

The Efficiency Gains from Coordinating Use of a Shared Resource:
Evidence from a Self-Selected Fishery Coop

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Abstract

We analyze a seldom used, but highly promising form of property rights-based management over shared natural resources. In the case we study the regulator of a fishery assigns one portion of an overall catch quota to a voluntary cooperative of heterogeneous fishermen, with the remainder exploited competitively under the original management regime by those choosing to fish independently. Data from an Alaska commercial salmon fishery confirm our model's key predictions, that the coop would facilitate the consolidation of fishing effort, coordination of harvest activities, sharing of information and provision of shared infrastructure. We estimate that the resulting rent gains were at least 33%. A lawsuit filed by two disgruntled independents led to the coop's demise, an outcome also predicted by our model. Our analysis provides guidance for designing fishery reform that leads to Pareto improvements for fishermen of all skill levels, which suggests a structure that enables reform without losers.

JEL classifications: Q22, D23, L23

1. Introduction

It is widely accepted that the design of property rights plays a key role in determining the value of natural resource stocks.¹ On one end of the property-rights spectrum is 'open access', the regime under which complete dissipation of the stock's value may ensue. On the other end lies 'sole ownership' which provides ideal conditions for maximizing the stock's value. Most of the world's natural resources are governed by property rights regimes that lie between these extremes.

In the modern regulatory state, with its emphasis on resource management by regulatory agencies, the predominant property rights regime for fisheries is limited entry. Limited entry,

¹ Two seminal contributions are Gordon (1954) and Scott (1955).

which is pervasive in the U.S., Canada, and Europe, caps the number of individuals permitted to fish but fails to assign property rights to the stock. In this system fishermen compete for an administratively determined fishery-wide quota or total allowable catch (TAC). Typically, permit holders are constrained by rules on open seasons, gear types and areas fished. Although the cap on licenses can keep fishermen profits above the open access zero-profit equilibrium, permit holders nevertheless have strong incentives to invest in socially wasteful racing capital.² These investments shorten fishing seasons, raise costs and impair the quality and timeliness of harvests relative to what single ownership would induce.

The recent literature on fishery regulation has sought to reform limited entry rights, with the goal of engendering incentives that resemble what a sole owner would face while recognizing that sole ownership is seldom a practical option in the modern regulatory state. Adoption of individual tradable quotas (ITQs), which assign each permit holder a secure share of a fishery's annual TAC, is the reform most commonly advocated by economists. Where ITQs have been adopted, e.g., in Iceland, New Zealand, Canada and the U.S., the race to fish has moderated and rents have increased. Yet despite these economic successes, as well as clear evidence that ITQ management can facilitate the recovery of 'collapsed' fish stocks, less than two percent of the world's fisheries use systems that assign quantitative catch rights to harvesters.³ Apparently, implementation of property rights in fisheries and in other mobile natural resources has been hindered by the transactions costs and political obstacles involved in shifting away from an existing regulatory regime.⁴ In the fishery, individuals who are well-suited to competing under an existing regime have incentives to block the transition.⁵

We examine an alternative path for fishery reform that can diminish this incentive to block and at the same time engender incentives that closely resemble what a single firm or 'sole owner' would face. This alternative system assigns a secure portion of the aggregate catch to a

² The 'race' and its consequences have been extensively documented in the literature; see Wilen (2005).

³ For recent empirical evidence on economic successes, see (Grafton et al. 2000, Hannesson 2004, Leal 2002, Linn et. al. 2008, Newell et. al. 2005). Costello, *et al.* (2008) present evidence on the reduced probability of collapse for stocks under 'catch share' management regimes, systems that grant some form of quantitative catch rights to harvesters, of which ITQ systems are one variant. The collapse of fisheries is documented in several studies (see, Halpern et al. 2008; Myers and Worm, 2003; Jackson et al., 2001); Worm et al. 2006). While pollution, climate change, and habitat damage can play important roles, ineffective management strategies are widely believed to be the root cause (Beddington et al. 2007; Hilborn et al 2005, Wilen 2005).

⁴ Libecap and Wiggins (1984) and Wiggins and Libecap (1985) show that rights-based approaches to managing common oil reservoirs also suffer from scant implementation due to transactions costs.

⁵ See Libecap (2008). Obstacles include contention over the initial allocation of quota among fishermen, and fish processor and local community objections to institutional change. Compounding the problem, inefficient fishery regulation can induce excessive investment in vessels and processing plants. Owners of this capital have incentives to resist regulatory change that would eliminate or impair its value.

cooperative group of harvesters, formed voluntarily, to manage as the group decides. Those choosing not to join continue to fish independently under the prior regime and are permitted access to the remainder of the aggregate catch. Under conditions we spell out, the transition from limited entry to this alternative regime can be Pareto improving, eliminating opposition to the change.⁶

To fully capture the efficiencies from coordinating input use, the entity that receives the catch allocation must be empowered to manage its members' fishing effort in a unified way, i.e., it must be structured as a Coasian firm. As Coase (1937) pointed out, managing inputs centrally via contracts with a manager rather than across markets allows an enterprise with this structure to capture gains from coordination without incurring excessive transactions costs.⁷ Reasoning developed in Alchian and Demsetz (1972) and Scott (2000) indicates that coordination gains are likely to be important in a fishery because the 'production process' requires that several inputs (individual harvesters) coordinate in the shared use a single input (the fish stock). As Costello and Deacon (2007) demonstrate, ITQ management will not accomplish the coordination needed to optimize the spatial and temporal deployment of fishing effort across an entire fleet.

We contribute to the literature on property-rights reforms by developing a model of this alternative regime and testing its implications with available data. Our analysis is motivated by the formation of a unique salmon harvesting cooperative that operated in Chignik, Alaska during 2002-2004. The original management structure at Chignik was limited entry and the key policy innovation was to assign a secure portion of the allowed catch to a single entity, the Chignik Coop, to manage as it saw fit. The coop was contractually empowered to manage the fishing effort of its members and to claim the resulting profit. Because this is the same contract and incentive structure observed in a firm, we model the coop as a profit maximizing firm constrained only by a limit on its allowed catch. Fishing with the coop was voluntary, however, and permit holders who opted out were free to fish competitively under the pre-existing rules. The regulator accommodated the two sectors by announcing separate fishing times for each. We use this rare circumstance, with the two fishing sectors operating in tandem, to observe the coordination the coop practiced and to measure the resulting efficiency gains of this firm-like structure. To set the stage, we first place the Chignik experiment in the progression of fishery management institutions and examine how and why this singular institution arose where and when it did. The next section

⁶ The result is 'reform without losers' in the sense of Lau, *et al* (2000) who argue that designing reform to be Pareto improving can minimize political opposition. Participants may still resist change, however, as part of a strategy to obtain a larger share of the gains from reform.

⁷ In fact, Coase (1937) refers to the firm's manager as an 'entrepreneur-coordinator'.

also sets the stage for our analysis of the demise of the co-op in 2005, a result of a lawsuit filed by permit holders who had competed successfully under the pre-existing regime.

2. Historical Context

Alaska Commercial Salmon Regulations

Commercial salmon fishing began in Alaska during the 1870s and was unregulated until 1924 when the White Act imposed catch limits linked to spawning goals.⁸ During the latter part of this unregulated phase most of the catch was taken by large stationary fish traps. When Alaska gained statehood in 1959 it immediately banned stationary fish traps despite their acknowledged efficiency, causing employment in the fishery to swell by 6,000 entrants and rents to fall.⁹ The resulting regime was essentially open access, but with a limitation on the gear allowed.

In 1973 Alaska adopted the limited entry system that is still used today in most of Alaska's fisheries. Under limited entry, the number of licenses is fixed and individual license holders compete for a fishery-wide catch limit set by regulators. A political motive for fixing the number of licenses was to prevent entry by fishermen from Washington State and elsewhere, where fishing opportunities were being eroded by court decisions and declining stocks.¹⁰ Alaskan limited entry licenses are transferrable and positive license prices indicate that rents were generated. Fish ownership was still governed by the rule of capture, however, encouraging fishermen to compete in an inefficient race to harvest a share of the allowed catch before competitors. It is well established that these racing behaviors dissipate rents.¹¹

Although ITQs are now used in several important Alaskan fisheries, they have not been implemented for salmon either in Alaska or to our knowledge elsewhere. This dearth of implementation arguably has several causes. Presumably, the political obstacles that have so severely limited ITQ implementation elsewhere have worked to hinder implementation for salmon as well. Further, due to the migratory nature of salmon and the pulse nature of salmon runs, complete rent capture requires extensive coordination on the spatial and temporal deployment of effort and on public input provision. Our model outlines this argument in more detail. ITQs alone fail to accomplish these tasks, and thus will forego these potential gains unless

⁸ See Colt (1999) and Crutchfield and Pontecorvo (1969).

⁹ According to Colt (1999), the rent reduction was equivalent to 12% of the exvessel price.

¹⁰ For example, the 1974 court decision in *U.S. vs. Washington* 1974 decreased by 50 percent the salmon allocation to fishermen who weren't members of Native American tribes (Nickerson *et. al*, 2010).

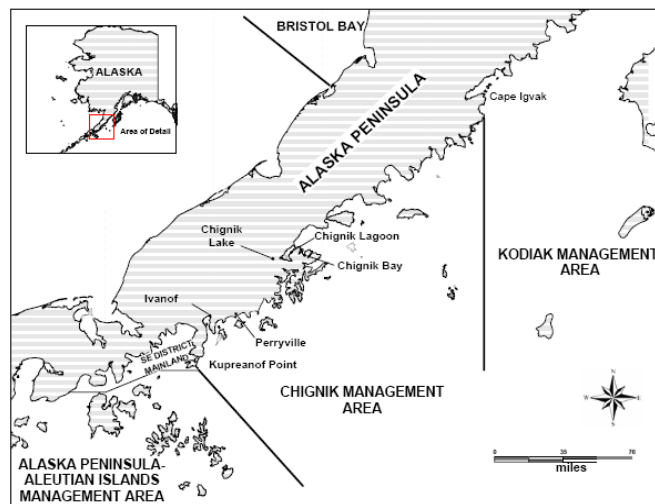
¹¹ Wilen (2005).

individual quota owners can collectively agree to coordinate their actions (Costello and Deacon 2007).¹²

The Rise and Fall of the Chignik Cooperative

Chignik (see Fig. 1) is one of Alaska's oldest and most important commercial salmon fisheries. The gear used is the purse seine, a large net deployed in the water like a curtain and then cinched from the bottom to prevent fish from escaping when the net is hauled.

Fig. 1. Chignik Management Area on the Alaskan Peninsula

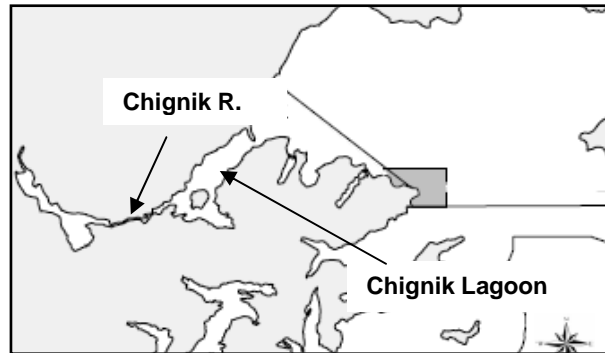


Source: Stichert (2007).

Sockeye salmon migrate towards only one river in the Chignik system, Chignik River, and are “funneled” into relatively dense concentrations as the migration proceeds from open ocean, through Chignik Bay, into Chignik Lagoon, and finally into Chignik River (see Fig. 2). Processing facilities are located and purse seine vessels are moored near the final destination.

