Common Property, Information, and Cooperation: Commercial Fishing in the Bering Sea

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Abstract

A substantial theoretical and experimental literature has focused on the conditions under which cooperative behavior among actors providing public goods or extracting common-pool resources arises. The literature identifies the importance of coercion, small groups of actors, or the existence of social norms as conducive to cooperation. This research empirically investigates cooperative behavior in a natural resource extraction industry in which the provision of a public good (bycatch avoidance) in the Alaskan flatfish fishery is essential to the duration of the fishing season, and an information provision mechanism exists to relay information to all individuals. Using a mixed logit model of spatial fishing behavior our results show that conditionally cooperative behavior is prevalent but deteriorates as bycatch constraints tighten.

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"…the world contains multiple types of individuals, some more willing than others to initiate reciprocity to achieve the benefits of collective action. Thus a core question is how potential cooperators signal and design institutions that reinforce rather than destroy conditional cooperation." **– Ostrom (2000, pg. 138)**

1. Introduction

A substantial theoretical and experimental literature has focused on the conditions under which cooperative behavior is likely to occur among actors providing public goods or extracting common-pool resources. Following from the assumption of rational self-interested agents, Olson (1970) argues that cooperation is likely when the group of individuals is small and when coercive authority lies with the group. Ostrom (2000) suggests these conditions may be too restrictive, given experimental evidence and numerous field studies. Norms, ethical codes, and institutions allowing for verification and coercion exist in many settings that reinforce cooperative behavior. These systems allow groups to identify non-cooperative behavior and impose sanctions.

We empirically examine a common property resource problem in which coercive legal authority is absent but peer pressure coercion is present: the Alaskan yellowfin sole and flatfish fisheries. The group of participants is fairly small, the group size and composition is stable (a limited-entry system is in place), and a voluntary information sharing arrangement among participants has evolved to overcome a common-property problem. This arrangement provides participants with information on where high levels of non-target species (bycatch) are caught with the hope that vessels will avoid these areas. Furthermore, information on non-cooperation is provided to other participants and peer pressure may be exerted to enhance cooperation.[1] Consequently, the system we investigate is similar to the institutional environment outlined in Ostrom (2000) and we are able to empirically investigate her hypotheses using field data.

Currently, fishermen operating in the Alaskan flatfish fisheries operate under a two-tiered total allowable catch (TAC) system. TACs are defined over target and bycatch species, in our case Pacific halibut, and once either TAC is reached all fishing ceases.

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[1] This information is provided regularly by both an industry group and by the National Marine Fisheries Service (NMFS) which publishes a list of the observed bycatch rates by vessel each week.

Consequently, reaching the bycatch TAC has direct economic consequences for the fleet, and in recent years bycatch TACs have prematurely shut down some fisheries leaving considerable un-harvested economic rents. From an individual fisherman's perspective catching halibut bycatch is a nuisance because by law it can not be sold. Avoidance comes with a large opportunity cost since the marketable species share similar habitat requirements with the bycatch species making them complements of production. Importantly, in terms of cooperation, the collective harvesting decisions made by the fleet determine the length of the season any one vessel enjoys.

The Magnuson-Stevens Fishery Conservation and Management Act defines bycatch as, "fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards" (16 U.S.C. § 1802 (2)). Bycatch often has a negative effect on either the contemporaneous or potential future value within other fisheries.[2] Because of this, organizations have been formed to collect production information from participating firms to inform members of spatial locations where bycatch should be avoided (Gilman et al., 2006).[3] This research investigates the role of one of these information organizations operating within the Bering Sea flatfish fishery, Sea State Inc. ("Sea State").[4] Using the Alaska catch and bycatch data collected by on-board NMFS observers, we are able to observe whether bycatch avoidance occurs (a signal of cooperation) and whether the level of avoidance varies during the fishing season as the bycatch TAC is approached. Changes in the level of bycatch avoidance within the season indicate the degree of conditional cooperation present within the fishery. Further, we examine the distribution of the fleet's cooperative behavior and find that as the fleet approaches the bycatch TAC the degree of avoidance deteriorates, further exacerbating the degree of conditional cooperation observed. However, we do observe a marginal

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[2] Shrimp fisheries are an excellent example of this as shrimp trawlers often catch large quantities of juvenile fish. See Gallaway and Cole (1999) and Reithe and Aschan (2004) for more discussion.
[3] Other efforts to reduce bycatch in fisheries have involved the utilization of bycatch reduction devices (Pascoe and Revill, 2004), spatial closures (Reithe, 2006), seasonal closures (Bisack and Sutinen, 2006).
[4] Sea State regularly provides vessel-specific daily bycatch rates during high-periods and also talks to fishermen about particularly high hauls to elaborate on their reports. In addition, NMFS provides vessel-level rates on a weekly basis, but the published numbers are perceived by industry to be difficult to interpret when vessels are operating in multiple areas and targeting multiple species so there is additional value in the more regular Sea State reports.

increase in aversion rates in the penultimate days of the fishery, which is consistent with the recent findings of Abbott and Wilen (2008a,b) studying a sub-set of vessels from the same fishery in our model during an earlier time frame, but is not readily explained.

The Sea State information, provided it is acted upon by the fleet, can be considered a public good. Within the experimental literature, common-pool resource and public goods games are often viewed as isomorphic games because they can be equally expressed as transformations of the individual payoff functions (Ledyard, 1995). However, the nature of the benefit-cost duality of these two environments generates fundamental differences in the decision environment (Sandler and Arce, 2003). Sandler and Arce (2003) illustrate that the difference lies in the "need for inaction" in common-pool resource environments versus the "need for action" in the public goods setting. Apesteguia and Maier-Rigaud (2006) add some additional insights by focusing on the degree of rivalry present in common-pool resource and public good environments. They define rivalry by the degree to which one's actions solely benefit oneself versus all others within the population. Given that avoiding bycatch benefits everyone in the fishery via an increased fishing season and not just the acting agent, bycatch aversion generates a public good. Furthermore, the "need for action" in this environment is the active aversion of bycatch within the fishery.

