Information Sharing and Cooperative Search in Fisheries

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Abstract

We present a dynamic game of search and learning by fishermen who seek the true location of a partially observable fish stock. Bayesian Nash equilibrium search patterns for non-cooperating fishermen and members of an information sharing cooperative are compared with first-best outcomes. Independent fishermen do not internalize the full value of information and do not replicate first-best search. A fishing cooperative faces a free-riding problem as each member prefers another undertake costly search for information. Contractual agreements among coop members may mitigate, but not likely eliminate free-riding. Our results explain why information sharing is rare in fisheries and offer guidance for improving fishery management.

Keywords: Search, Information sharing, Dynamic Bayesian game, Fishing cooperative
JEL codes: Q22, D8

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1 Introduction

Fishermen do not freely share valuable information. Anthropologists describe instead a culture of secrecy and deceit where fishermen share only *coarse* (nondescript) information about the location of productive fishing sites (Palmer (1990), Gatewood (1984), and Andersen (1980)). Economists, on the other hand, have argued that information sharing can increase harvest productivity, avoiding redundant search and costly congestion on the fishing grounds (Costello and Polasky (2008), Wilen and Richardson (2008), Costello and Deacon (2007), and Wilson (1990)). Carpenter and Seki (2005) present empirical evidence of increased catch rates among Japanese shrimp fishermen who share information, relative to their non-cooperating counterparts.[1] The two literatures present a puzzle: if information sharing is beneficial, why is it rare in the fishery? We wish to answer this question for more than curiosity sake. First, understanding the motivation and possible barriers to information sharing may suggest policies that can harness the accompanying economic benefits suggested by economists. Second, the role of fishing cooperatives has gained new importance in the design of fisheries management policy in the U.S. and elsewhere. Fishing cooperatives are viewed as one method to enhance property rights in fisheries and address common pool inefficiencies that plague fisheries resources. Understanding information exchange and coordination within a fishing cooperative is important for designing effective cooperative management programs.

We develop a simple model of a dynamic fishing game and examine the incentives for fishermen to undertake costly search, and share information. We compare Bayesian Nash equilibrium information acquisition under alternative institutional structures ranging from independent fishermen to a stylized fishing cooperative that utilizes simple contracts to coordinate the activities of its members. Outcomes under each alternative are compared to first-best search. We investigate the importance of cooperation, risk preferences, and internal governance on search and learning. Our results demonstrate the conditions under which independent fishermen and a fishing cooperative can be expected to replicate first-best outcomes.

Our results show that the benefits from information sharing are largest when learning is relatively complete, when congestion penalties are large, when information transmission among fishermen is costless, and when information about the true location of productive fishing sites does not quickly decay. A less obvious finding is the importance of free-riding. Our model emphasizes the role of active and costly information acquisition by fishermen. Steaming to an uncertain fishing site to learn about its true productivity utilizes fuel, labor and bait, and importantly, implies time lost fishing at some other site. Once acquired, information is an excludable and non-rival good, or club good. To prevent free-riding, an information sharing group must distribute informational rents among its members, while maintaining incentives to undertake costly search for fish. We show how the extent of the free-riding problem depends on the contract used to divide information acquisition costs and information rents among cooperative members. Devising contracts that result in optimal investment

[1] The potential gains of cooperation by fishermen have been recognized in U.S. fisheries management legislation. The Fisheries Collective Marketing Act (FCMA) of 1934 and the American Fisheries Act of 1998 allow the formation of fishing cooperatives. For a deeper discussion see Kitts and Edwards (2003).

in information may be particular challenging in fisheries, due to the club good characteristic of information, its costly acquisition, and the common property nature of the fishery resource.

Our results provide an explanation for the paucity of information sharing and coordinating efforts in fisheries, and provide important insights for regulators. The 1998 American Fisheries Act facilitates use of fishing cooperatives as a measure of addressing common pool inefficiencies that plague commercial fishery resources. Fishing cooperatives are now established in several U.S. fisheries.[2] An often cited benefit of cooperatives, one that is undocumented but regularly assumed, is that of free information exchange among members. For example, problems related to bycatch of undesirable or threatened stocks, may be reduced if cooperating fishermen warn colleagues when and where a non-target stock is present.[3] Our results suggest that policies based on presumption of free information flows among fishing coop members may fail to reduce bycatch, or address related management problems. We show which obstacles must be overcome before the information sharing benefits of fishing cooperatives will materialize.

Our paper is organized as follows. The next section presents further background on information sharing in fisheries. Section 3 presents our model and derives Bayesian Nash equilibrium outcomes. Section 4 summarizes the key findings and policy implications, and discusses extensions.

2 Background

Multiple theories have been offered for why fishermen may or may not share information. Wilson (1990) suggests fishermen discover productive fishing sites by chance and must then decide whether or not to divulge their location with members of a fishing *club*. He suggests information will be shared if the cost of doing so is not "too large". That is, when the number of club members is small, when club members have small catching capacity, and when transaction costs accompanying information transmission are small. Wilson suggests further that the benefits of joining the information sharing club increase when club members are equally skilled at finding fish and therefore are likely to reciprocate with valuable information at some future date. The anthropology literature offers similar explanations for information sharing. Palmer (1990), Gatewood (1984), Orbach (1977), and others suggest fishermen will be more secretive, when the direct cost of disclosing information is high.[4]

[2]According to U.S. Department of Agriculture (2009), there were 37 fishing cooperatives operating in the U.S. in 2009.

[3]Management problems, ranging from bycatch, to the design of marine protected areas, have been linked to problems of information acquisition and information sharing in fisheries (Abbott and Wilen (2010), Marcoul and Weninger (2008), Costello and Deacon (2007), and Curtis and McConnell (2004)). North Pacific Fishery Management Council (2011) discuss the use of fishing cooperatives in the Gulf of Alaska Pollock fishery to reduce incidental catch of Chinook salmon stating, cooperatives will "facilitate *information sharing and fleet coordination* that could be important to achieving Chinook avoidance" (pp. 3, emphasis added). Amendment 16 to the Northeast Multispecies Fisheries Management Plan, pushes for expansion of the use of fishing cooperatives (New England Fishery Management Council (2010)).