¹² Other authors have identified potential efficiency advantages for user-based organizations that coordinate the activities of individual members. Scott (1993, 2000), for example, relies on this basic reasoning in arguing that fishery governance by harvester-based organizations represents a logical next step—beyond ITQ regulation—in the development of fishery management. Sullivan (2000) discusses transaction-cost and enforcement advantages that harvester cooperatives may have over ITQ policies, but concludes that harvester co-ops may be less durable than ITQ systems because they exist at the pleasure of their members.

Fig. 2. Chignik Lagoon and Near Vicinities



Source: Stichert (2007).

In 2002 the Alaska Board of Fisheries approved a request by a group of Chignik permit holders to form annual cooperatives for voluntary joiners; this arrangement continued through 2004. The number of fishermen who joined ranged from 77 in 2002 and 2003 to 87 in 2004, with the total number of permits equaling 100 throughout the period. Each year the co-op was allocated a share of the total allowable catch (TAC) to harvest as it saw fit, with the remainder designated for traditional, competitive harvest by the independent sector. The two sectors fished at different times, determined by the regulator, and each sector's season was closed when its TAC share was reached. The co-op's TAC share in a given year was determined by the following rule: (i) if less than 85 percent of permit holders joined, the co-op received an allocation equal to nine-tenths of a per capita share for each joiner; and (ii) if 85 percent or more of permit holders joined, the co-op received a full per capita share for each joiner.

This history motivates several questions. First, why did the co-op form, and why at Chignik? One plausible reason is that Chignik fishermen had prior experience with the benefits of cooperative management because of a 1991 strike aimed at securing higher prices from local processors. During the strike the Chignik Seiners Association (CSA), a lobbying organization for local fishermen, negotiated an agreement in which local fishermen rotated efforts to bring pre-determined volumes of catch to alternative processors who offered higher prices. Experience with this rotational scheme convinced participating fishermen that effort coordination could yield much higher catch per unit effort than conventional fishing (Knapp 2007).¹³

¹³ As McCallum (1997) explains, strike participants found that the most cost effective fishing method involved the use guiding barriers to direct salmon within Chignik lagoon. This reduced the number of seiners required to harvest the allowed catch and saved on transportation costs by concentrating effort near processing sites. The strike also demonstrated the economic advantages of bargaining collectively with processors over price.

Second, what accounts for the time lag between the promising 1991 experience with coordinated fishing and the coop's eventual launch in 2002? Plausible reasons for the delay include the questionable legality of a cooperative under Alaskan law, hesitance by some fishermen to join a cooperative and disagreement over how any catch quota granted to the coop would be divided among members.¹⁴ The launch in 2002 was evidently precipitated by a second strike against processors in 2001 which once again demonstrated the advantages of coordination and consolidation.

Third, how did the co-op policy affect fishing practices and the level and distribution of rents, and why was it dismantled after only 3 years? We address these questions in detail in the remainder of the paper. Given the coop's contractual structure we model it as a profit maximizing firm constrained by a catch limit, while the independent sector is modeled as a group of independent harvesters participating in a noncooperative game. Because fishing with the coop was voluntary, our model allows for heterogeneous skills and examines the decision to join the coop or fish independently. This leads to empirical predictions on how different skill levels would sort between the two sectors, and to subsequent empirical tests. Finally, our model considers the question of whether the with-coop equilibrium represented a Pareto improvement over the equilibrium in which all participants competed in limited entry fishing. This leads to a close examination of the rule used to allocate the allowed catch between sectors and a discussion of the Alaska Supreme Court decision that overturned the coop. The model's presentation in the text stresses intuition; proofs and detailed derivations appear in the Appendix.

The side by side operation of the two sectors provides a rare opportunity to peer inside a firm-like organization and observe the type and extent of coordination it practices. We exploit this opportunity in our empirical analysis with data on the pace of harvests, effort consolidation, the location of fishing, prices received and fishing profits; we also present anecdotal evidence on provision of public inputs. The availability of data from Chignik in years before, during and after the coop, as well as data from Alaska's five other purse seine salmon fisheries, facilitates empirical tests. The tests provide clear evidence that the coop's behavior yielded substantial rent gains. Some of these gains arose through the oft-discussed channel of effort consolidation. Substantial additional gains came through channels that have received far less attention, including coordination on the location and timing of fishing, sharing of information on stock locations and provision of shared infrastructure. Our examination of the lawsuit and the allocation rule leads us

¹⁴ A 1997 letter from the CSA Director documents continuing concern with the allocation question (McCallum 1997).

to conclude that, although a Pareto-improving policy design was feasible, the rule actually implemented clearly disadvantaged the independent sector as coop membership increased.

3. Model

Theories of the firm stress its role in coordinating the actions of inputs used in combination, particularly when several inputs share the use of a single resource.¹⁵ Our model incorporates this consideration in two ways. First, it is well-known that harvesting efficiency can be enhanced by coordinating the spatial deployment of fishing effort if the unit value of the stock varies over space.¹⁶ In Chignik, cost per unit effort declines as the stock migrates toward a port where fishing vessels and processing facilities are based. A single firm coordinating the effort of all harvesters will rationally intercept the stock at the most advantageous location, typically near the port. Independent fishermen have an incentive to intercept the stock before rivals do, however, in order to exploit an unfished stock, and this can result in excessive costs. Our model incorporates this coordination problem by dividing the fishing grounds into two zones, regarding the distance to each as a single value, 0 or \bar{d} , and specifying that fishing at the greater distance raises the cost per unit effort. We refer to these zones as ‘inside’ and ‘outside’, respectively, and compare the coop’s choice of fishing location to the equilibrium locations of independent fishermen.

A second source of coordination gains involves the use of a non-rival public input. Fishery-related examples include shared information on stock locations and shared harvesting infrastructure (up to the point of congestion). A standard free-rider argument indicates that public inputs will be under-provided by independent agents contributing to their provision. However, efficiency in public input provision can be promoted by placing the agents who use them under the direction of a single firm empowered to claim the resulting net revenue. Our model includes a non-rival public input, G , that reduces the cost per unit effort. We assume the public input is available only to harvesters in the sector that provides it.¹⁷

These two opportunities for coordination are assumed to affect the cost per unit effort. Effort, in turn, is represented by the product of time spent fishing, T , and an individual skill

¹⁵ Coase (1937), Alchian and Demsetz (1972), Scott (1955).

¹⁶ See Costello and Deacon (2007).

¹⁷ Because the two sectors fish at different times in the Chignik case, this is an assumption that shared inputs are not permanent or durable. This clearly is true for day to day information on stock densities and for removable infrastructure.

parameter, γ , interpreted as the rate at which the individual can apply fishing effort. This specification implies that effort can be managed by controlling time spent fishing, which agrees with the way effort was managed in the fishery we study. Letting the subscript h refer to an individual fisherman, the individual's total cost is

$$c_h = \{\alpha + d_h - G(\sum_i x_i)\}\gamma_h T_h + \phi_h T_h + x_h. \quad (1)$$

The expression in brackets incorporates all cost components that are proportional to h 's effort. We include a common cost parameter, α , and measure distance, d_h , in units of cost. The term x_h is h 's contribution to the public input and $G(\sum_i x_i)$ is the amount of public input provided by h 's sector. We assume $G(0) = 0$, $G' > 0$, $G'' < 0$ and $\alpha + d_h - G(\cdot) > 0 \forall h$. We also include the opportunity cost of h 's time spent fishing, $\phi_h T_h$. 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.

Total catch, Q , is linked to aggregate effort, E , and the stock, Z , by a linearly homogeneous fishing technology,

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

where $F' > 0$, $F'' < 0$, $F(0) = 0$ and $F(E/Z) < 1$. The regulator imposes a biologically determined catch limit, expressed in what follows as a fraction of the stock $Q \leq \beta Z$. This catch constraint implies an upper limit on effort, $E \leq ZF^{-1}(\beta)$. Each season's allowed catch and the available stock are determined by the regulator's current and prior year actions. These terms are fixed from the industry's point of view, so we treat them as parameters in what follows and focus on within-season fishing activities.¹⁸

In the fishery we study the stock's migratory behavior enabled the regulator to divide the catch in such a way that one sector's catch did not interfere with the fishing opportunities of the

¹⁸ A firm assigned a secure catch quota could in principle choose to harvest less than what the regulator allows in a given year in order to increase future stocks, in which case its total catch would be a choice variable rather than a fixed quantity. We regard this possibility as remote in the case we study, and ignore it in what follows. We have two main reasons for this choice. First, if one sector reduced its harvest to generate a higher return in the future, part of that future return would be captured by the other sector and thus be external to the sector making the sacrifice. Second, biologically determined catch limits imposed by regulators often are lower than what a profit maximizing manager would choose.

other. Salmon predictably migrate through the fishing grounds toward their spawning stream during a known part of the year. Each sector was allowed to fish during a separate part of this migration period. The portion of the annual run arriving during the independent sector's open season was a stock available to that sector alone. Once the independent's season closed, the uncaught portion of its stock escaped up river. The same process could then be implemented for the cooperative sector, by opening its season for a period of time and effectively dedicating a portion of the annual run to the cooperative.¹⁹ We denote the independent and cooperative groups by I and J , respectively, their assigned stocks by Z_I and Z_J and the numbers in each group by $n(I)$ and $n(J)$. We specify that the run was partitioned in proportion to the number of permit holders in each group, e.g., $Z_J = Z n(J)/n(K)$ for group J , where $n(K)$ is the total number of harvesters in both groups. We later relax this allocation rule.

The independent sector's total effort is $\sum_{h \in I} \gamma_h T_h$. The regulator can ensure this sector meets its catch limit by closing the independents' fishing season after T_I periods, where

$$\sum_{h \in I} \gamma_h T_I = Z_I F^{-1}(\beta). \quad (3)$$

The cooperative faces a similar catch limit, but is free to meet it by choosing distinct fishing times for individual members. In addition, the cooperative's fishing times logically cannot exceed duration of the salmon run minus the length of the independent sector's season. We express this upper limit by \bar{T} .

It remains to specify how the location of fishing affects catch. To simplify we treat the stock available to a given sector as a dimensionless mass, Z , which moves along a migration route. Given the harvest technology, applying E_T units of effort to this stock will yield a catch of $ZF(E_T/Z)$. If this effort is applied sequentially, with E_0 units applied first and $E_T - E_0$ units subsequently, the first 'batch' of effort yields a catch of $ZF(E_0/Z)$ and the second yields a residual catch of $Z(F(E_T/Z) - F(E_0/Z))$. Concavity of $F(\cdot)$ implies that catch per unit effort for the first application of effort is greater than for the second. Because the stock's migration route takes it toward port, the first batch of effort is necessarily applied farther from port than the

¹⁹ For a sedentary species that does not redistribute itself over the fishing grounds as fishing proceeds, a similar stock division could be achieved on a spatial basis by allocating portions of its habitat to each sector. A spatial division would not work if the target stock redistributes while fishing occurs because harvests by one sector would subtract from the stock available to the other, setting off a race to fish.

second. Consequently, catch per unit effort is higher for those who fish outside than for those who fish inside.²⁰ This creates an incentive for the independent fisherman to fish at a distance. Offsetting this is the fact that fishing at a greater distance increases cost per unit effort.