The field data we examine provides a setting for testing how information with minimal levels of coercion impacts cooperation. Avoiding an otherwise preferable high bycatch zone generates a marginal return to each fisherman that is inferior to the non-cooperative return, but if all fishermen cooperate the aggregate returns would increase as the season would not be prematurely shut down.[5] The summary offered by Ostrom (2000) of the experimental literature on public goods games offers an informal baseline to which our econometric results can be compared. These results show that (1) even in the simplest public goods experiments of one-shot games where no coercion is possible, 40-60% of

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[5] It's conceivable that the aggregate benefits would not exceed the private costs of avoidance, but given that the actor choosing to avoid bycatch would discount aggregate benefits, this is very unlikely to occur.

participants choose cooperative strategies[6]; (2) in repeated games, cooperation decays as the number of rounds of play progresses but never reaches zero; (3) over 70% of respondents do not cooperate in the final period of multiple period games; and (4) knowing that others are cooperating tends to increase cooperation (the converse is also true). Our results support a number of these same conclusions, further validating many of the generalizations suggested by Ostrom (2000) obtained from laboratory experiments.

The remainder of the paper proceeds as follows: Section II describes the Alaska yellowfin sole and flatfish fisheries and the data utilized in our empirical analysis. In Section III, we describe the empirical model used to investigate the responsiveness of fishermen to bycatch. Section IV presents a discussion of the results and the final section summarizes our major findings.

2. Fishery Description

In order to manage bycatch within the Bering Sea, in-season fishery managers have utilized bycatch TACs combined with time/area closures.[7] The bycatch species are a target species within another fishery. Therefore, the bycatch TACs are set equal to a pre-specified percentage of the overall target TAC for each bycatch species within its target fishery. These bycatch TACs are further subdivided across different target species and into seasons in order to spread out the temporal distribution of fishing. Once the bycatch TACs are reached, in-season managers issue a fishery closure. These closures have resulted in a number of fisheries being prematurely terminated, forgoing a considerable portion of the target species TAC. For instance, over the time period studied in this research (2000-2004) the large yellowfin sole fishery was shut down by reaching the halibut bycatch TAC in 2001, 2002 and 2003. Furthermore, in 2001 over 20% of the TAC was left un-harvested.[8]

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[6] It is not entirely clear the degree of coercion that results from the NMFS bycatch reports. Therefore, the non-coercion results may still be a useful benchmark for measurement.

[7] The primary bycatch concerns surround prohibited species catch (PSC), which consist of crab, Pacific herring, Pacific halibut, Pacific salmon and steelhead trout harvested within the bottom trawl fishery (Witherell and Pautzke, 1997).

[8] There has been some research conducted on the optimal allocation of bycatch TAC among sub-fisheries in the Bering Sea flatfish fishery. Larson et al. (1996) illustrates that a substantial portion of the halibut quota should be reallocated from the longline fishery to the Alaska pollock fishery. Further results indicate

We focus our study on trawling vessels that target flatfish in the Bering Sea, which are significantly constrained by bycatch limits for halibut.[9] The primary species targeted are yellowfin sole, flathead sole and rock sole.[10] These species are caught by a fleet that has different targeted species which are opened and closed during the season as catch or bycatch caps are reached. To reflect these differences, we partitioned our data set into two groups: those targeting yellowfin sole and those targeting all other flatfish, which we refer to as 'flatfish'. Yellowfin sole was analyzed separately because during the study period it had by a considerable margin the largest TAC of all flatfish species within the Bering Sea. Weekly targeting designations are based on the NMFS specifications which designate a yellowfin sole/ flatfish target if the largest component of the catch is made up of yellowfin sole and flatfish species. Assuming this threshold is met, and the target is declared a yellowfin sole target if greater than 70% of the sum of all flatfish is yellowfin sole and is declared a flatfish target otherwise. Typically either the yellowfin sole fishery or the flatfish fishery is open during a particular point in the season, though there are overlapping periods and periods when both fisheries are closed.

The vessels that fish for yellowfin sole and flatfish are catcher processors which take trips that may last 2-4 weeks and process fish onboard. In order to minimize the frequency and duration of bycatch closures, the yellowfin sole and flatfish fleet contracted with Sea State in 1995 to begin analyzing government observer-collected bycatch information. Sea State provides spatial bycatch advisories to the fleet, which provide non-mandatory recommendations of areas to avoid in order to reduce halibut bycatch. The program operates using the real-time processing of the observer data recorded by the National Marine Fisheries Service (NMFS) on all vessels within the fleet. An example of the bycatch advisory is illustrated in Figure 1, which depicts the spatial distribution of halibut bycatch rates within the Bering Sea for the yellowfin sole fishery. Furthermore, Sea State

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that quasi-rents in the pollock fishery over the years 1991-92 could have been increased by 6-7% if the bycatch TAC shares had been optimally defined (Larson et al., 1998).

[9] In the past crab bycatch has also constrained these fisheries, but protected areas have pushed the fishery off of high crab bycatch grounds.

[10] Several other species are also caught and marketed (e.g., Dover sole, rex sole) which are jointly considered as 'other flatfish.'

and NMFS regularly report bycatch rates by vessel to enhance the information provided to the fleet, which may be used to exert coercive pressure on non-cooperators within the fleet. Given this informational structure, there is a widespread impression across the industry that the Sea State program has been successful in reducing bycatch.

Catch and bycatch data for this analysis come from the Alaska Fisheries Science Center's Observer Program Database. The North Pacific Groundfish Observer Program places observers on 100% of the days at sea for vessels that are greater than 125 feet in length, which captures the entire catcher processor fleet within our analysis.[11] Each data point represents a given haul made by a vessel while on a fishing cruise. Spatial data on fishing locations were used to calculate the distances from one haul to the next and from each haul to the centroid of areas that might potentially be chosen for sequential hauls. To complete the data set, we obtained price information from the Commercial Fisheries Entry Commission (CFEC) fish ticket and Commercial Operator Annual Report (COAR) data.

Table 1 lists the descriptive statistics for the yellowfin sole and flatfish fisheries over the time period studied (2000-2004). The mean revenue per haul in the flatfish fishery was approximately 38% greater than that in the yellowfin sole fishery. This is predominately the result of the targeting of rock sole, a high-valued flatfish species. In addition, bycatch rates and quantities are consistently higher in the flatfish fishery than in the yellowfin sole fishery. On average, a flatfish haul catches 44% more halibut than a yellowfin sole haul.[12] Aside from the disparity in revenues and bycatch rates and quantities within these two fisheries, on average fishermen in these fisheries visit a very similar number of spatial locations on a cruise (8.16 for the yellowfin sole and 7.32 for the flatfish fishery), suggesting a similar level of spatial mobility.