[4]Palmer (1990) finds that radio transmissions of Maine lobster fishermen convey detailed information about lobster size and fishing locations during pre-molting periods when lobster are hidden in rocks and less

Information sharing and coordination is considered to be profitable. Costello and Deacon (2007) suggest joining an information sharing group can prevent redundant search undertaken by independent fishermen (see also Wilson (1990)). A coalition of fishermen, may benefit from specialization with one or more members carrying out search activities while others specialize in harvesting fish. Another motive for coordinating fishing activities is to avoid congestion costs that arise when multiple fishermen visit the same fishing site (MacCall (1990)).

A common theme in previous literature is that of quid pro quo in information sharing; the hypothesis is that fishermen will voluntarily disclose information if and only if they receive something in return. But the criteria for forming an information sharing group must be more stringent. If there is to be a net expected gain from joining, it must be the case that expected profits per club member exceed the expected profits when fishermen act alone, i.e., there must be a return to scale in information gathering, or alternatively, an information synergy.[5]

Previous literature has assumed fishermen are myopic, passive learners (Costello and Deacon (2007), Lynham (2006), and Smith (2000)). This behavioral assumption precludes costly investment in information and overlooks the free-riding problem. Researchers tend also to ignore the internal governance structure of a fishing cooperative, and instead assume that the incentives of individual cooperative members become fully aligned after joining a fishing coop. Without this potential source of friction, behavior of the cooperative coincides with that of as single operator of a firm, in other words, first-best outcomes are assumed rather than tested. Third, models of active search and learning have featured risk neutral preferences (Marcoul and Weninger (2008) and Mangel and Clark (1986)). The model introduced next relaxes these assumptions.

3 Model

Our model features three key elements: uncertainty over true payoffs at competing fishing locations, the opportunity to actively learn about true productivity, and site congestion costs.

We introduce a two-period game played by two risk neutral fishermen who select from among two distinct fishing locations, or sites (risk aversion is introduced later). A subscript j distinguishes the site. To reduce notation, we present the model from the perspective of an arbitrary player and place a check above variables associated with this players counterpart.

accessible to trap gear, i.e., information is shared when it has little value.

[5] Gatewood (1984) identifies an example of such a synergy in the Alaskan purse seine fishery, where managers tightly control the length of openings. The author notes that “While it is true that one boat can scout as wide an area in four days as four boats can in one day, the utility of the information collected by the four boats scouting the day before the opening is much greater, provided they share what each has observed” (pp. 362). It is important to note that the information gathering setting for salmon seiner’s differs from the one that is modeled in this paper.

A prime is used to distinguish one-period ahead values.

The sequence of events in the fishing game is as follows. Fishermen choose a fishing site at date t_0 based on their belief about true but uncertain payoffs at each available site. Payoffs are uncertain due to unobserved true stock abundance, random weather, tides, etc. A fished site yields a first-fishing-period payoff realization. Fishermen then exploit the information contained in the first payoff to update beliefs about true payoffs at the fished site. A second site choice is made at date t_1 yielding a second-fishing-period payoff realization.

Payoff uncertainty is modeled as random beliefs about true payoffs. Beliefs are represented as a normal distribution. For our representative fishermen, current beliefs about the true payoffs are summarized with parameters, $\{\mu_1, \nu_1, \mu_2, \nu_2\}$ where μ_j denotes the mean payoff and ν_j denotes payoff variance at site j. Current beliefs of the opponent fisherman are $\{\breve{\mu}_1, \breve{\nu}_1, \breve{\mu}_2, \breve{\nu}_2\}$

The payoff realization from fishing at site j is,

$$s_j = u_j + \epsilon_j$$

where u_j is the unobservable true payoff and ϵ_j is a random term. We assume the distribution of ϵ_j is known; $\epsilon_j \sim N(0, \nu_s)$, where $\nu_s > 0$ denotes signal variance. Signal noise and therefore payoffs are independently distributed across sites. Realized payoffs are used to update beliefs about the true payoff distribution following Bayes' rule. Updating formulas are presented in A.

Player's choose a single site in each period. We use $a \in [0, 1]$ to denote the probability that site 1 is chosen by the representative fisherman. We assume fishing at some site is always preferred to not fishing at all and therefore the probability site 2 is fished is $1 - a$. Mixed strategies are permitted.

Second period payoffs are discounted by a factor $\delta \in [0, 1]$, assumed common across fishermen. Our analysis will feature the extremes of no discounting and myopic fishermen, $\delta = 1$, and $\delta = 0$, respectively. The impact of $\delta \in (0, 1)$ is considered in a numerical example later.

Lastly, we assume a fixed, common congestion penalty, denoted $\kappa \geq 0$, which denotes the amount each players payoffs is reduced when both select the same site during a fishing period.

Each fisherman understands that fishing a site provides information that guides future site choices, although myopic fishermen will ignore this fact when selecting sites. A component of the value from visiting a site is the information contained in a realized payoff signal. Much of the analysis that follows will focus on decisions to undergo costly information acquisition. We use the terminology *investment in information* to distinguish a site choice that yields a lower expected payoff than the alternative site, but high information value. If $\mu_i > \mu_j$ and site j is part of an optimal fishing strategy, it must be the case that the value of information from fishing at site j is expected to offset the cost of collecting the catch signal, which is the foregone expected payoff, $\mu_i - \mu_j > 0$.

Site choices are based on *beliefs* about true fishing payoffs and the strategy played by the rival fisherman. Payoffs at a site are increasing in own beliefs about true payoff and non-increasing the likelihood, a conjecture, that the rival will fish at the same site. Conjectures depend on *beliefs about the beliefs*, which is a standard feature of Bayesian games.

3.1 First-best

To characterize first-best site choices, we imagine a situation where a single manager directs each fisherman to a specific site in each period with the goal of maximizing cumulative two-period, two-fishermen expected profit. The site choice problem is solved recursively. At t_1, two payoff signals are available under three possible first-period scenarios: both fishermen fished site 1, both fished at site 2, and each fished a different site. We solve the first-best policy and payoffs for the case where both fishermen fished site 1. Analysis of remaining cases follows analogously and to conserve space is not repeated.