There are two kinds of decisions to examine, the initial joining decision and subsequent decisions on effort deployment. We model these as a two-stage entry game and identify subgame perfect Nash equilibria by backward induction.²¹

Effort deployment by the coop

Since total catch is fixed by the regulator, profit can be maximized by solving the following cost minimization problem:

$$\begin{aligned} \min_{d_i, T_i, i \in J; x_J} \sum_{i \in J} (\alpha + d_i - G(x_J)) \gamma_i T_i + \sum_{i \in J} \phi_i T_i + x_J, \\ \text{s.t. } \sum_{i \in J} \gamma_i T_i = Z_J F^{-1}(\beta), d_i \in \{0, \bar{d}\} \text{ and } T_i \in [0, \bar{T}] \text{ for all } i \in J, \end{aligned} \quad (4)$$

where x_J is the coop's expenditure on the public input.

The profit maximizing policy is straightforward.²² First, it sets $d_i = 0$ for each member that spends positive time fishing. This is obvious because (4) is non-decreasing in $d_i T_i$, $\forall i \in J$. Second, public input provision satisfies a Samuelson condition for optimal public good provision; for an interior solution this is $G'(x_J) F^{-1}(\beta) Z_J = 1$. Both results reflect of the gain from solving coordination problems within a firm. Third, the profit maximizing policy assigns positive harvest times to a subset of members who have the lowest values of the ratio ϕ_i / γ_i and limits the number of members who fish so that these efficient members fish as long as possible, \bar{T} periods. Other members do not fish at all (but still share in the coop's profits). Concentrating effort among this group is intuitive because ϕ_i and γ_i are i 's cost per unit time and effort per unit time, respectively, so the ratio ϕ_i / γ_i is i 's cost per unit effort. Slowing the rate of fishing to extend the season concentrates effort among these efficient harvesters to the greatest extent possible.

These results are summarized as follows:

²⁰ Costello and Deacon (2007) apply similar reasoning to harvesting of a non-migratory stock that inhabits patches at varying distances from port.

²¹ Consistent with positive permit values in the fishery examined, we assume each firm is capable of earning positive profit by fishing independently, regardless of the composition of the independent and coop fleets.

²² Because any coop member could have earned positive profit from fishing as an independent, the coop's maximal profit is necessarily positive.

Proposition 1 The cooperative's profit maximizing policy requires that:

- (i) All active members fish as close to port as possible;
- (ii) Provision of the public input equates the coop's marginal benefit from provision to marginal cost, satisfying a Samuelson condition;
- (iii) Fishing is restricted to members who have the lowest cost per unit effort (ϕ_i/γ_i) and effort is slowed to allow fishing to continue for as long as possible, \bar{T} periods.

Stage 2 choices by independents

Fishermen choosing to fish independently face a set of decisions similar to that of the coop manager. In this case, each fisherman must independently decide how much time to spend fishing, how much to contribute to the public good and where to fish. Because profit is linear and increasing in time spent fishing, each independent will fish the entire season. Recognizing this fact the regulator must set the season length to meet the desired catch (see Equation 3). The highest skill fisherman is the only fisherman who might be motivated to contribute to the public good, thus it is insufficiently provided by the independent fleet.

Finally, we find that the equilibrium fishing location choices of independent fleet members depend on a complex interplay of model parameters. The tradeoff involved has a straightforward intuition, however. Fishing outside is costly, but it enables an individual to contact the stock before all those who fish inside and consequently obtain a higher catch per unit effort. If the cost per unit effort of fishing outside is relatively low, all fishermen will fish outside in equilibrium and nobody will find it in his best interest to save on costs by deviating inside. On the other hand, if the cost per unit effort of deviating outside is very high, it is in all fishermen's best interest to fish inside; in this case the benefit of intercepting the stock earlier never outweighs the high cost of fishing outside. Intermediate cases, where some fishermen fish inside and some fish outside, can also be equilibria for intermediate values of the 'distance' cost. This decision calculus is based on our model's predictions of the consequences of deviating in location, derived from the average and marginal catch per unit effort; see Appendix. These results are summarized below.

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) For sufficiently low cost of fishing at the outside location (relative to the gain in catch per unit effort) some or all independents will choose to fish at the inefficient outside location.

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

$$T_I = \frac{ZF^{-1}(\beta) / n(K)}{\sum_{i \in I} \gamma_i / n(I)} \quad (5)$$

and is therefore inversely proportional to the group's average skill, a result that will become useful later.

The Stage 1 decision of whether or not to join

Having determined equilibrium behavior of the two fleets (independent and cooperative), we now turn to the stage 1 decision of which fleet to join. We adopt the convention that fishermen are indexed in increasing order of their γ terms, so low skill fishermen have low index numbers. To obtain a clear identification on the attributes of coop joiners, we assume that high skill harvesters (high γ) have low cost per unit effort (low ϕ/γ). This will be true if the ϕ terms are constant, if ϕ and γ are inversely ordered, or if ϕ does not increase more than proportionately as γ increases.

We start by examining the second stage profit shares of successive coops in which new members are added in order of their γ parameters. In the Appendix we focus on the marginal skill fisherman and his motivation to join (and thus contribute to) an existing cooperative, or to fish independently. We first show the intuitive result that, when new members are added in order of increasing skill, coop profit per member increases with coop size. This is illustrated by the upward sloping line $\pi_c(\gamma)$ in Fig. 3.²³ The left intercept of this curve corresponds to the profit of a 'single person cooperative'; while this case strains the definition of a cooperative, it really just represents a secure catch allocation and separate fishing period for the lowest skill fisherman in an amount that equals a per capita share of the entire TAC. This intercept is positive for two reasons: (i) by assumption, all fishermen could earn positive profit by fishing independently, and (ii) the per capita catch allocation exceeds what this (least skilled) harvester would catch as an independent. The same reasoning also implies that the single coop's profit exceeds what the same

²³ This solid line is a smooth curve connecting a set of discrete points indicating the per member profits for coops of different sizes.

lowest skill fisherman could earn by fishing independently with all other harvesters and this result is useful shortly.

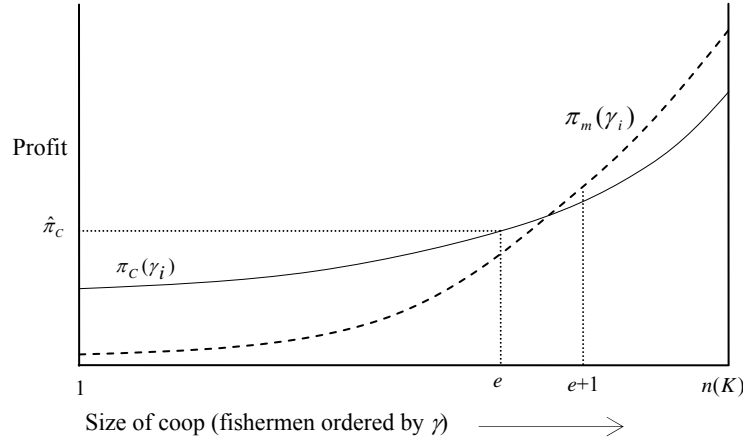


Fig. 3. Equilibrium coop size

Next we examine the marginal profit from independent fishing for independent fleets composed of successively lower skilled fishermen. This is illustrated by the dashed line $\pi_m(\gamma)$ in Fig. 3. When read from right to left this line indicates that as successively lower skill fishermen are added to the independent fleet, the lowest skill individual's profit declines. The left intercept of this curve necessarily lies below the solid curve that shows profit per coop member, as was just explained. If the right intercept lies above the solid curve, then the two must cross at least once in which case there is at least one equilibrium in which some harvesters join the coop and some fish independently. Fig. 3 illustrates this possibility. The fisherman for whom these lines cross is the marginal coop joiner, and the crossing point determines both the equilibrium cooperative size and the allocation of skills. If the solid line lies everywhere below the dashed line, all fishermen choose to join the coop.

These results are summarized as follows:

Proposition 3 Under our assumption on the relationship between effort rate and time cost parameters, a subgame perfect Nash equilibrium strategy profile satisfies the conditions in Propositions 1 and 2 and in addition has the following property:

The group choosing to fish independently consists of highliners; more precisely, all independents have skill levels greater than any coop member.

Characterizing Pareto-improving catch allocations

The above discussion characterizes the membership and economic behavior of heterogeneous fishermen composing the two fleets. Here we focus on whether all fishermen are likely to support the formation of the cooperative. In particular, we examine whether allowing formation of the self-selected cooperative can be Pareto improving.

The answer hinges on the allocation of catch between the two sectors. We have assumed thus far that the regulator assigns catch in proportion to membership: $Z_j = Z n(J)/n(K)$. To explore this issue more completely, we generalize the allocation formula to allow for disproportionate assignments: $Z_j = Z \theta n(J)/n(K)$ where the scalar θ controls the proportional assignment to the cooperative sector. For example, if $\theta=0.9$ then the cooperative is assigned a stock allocation that provides nine-tenths of a per capita share for each coop joiner. Intuitively, it would seem that cooperative members would be advantaged and independents disadvantaged by larger values of θ , but the endogeneity of self-selected membership may blur this intuition. We start by deriving the profit for an arbitrary fisherman, h , in a ‘completely independent fishery’, a term we use to refer to the counterfactual situation where no coop is allowed to form. We then compare this profit to what h would earn when the cooperative is allowed to form. Naturally, we must simultaneously solve for whether fisherman h fishes independently or as a member of the cooperative fleet, and for the associated season length and fishing locations in equilibrium; these choices will depend on θ .

We characterize our results relative to the benchmark allocation value, θ_c , at which each independent is equally well off whether or not the cooperative is allowed to form. Our earlier results (that the joiners are relatively less skilled and the independents more skilled) allow us to show that $\theta_c < 1$. When the cooperative receives a larger allocation (given by some $\theta > \theta_c$) independents are made worse off (indeed, so are the more productive cooperative members), so this cannot be Pareto improving. On the other hand, if the coop’s allocation is too low (given by some $\theta < \theta_c$) the incentive to join the cooperative is insufficient for any cooperative to form at all. But, we find that for intermediate values of θ fishermen of all skill levels (joiners and independents alike) are all advantaged by the ability of the cooperative to form. These striking results are summarized below.

Proposition 4 The formation of a self-selected cooperative has the following distributional consequences:

- (i) If $\theta_L \leq \theta \leq \theta_c$ the institutional design is Pareto improving – fishermen of all skill levels are made weakly better off by allowing the cooperative to form.
- (ii) If $\theta > \theta_c$ the institutional design is not Pareto improving – all would-be independents and some would-be cooperative fishermen are made worse off by allowing the cooperative to form.
- (iii) If $\theta < \theta_L$ then no cooperative forms.

4. Empirical Evidence

Summary of Testable Predictions

Many of the model's predictions can be tested empirically with time series data from Chignik and with data from adjacent salmon fisheries operating at the same time. The model's overriding prediction is that the cooperative will act as a single firm (rather than behaving as individual harvesters), and this will increase rents by lowering fishing costs through three channels. First, the coop will consolidate fishing effort among its most efficient members. This consolidation will necessarily lengthen the fishing season relative to a regime of individual competitive harvest (prop. 1.iii). Second, the coop will coordinate on the spatial location of harvest. Instead of competing on the exterior of the fishing zone, the coop's fleet will harvest on the 'inside' of the fishing zone (prop.1.i and prop.2.iii). Third, coop members will contribute more towards public inputs (that lower the collective fishing costs) relative to independent fishermen (prop.1.ii and prop.2.ii).