Following the establishment of bycatch TACs, NMFS tracks when fisheries approach and reach their annual limits and provides regular information to the public about the status of fisheries, including the issuance of fishery closures. For each observation in the dataset, we calculated the currently applicable bycatch TAC at a given point in the season.

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[11] In addition, during 2000-2004 over 99% of the catcher processors observed were Sea State members. Our data set does not contain the smaller catcher vessels that only have 30% observer coverage.

[12] Sea State relays bycatch information in terms of rates (tons of bycatch per haul as a percent of tons of catch haul) rather than raw quantities (tons of bycatch per haul). Flatfish hauls have an average bycatch rate that is 73% greater than yellowfin sole.

NMFS in-season managers also make bycatch TAC adjustments among fisheries within the season to allow a larger amount of yellowfin sole and flatfish to be caught without exceeding the overall bycatch limits. Through a careful investigation of the timing of these changes, we incorporated these adjustments into our analysis. Since this information is relayed through the fleet, both by Sea State and in-season management, fishermen are acutely aware of how binding bycatch TACs are at any given point in time.

Because structural differences in targeting behavior and halibut avoidance may exist for years when the halibut TAC is binding or not, we partitioned the yellowfin sole and flatfish data sets into binding and non-binding years. Although the halibut TAC was binding in all years for at least one of the flatfish fishery seasons, it was not binding in the summer and fall seasons in 2003 and 2004, so we elected to declare 2003 and 2004 as "non-binding" years within the analysis despite the fact that it was binding in the winter and spring seasons. The yellowfin sole fishery, on the other hand, was non-binding in 2000 and 2004 for all sub-seasons within the year. Having discussed the general nature of the yellowfin sole and flatfish fisheries, the following section outlines the econometric model utilized to investigate how fishermen respond to the spatial information provided by Sea State over the course of the season.

3. Econometric Model

Flatfish fishermen make repeated spatial choices on which region within the fishery to fish in during a given time period. Our definition of "space" divides the Bering Sea into 1 degree latitude by 0.5 degree longitude grids, which correspond with the statistical reporting zones utilized by the Alaska Department of Fish and Game. Given the discrete nature of the fisherman's choice set, random utility modeling is conventionally used to model fisherman's spatial behavior (Eales and Wilen, 1986; Curtis and Hicks, 2000; Holland and Sutinen, 2000; Smith and Wilen, 2003) and we follow this paradigm with one exception; we utilize a mixed logit model (McFadden and Train, 2000) to allow for heterogeneous responses to the spatial bycatch information.[13] To examine the degree of

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[13] Bockstael and Opaluch (1983) were the first to apply a random utility model (RUM) in the fisheries literature, but they did not directly investigate spatial behavior. Bockstael and Opaluch (1983) investigated

cooperation, we developed a model that incorporates site-specific factors that were hypothesized to influence spatial decisions made by fishermen (e.g., expected revenues per haul and distance to a site) and proxies for information supplied by Sea State characterizing the degree of bycatch expected at each site. If cooperation to reduce bycatch via information sharing was indeed happening then we would expect fishermen to avoid high bycatch areas *ceteris paribus*. The mixed logit model has been utilized in the spatial choice literature to investigate heterogeneity in risk preferences (Mistiaen and Strand, 2000), travel costs (Haynie, 2005), and state dependence in fisheries (Smith, 2005). However, this is the first application utilizing a mixed logit to investigate heterogeneous responses to spatial information signals and to investigate cooperative behavior with respect to information sharing. The foundation for our model rests on the commonly used RUM developed by McFadden (1974, 1978).

Consider a panel data set of M fishermen conducting C_m fishing trips or cruises with each trip consisting of $h_{c,m}$ hauls, the utility individual i derives from visiting site j on haul $h_{c,m}$ be defined as,

$$v_{ijh_{c,m}} = x_{jh_{c,m}}\beta_{i_c} + \varepsilon_{ijh_{c,m}}, \qquad (1)$$

where $x_{jh_{c,m}}$ is a vector of location and haul specific observations and β_{i_c} is an individual and cruise specific time-invariant preference parameter. The observation matrix, $x_{jh_{c,m}}$, is observed by both the researcher and the fisherman but $\varepsilon_{ijh_{c,m}}$, the unobserved (by the researcher) portion of site-haul-location specific utility, is only observed by the fisherman. Fisherman i will choose to fish in site j on haul $h_{c,m}$ if the utility of fishing in site j exceeds all other sites in the fishery on their $h_{c,m}^{th}$ haul. This is denoted as,

$$v_{ijh_{c,m}} \geq v_{ikh_{c,m}}, j \in N, \forall k \in N, \qquad (2)$$

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the effort supply response of fishermen in New England to expected fishery yields and corresponding variances.

where N is the total number of feasible spatial locations. If $\varepsilon_{ijh_{c,m}}$ is assumed to be an independently and identically distributed Type I Extreme Value and $\beta_{i_c} \sim MVN(\tilde{\beta}, \Omega)$, we can recover the probability $p_{ijh_{c,m}}$ that fisherman i selects location j on his/her $h^{th}_{c,m}$ haul. This probability nests the multinomial logit model (MNL) within the multivariate integral of the distribution for β_{i_c} and can be expressed as,

$$p_{ijh_{c,m}} = \int \frac{e^{X_{jh_{c,m}}\beta}}{\sum_{k=1}^{N} e^{X_{kh_{c,m}}\beta}} \phi(\beta \mid \tilde{\beta}, \Omega) d\beta \quad . \qquad (3)$$

Estimating the integral expressed in Equation 3 requires a simulation-based estimation algorithm which numerically approximates the integral using Monte Carlo simulation (Train, 2003).[14] Within the Monte Carlo simulation D draws are made from the multivariate normal distribution with each draw producing a hypothesized value for $p_{ijh_{c,m}}$, denoted $p^{d}_{ijh_{c,m}}$ where d indicates the d^{th} draw. In our analysis, we used 200 Halton draws from the multivariate normal distribution and there were 345 and 233 unique individual and cruise-specific identifiers (indicate by subscript c,m) within the yellowfin sole and flatfish fishery, respectively. From these draws a simulated likelihood function can be constructed,

$$L = \prod_{c=1}^{C_m} \prod_{i=1}^{M} \prod_{h=1}^{h_{c,m}} \frac{1}{D} \sum_{d=1}^{D} p^{d}_{ijk} \qquad (4)$$

Maximum likelihood maximizes the log transformation of equation (4). The specification of utility $v_{ijh_{c,m}}$ in our empirical model is[15]

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[14] Our estimator was programmed in MATLAB with the foundational code provided by Kerry Smith and Dan Phaneuf.