At t_1 the manager compares expected payoffs for each site choice combination based on current (updated) beliefs. The optimal policy takes a simple form,

$$\begin{array}{ll} a = \check{a} = 1 & \text{if } \mu_1 - 2\kappa > \mu_2 \\ a = \check{a} = 0 & \text{if } \mu_1 < \mu_2 - 2\kappa \\ a = 1,\ \check{a} = 0 & \quad \text{otherwise} \end{array} \tag{1}$$

It is convenient to express the above policy in terms of realized signals. Updated beliefs are linear functions of signals equation (1) and therefore easily inverted. We divide site 1 signals into mutually exclusive subsets:

$$\begin{array}{rl} S_{11} = & \{(s_1, \check{s}_1)|\ \mu_1 - 2\kappa > \mu_2\} \\ S_{22} = & \{(s_1, \check{s}_1)|\ \mu_1 < \mu_2 - 2\kappa\} \\ S_{12} = & \{(s_1, \check{s}_1) \notin S_{11} \cup S_{22}\}\,. \end{array} \tag{2}$$

The expected payoffs for the two fishermen can then be written as,

$$v^*(s_1, \check{s}_1) = \begin{cases} 2\mu_1 - 2\kappa & \text{if } (s_1, \check{s}_1) \in S_{11} \\ 2\mu_2 - 2\kappa & \text{if } (s_1, \check{s}_1) \in S_{22} \\ \mu_1 + \mu_2 & \text{if } (s_1, \check{s}_1) \in S_{12} \end{cases}$$

where the conditional dependence of beliefs on the observed signals $(s_1, \check{s}_1)$ is dropped to conserve space. In the above expression $v^*(s_1, \check{s}_1)$ denotes the optimal aggregate, two-fisherman expected payoff, conditional on having obtained signals $(s_1, \check{s}_1)$ in the first fishing period.

Now step back to the date t_0 site choice problem. Let $V^*(i, \check{j})$ denote the two-period expected payoff from sending one fisherman to site i and the other to site j in the first period. Sending both to site 1 yields,

$$V^*(1,\check{1}) = 2\mu_1 - 2\kappa + \delta E_{s_1,\check{s}_1|\mu_1,\nu_1}[v^{*\prime}(s_1,\check{s}_1)],$$

where $E_{s_1,\check{s}_1|\mu_1,\nu_1}$ is the expectations operator conditional on t_0 beliefs. Similarly, we have,

$$V^*(2,\check{2}) = 2\mu_2 - 2\kappa + \delta E[v^{*\prime}(s_2,\check{s}_2)]$$
$$V^*(1,\check{2}) = \mu_1 + \mu_2 + \delta E[v^{*\prime}(s_1,\check{s}_2)].$$

In the above and hereafter we use $E = E_{s_j,\check{s}_j|\mu_j,\nu_j}$ to denote the conditional expectations operator.

The first-best expected payoff is then,

$$V^* = \max\left\{V^*(i,\check{j})\right\} \quad i,\ j = 1,2.$$

There are features of first-best site choices and payoffs worth noting. Suppose $\mu_1 > \mu_2$. The manager will *invest* in one signal from site 2 if and only if $V^*(1,\check{2}) > V^*(1,\check{1})$ and $V^*(1,\check{2}) > V^*(2,\check{2})$. By manipulating these expressions we can derive a bound on the investment cost for which sending one fisherman to uncertain site 2 is optimal:

$$\delta\Big\{E[v^{*\prime}(s_2,\check{s}_2)] - E[v^{*\prime}(s_1,\check{s}_2)]\Big\} - \kappa < \mu_1 - \mu_2 < \delta\Big\{E[v^{*\prime}(s_1,\check{s}_2)] - E[v^{*\prime}(s_1,\check{s}_1)]\Big\} + \kappa. \quad (3)$$

The expression in (3) indicates that one signal will be collected when the investment cost is bound between the discounted total expected net gain from the collecting a second signal at a site. Two signals are warranted if and only if the added cost is less than the discounted total expected gain from more information. We see that the full costs and benefits of information are internalized. If $\delta = 0$, myopic decision making, no investments in information are undertaken. Lastly, congestion $\kappa > 0$ expands the belief space for which a single investment in information is optimal.

3.2 Independent fishermen

We assume independent fishermen choose sites simultaneously and non-cooperatively. At date t_1 each observes the site that was fished by his counterpart in the first fishing period. We assume the realized payoff is private information. To solve the model, we must specify what each fisherman believes about the beliefs of his counterpart. Suppose for a moment fishermen believe they have different beliefs at t_0. In this case, each must then believe his counterpart holds biased beliefs. If not, his own beliefs should be updated to incorporate the unbiased information. While our model can accommodate different initial beliefs, a motivation for non-congruent initial beliefs is not obvious. We therefore solve for a symmetric perfect Bayesian Nash equilibrium assuming common beliefs at date t_0. As above the site choice problem is solved recursively.

Suppose our representative fisherman chose site j in the first fishing period. Consider the following date t_1 strategy profile,

$$\begin{cases} \text{fish site } i & \text{if } s_j < s^L \\ a \in (0,1) & \text{if } s^L \leq s_j \leq s^U \\ \text{fish site } j & \text{if } s_j > s^U. \end{cases} \tag{4}$$

We assume both fishermen play similar strategies. In the above expression s^L and s^U demarcate regions of the signal space and can be explained with the help of an example. Suppose both fishermen fished site 1 in the first period. A fisherman who receives a high payoff at site 1 may favor at return trip. However, if both fishermen fished site 1 each must deduce that his opponent likely also received a high payoff, and is therefore also likely to return in the second fishing period. This will result in congestion and a reduced payoffs. The upper threshold s^U is the payoff that is sufficiently large such that the representative fisherman is indifferent between returning to site 1 as a pure strategy and adopting a mixed strategy. In other words, a sufficiently high payoff from site 1 will lead to a return trip regardless of impending congestion cost. As intuition would suggest, s^U is a non-decreasing function of congestion cost, κ.

