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Deepwater Horizon Oceanic Fish Restoration Project: An Application of Market Mechanisms for Conservation

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Jorge Holzer worked as a consultant for the National Fish and Wildlife Foundation (NFWF) in the design of the compensation program described in this paper. Kristen Byler is staff at NFWF and was part of the team implementing the project. Otherwise, the authors have nothing to disclose.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by the two of us.

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Abstract

Deepwater Horizon in 2010 marked the largest oil spill in United States history. Following the spill, a council of federal and state trustees was established to assess the impact of the released oil on natural resources in the Gulf of Mexico. The Programmatic Damage Assessment and Restoration Plan developed by the trustees specifically called for restoration approaches that would directly reduce known sources of mortality by providing fishing communities with tools and incentives to limit impacts on fishery resources. The first project selected to restore a portion of the injuries sustained by pelagic fishes, the *Deepwater Horizon* Oceanic Fish Restoration Project, was developed by the National Oceanic and Atmospheric Administration to reduce bycatch in the Gulf of Mexico Highly Migratory Species fishery. Participating vessel owners are compensated to voluntarily refrain from using pelagic longline gear for the first six months of the year, and are encouraged to adopt alternative fishing gear that results in low bycatch mortality. This paper describes the various mechanisms considered, posted-price offer, pay-as-bid auction, and uniform price auction, leading to the design of the compensation for both the repose and alternative gear components of the *Deepwater Horizon* Oceanic Fish Restoration Project, and draws lessons from the first two years of the project's implementation.

Keywords: auction, bycatch reduction, compensation, Deepwater Horizon, Gulf of Mexico, oil spill

1 Introduction

Policymakers have traditionally relied on command-and-control regulation and −to a lesser extent− on market-based instruments such as taxes and cap-and-trade programs for environmental protection and natural resources management. More recently, however, non-regulatory voluntary approaches have become increasingly common (Khanna 2001, Lyon and Maxwell 2002, Segerson 2013). Voluntary initiatives have been adopted worldwide (Morgenstern and Pizer 2007) to address a wide range of environmental concerns from air and water pollution to deforestation (Blackman et al. 2010, Pattanayak et al. 2010). In particular, there is growing interest in the use of payments for ecosystem services as a means of promoting conservation (Ferraro and Kiss 2002, Segerson 2010, Lau 2013, Bladón et al. 2016). Under these programs, resource users are paid for engaging in conservation-related activities. For example, the Conservation Reserve Program in the United States compensates farmers for changing land use decisions or practices in favor of conservation (Classen et al. 2008). Payment schemes have also been successfully applied in the protection of land-based endangered species (Langpap 2006), and been adopted −less successfully− in the protection of threatened marine mammals like vaquita marina in the Northern Gulf of California (Avila-Forcada et al. 2012). Despite this trend, some critics question the effectiveness of voluntary approaches and their ability to achieve conservation goals at least cost (Morgenstern and Pizer 2007). These contrasting views highlight the need to conduct further research on the elements of program design that are key determinants of success.

This article describes the design and implementation of the *Deepwater Horizon* Oceanic Fish Restoration Project, a voluntary bycatch reduction project launched in 2017 in the Highly Migratory Species (HMS) pelagic longline fishery in the Gulf of Mexico. The project aims to reduce bycatch by compensating participating vessel owners in the Gulf of Mexico for voluntarily refraining from pelagic longline (PLL) fishing during the months of January through June each year. The project also provides financial incentives for participating fishermen to try alternative gear types that are less likely to impact non-target species. Thus, from the perspective of impure public goods, which captures the defining features of environmentally friendly goods and services, the project subsidizes adoption of a "green" alternative that would be otherwise under-provided by industry (Kotchen 2013). The HMS fishery in the Gulf of Mexico already utilizes several bycatch reduction strategies that have long been important to effective and sustainable fisheries management (Wilson and Diaz 2012; NOAA 2014), but the use of non-regulatory, decentralized, bycatch reduction approaches for the purposes of injured resource restoration remains a novel application. The *Deepwater Horizon* Oceanic Fish Restoration Project adds to the marine policy toolbox with a viable strategy to compensate participants for contributing to open ocean restoration targets by voluntarily decreasing fishing mortality via bycatch reduction.