[15] A large number of alternative empirical specifications for Equation (5) were estimated to investigate the robustness of our results to the reduced from specification of the utility function. These models included

$$v^{f}_{ij\,h_{c,m}} = \beta_1 Dist_{j\,h|k_{c,m}} + \beta_2 Rvn_{ij\,h_{c,m}} + \beta_{3i} b_{ij\,h_{c,m}} + \beta_{4i}(b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}}) \\ + \beta_{5i}(b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}})^2 + \beta_6 MissDum + \varepsilon_{ij\,h_{c,m}} \tag{5}$$

The superscript f denotes the sub-fishery within the fishery: flatfish catcher processors (FLAT_CP) and yellowfin sole catcher processors (YELL_CP), respectively, further subdivided into binding and non-binding years. The distance traveled from one's current location k to location j on the current haul $h_{c,m}$ is captured by $Dist_{j\,h|k_{c,m}}$ and is measured in kilometers. $Rvn_{ij\,h_{c,m}}$ is the expected site-specific revenues for haul $h_{c,m}$ and is calculated using the seven-day moving average of site-specific revenues observed over each of the respective sub-fisheries. The bycatch information signal, denoted $b_{ij\,h_{c,m}}$, is specified as the expected site- and time-specific bycatch rate, defined as the ratio of expected bycatch to expected catch of the primary target species. This treatment is utilized to capture the information provided by Sea State (see Fig. 1). The expected spatial bycatch rates are calculated using 7-day moving averages for each site within the fishery. Seven-day moving averages were selected because this closely mimics the weekly intervals used by in-season management when declaring the available bycatch TAC remaining, as well as the time intervals used by Sea State.

To investigate the intra-seasonal spatial response of vessels to bycatch information, we interacted the bycatch signal $b_{ij\,h_{c,m}}$ variable with the amount of bycatch remaining at a particular point in time within the fishery, denoted $Rmn_{ij\,h_{c,m}}$. In addition, the square of this interaction term was added to the specification to account for second-order effects. The final variable used in the analysis, $MisDum$, takes a value of one whenever the expected location- and haul- specific estimates of revenues are zero because no fishing activity has taken place in that area over the past 7 days. Utilizing this reduced form specification facilitates the analysis of the fishermen's behavioral responses when the

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alternative variable interaction models and using tier specific parameter estimates for the amount of remaining bycatch present. These models yielded similar results to those discussed in the paper and are available upon request from the authors.

bycatch TAC becomes more binding on fleet behavior, where binding is defined as less bycatch TAC remaining.[16] Furthermore, partitioning the data into binding and non-binding years in the analysis allows us to investigate whether or not vessels possess asymmetric response functions to the state of remaining bycatch TAC. Regression results are displayed in Tables 2 and 3 for the yellowfin sole and flatfish fisheries, respectively.

In addition to the results presented in Tables 2 and 3, we have estimated spatial response elasticities for the mixed logit models. To estimate these elasticities, a two-stage Krinsky-Robb method (Krinsky and Robb, 1986, 1990) was utilized to obtain confidence intervals for our elasticity estimates. The elasticity distributions are used to estimate the fleet-wide response to a 1% increase in the bycatch rate within a given area as the amount of bycatch remaining decreases within the season. In the first stage of the estimation, a draw is taken from the multivariate normal parameter distribution utilizing the variance-covariance matrix from our estimation. In the second stage, a draw from each random parameter's distribution is taken conditional on the mean and standard deviation estimate drawn from the first stage. This second-stage process is repeated for each β_{i_c} in the empirical model. The resulting parameters are then used to construct the spatial response elasticities. All elasticity estimates are conducted at the haul level and enough draws were taken from the parameter distribution to ensure that 500,000 haul-specific elasticities were estimated for each model. The results are reported in Tables 4 and 5 for the yellowfin sole and flatfish fisheries respectively.

4. Results

The empirical results for the models possess three commonalities: (1) the distance coefficient in each model is negative and highly significant, (2) the revenue coefficient is positive and statistically significant in most models and, (3) the coefficient on $Mis.Dum$ is negative and highly significant in all models. The coefficients on distance and revenues are consistent with the general results in the literature indicating that travel is

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[16] Alternative thresholds were experimented with in our preliminary analysis. Our tiering of the remaining bycatch TAC allows us to focus on the end-of-season dynamics within the fishery and the fishermen's responses to bycatch information during these respective time periods.

costly and that fishermen select sites which possess higher expected revenues. In addition, the coefficient on $Mis.Dum$ is consistent with the results in the literature which indicate that fishermen tend to fish in locations which have been fished in the recent past (Holland and Sutinen, 2000).[17] Beyond these similarities, each of the fisheries possesses a unique profile of response to bycatch information within the fishery.

The mixed-logit parameter estimates illustrate that fishermen participating in both fisheries possess an initial propensity to avoid locations with a higher bycatch rate, captured by $b_{ijh_{c.m}}$, but when the amount of bycatch quota remaining is large this propensity is lower (captured by the interaction terms). Furthermore, in the non-binding years for both fisheries the baseline aversion rate is larger than in binding years. Describing the spatial responses beyond this level is complicated by the bycatch interaction terms, therefore we will focus primarily on the spatial elasticity estimates conditional on a given level of bycatch quota remaining.