By similar arguments, a particularly low signal from site 1 favors a switch to site 2 in the second period. s^L is the threshold signal at which the representative fisherman is just indifferent between switching sites as a pure strategy and adopting a mixed strategy. Upon receiving an intermediate payoff, the fisherman must deduce that his counterpart likely also received an intermediate payoff. Updated beliefs of both fishermen then suggest that congestion is likely and therefore a mixed strategy is played.

The profile in equation (4) determines the period 2 site choice for all possible first period signals. The expected payoff at t_1, conditional on both fishermen fishing site 1 in the first period, is given as,

$$v(s_1, E[\check{s}_1]) = \begin{cases} \mu_1 - \check{a}\kappa & \text{if } s_1 > s^U \\ \mu_2 - (1-\check{a})\kappa & \text{if } s_1 < s^L \\ a(\mu_1 - \check{a}\kappa) + (1-a)(\mu_2 - (1-\check{a})\kappa) & \text{if } s^L \leq s_1 \leq s^U \end{cases}$$

where the conditional dependence of beliefs on the observed signal s_1 is dropped to conserve space. As $\check{s}_1$ is the private information of the representative fisherman's counterpart, the term $E[\check{s}_1]$ in $v(\cdot)$ captures the representative fisherman's best belief about this private information based on his date t_1 Bayesian updated beliefs. Expected payoffs at t_1 for other first period site choice combinations are derived similarly.

We now step back and consider date t_0 choices. The strategy profile introduced above outlines a best response for all payoff realizations and allows us to determine the two-period expected payoff for all site choice strategies. As an example, suppose both fishermen select site 1 at t_0. The expected payoff for the representative fishermen is,

$$V(1, \check{1}) = \mu_1 - \kappa + \delta E\Big[v'(s_1, E[\check{s}_1])\Big] \tag{5}$$

The fisherman conditions his expected future payoffs on his best belief about the payoff signal observed by his rival. This knowledge is incorporated into his conjecture about the probable action of his rival in the second fishing period. The remaining cases are calculated similarly and take the form,

$$V(1,\check{2}) = \mu_1 + \delta E\Big[v'(s_1, E[\check{s}_2])\Big] \tag{6}$$

$$V(2,\check{1}) = \mu_2 + \delta E\Big[v'(s_2, E[\check{s}_1])\Big] \tag{7}$$

$$V(2,\check{2}) = \mu_2 - \kappa + \delta E\Big[v'(s_2, E[\check{s}_2])\Big] \tag{8}$$

Using the conditional expected payoffs in equations (5) − (8), we can construct a 2×2 normal form representation of the date $t = 0$ site choice game. The Perfect Bayesian Nash Equilibrium (PBNE) fishing strategy of this normal form game is,

$$a = \begin{cases} 1 & \text{if } V(1,\check{1}) > V(2,\check{1}) \text{ and } V(1,\check{2}) > V(2,\check{2}) \\ 0 & \text{if } V(2,\check{2}) > V(1,\check{2}) \text{ and } V(2,\check{1}) > V(1,\check{1}) \\ \frac{V(2,\check{2}) - V(1,\check{2})}{V(1,\check{1}) - V(2,\check{1}) + V(2,\check{2}) - V(1,\check{2})} & \text{otherwise} \end{cases}$$

The maximum expected payoff for an independent fisherman is given as,

$$V^I = a\Big[\check{a}V(1,\check{1}) + (1-\check{a})V(1,\check{2})\Big] + (1-a)\Big[\check{a}V(2,\check{1}) + (1-\check{a})V(2,\check{2})\Big]$$

3.3 Inefficiency of Independent Search

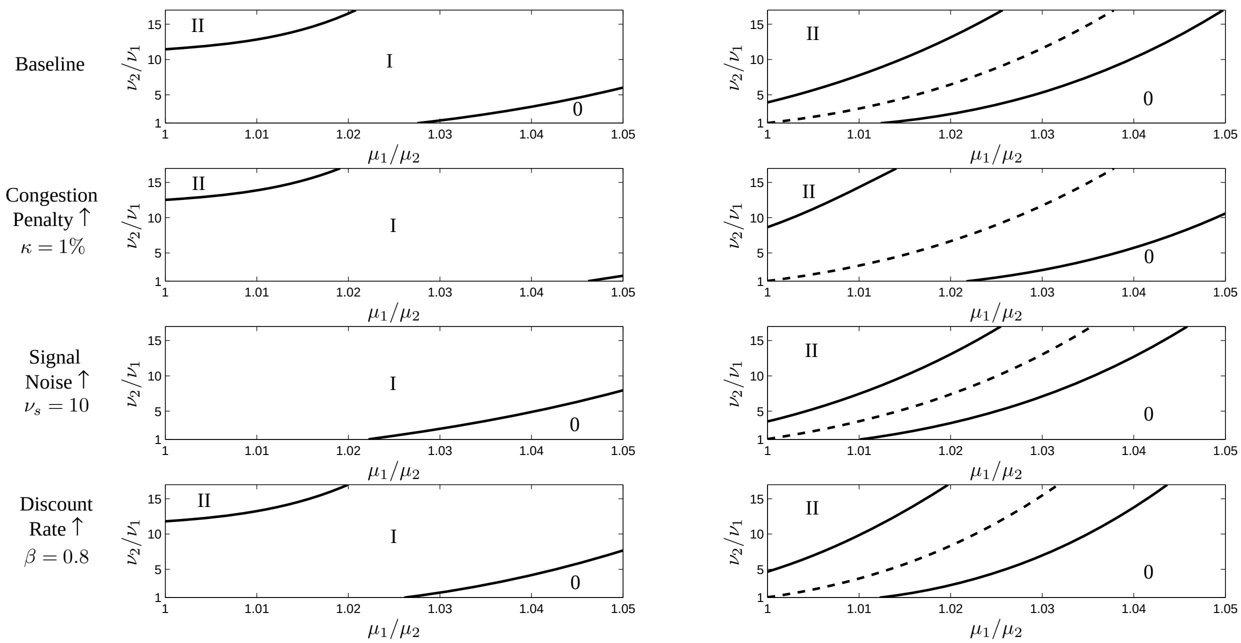
This section contrasts PBNE and first-best site choice strategies over a range of initial beliefs about payoffs. We characterize inefficient search, which takes the form of over- or under-investment in information by non-cooperating fishermen.