For this innovative project to be successful, however, it is important that the design of the compensation ensures both adequate vessel owner participation and efficient use of the project resources. This paper discusses the various mechanisms that were evaluated to financially compensate vessel owners. Posted-price offers and first-price auctions, along with the multi-unit pay as bid generalization, are mechanisms used in a wide variety of conservation markets: mineral resource extraction rights (Matoso and Rezende 2014), water use rights (Cummings et al. 2004), timber (Haile 2001), fish resources (Schelle and Muse 1984, Curtis and Squires 2007), conservation-related land use practices (Stoneham et al. 2003, Cason and Gangadharan 2004), and endangered species habitat protections (Langpap 2004). Alternative mechanisms such as the Vickrey and uniform-price auctions are less frequent. In what follows we discuss the rationale for adoption of the latter for this project and draw lessons that we expect could be useful for practitioners and policymakers alike. The next sections provide background on the origins of the project, describe the design of the compensation for both the repose and alternative gear components, and reflect on the implementation of the first two years of the *Deepwater Horizon* Oceanic Fish Restoration Project.

2 Background

In order to understand how the *Deepwater Horizon* Oceanic Fish Restoration Project offers an example of a voluntary approach to improved environmental outcomes, it is instructive to provide context for how the project was conceived and developed. The *Deepwater Hori-*

zon oil spill was the largest spill in United States history, resulting in the release of 3.19 million barrels of oil into the northern Gulf of Mexico over 87 days from April through September 2010 (DWH-NRDA 2016).[1] Following the oil spill, a council of federal and state trustees was established to assess the impact of the spill on natural resources and determine the type and extent of restoration needed to compensate for those injuries (DWH-NRDA 2016, Barron 2012). While all major coastal and marine ecosystems throughout the northern Gulf of Mexico were impacted, of particular concern were epipelagic and mesopelagic fishes and invertebrates, which were directly exposed to oil and dispersants that are known to result in lethal and sublethal effects (DWH-NRDA 2016, Incardona et al. 2011, Collier et al. 2013, Buskey et al. 2016). Not only did the waters proximate to the oil spill serve as important nursery and spawning habitat, the spill occurred during a time of peak seasonal spawning productivity for many commercially and ecologically important pelagic fishes including yellowfin and bluefin tuna, mahi mahi, swordfish, sailfish, blue and white marlin, amberjacks, and mackerels (Harris et al. 2007, McBride et al. 2012, Richardson et al. 2016, Rooker et al. 2012, Weng et al. 2009). Accounting for natural mortality, the trustees estimated that direct kills and forgone production of pelagic fishes exposed to surface oil resulted in the death of 2-5 trillion fish larvae. Additionally, at least 86 million fish larvae were likely killed due to exposure to the deep water oil plume and oil rising through the water column (DWH-NRDA 2016).

While the injuries to oceanic resources are clear, effective restoration strategies for open ocean and deep sea species and habitats are understudied, expensive, and logistically challenging (Van Dover et al. 2014). Restoration of injured resources is particularly challenging for pelagic and highly migratory species that exclusively utilize open ocean habitat. Therefore, the Programmatic Damage Assessment and Restoration Plan developed by the trustees calls for innovative restoration approaches that directly reduce known sources of mortality by providing fishing communities with tools and incentives to limit impacts on fishery resources. Since fishing mortality is one of the largest sources of non-natural mortality in many fish species, efforts to decrease take −particularly through bycatch reduction

[1] For the impacts of the oil spill on the Gulf of Mexico seafood industry see, for example, Carroll et al. (2016).

strategies− could provide an effective and practical means of restoring pelagic fishes and invertebrates injured by the spill.

Building on this innovative restoration approach, in 2015, following public review and comment, the trustees approved the *Deepwater Horizon* Oceanic Fish Restoration Project, which was developed by the National Oceanic and Atmospheric Administration (NOAA) and implemented in partnership with the National Fish and Wildlife Foundation (NFWF). The project aims to reduce bycatch and bycatch related mortality in the Highly Migratory Species (HMS) pelagic longline fishery in the Gulf of Mexico. PLL gear is used to primarily target yellowfin tuna and swordfish, but may also unintentionally catch other, non-target, species such as bluefin tuna, sharks, and marlin as well as individuals of target species that are too small to harvest. This incidental catch −known as bycatch− is discarded due to regulatory requirements or because it has limited market value. By reducing bycatch and bycatch related mortality through a voluntary and temporary reduction in fishing effort, the project is designed to restore a portion of the injuries sustained by pelagic fishes during the oil spill (DWH-NRDA 2015).