The elasticity of spatial responses in the yellowfin sole fishery resulting from an increase in the bycatch rate, conditional on a level of bycatch quota remaining, are listed in Tables 4 and 5 for the binding and non-binding years respectively. The results indicate that the mean spatial responses unilaterally decrease as the bycatch quota is reduced, with mean aversion rates being larger in the non-binding years. In the binding-years model the deterioration in aversion rates results in the mean aversion switching to an attraction model when the remaining bycatch quota is less than 0.4. In the case of the non-binding years the switch occurs when the remaining bycatch quota is less than 0.1, which rarely occurs given that it is non-binding year.[18] Another interesting common feature of the two models is the degree of heterogeneity within the fishery, as measured by the span between the upper and lower bound, decreases and then increases as the remaining bycatch quota falls. In fact the largest rates of aversion and attraction are observed when the remaining bycatch quota is 1. In binding years this spread is between -2.47% and

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[17] A more rigorous specification of the utility function would incorporate a state dependence variable (Smith, 2005) to investigate this phenomenon in more detail but this is beyond the scope of this research effort.

[18] Although the remaining bycatch rarely, if ever, goes below zero in a non-binding years we have elected to estimate the elasticities at these levels to parsimonious with the other elasticity models.

1.25% and in non-binding years the spread is larger, between -3.58% and 0.88%. Interestingly the larger aversion rates for the non-binding years suggest that more cooperative behavior is observed in non-binding years.

Although the mean aversion rates are predominately negative in the yellowfin sole fishery, the confidence intervals for our elasticity estimates indicate that the mean haul-specific elasticity measure in both binding and non-binding years is not statistically significant from zero. This complicates the interpretation of the results. However, by calculating the distributional mass of our haul-specific elasticity estimates that lie above zero we can determine the degree of and change in non-cooperation within the yellowfin sole fishery because a positive elasticity is consistent with non-cooperative behavior and the change in cooperation captures conditional cooperation. Therefore, we can still investigate the degree of conditional cooperation present when using these empirical results. The degree of non-cooperation within the yellowfin sole fishery is illustrated in Figure 2 for both binding and non-binding years.

Analyzing this metric uncovers four generalizations within the yellowfin sole fishery: (1) non-binding years possess a higher degree of cooperation, (2) the degree of non-cooperation increases as the season progresses, (3) the rate of increase in non-cooperation increases more rapidly in non-binding years, and (4) when the remaining bycatch approaches a level at which the shut-down of the fishery is imminent the degree of non-cooperation decreases as the aversion rates rise. In non-binding years the rate of non-cooperation always lies below that observed in binding years. When the season begins, remaining bycatch quota is 1, the degree of non-cooperation is roughly 26%, compared to nearly 40% in binding years. The spread between the non-binding and binding years is greater than 10% up until the remaining bycatch quota is 0.5, at which time degree of non-cooperation increases until it is less than a percentage point below the binding year counterpart when the remaining bycatch quota approaches -0.1. This rapid decrease in cooperation is perfectly rational within the non-binding years because as the season progresses and it becomes more evident that closure is not eminent a fishermen would tend to disregard the knowledge of where high bycatch rates are located and focus more on the expected revenues they will obtain in a given location. This is not to say that they do not avoid bycatch, it suggests that they have already avoided bycatch enough to prolong the season to successful completion.

The degree of non-cooperation increases from the initial levels to greater than 60% in the binding years and slightly less than 60% in the non-binding years. The sharp increase in non-cooperation within both binding and non-binding years is consistent with Ostrom's (2000) observations on conditional cooperation as well as her finding that end-of-game non-cooperation rates approach 70% in the experimental literature. As mentioned above caution should be used when applying this logic to the non-binding years because cooperation is not necessary in the later part of the season. However, the increasing decay in cooperation in non-binding years is consistent with Ostrom's (2000) generalizations of non-cooperation discussed earlier. This said, it should also be noted that the degree of cooperation is still greater than Ostrom's (2000) generalizations, which may be a direct result of the coercive power of fishermen in the yellowfin sole fishery resulting from the NMFS weekly vessel-specific bycatch rate reports. Coercive pressure may also be used explain why at the very end of the season the aversion rates marginally increase and the degree of non-cooperation decreases, but we do not have sufficient information to confirm this conjecture. However, this observation is consistent with other research which has observed that these same fishermen possessed an increasing aversion rate in the waning days of this fishery prior to the time period studied in our analysis (Abbott and Wilen 2008a,b).

Combined, these results suggest that as the fishing season progresses within the yellowfin sole fishery, fishermen tend to avoid bycatch less. This behavior is rational because halibut and yellowfin sole inhabit the same regions of the Bering Sea and fishing in areas with a higher halibut concentration could decrease the fisherman's cost per unit of harvest. Furthermore, the conditional cooperation results illustrate that if other fishermen are not willing to avoid high-bycatch regions then others will follow suit. However, it is important to note though that the model, by allowing for heterogeneous preferences, illustrates that some portion of the fleet continues to avoid areas with high bycatch rates despite the conditionality of cooperation.

The elasticity results for the flatfish fishery illustrate that the mean aversion rates are larger than in the yellowfin sole fishery. When the remaining bycatch quota is 1 the mean aversion rate is -3.3% in binding years and 4.1% in non-binding years. This is nearly ten orders of magnitude greater than in the yellowfin sole fishery. Although this would suggest that fishermen in the flatfish possess a high degree of aversion, the elasticity estimates are also much more heterogeneous than those observed in the yellowfin sole fishery. The confidence interval for the first level of remaining bycatch, value of 1, is between -30% and 1.3% for the binding years and -54% and 1.5% on non-binding years. Although this spread does narrow as the remaining bycatch quota decreases it still remains quite large relative to that observed in the yellowfin sole fishery.

Given the large confidence intervals, it is evident that the mean elasticity estimates are not statistically significant from zero. However as was conducted in the yellowfin sole fishery, we can estimate the distributional mass that lies above zero to measure the degree of cooperation present in the fishery and the presence of conditional cooperation. Only two behavioral characterizations of the yellowfin sole fishery apply to the behavior of fishermen within the flatfish fishery: (1) the degree of cooperation deteriorates as the season progresses and (2) when the termination of the fishery in eminent the rate of aversion, and therefore degree of cooperation, increases. Figure 3 graphically illustrates the degree of non-cooperation within the flatfish fishery.

The first generalization observed in the yellowfin sole fishery is not observed in the flatfish fishery because the degree of non-cooperation appears to not vary substantially between the binding and non-binding models. In fact the absolute differences between the two models never exceeds one percentage point, which indicates that fishermen within the flatfish fishery possess a baseline propensity to avoid zones with high bycatch rates, conditional on a given level of bycatch quota remaining, which does not vary. This suggests that the only way fishermen were able to not exceed the PSC TAC in a given year was if the realized values of PSC caught managed to stay below the TAC, not as a result of changed targeting strategies. The deterioration on cooperation within the fishery is observed in the flatfish fishery.