Figure 1 reports numerical solutions for the first-best (left-hand panels) and perfect Bayesian Nash equilibrium (PBNE) policies (right-hand panels), over a subset of the belief space. Beliefs for which a visit to site 2 implies an investment in information are featured. The top panels report results for the baseline calibration[6] Panels (c) and (d) report results for an increase in the congestion costs, panels (e) and (f) for an increase on the signal noise, and panels (g) and (h) for an increase in discount rate.

Units on the horizontal axis are the ratio of mean payoffs μ_1/μ_2. Units on the vertical axis are the ratio of payoff uncertainty at site 2 relative to site 1, ν_2/ν_1. Beliefs at the two sites are identical at the origin. Moving left to right raises the cost of investing in information at site 2 and moving vertically corresponds to higher uncertainty at site 2 and thus a potentially increased upside value of investing in information.

[6] We set $\mu_2 = 100$, $\nu_1 = 3$ and $\kappa = 0.5$. μ_1 is varied between 100 and 110; ν_2 ranges between 3 and 48. Payoff signal variance is $\nu_s = 2$.

Figure 1: Equilibrium Site Choices - Risk Neutrality



Marcoul and Weninger (2008) show in a single agent model that for a given investment cost there will exist a threshold payoff uncertainty at which an investment in information becomes optimal. The equilibrium policies in Figure 1 illustrate this feature of the site choice problem. We have separated the belief space into regions. In Region 0, no investments in information are made. Region I, in the first-best panels, denote beliefs for which a single investment in information is optimal. Finally, Region II contains the set of beliefs where the first-best policy sends two fishermen to site 2 to gather information. For non-cooperative fishermen we calculate total investments in information as the sum of the probability that an investment is made. Recall that independent fishermen play a mixed strategy over a fairly wide range of the belief space, and therefore under the PBNE strategy region I is shown as the dashed line. Mixed strategies are continuous in beliefs and therefore expected investments in information exceed unity for beliefs to the north and west of the dashed line are less than unity for beliefs to the south and east of the dashed line.

To gain some intuition for the results, examine the first-best policy under the baseline parameters (panel (a)). For beliefs in region II, both fishermen are sent to uncertain site 2 to gather information. This is optimal because the cost of collecting the information is low and the value of signals in terms of guiding second period site choice is high. As the cost of the information increases, moving left to right, or if uncertainty at site 2 is less, it is optimal to collect one signal from site 2. For beliefs in the south east region 0, no investments in information are made as the costs outweigh the benefits.

Next compare the first-best results in panel (a) and the PBNE results in panel (b). The location and shape of the boundaries that define intensity of information investment differ. Region II (two investments in information) is larger for non-cooperating fishermen, indicating over-investment in information relative to the first-best policy. The reason non-cooperating fishermen over-invest is because information, once gathered, is a public good that should be freely shared among the two fishermen. Because it is not in the independent case, redundant information and added cost are incurred, relative to the first-best. This result confirms the insights of Costello and Deacon (2007) who suggest non-cooperation can lead to excessive or redundant search, alternatively, cooperation can eliminate excessive or redundant search for fish.

Further comparison however reveals that beliefs exist for which independent fishermen under-invest in information relative to the first-best policy. Region 0 (no information investment) is larger under the PBNE policy than under the first-best policy. The reason is that independent fishermen each incur the cost of gathering information but do not share the benefit. When both fishermen benefit from information under the first-best, there exists a higher cost threshold at which information investment is optimal.

Panels (c) and (d) reveal that higher congestions costs shrink regions 0 and II, i.e, the belief space where both fishermen fish at the same site. Put another way, higher congestion costs expand the region of beliefs for which a single investment is optimal under the first-best policy. This results is not surprising since congesting a site is now more costly. Panels (e) and (f) show that less information investment is undertaken when catch signal noise increases, while results in panels (g) and (h), show that less investment occurs under a higher discount rate. Again an expected result. A comparison of the fist-best and PBNE policies reveals as above regions where non-cooperating fishermen over- and under-invest in information relative to the first-best policy.

3.4 Risk aversion

In this section we examine the effects of risk averse preferences on site choices. Assume preferences follow a negative exponential utility function,

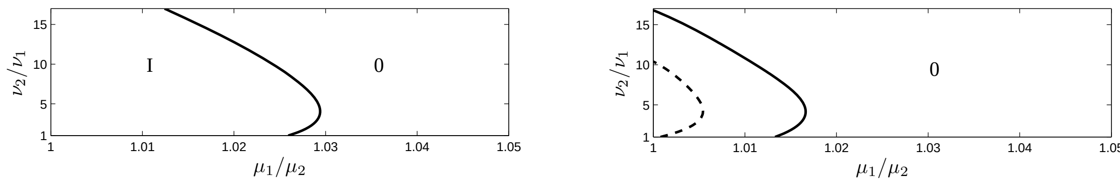
$$U(s) = 1 - \exp(-\lambda s)$$

where s is the realized payoff and $\lambda > 0$ is a risk preference parameter.[7]

As above suppose fisherman are have less information about the true payoff at site 2. A decision to gather information at an uncertain site now carries an added current period cost in the form of exposure to a risky payoff. On the other hand, with multiple fishing periods, active learning reduces uncertainty which reduces exposure to future risk. A first-period investment in information reduces payoff uncertainty in the second period in addition to providing information that guides site choice. The net effect of risk aversion on the demand

[7] The negative exponential function has several attractive properties. It exhibits constant absolute risk aversion. As $\lambda \to 0$ preferences are consistent with risk neutrality. Utility lies in the interval $(0, 1)$. Finally, simple expressions for expected utility exist.

Figure 2: Equilibrium Site Choices - Risk Aversion ($\lambda = 0.1$)



for information is therefore ambiguous in a dynamic setting (Freixas and Kihlstrom, 1984). Figure 2 reports the first-best and PBNE policies for a subset of beliefs under negative exponential utility ($\lambda = 0.1$) and the baseline parameters.[8] The units of the axes are unchanged, and hold the same meaning as above.

A first observation is that there is less investment in information under risk averse preferences. The results show at most a single visit to uncertain site 2 is made under the first-best policy. The maximum cost warranting an investment in information is 1.03, or a 3% reduction in the expected payoff. Independent fishermen are also less willing to expose themselves to risk; gathering information at site 2 is optimal over a smaller range of the belief space.

