frac{\partial NB\big(n(J)\big)}{\partial n(J)} = \frac{1}{n(J)} &\left\{ F^{-1}(\beta) \frac{Z}{n(K)} - \left(F^{-1}(\beta) Z \frac{n(J)}{n(K)} G'(x_J) - 1 \right) \frac{\partial x_J}{\partial n(J)} \right\} \\ &- \left\{ F^{-1}(\beta) Z \frac{n(J)}{n(K)} G(x_J) - x_J \right\} \frac{1}{n(J)^2} \end{aligned} \qquad \text{(A.4)}$$

Making use of the first-order condition (A.2) and simplifying, the becomes

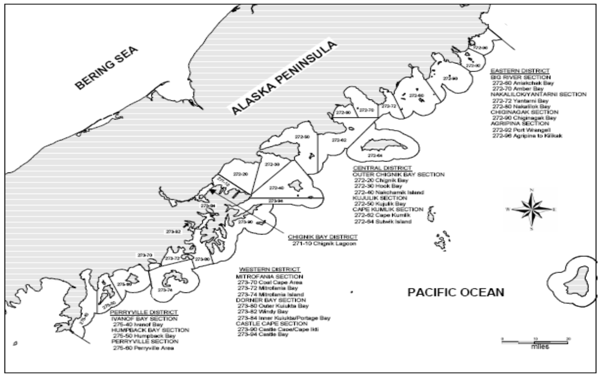
$$\frac{\partial NB\big(n(J)\big)}{\partial n(J)} = \frac{x_J}{n(J)^2} > 0 \,. \qquad \text{(A.5)}$$

Fig. A1
Map of Chignik Management Area on the Alaskan Peninsula



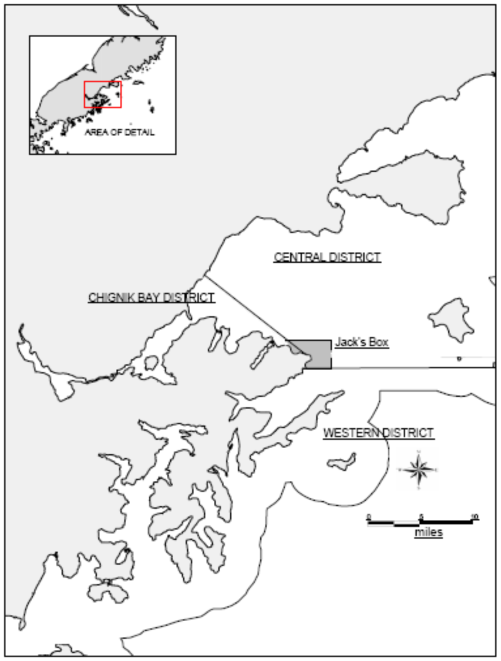
Source: Stichert (2007).

Fig. A2
Chignik Management Area with District Boundaries and Statistical Areas



Source: Stichert (2007).

Fig. A3
Map of Chignik Bay and Near Vicinities



Source: Stichert (2007).