Additionally, two features not specifically addressed by our model imply that the coop's formation could increase rents to fishermen by raising salmon prices. The first is the presence of monopsony power in Chignik under traditional, non-cooperative fishing – with 100 fishermen, and only one or two processors in the period we study. It is widely believed that processors extract most of the rents from negotiation with independent fishermen; presumably, a coordinated harvester group could wield its own market power. The second is a potential price premium for higher quality product; indeed, the possibility of exercising greater care in harvesting in order to

deliver a higher quality product was prominent in initial discussions on forming a coop. Both considerations indicate that the coop's formation might lead to higher prices to coop fishermen.²⁴

The model's secondary predictions concern the skill composition of the coop and its stability. The model predicts that fishermen choosing to join the coop will have lower skill than those choosing to remain independent; i.e., the group choosing to fish independently will consist of highliners (prop.3). The model also predicts that the stability of the coop will depend on the allocation rule (prop.4). If the allocation rule is not Pareto improving, then those who lose rents from the coop policy will protest its existence and this could lead to its demise.

Data Description

The empirical tests we present shortly rely on three data sets that we have constructed. We also supplement the standard empirical tests with anecdotal evidence when appropriate. For example, we use anecdotal evidence to describe differences in the provision of public inputs between the coop and the independents, and to identify the skill attributes of the fishermen who challenged the coop policy in court.

We rely on panel data when available to test the effect of the coop on fishery rents, consolidation, and salmon prices at Chignik. The panel data help control for the impacts of region-wide, annual shocks to all Alaskan purse seine salmon fisheries that may have also impacted outcomes at Chignik during the coop years. The panel data set consists of 78 fishery-year observations ($n=6$ fisheries, $t=13$ years). The six fisheries are Chignik and the other five purse seine salmon fisheries in Alaska. We focus on thirteen years of data (1997-2009) because this time span affords five years of data before and after the coop was active.²⁵ Table 1 gives summary statistics for the panel data. The dependent variables are the average price of a fishing permit that was permanently transferred to another fisherman, the proportion of licenses owned that are actively fished, and price received by fishermen (from processors) per pound of salmon. Note that we use the sale prices of fishing permits to proxy expected rents from the fishery; permits are permanent rights to compete for a share of each season's TAC. The key independent variable is binary; it takes a value of 1 during the 2002-2004 coop years at Chignik. The other

²⁴ We chose not to incorporate the market power feature explicitly in the model in part because its effect seems obvious and in part because this seems specific to Chignik. The coop's incentive to coordinate to guarantee higher product quality is similar to its incentive to provide club goods, and in that sense is consistent with our model. The difference is that enhanced product quality raises price, while we treat the effect of club goods as decreasing costs.

²⁵ The availability of data over three distinct time periods (before, during, and after the coop) helps us isolate the casual effects of the cooperative from fishery specific time trends (Meyer 1995, p. 158). The three distinct periods also helps eliminate serial correlation in our panel regression models (Bertrand et. al. 2004, p. 251).

independent variables are fishery-specific fixed effects, year effects, and the total allowable catch (TAC).

Table 1
Summary Statistics of Panel Data Set

	Obs.	Mean	St. Deviation	Minimum	Maximum
<u>Dependent Variables</u>					
Average Permit Price (2009 \$s)	78	65,823	69,304	10,062	252,510
Proportion of Permits Actively Fished	78	0.519	0.194	0.159	1.000
Price Per Pound (2009 \$s)	78	0.397	0.25	0.126	1.095
<u>Independent Variables</u>					
Coop Policy (=1 if in place, otherwise 0)	78	0.038	0.193	0.000	1.000
Fishery-Wide TAC (lbs of salmon, 000s)	78	66,336	69,612	1,619	295,817

Notes: (1) There are 78 fishery-year observations with $i=6$ fisheries and $t=13$ years. (2) The six purse seine fisheries are: Alaska Peninsula, Chignik, Cook Inlet, Kodiak, Prince William Sound, and Southeast. (3) The years are 1997-2009. (4) The data come from the fishery participation and earnings statistics of the Alaska Commercial Fisheries Entry Commission. The data can be downloaded at: www.cfec.state.ak.us/fishery_statistics/earnings.htm

To test the predictions on season length and spatial deployment of effort we rely on annual time-series data from the Chignik fishery rather than panel data. We rely on time series data because we were unable to find comparable data on season length and spatial location of harvest for the other purse seine fisheries. For season length, we use annual observations on the number of days fished at Chignik over 1980- 2008; these are the years for which we have data. For the coop years, season length gives the number of days fished by either the independent or cooperative fleet; these fleets usually fished on different days. For spatial deployment of effort, we examine annual time-series data to see how the proportion of sockeye caught ‘inside’ the Chignik Lagoon deviated during 2002-2004 from longer time trends over 1973-2008. (The latter period includes all years since entry was first limited in Alaska fisheries and for which we have data.) Our measure of location is the annual proportion caught in Chignik Lagoon (see Fig. 1 and Fig. 2), the ‘inside’ location.²⁶ Table 2 gives summary statistics for the time series data.

²⁶ Salmon caught elsewhere are harvested from ‘outside’ districts.

Table 2
Summary Statistics of Time Series Data Set

	Obs.	Mean	St. Deviation	Minimum	Maximum
<u>Dependent Variables</u>					
Number of Days Fished	28	68.89	11.60	50.0	102.0
Proportion Caught 'Inside'	36	0.787	0.151	0.450	1.000
<u>Independent Variables</u>					
Coop Policy (=1 if in place, otherwise 0)	36	0.083	0.280	0.000	1.000
Fishery-Wide TAC (# of Sockeye, 000s)	36	1,381	593.4	399.6	3,116

Notes: (1) The table summarizes 36 years of Chignik fishery data for Number of Days Fished, Coop Policy, and Fishery-Wide TAC (1973-2008). (2) The table summarizes 28 years of data for Number of Days Fished (1980 – 2008). (3) Source: Annual Chignik Management Report for 2002-2008, published by the Alaska Commercial Fisheries Entry Commission.

To test the predictions that coop joiners will be less efficient fishermen than non-joiners, and that the most efficient coop members will actively fish on behalf of the coop, we rely on data on the catch-share history of fishermen during the pre-coop period to proxy fisherman skill. While individual catch shares are not disclosed due Alaska confidentiality laws, we were able to obtain catch share data that are aggregated to groups of three fishermen.²⁷ The procedure for carrying out these aggregations was designed to minimize catch share heterogeneity among the observations that were grouped. Because some harvesters changed status during the coop period, different aggregations were formed, using the same procedure, for 2002, 2003 and 2004. For 2002 aggregations, individual fishermen were first partitioned into three groups depending on their 2002 coop status: coop joiners who fished, non-fishing coop joiners and independents. All fishermen in a given group were ordered by average sockeye catch share over the historic 1995-2001 period.²⁸ Successive fishermen were then clustered into groups of three and the average historic catch share within each cluster was reported to us. This procedure was then repeated for groups formed on the basis of 2003 and 2004 coop status.

The end result is a set of roughly 100 observations on coop status each year during 2002-2004 and average historic per-fisherman catch share during 1995-2001. The mean catch share is 1.01%, indicating that the average fishermen caught about 1 percent of the TAC. This statistic makes sense as there were approximately 100 permit holders at Chignik in each year preceding

²⁷ We are indebted to the Alaska Commercial Fisheries Entry Commission for performing these aggregations for us. In a few cases it was necessary to aggregate over four firms.

²⁸ 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 coop fished exclusively for sockeye.

coop formation. The maximum and minimum catch shares imply that highliners in the fishery caught 2.22% of the TAC and the least successful fishermen caught 0.42%.

Fishery Rents

We begin by examining the effect of the coop policy on rents in the fishery. We lack data on individual firm-level profits, but we do have data on the value of fishing permits. The value of a Chignik fishing permit should reflect the expected present value profit that a marginal (low skill) fisherman could earn in this fishery. The marginal fisherman's profit is relevant, rather than the highliner's profit, because (ignoring differences in non-pecuniary returns) the marginal fisherman would have the lowest reservation price for selling a permit and would therefore determine the transaction price to potential buyers.

Table 3 shows our estimate of the effect of the coop policy on permit value using the panel regression model in equation (6).

$$LicenseValue_{it} = \delta_t + \alpha_i + \beta(coop\ policy)_{it} + TAC_{it} + u_{it} \quad (6)$$

Identification of β , the coop policy effect, comes from within-Chignik annual changes in permit values, controlling for annual shocks (δ_t) that could affect permit values in all purse seine salmon fisheries (e.g., fuel prices and the price of farm-raised salmon) and time invariant differences in permit values across the six fisheries (α_i). The model also controls for time-variant differences in salmon runs as reflected in the fishery-specific annual TAC. The result in table 3 indicates that the coop policy increased the value of a permit by \$59,130 in 2009 dollars. This implies that the option to join a voluntary coop substantially increased the amount that buyers would pay for a permanent right to fish at Chignik. This is a 32.6 percent increase relative to \$181,004, which was the mean value of a Chignik permit over 1997 to 2009 excluding the coop years.²⁹

²⁹ To correct for possible serial correlation of errors within each fishery we conduct a robustness check recommended by Bertrand et. al. (2004). We collapse the data into averages for each fishery during three time periods – before, during, and after the coop years. We next run a panel regression using the 18 observations (6 fisheries and 3 time periods) and include fishery and time period fixed effects along with the average fishery-wide TAC. This generates consistent standard error estimates (Bertrand et. al. 2004). In our case, the coefficient on coop policy for the collapsed data is 59,115 with a t-statistic of 1.46.

Table 3
Panel Regression of Permit Value
(in 2009 dollars)

<i>Independent Variables</i>	<i>Y = permit value</i>
Constant	69,028*
Coop Policy	59,130*
t-statistic	(2.42)
Fishery-Wide TAC	-0.093 (0.69)
<u>Fixed Effects</u>	
Year Dummies	Included
Fishery Dummies	Included
Observations	78
Adjusted R ²	0.820

Notes: (1) * Significant at 0.05 level for a one-tailed t-test. (2) Year dummies span 1997-2009. (3) The permit value data are adjusted by the CPI and are presented in 2009 dollars. (4) The 5 control fisheries are the other purse seine fisheries: Alaska Peninsula, Cook Inlet, Kodiak, Prince William Sound, and Southeast. (5) The omitted observation is the Cook Inlet fishery during 1997. (6) Summary statistics are provided in Table 1.

We translate the permit value effect into an annual profit effect, as follows. The permit value difference in Table 3 presumably reflects the coop's effect on the present value of expected future profit for the marginal harvester. While it was operating, however, the coop's life span was unknown. We deal with this uncertainty by estimating a range of values for the implied annual profit effect, each based on a different assumption about the coop's expected life span. The lawsuit that eventually ended the coop was filed in April 2002 (*Grunert v. State* 2005, p. 928), just before its first year of operation. We therefore set the lower bound life expectancy at 3 years, its actual period of operation. We set the upper bound at infinity, corresponding to an expectation that it would persist in perpetuity.