A second observation is non-monotonicity in the demand for information. At low levels of uncertainty, an increase in the cost of gathering information can be offset by an increase in information value. As payoff variance increases however the disutility associated with high risk payoffs outweigh information value. The boundary between regions of the belief space, which may be interpreted as payoff mean and variance indifference curves, becomes negatively sloped; fishermen are willing to expose themselves to high risk payoffs only if the utility cost of learning is small.

As with risk neutral preferences investments in information under the PBNE policy is inefficient. Relative the the first-best policy, independent fishermen over-invest in information in some regions of the belief space and under-invest in others.

3.5 Fishing cooperatives

In the first-best analysis above, fishermen are directed to sites by a fictitious manager. This construct ignores crucial characteristics that distinguish cooperatives from owner-investor firms. Two that are of particular relevance for costly information gathering are decision rights within the organization, and the residual claims on earnings. In this section we consider simple, but illustrative, examples of internal governance structures that might be operational in a real-world fishing cooperative. Our goal is to illustrate some key challenges

[8]First-best utility is calculated as $U = 1 - \exp(-\lambda(s + \check{s})$. Our selection of λ does not qualitatively change our results.

that must be overcome in fishing cooperatives before efficient search is achieved.[9]

In the context of our fishing problem, the right to decide which site is fished by individual cooperative members will have important welfare and efficiency implications. In what follows we do not consider a formal assignment of decision rights. Instead, we discuss, informally, the implications of decision rights such as majority rule or unanimous voting by cooperative members.

Suppose cooperative members are compensated for their fishing efforts under a piece-meal remuneration contract (McConnell and Price (2006)). Each fisherman receives a per-period payment, which we denote ω, plus a share, α, of the payoff realized at a fished site. Under this scheme, the expected single-period payoff from fishing are site j is,

$$\omega + \alpha\mu_j$$

Following some preliminary analysis we will consider a profit sharing arrangement where ω is determined by the aggregate payoffs earned by all cooperative members. This simple setup is general enough to capture egalitarian profit-sharing or full retention of the payoff at a site. We next show that a preference for exploitation over exploration will arise under a remuneration contract that allows fishermen to retain a disproportionate share of their realized fishing payoff.

3.5.1 Site choice in a fishing cooperative

Assume risk neutral members of a fishing cooperative share common initial beliefs about true payoffs at competing sites. Suppose beliefs satisfy $\mu_1 > \mu_2$ and $\nu_1 < \nu_2$. The cooperative fishermen are capable of solving for the first-best site choice policy and agree that the first-best policy yields the highest expected payoffs for the cooperative. What is less clear is the mechanism that determines where each coop member will fish, how payoffs are distributed, and which internal governance structure can implement the first-best site choice policy.

No tension will arise if the first-best policy sends both fishermen to the same site. We therefore focus on the case where it is optimal, under the first-best, to send one fisherman to each site in the first period. Suppose also that there is no congestion penalty. With no congestion costs, the period 2 payoffs will be the same for both fishermen since both will fish at the highest expected payoff site in period 2. Lastly, suppose ω is used to redistribute the total earnings back to cooperating fishermen, and that the coop balances its budget in each period. Each member retains an α share of his own fishing payoff. With two fishermen, the residual that is re-distributed (equally) to each member is $(1-\alpha)(s_1 + \check{s}_2)$.

[9] Our approach follows the "new institutional economics" viewpoint which emphasizes the role of transactions costs, property rights and agency relationships for understanding the organizational structure (Fama (1980), Williamson (1975), and Alchian and Demsetz (1972)). A comprehensive review of contracts that might be used to assign rights and residual claims within a fishing cooperative is beyond the scope of this paper. See Fama and Jensen (1983) for additional discussion of contracting in producer organizations.

In expectation, a cost $\mu_1 - \mu_2$ must be incurred to obtain information about site 2's true payoff. Our assumption for profit redistribution implies an expected wage,

$$\omega = \frac{(1-\alpha)}{2}(\mu_1 + \mu_2).$$

Simple algebra finds that the first period payoff for the fisherman who exploits the relatively certain site 1 is,

$$\frac{1}{2}(\mu_1 + \mu_2) + \frac{\alpha}{2}(\mu_1 - \mu_2), \tag{9}$$

whereas, the payoff for the fisherman who explores the uncertain site 2 is,

$$\frac{1}{2}(\mu_1 + \mu_2) - \frac{\alpha}{2}(\mu_1 - \mu_2). \tag{10}$$

These expressions simply illustrate that for $\alpha > 0$, coop members will prefer exploitation over exploration, i.e., each will prefer that some other member be responsible for investments in information.[10] Each coop member has an incentive to free-ride on the costly search efforts of others.

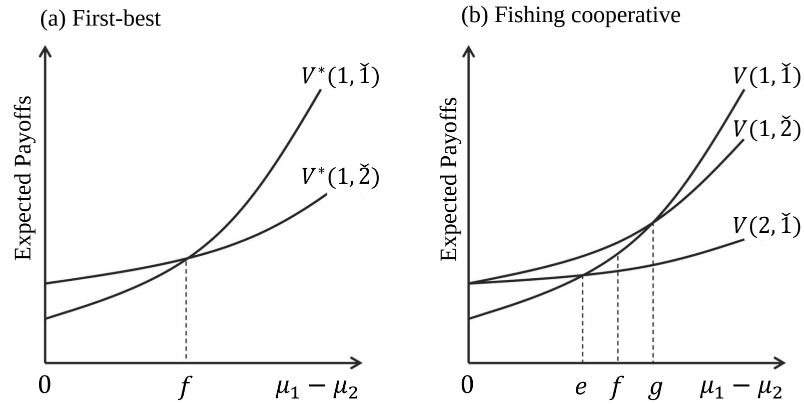
A broader question is how free-riding impedes the cooperative's ability to implement first-best site choices. The issue here is the extent to which the internal distribution of information rents and costs distort site choices. To demonstrate, Figure 3 shows the full expected payoffs under the first-best, and when remuneration follows a piece-meal contract with $\alpha > 0$. Uncertainty is fixed, with $\nu_1 < \nu_2$. Units on the horizontal axis are $\mu_1 - \mu_2$ which increase moving left to right. As above, the cost of gathering information at uncertain site 2 increases moving left to right in the figure, but now the cost increases are in absolute terms.