Specifically, the *Deepwater Horizon* Oceanic Fish Restoration Project compensates participating vessel owners for voluntarily refraining from using PLL gear during a temporary repose period in the first six months of the year (January – June).[2] A reduction in fishing effort through a voluntary repose period is expected to reduce bycatch by as much as 25% over the life of the project and contribute to over 11,000 discounted kilograms[3] of pelagic finfish biomass left in the water each year of the project (DWH-NRDA 2015). In order to achieve these restoration targets, the project aims to reach at least 60 vessel-years of participation, where a vessel-year is equal to a single pelagic longline vessel participating in a single repose period. The 60 vessel-year target is based on the assumption that participation by a single vessel will reduce dead discards at a rate approximately equivalent

[2]The project was initially named the Pelagic Longline Bycatch Reduction Project as described in the *Final Phase IV Early Restoration Plan and Environmental Assessment.* NOAA partnered with the National Fish and Wildlife Foundation (NFWF) in 2016 to help implement the project, which was renamed *Deepwater Horizon* Oceanic Fish Restoration Project.

[3]The trustees conducted a resource equivalency analysis to estimate pelagic finfish offsets, using a discounting rate that converts annual offset produced (relative to a common base year). For a more detailed account of project offsets, see the *Final Phase IV Early Restoration Plan and Environmental Assessment* (DWH-NRDA 2015).

to the discounted kilogram calculations (DWH-NRDA 2015).[4]

The project's ability to meet its restoration targets and reduce bycatch in the Gulf of Mexico PLL fishery rests principally on attracting sufficient participation among PLL vessel owners in the Gulf of Mexico.[5] However, the HMS fishery in the Gulf operates year round, and abstaining from the use of PLL gear for the first six months of the year results in losses in net revenue to fishermen. To further offset potential losses throughout the supply chain, the project aims to reduce negative economic impacts from potential reductions of target species catch by encouraging participating vessels to continue to harvest yellowfin tuna and swordfish during the repose period using alternative fishing gear that results in low bycatch and bycatch mortality, including greenstick, buoy, and deep drop gear (Kerstetter et al. 2014, DWH-NRDA 2015).[6]

In sum, the project offered eligible vessel owners a pair of sequential decisions: (i) the option to join the repose (i.e., to refrain from fishing with PLL gear during the first six months of the year), and, for those vessels participating in the repose, (ii) the option to fish with a specific type of alternative gear for the duration of the repose. Thus, in addition to direct compensation for participation in the repose, the project also developed mechanisms to help vessel owners offset costs associated with the use of and experimentation with alternative fishing gear.

3 Compensation Design

The *Deepwater Horizon* Oceanic Fish Restoration Project is a voluntary initiative. A rational harvester will opt into the project if and only if participation yields a net gain. In other words, for the project to be successful, it must satisfy the inherent participation constraint (Segerson 2013). One of the primary objectives of the compensation design was to ensure that the 60 vessel-year target would be met cost-effectively (i.e., at least-

[4]"Discards" refers to the portion of the catch that is not retained but released at sea.

[5]To be eligible to participate in the project, vessel owners must have a history of fishing PLL in the Gulf of Mexico within the last two years, possess all necessary permits and sufficient Individual Bluefin tuna Quota (IBQ) to use PLL gear in the Gulf of Mexico.

[6]The greenstick is a large fiberglass pole with a 500-800 feet fishing line with 10 squid lures to attract tuna species. Buoy gear is a setup of typically 2-3 free-floating buoys attached to a fishing line. Deep drop rod and reel gear is typically used to target swordfish at depths of 1200-1800 feet.

cost) while inducing the greatest possible interest in the use of the alternative gear types available to project participants. When specifying the original project targets, every vessel-year was treated as identical, regardless of the historical bycatch rates of the participating vessels. Thus, the project is practice based (i.e., PLL fishing early in the year) rather than performance based. As in most voluntary programs, monitoring and verification are easier for practices than for environmental performance, which is typically subject to random variation (Segerson 2013). This assumption of a standardized vessel-year is important to the initial compensation design described herein; however, as the project advances with continuous assessment of progress towards restoration, this assumption may be modified to explicitly incorporate fishermen's heterogeneity in terms of bycatch, which would require the compensation design described here to be revisited accordingly. To design the compensation approach decisions were made regarding the following components: the length of the project, the mechanism to attract interest in the repose, and the additional incentives needed to encourage participants to willingly adopt and experiment with the alternative gear.