The estimated profit effect is calculated as follows. Let π indicate the expected annual profit before the coop formed, and assume it is constant; let V indicate the pre-coop license value and let r be the interest rate. Assuming license values observed before the coop formed did not incorporate expected profits from the coop's possible formation, the preceding variables are linked by $V = \pi / r$. Let ΔV be the change in license value resulting from the coop's formation, which we estimate, and let T indicate the number of years the coop was expected to operate. We wish to estimate the proportionate change in profit resulting from allowing the coop to form, Φ . The appropriate present value formula gives $\Delta V = \{\Phi \pi / r\} \cdot \{1 - 1/(1 + r)^{T+1}\}^{-1}$. The term of

interest, Φ , can now be found by combining the two preceding expressions:

$$\Phi = \Delta V / V \cdot \{1 - 1/(1+r)^{T+1}\}^{-1}.$$

Table 4
Proportionate profit increase from allowing coop to form

Increase in license value	\$59,130			
Baseline license value	\$181,004			
Coop operating horizon (years)	3	5	10	∞
Proportionate profit gain (Φ) ($r=.10$)	1.03	0.75	0.50	0.33
Proportionate profit gain (Φ) ($r=.07$)	1.38	0.98	0.62	0.33

Applying this formula to the data yields the results in Table 4. The lower-bound estimate of the annual gain in the marginal fisherman’s profit due to the coop’s formation is 33 percent. If parties bidding for Chignik licenses thought the coop would last for 5 years, the implied proportionate effect on annual profit is a 75 to 98 percent increase and other entries in Table 4 have similar interpretations.

A natural question to ask is: did the coop policy cause the increased rents or is some other confounding factor responsible? In the sections that follow we test the specific predictions of the theory regarding the channels through which rents should be increased. Because the specific rent-increasing behavioral changes our model predicts are indeed observed in the data, we argue that the causal interpretation of our results for Chignik are not in doubt.³⁰

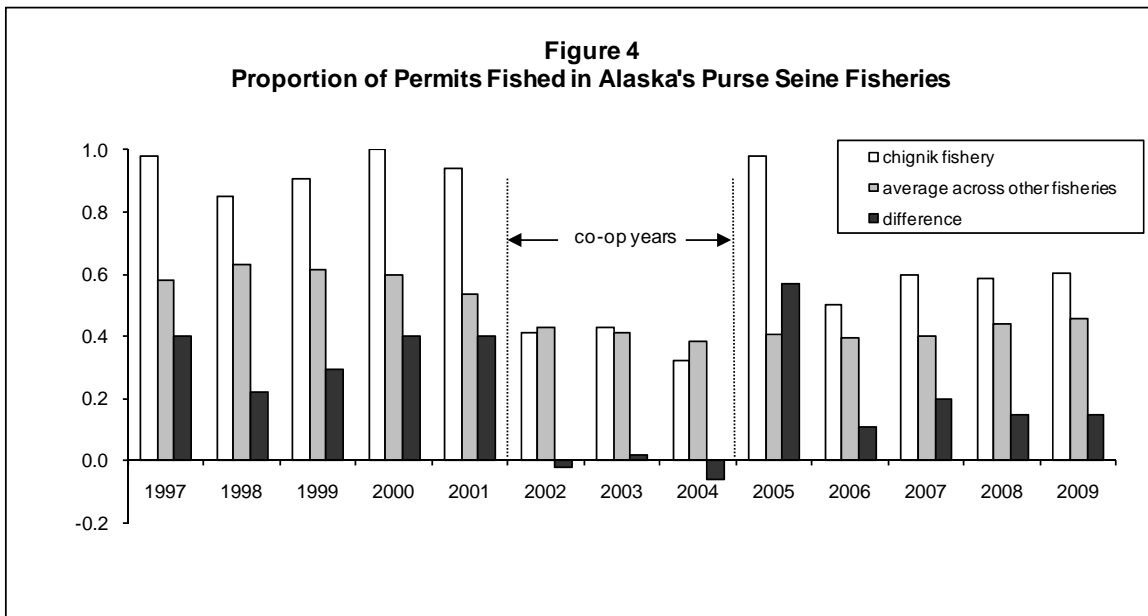
Channels through which Rents were Increased

Consolidation of Fishing Effort: The model predicts that a profit-maximizing cooperative will consolidate fishing effort among its most skilled members. In order to make maximal use of its most efficient harvesters the coop limits the *number* of members who actually fish, which slows the rate of fishing and lengthens its season. By contrast, all independents are predicted to fish each day their season is open, causing the regulator to shorten the season in order to meet the

³⁰ In the paper’s conclusion we comment on whether or not the causal effects of the policy at Chignik can be validly applied to other fisheries.

TAC constraint. Thus, we expect to see the following patterns in the data: a decline in the proportion of permits actually fished at Chignik during 2002-2004, an extension in the number of days fished during this period, and a concentration of fishing effort among the coop's more efficient members.

We test the first of these predictions by examining the effect of the coop on the proportion of licenses actually fished using the panel data summarized in Table 1. Fig. 4 shows simple and transparent evidence that the coop policy dramatically consolidated the Chignik fishery. As the figure shows, the proportion of permits actively fished in Chignik fell from 0.94 in 2001 to 0.41 in 2002 when the coop first operated, and then increased after the coop was effectively dissolved in 2005.³¹ The darkest bars show the difference between Chignik and the average across the other purse-seine fisheries. This difference was strictly positive before and after the coop years, but approximately zero during 2002-2004.



A panel regression provides a more rigorous test of the consolidation prediction. The estimates shown in table 5 are from Equation (6), but the dependent variable is now the

³¹ The spike up to 0.98 in 2005 is worth explaining. In early 2005, shortly before the start of the fishing season and after the coop was already formed for the 2005 harvest, the Alaska Supreme Court ruled that the coop violated an Alaska law prohibiting permit holders who did not actively fish from accruing profits. The state's remedy for the 2005 season was to allow the coop to fish but to require that all coop members actively fish for a small part of the season. In 2006, the coop was entirely dissolved. We discuss the Court decision in more detail later.

proportion of licenses actively fished. The result indicates that the coop policy reduced the proportion of permits fished by 0.31. The direction of the effect, a reduction, is consistent with expectations and the coefficient estimate is economically and statistically significant.³² The result is particularly striking because it pertains to consolidation across the entire fishery. Consistent with our theory, annual Chignik Area management reports indicate that almost all of the consolidation occurred within the coop; during 2002-2004 the proportion of permits actively fished was 0.25-0.28 for the coop and 0.92-1.0 for independents.³³

Table 5
Panel Regression of the Proportion of Active Permits

<i>Independent Variables</i>	<i>Y = proportion of permits fished</i>
Constant	0.441**
Coop Policy	-0.311*
t-statistic	(5.07)
Fishery-Wide TAC	3.79e-08
	(0.11)
<u>Fixed Effects</u>	
Year Dummies	Included
Fishery Dummies	Included
Observations	78
Adjusted R ²	0.855

Notes: See notes for Table 3.

To test the season length prediction we employ time-series data on the annual number of sockeye salmon fishing days at Chignik during 1980-2008 (see table 2 for summary statistics). The time-series regression model is shown in equation (7).

$$\begin{aligned}
 \text{Days fished}_t = & \alpha + \beta(\text{coop policy})_t + \pi_1 t + \pi_2 t^2 + \pi_3 t^3 + \pi_4 t^4 \\
 & + \mu_1 TAC_t + \mu_2 TAC_t^2 + \mu_3 TAC_t^3 + \mu_4 TAC_t^4 + u_t
 \end{aligned}
 \tag{7}$$

³² As before we estimated a version of the regression in Table 5 by collapsing the data into averages for each fishery during three time periods – before the coop years, during the coop years, and after the coop years. This approach generates consistent standard error estimates (Bertrand et. al. 2004). The resulting coefficient on the coop policy for the collapsed data is of -0.311 with a t-statistic of 4.15.

³³ Members who fished on behalf of the coop were paid salaries to compensate for their costs. All coop members were then paid equal shares of the profit remaining after these salaries and other coop costs were deducted; Knapp and Hill (2003).

The time-series model accounts for the cyclical nature of the time-series data by including a 4th-order polynomial time trend and controls for variation in harvest by including a 4th-order polynomial in the annual allowed catch. The regression estimate in table 6 indicates that, on average, the presence of the coop lengthened the season by 32 days, a 48 percent increase in season length from the long run average of 67 days in non coop years.

Table 6
Time-Series Regression Analysis of Season Length

<i>Independent Variables</i>	<i>Y = number of days fished</i>
Constant	509.7*
Coop Policy	32.15*
t-statistic	(3.92)
Fishery-Wide TAC	0.0004
Fishery-Wide TAC ²	-3.17e-10
Fishery-Wide TAC ³	1.04e-16
Fishery-Wide TAC ⁴	-1.19e-23
Year	--114.65*
Year ²	7.649*
Year ³	-0.217*
Year ⁴	0.002*
Observations	28
Adjusted R ²	0.533

Notes: (1) * Significant at 0.05 level for a one-tailed t-test (2) The data used here come from Chignik area annual management reports and are summarized in table 2. We lack data on season length prior to 1980.

We test the prediction that the coop consolidated effort among its most skilled members by comparing mean historic catch shares for fishing versus non-fishing coop members. The comparison, shown in Table 7, indicates that those who fished for the coop had higher historic catch shares than those who did not (1.11 percent compared to 0.90 percent), which agrees with our prediction.

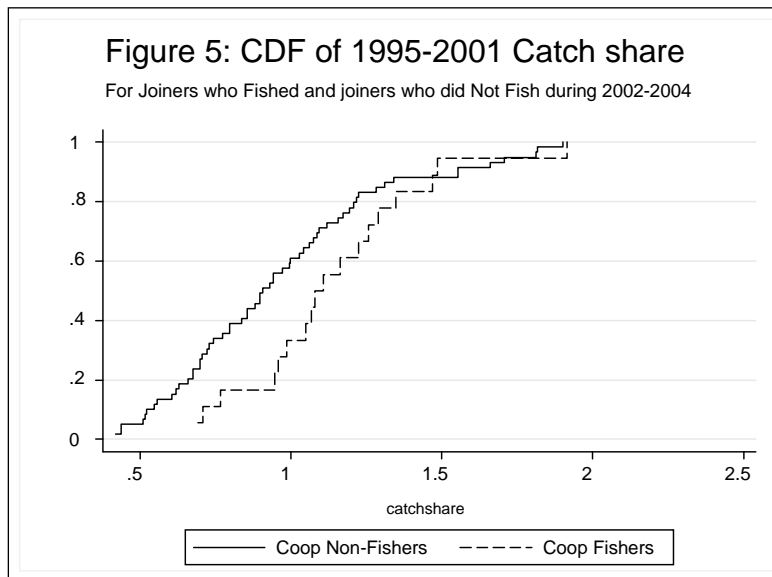
Table 7
Comparison of Mean Catch Histories for Ranked and Sorted Clusters of Fishermen

	<i># of Obs.</i>	<i>Mean Catch Share</i>	<i>t-stat for diff. (abs. value)</i>
Coop members who fished	18	1.11	1.83*
Coop 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.

Tests for first-order stochastic dominance in the empirical distribution functions also agree with prediction that the most efficient members fished on behalf of the coop. Fig. 5 plots the harvest share cumulative density functions for coop members who fished and coop members who did not fish using the ranked and clustered data described above. From visual inspection, the empirical CDF for coop members who actively fished stochastically dominates, i.e., the fraction of observations with catch share value less than or equal to a given value is greater for active fishermen than for members who did not fish for all observed catch share values except for a single exception near the right tail. Kolmogorov-Smirnov tests confirm that the differences in the CDFs are statistically significant by conventional standards.³⁴

To summarize, the tests in this section show that coop consolidated effort among its most efficient members and this consolidation lengthened the fishing season (and presumably lowered costs) as the model predicts.



³⁴ The test results are available from the authors.