Panel (a) in Figure 3 reports the first-best two-period expected payoffs to the cooperative for different first period site choices. These curves are, respectively, the expected payoff from sending both fishermen to site 1 and sending one fishermen to site 2 to gather information. The first-best policy is determined by the maximum of $V^*(1, \check{1})$ and $V^*(1, \check{2})$. For investment costs below f, i.e., beliefs for which the perceived cost of collecting information from uncertain site 2 is not too large, it is optimal under the first best policy to send one fishermen to site 2.

Panel (b) depicts expected payoffs under a piece-meal contract with $\alpha > 0$. Following our notational convention $V(1, \check{1})$ is the two-period expected payoff for the representative fisherman when both fish at site 1. $V(2, \check{1})$ is the two-period expected payoff if the representative fisherman visits uncertain site 2 and $V(1, \check{2})$ denotes his two-period expected payoff if the counterpart visits the uncertain site in the first fishing period. Given the symmetry of beliefs, the two-period expected payoffs to the counterpart are identical. Panel (b) clearly illustrates

[10] This holds under risk aversion as well. Let $\pi_{12} = \frac{1}{2}(s_1 + \check{s}_2) + \frac{\alpha}{2}(s_1 - \check{s}_2)$ and $\pi_{12} = \frac{1}{2}(s_1 + \check{s}_2) - \frac{\alpha}{2}(s_1 - \check{s}_2)$. π_{12} and π_{21} are random variables. Using the convolution of s_1 and $\check{s}_2$ we can derive the mean and variance for these random payoffs and compute the corresponding expected utilities. Given our assumptions on beliefs, $E[\pi_{12}] > E[\pi_{21}]$ and $Var[\pi_{12}] < Var[\pi_{21}]$, which imply $EU[\pi_{12}] > EU[\pi_{21}]$.

Figure 3: Conditional Two-Period Expected Payoffs



the source of internal conflict within the cooperative. The exploiting fisherman benefits from an investment in information for investment costs are below g, and is likely to support a policy that sends some other fisherman to site 2. The fisherman assigned to explore the uncertain site will be willing to do so only for investment costs in the range 0 to e. Further calculations reveal,

$$e = \frac{f}{1+\alpha} \quad \text{and} \quad g = \frac{f}{1-\alpha},$$

which demonstrate a clear trade-off between a performance-based remuneration and potential internal conflict over site choice. Whether this conflict leads to inefficient search will depend on the specific decision rights used to direct members to alternate sites and the size of the fishing cooperative. Suppose there are more than two fishermen in the cooperative. If, for example site choices are determined by a 50% majority vote of cooperating fishermen, investments in information with costs in the range e to g would be determined democratically; a potential over-investment in information will occur for perceived investment cost between f and g. If, alternatively, all cooperative fishermen must agree on the site choice plan, i.e., exploration may occur only for costs in the range 0 to e in Figure 3. In either case, site choices determined by voting rights can diverge from the first-best plan. Of course, this will result in lower total payoffs than under the first-best.

Can the piece-meal contract be modified to remedy the free-riding problem? Suppose for example a fee is charged to fishermen who are the net beneficiaries of investments in information, and a subsidy is paid to fishermen who bear the burden of costly search. In order for fishermen to be indifferent between exploration and exploitation, the first-period remuneration must be equalized. From equations (9) and (10) we find that the fee collected from the exploiting fishermen and transferred to the exploring fishermen must fully offset the retained profits at each fishing site. In other words, the fee and subsidy must counter the effect of the residual claim on realized fishing payoffs. A system of fees and subsidies that removes the free-riding problem and reproduces the first-best must correspond to the case of $\alpha = 0$, i.e., fishermen remuneration is independent of the realized fishing payoffs at the sites at which they fish.

Similar insights obtain under alternate parameterizations of the model, and under risk averse preferences. Internal disagreement over site choices, driven by the incentive to free ride will affect the site choice and ultimately catch performance of a fishing cooperative. Congestions costs, signal noise, discount rates and risk preferences will affect level of disagree, along with the form of contract used to distribute fishing profits among coop members.

4 Conclusions

We have introduced a dynamic game of information sharing in a fishery with incomplete information about payoffs at competing fishing sites. We contrast first-best and non-cooperative site choice policies under various model parameters and risk preferences. We show that privately optimal investments in information by non-cooperating fishermen diverge from first-best investment over a range of beliefs about true payoffs at competing sites. Our results confirm that non-cooperating fishermen engage in redundant and inefficient search over a subset of the belief space (Costello and Deacon (2007)). Non-cooperating fishermen under-invest in information relative to the first-best in other regions of the belief space. The simple intuition for the divergence between the Perfect Bayesian Nash Equilibrium policies we study and first-best outcomes is that information, once collected, is a public good that should be made available to all fishermen. When information value is shared among multiple fishermen, as in our first-best scenario, a lower benefit threshold is required before costly information gathering proceeds.

Our analysis shows that while fishermen can benefit from sharing information about productive fishing sites and coordinating site choices to avoid congestion, free-riding problems can detract from the potential gains. We show how the level of efficiency attained in a cooperative of fishermen will depend on the internal governance structure of the organization. Remuneration schemes must be designed to distribute information rents while maintaining incentives to undertake costly search in order to replicate first-best outcomes. Devising such schemes can be particularly challenging in fisheries, e.g., eliminating free-riding problems may be inconsistent with performance-based remuneration schemes. Egalitarian profit-sharing can overcome the free-riding problem, but requires full disclosure, and likely costly monitoring, of costs incurred by individual cooperative members.

Extensions of the current analysis to formally study membership decisions under an endogenous contract design, and strategic information disclosure may provide additional insights and explanations for the paucity of information sharing in fisheries. In particular, deceit is common among commercial fishermen (Palmer (1990), Gatewood (1984), and Andersen (1980)). Identifying conditions under which truthtelling is an equilibrium strategy in an information sharing game could provide more insight.