The degree of non-cooperation starts at roughly 33% for both binding and non-binding years and increases to nearly 43% percent falling again to 42% in the penultimate days of the fishery. Comparing this rate of change to that observed within the yellowfin sole fishery illustrates that the flatfish fishery exhibits a more stable and lower level of non-cooperation. Although the degree of cooperation is larger than observed in the experimental literature (Ostrom 2000), the decay in cooperation is consistent with Ostrom's (2000) discussion on conditional cooperation. The final common generalization observed, aversion rates marginally increasing at the very end of the season, is similarly consistent with Abbott and Wilen's (2008a, b) research on this fishery in an earlier time period. However, this phenomenon can not be readily explained in either model.

5. Conclusion

The impact of information on the sustainability of cooperation in the provision of a public good while harvesting a common property resource was largely consistent with results arising from the experimental economics literature, most notably Ostrom's (2000) notion of conditional cooperation. In both fisheries that we examined, we found that the level of cooperation generally fell as the season progresses and as bycatch TAC approaches the cap. These changes are more pronounced in the yellowfin sole fishery, whereas cooperation rates are higher in the flatfish fishery. Within the experimental literature it has been illustrated that a higher marginal rate of substitution (MRS) for the private versus the public good enhances the degree of cooperation (Isaac et al., 1984). Therefore, the MRS may be greater in the flatfish fishery than the yellowfin sole fishery. Overall our results illustrate that information provision alone, with moderate peer pressure, cannot completely overcome collective action problems. Despite the presence of these factors substantial externalities still exist within the fishery, resulting from the common-pool nature of the bycatch TAC, which preclude the efficient utilization of these resources.

In general our results indicate that fishermen predominately avoid regions with historically high bycatch rates early in the season. However, as the season progresses, fishermen reduce their degree of aversion. This reduction is greatest in the yellowfin sole fishery where a fair number of fishermen gravitate toward those regions that possess high bycatch rates. This suggests that these fishermen may be utilizing the bycatch information to enhance their production later in the season, presumably because the target species and halibut are complements in production. Alternatively, given that the flatfish fishery season is shorter than the yellowfin sole season, there may be less time available for conditional cooperation to develop in the repeated game fishermen play.

While this analysis supports the economically consistent arguments of changing levels of non-cooperation during the season and between binding and non-binding years, there is also the possibility that what we are observing is due to changing intra-seasonal levels of halibut abundance. However, since the only biological information that we have is trawl surveys conducted every 1-3 years, this is not a testable proposition but should be noted as a potential alternate explanation for the behavior exhibited in the fishery.

This analysis generally supports the hypothesis that Sea State has been successful at helping fishermen within the yellowfin sole and flatfish fisheries avoid bycatch. However, there does appear to be a substantial opportunity to increase economic efficiency in these fisheries because perfect cooperation is not observed. With the recent rationalization of this fishery by the NPFMC under Amendment 80 of the Bering Sea Fishery Management Plan, there will be progress toward reducing this economic inefficiency. However, complete efficiency is unlikely to be obtained unless fishermen participating in the flatfish fisheries are allowed to own halibut quota and vice versa. With Amendment 80, the common pool nature of the bycatch TAC has been minimized for the rationalized yellowfin sole and flatfish fisheries that now have the majority of the fleet functioning with individual bycatch allocations. More information will be available over then next few years about bycatch behavior and values under the rationalized fishery and this may prove to be a fruitful area of research in the future and one which we intend to pursue.

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Figures and Tables:

Figure 1: Spatial distribution of Sea State halibut bycatch information
(Courtesy of Sea State Inc.: Report issued on August 18, 2003)

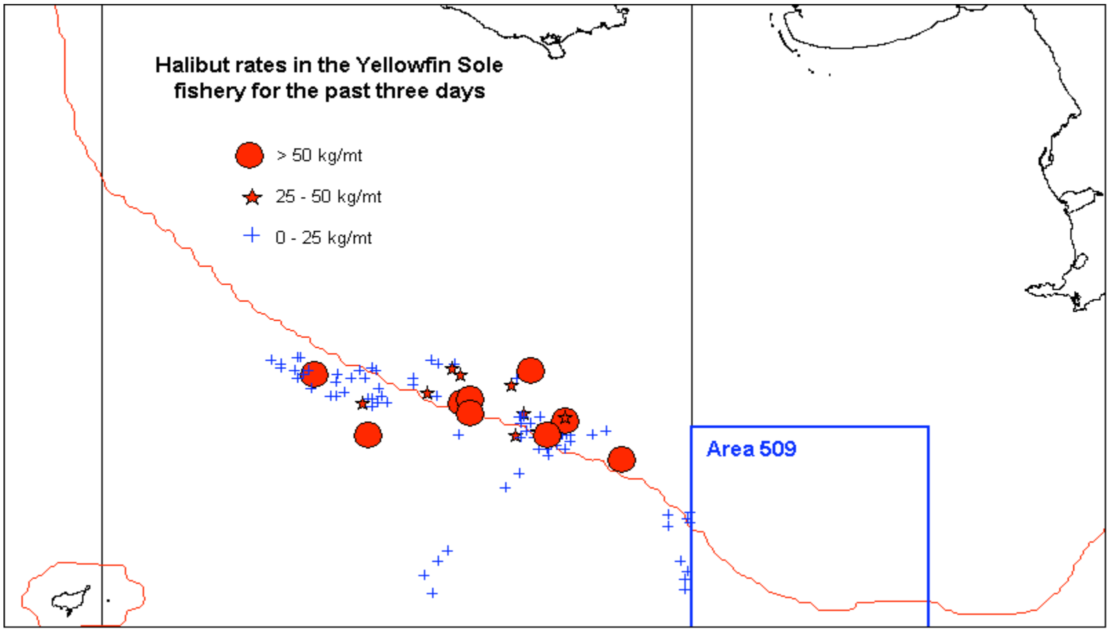

Figure 2: Degree of non-cooperation within the yellowfin sole fishery conditional on a given level of bycatch quota remaining.