Spatial Deployment of Effort. The model further predicts that the coop will coordinate on the *location* of harvest in order to reduce costs. Because the coop secures a guaranteed allocation of catch, coop harvesters should wait until fish migrate inside, at which time the harvest will be more efficiently executed (Prop. 1.i). In contrast, some or all of the independent sector’s harvest is expected to take place ‘outside’ (Prop. 2.iii). We use data on the spatial location of catch to test these propositions in two different ways. First, we examine 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 then use within-fishery cross-section data to assess how the proportion of ‘inside’ catch differed between coop and independent fishermen during 2002-2004. Our measure of location is the annual proportion caught in Chignik Lagoon (see Fig 1. and Fig. 2), the ‘inside’ location.

Figure 6 shows the fishery-wide proportion of sockeye caught ‘inside’ over an 11 year period that includes 2002-2004, the coop’s years of operation, and provides transparent visual evidence that the proportion caught ‘inside’ peaked during the coop years. We employ a time-series regression model to more rigorously test for the effect of the coop on inside catch. The time-series model is the same as Equation (7) except that now the dependent variable is the proportion of sockeye salmon caught ‘inside’; the data employed are summarized in table 2. The regression results shown in table 8 suggest that the coop policy increased the proportion caught inside by 0.28. Note that this proportion applies to the entire fishery, including both coop fishermen and independents, and in that sense understates the behavioral change the coop implemented.

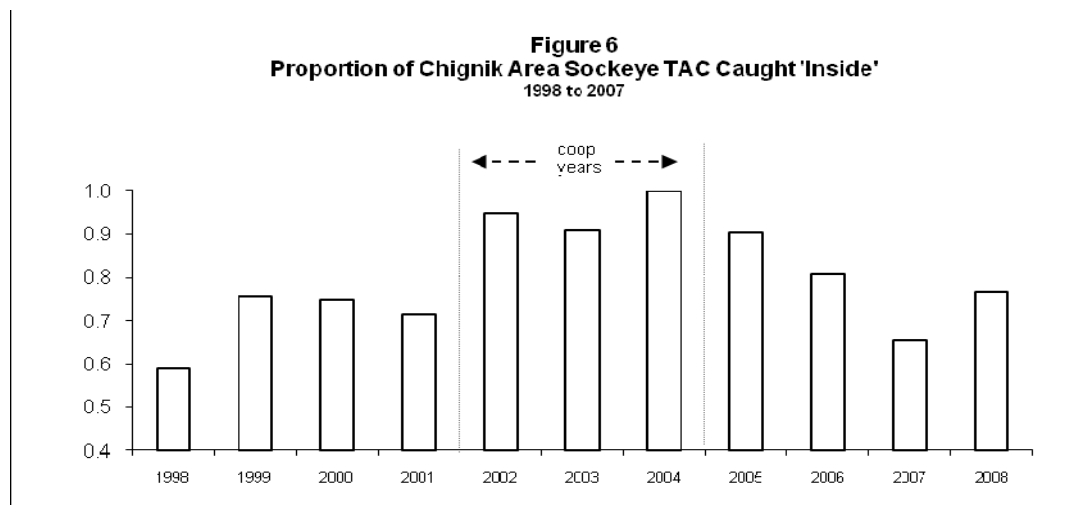


Table 8
Time-Series Regression Analysis of Inside Catch

<i>Independent Variables</i>	<i>Y = proportion of catch from inside</i>
Constant	0.994*
Coop Policy	0.284*
t-statistic	(3.50)
Fishery-Wide TAC	-1.03e-06
Fishery-Wide TAC ²	1.45e-12
Fishery-Wide TAC ³	-7.47e-19
Fishery-Wide TAC ⁴	1.23e-25
Year	0.045
Year ²	-0.004
Year ³	0.0001
Year ⁴	-5.86e-07
Observations	36
Adjusted R ²	0.642

Notes: (1) * Significant at 0.05 level for a one-tailed t-test (2) The data used here span 1973-2008, come from Chignik area annual management reports, and are summarized in table 2.

Table 9 compares the location choices of coop and independent fleets during 2002-2004 using detailed data from the 2002-2004 annual Chignik management reports. As the model predicts, the coop harvested its *entire allocation* inside Chignik Lagoon in each year.³⁵ By comparison, the independent fleet harvested from both inside and outside in 2002 and 2003, which is consistent with the possibility of a mixed equilibrium (prop. 2iii). During 2004 when there were only 13 independents, all independent harvest took place inside the lagoon.

³⁵ The following account from a coop founder makes clear that fishing inside was a conscious operating policy: “We had originally planned to employ a couple of large ... seiners to fish out on the capes [outside], but we realized that the extra running time would increase costs and reduce product quality. Harvesting in the close proximity and concentrated harvest area of the Chignik Lagoon [inside] was simply the most efficient and quality conscious method to pursue.” (Ross 2002a).

Table 9
Proportion of Sockeye Caught Inside by Coop 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

Notes: (1) The data come from 2002-2004 Chignik annual management reports. (2) In a few instances, each fleet fished on the same day, but at different times. Because the data on spatial catch is reported on a daily basis, we restrict the comparison to those days reserved exclusively for one of the two fleets.

Public Input Provision. Our evidence on provision of shared or public inputs by the coop is anecdotal, gleaned from trade press accounts and annual management reports of the Alaska Department of Fish and Game (ADFG). The most prominent shared inputs installed by the coop were ‘fixed leads’, stationary nets placed along the fish migration route to funnel the stock toward waiting purse seiners.³⁶ The fixed leads altered the style of fishing and dramatically reduced the number of vessels required to achieve a given catch. This sort of shared infrastructure was not employed by the independent fleet.³⁷

Other actions we characterize as public good provision by the coop amount to very precise coordination of members’ actions. One important form of coordination was a finely tuned temporal allocation of its members’ effort (Stichert, 2007). During low tides Chignik Lagoon, the inside location where the coop harvested, shrinks to a fraction of its size at high water. This concentrates the fish and reduces harvest cost. A prominent coop member described how the coop coordinated effort to exploit this phenomenon:

“Instead of [a coop member] making four or five sets ... during the flood [high tide] for 200 to 300 [fish] a haul, he now could wait till the Lagoon drained out. At low tide ...

³⁶ See Pappas and Clark (2003).

³⁷ Ross (2002a). Note that the use of shared infrastructure was also a hallmark of Native American salmon fishing in the Pacific Northwest prior to commercialization. Certain types of fishing gear required cooperative effort in handling and construction, and ownership of this gear was apparently shared among individuals and tribes (Higgs 1982).

[the channel] became a slow, meandering river of concentrated sockeye. And now, fishing for the entire coop, he could make one giant drag for 3,000 to 5,000 fish.”³⁸

This strategy required that coop harvesters allow fish to escape up river during high tides, even though it is legal to catch them. Given the coop’s secure catch allocation and its ability to coordinate, however, the incentive to do this was present. We know of no instances of independent fishermen intentionally allowing fish to swim up river.

The coop also coordinated its members’ actions to improve the quality of fish delivered to processors. It received permits to hold live fish in net pens for up to three days, which allowed it to better match deliveries to processing capacity. On occasion, the coop even released live fish from capture when processing capacity was insufficient.³⁹ Independent harvesters have no incentive to engage in such practices and we are aware of no evidence indicating that they did. The coop also 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.

Finally, the coop’s ability to coordinate benefitted the fishery manager by enabling precise control of a day’s catch. With independent fishing the fishery manager must forecast the rate of catch and announce a closing time calculated to meet the overall catch target, an imprecise process at best. On days the coop fished, the manager could hit the target precisely simply by requesting that the coop cease fishing when the desired number of fish was caught (Pappas and Clark, 2003).

Salmon Prices. We noted earlier the coop’s potential to raise price by delivering higher quality fish or by exercising increased market power in negotiations with processors. We cannot separate these two effects but we can test for a price increase using the panel-regression format in Equation (6), using the price per pound of salmon as the dependent variable. The regression results (table 10) indicate that formation of the coop was accompanied by an average price increase of \$0.24 per pound in the Chignik fishery (in 2009 dollars). This represents a 32 percent increase from the Chignik average of \$0.75 outside of the coop years during 1997-2009.⁴⁰ Note

³⁸ Ross (December 2002).

³⁹ 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)

⁴⁰ The price data are inflation adjusted and are in 2009 dollars. As before we estimated a version of the regression in Table 10 by collapsing the data into averages for each fishery during three time periods –

that this is a lower-bound estimate of any price premium the coop achieved because nearly one-third of the sockeye caught at Chignik were harvested by independents during 2002-2004.⁴¹

Table 10
Panel Regression of Gross Earnings Per Pound
(in 2009 dollars)

<i>Independent Variables</i>	<i>Y = gross earnings per pound</i>
Constant	0.581*
Coop Policy	0.238*
t-statistic	(2.73)
Fishery-Wide TAC	-1.25e-06*
	(2.62)
<u>Fixed Effects</u>	
Year Dummies	Included
Fishery Dummies	Included
Observations	78
Adjusted R ²	0.818

Notes: See notes for Table 3.

To summarize, we find substantial evidence that the coop policy reduced fishing costs at Chignik through consolidation and coordination of effort. We also find evidence that the coop policy increased prices received by fishermen, either because the coop could deliver higher quality salmon or because the coop wielded more market power than independent fishermen. We now turn to tests of the model's predictions concerning the decision to join and the stability of the coop.

Decision to Join the Coop

Our model predicts that highliners will remain independent while less-skilled fishermen will opt into the coop (Prop.3.i). The model also suggests that an individual's historic catch share under independent fishing is a good proxy for the critical skill parameter, γ , so we test skill-related predictions with data on individual catch shares during the pre-coop period. Accordingly,

before the coop years, during the coop years, and after the coop years. This approach generates consistent standard error estimates (Bertrand et. al. 2004). The resulting coefficient on the Coop Policy for the collapsed data is 0.238 with a t-statistic of 2.66.

⁴¹ We lack cross-section data during 2002-2004 that would allow us to compare output prices between the coop and independent sectors.

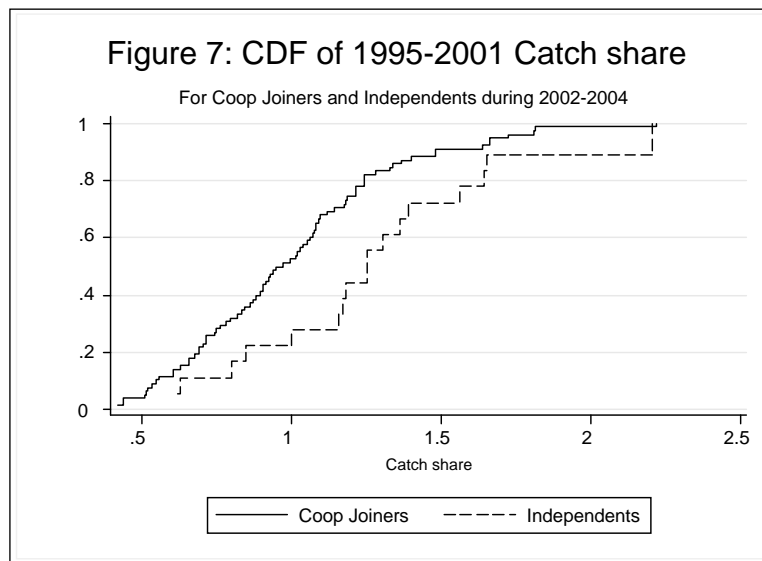
we use the ranked and clustered individual catch share data described earlier to test this prediction.