In order to determine the most suitable mechanism for attracting participation in the repose and determine the desired overall length for the project, the implementation team took the following steps: (i) estimated the distribution of vessel owners' opportunity costs of joining the repose; (ii) identified possible alternative lengths for the project; (iii) identified the candidate compensation mechanisms; and (iv) simulated the implementation of the project under various compensation mechanisms and project lengths. According to these analyses, the desired timeline and preferred compensation mechanisms were determined based on simulated outcomes of the overall project's costs and efficiency.

3.1 The Willingness to Accept Distribution

In the absence of the *Deepwater Horizon* Oceanic Fish Restoration Project −i.e., under the business-as-usual scenario− PLL vessels would be able to harvest HMS species during January-June. As mentioned above, individuals must perceive a net benefit to be willing to participate in a voluntary project. Consequently, the first stage in the design of the project compensation was to determine the vessel owners' opportunity costs of joining the repose, which can be described as the value vessel owners place on using their PLL gear commercially during the first six months of the year, the period during which the repose would be implemented. With this information, the project manager is able to determine the minimum payment required for a vessel owner to join the project since net benefits from participation require a compensation of at least their opportunity cost.

Data from commercial PLL fishing trips taken in the Gulf of Mexico from 2010-2015 were obtained from the National Marine Fisheries Service (NMFS), including vessel trip reports (logbooks), cost-earnings reports, dealer reports, and weigh-out slips.[7] First, cost and earnings survey data were combined with logbooks to separately fit trip-level fuel and non-fuel cost equations using linear regression. These results were then used to estimate variable costs for those trips where no cost information was available. The following variables were used as regressors: vessel length, engine horsepower, distance travel, hull capacity and material (steel or fiberglass), days-at-sea, crew size, amount of gear used, species targeted, region where fishing occurred (i.e. in the Gulf of Mexico or in a different area) and whether the vessel relies on ice (or a freezer) to store the catch.[8]

Next, dealer reports and weigh-out slips were combined to estimate trip revenues for all PLL trips taken in the Gulf of Mexico from 2010-2015. Trip revenues for each species were computed as price times landings, which were then added across all the commercial species harvested during a given trip to arrive at total trip revenues. These data were used to compute net revenues −defined as total trip revenues minus variable costs (fuel and non-fuel)− for each vessel. Since only vessel owners are eligible for participation in the program, to determine the fraction of net revenues for each vessel owner, the trip net revenue was then multiplied by the share corresponding to the vessel owner according to the contract with the crew (i.e. this information is reported and available to NMFS).[9] Net

[7]Each year 20% of active Atlantic HMS commercial permit holders are randomly selected to report economic information along with their Atlantic HMS logbook or Coastal Fisheries logbook submissions. Selected permit holders provide trip costs for all HMS trips taken during the selected year (Thunberg et al. 2015).

[8]The linear regression estimates for the fuel and non-fuel components of variable costs are available from the authors upon request.

[9]Crew shares of net revenues were not included in the estimation of vessel owner's opportunity costs. The lack of reliable information on the identity of crews in the fishery rendered unfeasible any attempt to design enforceable contracts that would require vessel owners to compensate crew members for participation in the repose. Moreover, the option given to vessel owners to fish with the alternative gear during the

revenue was then limited to the trips taken between January and June and aggregated, for each eligible vessel owner, into a first half of the year net-revenue, which was then averaged over fishing seasons from 2010 through 2015. This provided an estimate of the true, private value that each eligible vessel owner attached to the opportunity to use their PLL gear during the repose period from January through June.