It is now recognized that solutions to global depletion of marine fish stocks will likely require some form of strengthened property rights for resource users (Costello et al. (2008)). Fishing cooperatives are considered a form of enhanced property rights capable of addressing various inefficiencies that plague common pool resources (National Oceanic and Atmospheric Administration (2010)). Cooperatives are being considered as potential solutions to other management problems including bycatch of unwanted species (North Pacific Fishery Management Council (2011)). Our results suggest that the ability of fishing cooperatives to remedy fishery management problems requires further study. Forming a cooperative does not guarantee a solution to free-riding and other agency problems. Our results illustrate information sharing incentives within fishing cooperatives, and offer insights that may help policy makers faced with the difficult problem of designing effective management policies in marine fisheries.

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A Belief Updating

The three possible updating scenarios are possible in our model: no signal, one signal and two catch signals from a site. Under the independence assumption, updated beliefs at site i conditional on signal s_j are equal to the prior belief. For prior beliefs μ_j, ν_j and single catch signal s_j updated beliefs at site j are given as,

$$\begin{aligned} \mu_j' \, | s_j &= \theta_j \mu_j + (1-\theta_j) s_j \\ \nu_j' \, | s_j &= \theta_j \nu_j \end{aligned}$$

where $\theta_j = \frac{\nu_s}{\nu_j + \nu_s}$. When two signals are available from site j updated beliefs are given as,

$$\begin{aligned} \mu_j' \, | s_j, \check{s}_j &= \ \theta_j \mu_j + (1-\theta_j) \bar{s}_j \\ \nu_j' \, | s_j, \check{s}_j &= \theta_j \nu_j \end{aligned}$$

where $\theta_j = \frac{\nu_s}{2\nu_j + \nu_s}$ and $\bar{s}_j$ denotes the average payoff signal observed at site j.

B Bayesian Nash Equilibrium

This section solves the date t_1 Bayesian game for independent, expected utility maximizing fishermen. Risk neutrality is a special case of this solution ($\lambda \to 0$). We solve for the thresholds s^U, s^L, $\check{s}^U$, and $\check{s}^L$ from (4) which separate feasible signals into regions where pure and mixed strategies are played. There are four possible scenarios to consider depending on the period 1 site choices. We present the calculations for the case where both fishermen fish site 1 in the first fishing period. The analysis of the remaining cases follows analogously and is not repeated.

We begin by specifying how fishermen form beliefs about beliefs. Since both fishermen fished site 1 in the first period, their belief about their rival's private information should be a function of their own private information from fishing site 1. That is, the best information available about the other fisherman's private signal comes from their own updated beliefs. As such, each fisherman believes they share the same updated beliefs about sites 1 and 2.

Suppose $\check{s}^U$ and $\check{s}^L$ exist such that the representative fisherman's counterpart plays the strategy outlined in equation (4). For the representative fishermen with $s_1 \in [s^L, \; s^U]$ to play a mixed strategy, $a' \in (0,1)$, it must be the case that based on his conjecture about his counterpart's strategy he is indifferent between fishing site 1 and site 2. Setting the expected utility of fishing these sites equal and solving for $\check{a}'$, we find,

$$\check{a}' = \frac{\mu_1' - \mu_2' - \frac{\lambda}{2}(\nu_1' - \nu_2') - \kappa + 2\kappa \Pr\left(\check{s}_1 < \check{s}^U | s_1\right)}{2\kappa \Pr\left(\check{s}^L \leq \check{s}_1 \leq \check{s}^U | s_1\right)} \quad \forall \; s_1 \in [s^L, \; s^U] \tag{11}$$

Using the same method, we can calculate the mixed fishing strategy for the representative fisherman, a'.

In a BNE, each player's action must be optimal subject to their Bayesian updated belief about the strategy of their rival. Using a' and $\check{a}'$ we derive four equations that define the parameters s^U, s^L, $\check{s}^U$, and $\check{s}^L$ that will satisfy a BNE.

The representative fisherman believes that his counterpart is indifferent between mixing and fishing site 1 when $\check{a}'$ exactly equals one (his counterpart knows that this is the representative fisherman's belief). For site 1 to be strictly dominant, it must be that it is still preferred even under the worst case (when both fish the site). Using this fact, the updating rules in A, and the strategy profile in equation (4), the representative fisherman's upper signal threshold s^U must satisfy,

$$s^U = \frac{1}{1-\theta_1}\left\{\left[\mu_2 - \theta_1\mu_1\right] - \frac{\lambda}{2}\left[\nu_2 - \theta_1\nu_1\right] + \kappa\right\} \tag{12}$$

Similarly, the representative fisherman believes that his counterpart is indifferent between mixing and fishing site 2 when $\check{a}'$ exactly equals zero (his counterpart knows that this is the representative fisherman's belief). For site 2 to be strictly dominant, it must be that it is still preferred even under the worst case (when both fish the site). Using this fact and given the strategy profile, the representative fisherman's lower signal threshold s^L must satisfy,

$$s^L = \frac{1}{1-\theta_1}\left\{\left[\mu_2 - \theta_1\mu_1\right] - \frac{\lambda}{2}\left[\nu_2 - \theta_1\nu_1\right] - \kappa\right\} \tag{13}$$

Using the same argument, we construct the following for the representative fisherman's counterpart,

$$\check{s}^U = \frac{1}{1-\check{\theta}_1}\left\{\left[\check{\mu}_2 - \check{\theta}_1\check{\mu}_1\right] - \frac{\lambda}{2}\left[\check{\nu}_2 - (1-\check{\theta}_1)\check{\nu}_1\right] + \kappa\right\} \tag{14}$$

$$\check{s}^L = \frac{1}{1-\check{\theta}_1}\left\{\left[\check{\mu}_2 - \check{\theta}_1\check{\mu}_1\right] - \frac{\lambda}{2}\left[\check{\nu}_2 - (1-\check{\theta}_1)\check{\nu}_1\right] - \kappa\right\} \tag{15}$$

The thresholds that satisfy the BNE , s^U, s^L, $\check{s}^U$, and $\check{s}^L$, defined by equations (12) - (15), must simultaneously hold.