Table 11 shows that the historic catch shares of those who fished independently during 2002-2004 significantly exceeded catch shares of coop joiners (1.29 percent compared to 1.00 percent), which agrees with our prediction. Tests for first-order stochastic dominance in the empirical distribution functions provide further corroboration. Figure 7 plots the historic catch share cumulative density functions for joiners and independents. From visual inspection, the empirical CDF for independents stochastically dominates that for joiners and a Kolmogorov-Smirnov test confirms that the differences in the CDFs are statistically significant.⁴²

Table 11
Comparison of Mean Catch Histories for Ranked and Sorted Clusters of Fishermen

	<i># of Obs.</i>	<i>Mean Catch Share</i>	<i>t-stat for diff. (abs. value)</i>
<i>Independents v. All Joiners</i>			
Independents	18	1.29	2.90*
All coop members	78	1.00	

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



⁴² The test results are available from the authors.

Stability of the Coop

Our empirical evidence on the question of coop stability and Pareto improvements consists of data on the historic catch of coop joiners and independents, the regulator's TAC allocation rule and the lawsuit that challenged the coop. Our model (Prop. 4i) indicates that dividing the TAC between the coop and independent sectors in proportion to aggregate skill, corresponding to $\theta = \theta_c$, would make those who choose to join the coop better off and leave those who choose to fish as independents indifferent. This is a 'knife-edge' Pareto improvement, however; even a slight deviation from this TAC division that disfavors the independents ($\theta > \theta_c$) would make all independents worse off and presumably cause them to oppose the coop's formation.

The allocation rule set forth when the coop was first authorized (described in section 2) resulted in a TAC share for the coop of 0.693 in 2002, its first year of operation. This share resulted from having 77 joiners and a nine-tenths per capita share ($\theta = 0.9$) for each ($77 \times 0.9 = .693$). The coop's assigned catch share was within 1 percentage point of the aggregate historic catch share of fishermen who chose to join and the outcome in 2003 was essentially identical. Using historic pre-coop catch share as a measure of skill (as we argue is appropriate), our model implies that the 2002-2003 allocation was right on the knife's edge for a Pareto improvement (i.e. it was almost exactly set at our critical value, θ_c). Any deviation that worked against independents would create a situation in which all independents would gain if the coop was abolished.

In 2004 the coop's membership increased 87. To ensure a Pareto improving outcome as the size of the independent fleet declined, the TAC allocation granted for each independent permit holder would need to be increased (i.e. θ would need to decline). This is true because those leaving the independent sector to sign on with the coop would be the least skilled independents (Prop. 3), while those remaining would be the most skilled. The allocation formula put in place by the regulators did just the opposite. Once coop membership reached 85 in 2004 the allocation rule *reduced* the independent sector's TAC share to coincide with the proportion of permit holders that chose to fish independently. This corresponds to an allocation based on $\theta = 1$, which our model suggests will disadvantage all independents. Rough calculations indicate that it would have been necessary to increase the independent sector's per capita TAC allocation by at least 10% to ensure a Pareto improvement; instead it was reduced by 40%.

The lawsuit challenging the coop policy was filed by Michael Grunert and Dean Anderson. Consistent with the model's predictions, both were among the highest earning Chignik

permit holders and neither joined the coop. The fact that Grunert and Anderson filed the lawsuit in 2002 suggests that they assigned a positive probability to the number of joiners growing over time to the point where highliners would become disadvantaged, which clearly seems to be what happened by 2004.

5. Conclusions

The literature on fishery management emphasizes the ability of more fully delineated property rights, such as individual catch shares (ITQs), to eliminate redundant fishing units and end wasteful races that result from the rule of capture. We extend this work by demonstrating that the value of a shared natural resource can be further enhanced by regulatory schemes that encourage those who use the resource to coordinate their actions. While individual rights holders acting independently will have to overcome potentially large transaction costs to achieve this coordination, a harvesting group with a secure allocation and with the contractual authority to direct its members' inputs can be structured to capture these gains, essentially by acting as a single firm.⁴³ Coordination gains result from providing public inputs such as shared infrastructure and shared information on stock locations and from coordinating harvesters' actions over space and time. Our empirical results from the Chignik case indicate that the efficiency gains can be substantial.

Allocating a portion of the allowed catch to a group of harvesters, to manage as they see fit within broad constraints, is a growing trend in fishery management. Examples from the U.S. are recently formed sector allocations for groundfish in the New England region, allocations to cooperatives for harvesting Alaska pollock and Pacific Whiting and the Chignik cooperative. The reasons cited for this trend include the relative political ease of assigning rights among a few sectors (rather than scores of individual harvesters) and the gains from coordinating effort.⁴⁴

⁴³ Coordination can improve on the use of shared resources whenever ownership is determined by the rule of capture (e.g., ground water, oil, fisheries). In the case of oil, gains from coordination are realized through the unitization of oil fields. Regulatory schemes that encourage unitization include laws in some U.S. states that force all landowners to join if a certain percentage of property owners agree to do so. An important difference in the fishery case that we examine is that co-op membership was strictly voluntary.

⁴⁴ Sullivan (2000) comments on the ease of assigning catch shares among members of two important fishing cooperatives. Evidence from New Zealand demonstrates that coordinating entities can be layered onto existing individual catch share systems, by allowing quota holders to form associations of harvesters to coordinate their actions. In New Zealand's *paua* (abalone) and sea scallop fisheries, harvester groups have formed associations (or a single firm in the case of scallops) that allocate effort spatially, share information on stock densities, support research and stock enhancement efforts and carry out other actions that benefit the fishery as a whole. None of these actions is in the interest of any single harvester.

The lawsuit that ended the coop highlights a consideration seldom mentioned in the literature: the value and difficulty of designing policy in a way that enables reform without losers. In the Chignik case, the question of whether or not the coop's formation would lead to a Pareto improvement was determined by three factors: the fact that joining the coop was voluntary, the regulator's rule for dividing the allowed catch between coop and independent sectors, and the coop's internal rule for sharing profits. The coop's voluntary nature was advantageous because it provided a vehicle for limiting individual losses by allowing any dissenting parties to continue under a regime that resembled the status quo. To achieve actual loss avoidance, however, required a very careful division of the allowed catch between sectors and this was complicated by the fact that individuals self-selected into the two sectors on the basis of skill. Consistent with our theoretical argument, higher skill fishermen in Chignik chose to remain independent, necessitating that this sector receive a disproportionately large catch allocation. While the actual division incorporated this to a degree, it apparently did not go far enough. Finally, it is clear that the coop could have altered its equal-profit share rule in a way that would have gained more support from high skill fishermen.⁴⁵ The coop's founders considered alternative profit share rules in initial deliberations, but these negotiations proved difficult. In the end a simple equal division rule was adopted.

Despite evidence of potential gains from management reforms based on assigning rights, less than 2% of the world's fisheries currently employ the most prominent rights-based regime, the individual catch share. At least three factors account for this dearth of implementation. First, 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 by failing to achieve potential gains from coordinating the actions of independent quota holders.

The approach exemplified by the Chignik experiment, with catch rights assigned to groups formed voluntarily, makes progress toward overcoming each of these impediments. It helps to defuse the right to fish argument by offering all participants the right to opt into a sector governed by the status quo management regime. While it does not eliminate wasteful struggles over the initial allocation, it arguably reduces the magnitude of the problem by assigning to voluntary groups the task of negotiating catch shares among their members, while requiring the

⁴⁵ In fact, one of the two highliners who filed the suit that ended the coop has argued in favor of a fishery management approach in which all harvesting is by cooperatives and coop profits are shared in proportion to historic catch shares. See Anderson (2002).

regulator only to make the gross division of catch between sectors. Finally, by enabling coordination among individuals this approach can substantially increase rents in the fishery, making the often contentious process of reform a more lucrative positive sum game than it otherwise would be.

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Appendix

A.1 Coop's optimal policy

The coop's optimal allocation solves:

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

subject to $\sum_{i \in J} \gamma_i T_i = F^{-1}(\beta)Z_J$, $d_i \in \{0, \bar{d}\}$, $T_i \in [0, T_J]$ 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 $G(x_j)$ and assuming an interior solution, the following first-order condition is necessary and sufficient for minimizing (A.1) with respect to x_j :

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

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. The catch constraint for group J implies the following constraint on effort:

$$\sum_{i \in J} \gamma_i T_i \leq Z_J F^{-1}(\beta). \quad (\text{A.3})$$

We index coop members in increasing order of the ratio ϕ_i/γ_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, denoted \mathcal{A} which assigns fishing time \bar{T} to successive coop members in order of their index, until the constraint (A.3) is violated or satisfied with equality. If (A.3) is violated, let \hat{i} indicate the highest indexed member in this low indexed subset and assign this member a fishing time that satisfies (A.3) 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 to policy A 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 ϕ_i/γ_i , this alternative assignment would necessarily result in higher total cost. Therefore the assignment of fishing times in policy A is cost minimizing.

A.2 Proposition 2

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 from fishing at location d by $H(d; d_i, \gamma_i, T_i, i \in I, Z_I)$ and assume each independent takes it as given.⁴⁶ Independent h 's profit when the set I fishes independently is

$$\pi_h = H(d_h; d_i, \gamma_i, T_i, i \in I, Z_I) \gamma_h T_h - (\alpha + d_h - G(\sum_{i \in I} x_i)) \gamma_h T_h - \phi_h T_h - x_h. \quad (\text{A.4})$$

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 . This implies $T_h = T_I$ for all $h \in I$, i.e., all independents fish the entire time their season is open.

Independent h 's optimal public input contribution satisfies the first-order condition

$$G'(\sum_{i \in J} x_i) \gamma_h T_I \leq 1, \quad (\text{A.5})$$

where $x_h \geq 0$ and (A.5) holds with strict equality if $x_h > 0$. The left-hand and right-hand sides of (A.5) 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 γ parameters are distinct, if $G'(0) \gamma_{i^*} T_I > 1$ then the unique Nash equilibrium requires this harvester and only this

harvester to make a contribution; i^* 's contribution in this case satisfies (A.5) with equality.⁴⁷ Alternatively, if $G'(0)\gamma_i T_i \leq 1$ 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 $A(E, Z) \equiv Q/E = F(E/Z)/(E/Z)$. These functions are shown in Fig. A1 and their shapes are determined by the monotonicity and concavity of $F(\cdot)$. To meet the catch target the regulator fixes total independent effort according to Equation (3), at a level denoted κ_I . If all independents fish at the same distance, all obtain the same *average* catch per unit effort, $A(\kappa_I, Z)$, regardless of whether all fish inside or outside.⁴⁸ 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 fishes outside while all other independents fish inside, h 's catch per unit effort would be the marginal catch from the first unit of effort, $M(1)$ in Fig. A1.⁴⁹

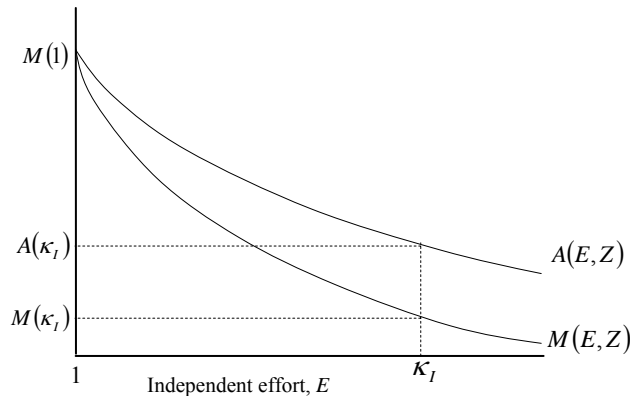


Fig. A1. Independent fisherman h 's catch per unit effort, depending on where other independents fish

If all independents are fishing outside, any individual who 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

⁴⁷ Given that (A.5) 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.