Finally, in order to simulate the outcomes for the various scenarios of project length and compensation mechanisms (see below), a kernel distribution was fitted to the empirical vessel owners' private values estimated previously. Figure 1 displays the cumulative distribution function (cdf) corresponding to that fitted distribution. The mean of the distribution was $38,407, while the median was $37,025 and the standard deviation $32,002. The long right-tail of the value distribution indicates that there are several high performing fishermen that value the opportunity to use PLL gear during the first half of the year significantly higher than the remainder of the fleet. The analysis also revealed differences between vessel owners with hailing ports in the eastern and western Gulf of Mexico.

[FIGURE 1 HERE]

3.2 Length of the Project

Once the willingness to accept (i.e., opportunity cost) distribution was estimated for individual vessel owners, the value distribution (Figure 1) was used to simulate the average cost of the project per vessel-year over variable project lengths.[10] Not surprisingly, this analysis quickly revealed that increasing the overall duration of the project reduces the required number of vessels needed to participate annually to achieve the 60 vessel-year goal. As a result, regardless of the compensation mechanism evaluated (see the next section below), the longer the project, the lower the average cost per participant in the repose (Figure 2). The reason for this decrease in cost is twofold. First, lowering the number of available slots each year effectively increases competition among eligible vessel owners for each slot, which

repose was partly a strategy to keep crews employed during this time and to avoid hardship in the fishery.

[10]In conducting the simulations for different project lengths, the vessel-years were allocated equally across periods. Assuming an alternative allocation would not have changed the qualitative results described in this section. Furthermore, in the simulations, project length was capped at 10 years because it was considered that fewer than six participants per year (on average) would not have justified the administrative burden of conducting the auctions and running the project each season.

in turn translates into lower bids. Second, with a longer project timeline, a smaller number of participants are needed each year to meet the restoration targets, which means that the project manager only needs to recruit the vessel owners at the left-tail of the distribution of valuations, i.e., those businesses that have the lowest valuations (Figure 1). Therefore, when designing and implementing a project of this complexity it is important to critically evaluate the optimal length of the project, which must balance a reduction in the cost per participant due to higher competition with the potential increase in administration costs associated with implementing a longer project.

An additional key consideration for the *Deepwater Horizon* Ocean Fish Restoration Project was the potential impact on the HMS fishery in the Gulf of Mexico, as one of the restoration objectives of the project is to minimize negative economic effects associated with potential reductions in the catch of target species. With fewer than 45 eligible pelagic longline fishing vessels active in the Gulf of Mexico, a longer project makes it possible to restrict the number of participants to help ensure that the majority of the PLL fleet remains active and continues to supply HMS fishes to domestic and international markets year round. Since the majority of effort is concentrated around a small number of ports, the geographic distribution of participants must also be carefully considered. To avoid concentrating potential impacts to any one fishing community, it may be appropriate to limit participation within a given region, which may also influence annual participation and overall project length. Finally, implementing a longer project has the added benefit of being able to incorporate lessons learned over time.

In order to help evaluate these potential tradeoffs, NOAA and NFWF facilitated extensive industry outreach with vessel owners, fish dealers, and other key industry stakeholders, in the form of face-to-face meetings, printed instructional materials, and regular contacts with industry through community liaisons project contractors. The feedback received influenced project design and implementation, including the decision to launch the project as a pilot with limited participation. The 2017 pilot year included a shortened, four-month repose period with participation limited to seven vessels. This provided the opportunity to evaluate implementation, continue industry engagement, and make project adjustments and enhancements prior to the implementation of the full six-month repose period. With the full implementation of the project in 2018, the number of participants was increased to include 10 vessels. Therefore, recruiting an average of 11 participants per year over the next four seasons achieves the project target of 60 vessel-years, striking an appropriate balance between the overall number of annual participants and the costs associated with implementing the project. A shorter timeframe would decrease total administrative expenses, but that reduction would be outweighed by higher participation costs in the repose. Conversely, a longer project would result in additional administrative expenses that would exceed the savings in repose costs.

[FIGURE 2 HERE]

3.3 Choice of Repose Compensation Mechanism

The project manager must account for a critical information asymmetry in the compensation design of this project. Eligible vessel owners have better information about their opportunity cost of joining the repose than the project manager. Eligible vessel owners may attempt to secure larger payments for their participation by claiming that their opportunity costs are higher than they actually are, thereby seeking to extract information rents from the project manager. Information rents, in turn, undermine the cost-effectiveness of the project. Thus, the compensation design must limit those information rents while securing vessel owners' voluntary participation. Three candidate compensation mechanisms were considered: posted-price offer, discriminatory auction, and uniform-price auction.