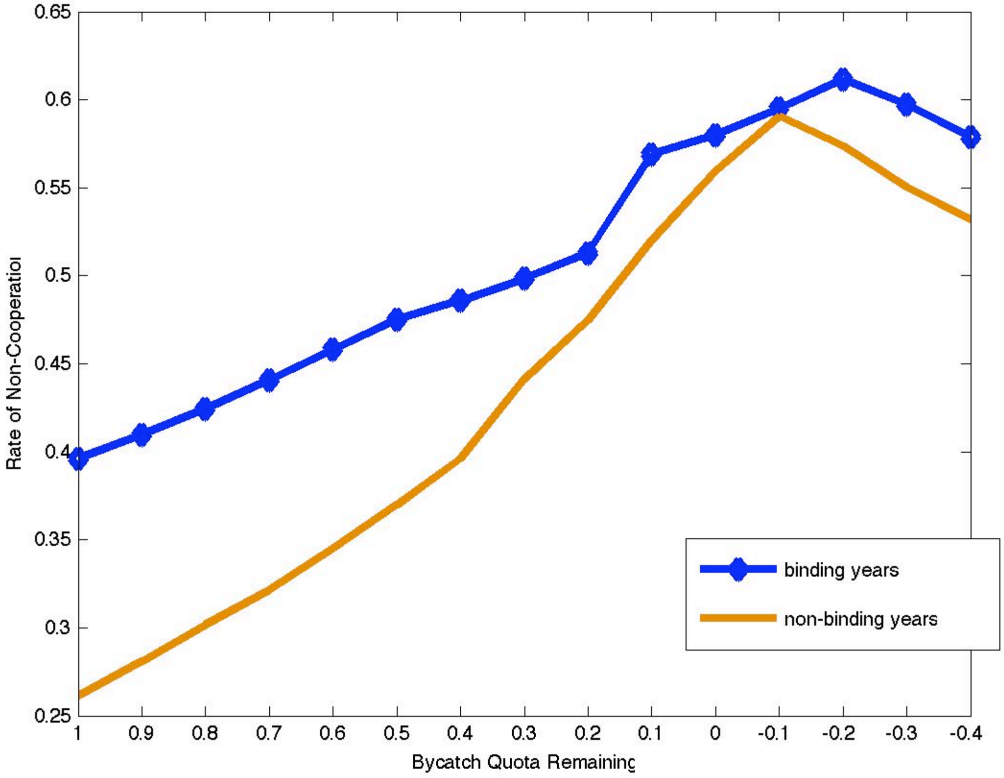

Figure 3: Degree of non-cooperation within the flatfish fishery conditional on a given level of bycatch quota remaining.

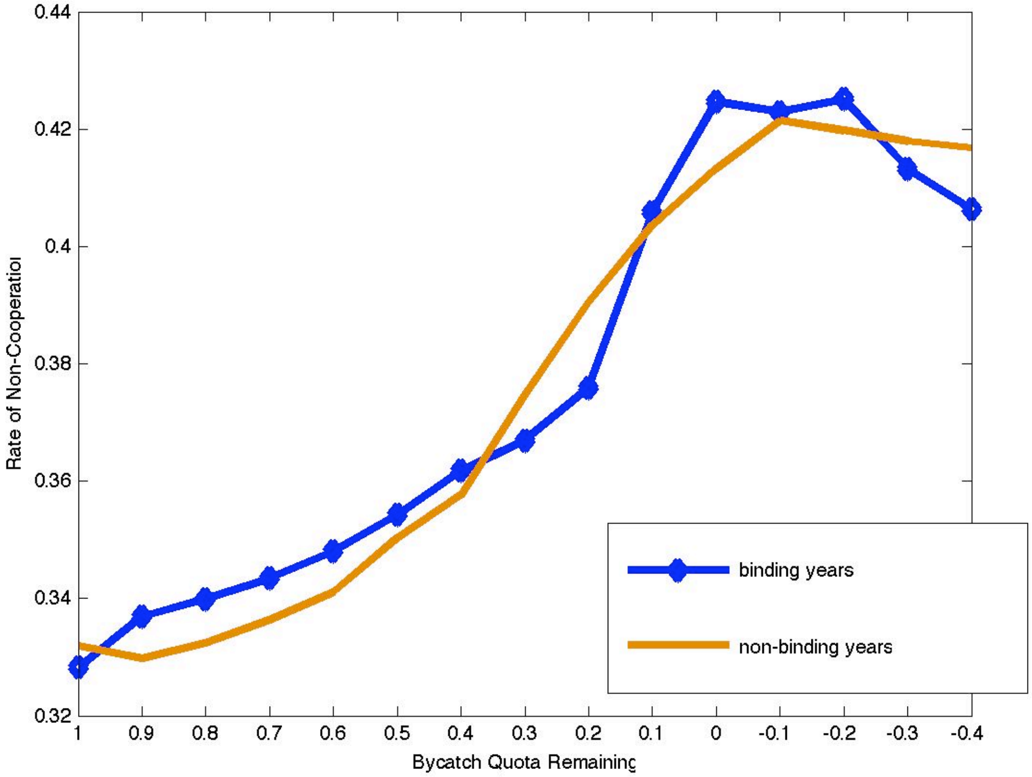

Table 1: Summary Statistics

Yellowfin Sole	**Mean**	**Std. Dev.**	**Min**	**Max**
Cruise Revenue	56,653.30	50.646.37	0	241,213.93
Haul Revenue	611.49	983.22	0	16,589.69
Cruise Length (hauls)	80.19	62.02	1	335
Cruise Length (days)	21.00	16.61	<1	79
Bycatch (rates)	16.37	32.24	0	553.52
Bycatch (quantities)	285.20	667.98	0	14,463.10
Sites Visited per Cruise	8.16	4.93	1	32
Flatfish Fishery				
Cruise Revenue	117,984.24	87,826.47	0	768,824.00
Haul Revenue	719.71	1152.25	0	14,232.27
Cruise Length (hauls)	120.83	102.64	1	452
Cruise Length (days)	29.57	22.97	<1	95
Bycatch (rates)	28.26	40.83	0	512.37
Bycatch (quantities)	410.82	679.59	0	13,086
Sites Visited per Cruise	7.32	4.65	1	30

Table 2: Yellowfin estimates – Mixed Logit: *Mean* and *Standard Deviation*, and *t-stat*