⁴⁸ We henceforth suppress the second argument in $A(\cdot)$ and $M(\cdot)$, since it remains unchanged.

⁴⁹ Fisherman h 's catch equals h 's catch per unit effort times the effort h applies, $\gamma_h T_h$. Catches from the same location will therefore differ among fishermen in proportion to their γ parameters.

profitable to deviate inside.⁵⁰ If Condition (i) holds, which is more likely when \bar{d} is small, the Nash equilibrium strategy profile in this subgame is unique and requires that all κ_I units of effort fish 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} , while 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 large, a Nash equilibrium in this subgame is unique and requires that all κ_I units of effort fish inside.⁵¹

Finally, suppose $A(\kappa_I) - M(\kappa_I) \leq \bar{d} \leq M(1) - A(\kappa_I)$ so neither condition holds. This implies that a Nash equilibrium strategy profile for the second stage subgame cannot have all effort fishing either inside or outside. We illustrate this case in Fig. A2. The horizontal axis now indicates *outside* effort and the dashed line $A(E) - \bar{d}$ shows outsider profit per unit effort. To characterize Nash equilibrium choices of distance, suppose all independent effort was initially fishing outside and successive units were transferred inside. The first unit transferred inside would earn profit $M(\kappa_I)$, shown by point c , which exceeds the profit from fishing outside. Transferring successive effort units inside causes insider profit per unit effort to increase toward point a , at which point all effort is fishing inside and profit per unit effort equals $A(\kappa_I)$. The dot-dash line labeled ‘insider profit’ traces out one possible locus of insider profits.⁵² 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.⁵³ Accordingly, a Nash equilibrium strategy profile in this case is described by this division of inside and outside fishing.

⁵⁰ The common cost term $\phi_h T_I$, which appears in both profit comparisons, has been ignored.

⁵¹ In both cases, uniqueness follows from concavity of $F(\cdot)$. Details are available on request.

⁵² It can be shown that the dot-dash line is monotone and continuous.

⁵³ Fig. 3 is drawn so these curves only cross once; we have not excluded the possibility that they cross more than once.

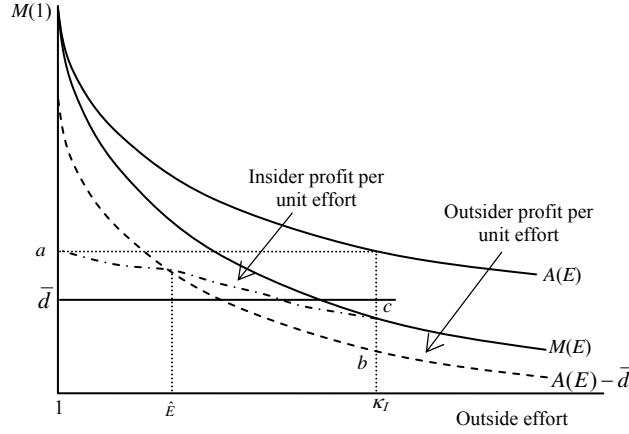


Fig. A2. A NE strategy profile in which some independents fish outside while others fish inside.

A.3 Proposition 3

First, we demonstrate that larger coops formed by adding successively higher skill members necessarily have higher profit per member. Writing out the coop's profit share equation and incorporating its optimal policy choices and the regulator's TAC assignment yields

$$\pi_J(J) = \frac{Z}{n(K)} (\beta - \alpha F^{-1}(\beta)) + \frac{1}{n(J)} \left\{ G(x_J^*) F^{-1}(\beta) \frac{Zn(J)}{n(K)} - x_J^* \right\} - \frac{1}{n(J)} \sum_{i \in J_{\min}} \phi_i \bar{T} \quad (\text{A.6})$$

where J_{\min} indicates the set of coop members selected to fish and x_J^* is the coop's optimal public input contribution. The rhs consists of three components. The first is catch per member minus the common cost term involving a . Given the TAC allocation formula, this does not depend on coop size. The second component is the coop's maximal net public good benefit per member, which necessarily is increasing in $n(J)$.⁵⁴ The third component is the opportunity cost of time spent fishing divided by the number of coop members; it decreases with coop size for the following reason. If a new member is added the TAC allocation rule causes a proportionate increase in the coop's effort, so effort per member remains unchanged. Consequently, the effect of a new member on the third component in (A.6) coincides with the new member's effect on the coop's *average* time cost per unit effort. Given the order in which members are added, 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 coop's average time cost per unit effort falls.

⁵⁴ A demonstration of this is available on request.

Next, we explore the effect of a larger independent fleet on the profit to the marginal independent. To simplify, we assume the independent fleet's equilibrium public input provision is 0, which is always approximately true. 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 into Equation (A.6), independent harvester h 's profit in the case where all independents fish outside is

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

which we write as

$$\pi_h(I) = \left\{ \frac{\beta}{F^{-1}(\beta)} - \alpha - \bar{d} - \frac{\phi_h}{\gamma_h} \right\} \gamma_h T_I. \quad (\text{A.7})$$

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 (A.7) 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.⁵⁵

The dashed line $\pi_m(\gamma_i)$ in Fig. 1 in the text 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 in the text, a 1 member coop'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 coop, indicating that the highest skilled fisherman could earn more by fishing as a lone independent than by joining an all-inclusive coop, but this is not

⁵⁵ 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.

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 coop joiners from independents. In Fig. 1 the threshold is index value e , referring to a fisherman with skill level γ_e . If all harvesters with skill less than or equal to γ_e are in the coop then: (i) all those in the coop earn $\pi_c(\gamma_e)$, which exceeds what they would earn by fishing independently, and (ii) all those who fish independently earn more than they would in the coop since $\pi_m(\gamma_i) > \pi_c(\gamma_e) \forall i > e$.⁵⁶ This allocation of fishermen to groups, together with Nash equilibrium strategy profiles in stage 2, is therefore a subgame perfect Nash equilibrium. If $\pi_m(\gamma_i)$ lies entirely below $\pi_c(\gamma_i)$, the allocation in which all harvesters join the coop is the only Nash equilibrium. If the two curves cross more than once, there is 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; by definition highliners compete most successfully in the race to fish and joining the coop would necessitate sharing their harvest profits with less skilled fishermen.⁵⁷

A.4. Proposition 4

In a completely independent fishery (i.e. if the coop were not allowed to form), h would earn the following profit from independent fishing:

$$\tilde{\pi}_h = \left(\frac{\beta}{F^{-1}(\beta)} - \alpha - \bar{d} - \frac{\phi_h}{\gamma_h} \right) \gamma_h \tilde{T}, \quad (\text{A.8})$$

where \tilde{T} is the season length in the absence of a cooperative, given by: $\tilde{T} = ZF^{-1}(\beta) / \sum_{\forall i} \gamma_i$.

When the voluntary cooperative is allowed to form, h 's profit depends on whether he/she decides to join or to fish independently. Suppose h chooses to fish in the independent fleet. The resulting profit is:

⁵⁶ We assume a fisherman joins the coop if profits from the two choices are equal. The condition stated in the text is equivalent to the internal and external stability conditions for cartel formation developed by d'Aspremont, et al. (1983).

⁵⁷ 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 from greater skill.

$$\pi_h = \left(\frac{\beta}{F^{-1}(\beta)} - \alpha - \bar{d} - \frac{\phi_h}{\gamma_h} \right) \gamma_h T_I, \quad (\text{A.9})$$

Here, T_I is the season length for the independent fleet, given by $T_I = Z_I F^{-1}(\beta) / \sum_{i \in I} \gamma_i$. The stock assignment Z_I depends on the allocation rule as follows: $Z_I = \left((1 - \theta) + \theta \frac{n(I)}{n(K)} \right) Z$. Fisherman h gains from the coop's formation if $\tilde{\pi}_h < \pi_h$, and loses if $\tilde{\pi}_h > \pi_h$, which clearly depends on the allocation parameter θ . Setting the right-hand sides of equations (A.8) and (A.9) equal, we can solve for the critical parameter value, θ_c , that yields the same profit for independent fisherman h regardless of whether the coop forms:

$$\theta_c = \frac{\sum_{i \in J} \gamma_i / n(J)}{\sum_{\forall i} \gamma_i / n(K)}. \quad (\text{A.10})$$

where J is the set who would join.⁵⁸ The rhs of (A.10) is the ratio of average skill for those who would join to the average skill of all fishermen. By Proposition 3, joiners have below-average skill, so $\theta_c < 1$. Those who would choose to fish as independents are disadvantaged by allowing the coop to form if $\theta > \theta_c$ and they are advantaged if $\theta < \theta_c$.

Next, consider the fate of those who opt to join the cooperative if it is allowed to form. Proposition 3 indicates that these individuals are apt to be the lower skilled members of the fleet. Because they coordinate on fishing location and public goods provision (both of which lower costs) their calculus is somewhat different, but it still hinges on how θ compares to θ_c .

If $\theta > \theta_c$, the most skilled members of the cooperative are actually disadvantaged by the fact that it forms. Consider the most highly skilled joiner. In the limit, if the number of fishermen is large this individual earns the same profit as the least skilled independent. We established above that all independents are strictly worse off in the presence of the cooperative when $\theta > \theta_c$, so the same is true for the highest skill joiner.

⁵⁸ In a situation where all are fishing the same amount of time per season, as was the case with independent fishing before the coop was allowed to form, this ratio would equal the ratio of average catches for coop joiners to the average catch for the entire fleet. It follows that the critical parameter θ_c can be estimated from information on average catch shares of joiners and independents in a pre-coop period.

We next show that if $\theta = \theta_c$, a cooperative still forms and all who join are made better off by the opportunity to join. A sufficient condition for the formation of a cooperative is that the lowest-skill fisherman can earn higher profit by forming a one-person cooperative than by fishing in a completely independent fishery. Revenue in the two situations is the same when $\theta = \theta_c$ because a one person cooperative's catch allocation equals what the individual would have caught by completely independent fishing. Cost for the one person cooperative is lower than with independent fishing, however, because the cooperative coordinates on fishing location; so this individual would benefit by forming a one-person coop. How does the highest skill joiner in a multi-person coop fare? Given the decision to join, this person's profit as a coop member is at least as great as what he/she could have earned by opting into the independent fleet. In turn, since $\theta = \theta_c$ the profit that would have been earned by choosing to fish as an independent equals what this individual would have earned in a completely independent fishery. Thus, all joiners are at least weakly advantaged by the ability to join a cooperative.

Finally, if $\theta < \theta_c$ a cooperative may or may not form. Clearly, if θ is sufficiently near zero the loss from a low catch allocation more than offsets the gains from coordination for a coop of any size, so no coop will form. Let $\theta_L < \theta_c$ be the lowest value of θ for which a cooperative of some size will form. Then for θ values in the interval $\theta_L \leq \theta < \theta_c$ a cooperative forms and all fishermen, including independents and joiners, benefit from its formation. To see this, first note that if the independent fleet contains $N(I)$ fishers, then even the least skilled of these individuals is advantaged by coop's formation because an allocation satisfying $\theta < \theta_c$ advantages those who opt into the independent fleet. Next, consider the highest skilled joiner. Given the decision to join, the individual's coop profit necessarily exceeds what he/she could have earned by opting into the independent fleet. This potential independent fleet profit, in turn, necessarily exceeds what he/she would have earned in a completely independent fishery because $\theta < \theta_c$. Therefore the highest skilled joiner is better off from the coop's formation. All lower-skilled joiners earn the same profit as the highest skilled joiner and would have earned less in a completely independent fishery, so they are all advantaged as well.