A posted-price offer, sometimes referred to as a fixed price offer, is a take-it-or-leave-it offer that sets the same price for everybody. This mechanism is easy to understand because a vessel owner will choose to participate if his/her private value is below the offer price, but will otherwise abstain. Since all participants receive identical compensation, a post-price offer is also typically perceived as fair (Heyman and Mellers 2008). However, this mechanism is allocatively inefficient and does not guarantee that the vessel owners with the lowest valuations will join the repose.

A discriminatory auction (or pay as bid auction) requires eligible vessel owners to submit bids with the amount they would need to be compensated for their participation in the repose. The project would then pay participants the price they bid, selecting the lowest bids first. This mechanism tends to attract high participation as bidders see an opportunity to extract surplus from the project (through bid shading, that is, by placing a bid that is above what they believe PLL fishing during January-June is worth; see, for example, Nautz and Wolfstetter 1997). Additionally, the payment structure associated with this type of auction is straightforward for bidders to understand: they are paid what they bid if they are selected to participate. However, determining the optimal bidding strategy may be challenging for potential participants as it essentially involves solving a non-cooperative game.[11] Thus, a discriminatory auction may require significant outreach to eligible vessel owners −e.g., face-to-face meetings in addition to printed materials− to provide technical assistance. Furthermore, under this mechanism participants are paid different amounts for joining the repose. There is the risk that they may feel cheated if they are paid less than their peers for participating in the same project.

Finally, in the uniform-price auction, vessel owners submit their bids, but all the selected participants are paid an identical amount equal to the lowest rejected bid (or the reserve price, whichever is lowest, where the reserve price is the maximum amount the project manager is willing to pay for a vessel-year). Thus, all participants in the project are paid at least what they bid. The advantage of this mechanism is that the optimal bidding strategy is simpler than in the pay-as-bid auction since vessel owners should bid their true private value. As such, it allows the project manager to assess the reliability of the data used to determine the distribution of vessel owners' values.

The fixed-price offer and the pay-as-bid auction have been used previously in the context of fisheries management and conservation (Curtis and Squires 2007), but to the best of our knowledge, the uniform-price auction had not yet been employed in this context. Of these three mechanisms, the auctions are most cost effective in attracting participation as they reduce bidders' informational rents by harnessing competition. While in a posted-price offer the informational burden is on the project manager, who must determine the

[11] For a symmetric equilibrium, the optimal biding strategy is given by $b(v_i) = \frac{1}{(1-H(v_i))}\left(\int_{v_i}^{r} x dH(x) + r[1-H(r)]\right)$ if $v_i \leq r$, where r denotes the reserve price and $H'(\cdot)$ the pdf of the $n-q$ order statistic among the $n-1$ rivals' valuations, with q the number of slots available for the repose. The reserve price is the maximum amount the project manager is willing to pay for a vessel-year.

appropriate compensation for participating in the repose, the auctions are market mechanisms that allow for price discovery. Indeed, in a posted-offer, if the price is set too low, few participants may be attracted into the project. Conversely, if the price is too high, an excessive number of participants will attempt to enter the project and could exceed available funding. In both cases the posted offer may fail to contract enough vessel-years.

In order to evaluate which compensation mechanism should be applied to the project, implementation was simulated under each compensation mechanism. In addition, the simulations considered variable project lengths to ensure sufficient participant at least cost. The results corresponding to 1,000 simulations of the 5-year project under each the three mechanisms are depicted in Figure 3. For the two auction formats, the simulations assume that a single auction is conducted for all potential participants in the Gulf.[12] For each of these simulation runs, the following steps were taken: (i) randomly draw a sample of vessel owners' valuations −of size equal to the number of eligible vessels− from the fitted distribution in Figure 1; (ii) derive the bids for each of the potential participants using the optimal bidding strategy for each compensation mechanism, (iii) determine the predicted winners (here assumed 12 participants per repose year) under each compensation scheme based on the rules of the mechanism; and, (iv) given the identity of the winners, compute project costs and efficiency.[13]

The simulations for both auction formats −discriminatory and uniform-price− resulted in a similar expected cost per participant in the repose (Figure 3). The results for the uniform-price auction, however, exhibited higher variation in costs, due primarily to the fact that this auction's costs are more sensitive to the valuation of the marginal bidder drawn from the distribution in Figure 1 in each simulation run (since this valuation determines all participants' payment amount).[14]

While cost effectiveness −limiting the expected costs of achieving the 60 vessel-year target− was a critical consideration in the compensation design, the selection of the auc-

[12] In the second year of the project two separate auctions were conducted, in the eastern and western Gulf. The simulations corresponding to this scenario were conducted as in the single auction case, but separately for each subregion.