Coefficient/Fishery	**YELL_CP**	**YELL_CP**
	RPL	**RPL**
Model	*Binding Years*	*Non-Binding Years*
$Distance$	-38.4995**	-37.1966**
	(-127.75)[a]	(-96.75)[a]
$\mathrm{Re}venue$	0.1074**	0.0188
	(5.91)[a]	(0.80)[a]
$b_{ij\,h_{c,m}}$	-9.4897**	-18.6975**
	(3.70)	(3.96)
$std.deviation$	16.7089**	-22.5769**
	(7.72)	(11.86)
$b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}}$	15.1598**	37.5530**
	(2.51)	(4.43)
$std.deviation$	21.7821**	4.6021
	(6.64)	(0.44)
$\left(b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}}\right)^2$	-1.2104**	-1.3481**
	(4.34)	(-6.14)
$std.deviation$	1.0206**	0.9895**
	(4.82)	(7.32)
$Mis.Dum$	-1.8495**	-1.7338**
	(-43.97)[a]	(-34.61)[a]
Number of Obs.	16,715	10,220
$\log(L_0)$	-72,822	-44,526
$\log(L)$	-26.007	-15,458
Likeli. Ratio Index (ρ)	0.6429	0.6528

(* indicates significant at the 90% level; ** indicates significant at the 95% level)

[a] indicates *t-stat* because parameter is not random.

Table 3: Flatfish fishery estimates – Mixed Logit: *Mean*, *Standard Deviation* and *t-stat*

Coefficient/Fishery Model	**FLAT_CP** **RPL** *Binding Years*	**FLAT_CP** **RPL** *Non-Binding Years*
$Distance$	-37.6316**	-35.5354**
	(-103.95)[a]	(-63.62)[a]
$Revenue$	0.2574**	0.1840**
	(12.12)[a]	(7.57)[a]
$b_{ij\,h_{c,m}}$	-8.9532**	-10.5624**
	(2.84)	(4.87)
$std.deviation$	64.15**	12.8627**
	(19.49)	(5.93)
$b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}}$	14.2410**	8.0772
	(2.89)	(1.43)
$std.deviation$	14.2682**	15.3245**
	(4.96)	(2.94)
$\left(b_{ij\,h_{c,m}} * Rmn_{ij\,h_{c,m}}\right)^2$	-0.2920**	-0.3823**
	(-6.33)	(-4.28)
$std.deviation$	0.6561**	0.0946*
	(9.58)	(1.71)
$Mis.Dum$	-1.4818**	-1.9073**
	(-30.69)[a]	(-22.74)[a]
Number of Obs.	12,517	5,399
$\log(L_0)$	-54,042	-23,310
$\log(L)$	-17,876	-7,389
Likelihood Ratio Index (ρ)	0.6692	0.6830

(* indicates significant at the 90% level; ** indicates significant at the 95% level)

[a] indicates not a random parameter.

Table 4: Yellowfin sole fishery elasticities, 95% confidence intervals.

Data Set	**YELL_CP Binding**			**YELL_CP Non-Binding**		
Bycatch Quota Remaining	**Lower 2.5%**	**Mean**	**Upper 97.5%**	**Lower 2.5%**	**Mean**	**Upper 97.5%**
1.0	-0.0247	-0.0043	0.0125	-0.0358	-0.0086	0.0088
0.9	-0.0207	-0.0033	0.0119	-0.0306	-0.0070	0.0088
0.8	-0.0168	-0.0023	0.0122	-0.0258	-0.0054	0.0086
0.7	-0.0133	-0.0014	0.0103	-0.0210	-0.0040	0.0083
0.6	-0.0104	-0.0007	0.0094	-0.0168	-0.0027	0.0079
0.5	-0.0078	-0.0002	0.0084	-0.0140	-0.0018	0.0071
0.4	-0.0056	0.0000	0.0074	-0.0118	-0.0011	0.0063
0.3	-0.0043	0.0002	0.0065	-0.0093	-0.0006	0.0058
0.2	-0.0044	0.0002	0.0058	-0.0073	-0.0002	0.0055
0.1	-0.0058	0.0001	0.0055	-0.0066	-0.0001	0.0055
0	-0.0063	0.0001	0.0056	-0.0058	0.0001	0.0057
-0.1	-0.0047	0.0004	0.0059	-0.0049	0.0004	0.0062
-0.2	-0.0032	0.0006	0.0066	-0.0048	0.0005	0.0067
-0.3	-0.0032	0.0008	0.0074	-0.0060	0.0004	0.0072
-0.4	-0.0046	0.0007	0.0083	-0.0082	0.0000	0.0076

Table 5: Flatfish fishery elasticities, 95% confidence intervals.

Data Set	**FLAT_CP Binding**			**FLAT_CP Non-Binding**		
Bycatch Quota Remaining	**Lower 2.5%**	**Mean**	**Upper 97.5%**	**Lower 2.5%**	**Mean**	**Upper 97.5%**
1.0	-0.3002	-0.0326	0.0126	-0.5387	-0.0413	0.0145
0.9	-0.2486	-0.0275	0.0120	-0.4816	-0.0361	0.0141
0.8	-0.2021	-0.0231	0.0114	-0.4227	-0.0312	0.0139
0.7	-0.1711	-0.0196	0.0109	-0.3502	-0.0273	0.0140
0.6	-0.1462	-0.0168	0.0106	-0.2791	-0.0238	0.0135
0.5	-0.1281	-0.0149	0.0102	-0.2132	-0.0215	0.0130
0.4	-0.1196	-0.0141	0.0098	-0.1816	-0.0200	0.0130
0.3	-0.1109	-0.0143	0.0095	-0.1751	-0.0198	0.0126
0.2	-0.1114	-0.0146	0.0094	-0.1752	-0.0210	0.0126
0.1	-0.1135	-0.0148	0.0094	-0.1811	-0.0233	0.0126
0.0	-0.1129	-0.0146	0.0094	-0.1807	-0.0223	0.0127
-0.1	-0.1090	-0.0138	0.0094	-0.1762	-0.0208	0.0127
-0.2	-0.1021	-0.0126	0.0096	-0.1623	-0.0182	0.0128
-0.3	-0.0957	-0.0112	0.0098	-0.1553	-0.0158	0.0130
-0.4	-0.0950	-0.0103	0.1010	-0.1583	-0.0146	0.0135