[13] Throughout the simulations we assumed zero transaction costs from submitting bids.

[14] By spreading the project over multiple years, thereby limiting the number of required participants each season, the project manager limited its exposure to this variability in costs (i.e. since the auction format could always be revised in future years if realized costs proved excessively higher than anticipated).

tion format took additional considerations into account. One of the most important considerations raised during discussions with the industry was the perceived fairness of the compensation, which for potential participants meant equal payment for the vessel-year. The uniform-price auction was thus an attractive option since it compensates all participants equally (i.e., it is perceived as fair; Spagnolo et al. 2006; Squires 2010; Brenner et al. 2015) while retaining cost-effectiveness in attracting participation.

Consequently, the uniform-price auction was selected and implemented in both the 2017 and 2018 project years. Since to the authors' knowledge, a uniform-price auction has never been implemented in this context, several key challenges had to be overcome in order to administer the auction. The possibility of collusion is a concern for this auction format, and thus applicants were required to prepare their irrevocable sealed bids (or "quotes") in the presence of a notary public and were required to sign a declaration certifying that they did not engage in any collusive behavior.[15] Another challenge, as described above, is that the PLL fleet is not uniformly distributed and there are key operational differences between eligible vessel owners in the eastern and western Gulf of Mexico. While a single uniform-price was implemented in the pilot year, only vessels based in Louisiana submitted bids that turned out to be competitive. Therefore, to ensure broader geographic participation and to account for regional variation in costs and earnings across the Gulf, separate uniform-price auctions were run in the western (TX, LA, MS, and AL) and the eastern Gulf (Florida and the Atlantic Coast) in 2018. To avoid overpaying participants, each auction included its own reserve price. The reserve price was set at the minimum dollar value that would ensure, for 100% of the simulation runs in Figure 3, that enough participants would enroll in the program each season to achieve the 60 vessel-year target with a five-year project.

[FIGURE 3 HERE]

[15] A prevailing view among practitioners is that open auctions are more prone to bidder collusion since participants are face to face and can react immediately to other bidders' behavior (see, for example, Athey et al. 2004).

3.4 Implementing the Uniform-Price Auction for the Repose

A total of 22 eligible vessel owners submitted bids for participation in the 2017 pilot repose, of which seven bids were accepted, all based in Louisiana. Table 1 presents summary statistics for the actual bids and the corresponding predictions for 2017, while Figure 4 shows a plot of actual bids versus predictions. As detailed in subsection 3.3, predicted opportunity costs for each eligible vessel owner were computed as the owner's share of net revenues sum across all the trips taken by his/her vessel during the first half of the year, averaged over the period 2010-2015. Since the pilot repose in 2017 only lasted four months, the bids in Table 1 have been adjusted to reflect the implied bids for a six-month repose. For the 2018 repose, 16 bids were submitted, of which 10 were accepted: three from the eastern Gulf and seven from the western Gulf. Table 2 presents summary statistics for the bids and the respective predicted values, and includes the bids for auctions in both the eastern and western Gulf. Figure 5 depicts a plot of actual bids versus predictions for the 2018 repose. All bids were considered, but bids submitted by vessel owners with a history of enforcement violations were dismissed.[16] In the case of identical bids, ties would be broken based on willingness to adopt the alternative gear and, in the 2018 repose, on the number of years enrolled in the project (i.e. whether the vessel was participating for a second consecutive year).

[TABLE 1 HERE]

[TABLE 2 HERE]

For a uniform-price auction in which each participant offers a single item (i.e., participation in the repose in a given season), the optimal strategy is for participants to bid their private values (see, for example, Krishna 2002). The majority of the bids received seemed to follow this pattern, with the exception of a handful of outliers.[17] These results suggest

[16]The Request for Quotation (RFQ) used to solicit eligible vessel owners included the following description of eligibility: "...NOAA will also evaluate past enforcement history. Past or outstanding violations may preclude participation in the project; however, minor violations that have been resolved are not expected to have any bearing on eligibility." Therefore, prospective applicants were aware that enforcement violations would be evaluated upon submission of a bid, and applicants had discretion as to whether they felt it appropriate to apply dependent on the severity of past violations. The RFQ packages for both the 2017 and 2018 repose years are available upon request.

[17]The Mann-Whitney rank-sum test fails to reject the null hypothesis that the two samples come from

that vessel owners understood the key features of the repose compensation mechanism and attempted to bid optimally. This evidence, coupled with the fact that by design, the auction selects the lowest submitted bids, supports the view that the mechanism was successful in attracting into the repose the vessel owners with the lowest opportunity costs. Furthermore, these results indicate that the data used to estimate private values —logbooks, dealer reports, and costs and earnings survey data periodically collected by NMFS— are indeed reliable, as was suggested by potential participants during initial outreach meetings. The fact that the available data seem trustworthy provides additional confidence in the results of the initial simulations, which were conducted using self-reported information.

[FIGURE 4 HERE]

[FIGURE 5 HERE]

3.5 An Extra Payment Option: Adopting the Alternative Gear

As previously mentioned, once the repose participants were selected through the auction, they were given the option to fish with experimental gear (greenstick, buoy, or deep drop) during the duration of the repose. To attract interest for this option, repose participants were offered additional incentives for using the alternative gear. However, determining the appropriate level of compensation for participation in the alternative gear component of the project proved challenging. At the time the *Deepwater Horizon* Oceanic Fish Restoration Project was implemented in 2017, there was little information available regarding the profitability of fishing with greenstick, buoy, or deep drop gear in the Gulf of Mexico. Existing data were largely limited to: i) vessel trip reports from fishing trips using buoy gear on the east coast of Florida, and ii) data gathered from a study conducted in the northern Gulf of Mexico from 2011-2013 in which four commercial fishing vessels took 30 trips using greenstick and buoy gear (Kerstetter et al. 2014); deep drop gear was not evaluated. The pilot study showed losses at the trip level for all participants due to the intensive fuel use, which suggested the need to subsidize the adoption of these gear types (Kerstetter et al. 2014).

the same population (at the 5% level) for both repose years.

Given the minimal data available, one initial option considered was to compensate repose participants that selected the alternative gear option based on trip expenses via reimbursement. However, this idea was quickly discarded as it could create perverse incentives for harvesters to overstate their trip costs. Furthermore, the results from Kerstetter et al. (2014) suggest that the alternative gear may be best suited for small, fast, fuel efficient vessels. If costs were reimbursed, it might discourage participants from exploring opportunities to use smaller boats, which was an option promoted by the project development team.

Of the existing information on alternative gear, vessel trip reports for Florida east coast fishing trips using buoy gear did offer sufficient data to approximate a level of payment for participating in this portion of the project. Logbook reports were combined with cost and earnings data from all buoy gear trips on the Florida east coast during the period 2006-2015 in order to determine net revenue per day-at-sea using the alternative gear types. On average, net revenue per day-at-sea was $793 for vessels operating on the Florida east coast. In comparison, the mean net revenue of vessels using PLL gear was $1,760 per day-at-sea. Therefore, a payment of approximately $1,000 per day-a-sea would help compensate vessel owners using alternative gear for the forgone net revenue associated with not using PLL gear.

Ultimately, the *Deepwater Horizon* Oceanic Fish Restoration Project opted to implement a flat payment per day-at-sea with a 10 sea-day per month cap, which aimed to encourage adoption of the alternative gear and generate data for the revision of these parameters in ensuing years. The payment was set between $1,000 and $1,500 per day-at-sea ($1,500 in 2017, lowered to $1,000 in 2018). Thus, participants could receive up to an additional $60,000 for using alternative fishing gear during the repose. For the purposes of compensation, the day-at-sea was defined as a 24-hour period in which fishing for yellowfin tuna and/or swordfish occurs and gear is actively deployed and monitored for eight hours or more during times of day and in habitat where the targets are likely to occur.

In the 2017 pilot repose, all seven participants selected the alternative gear option, fished the maximum 40 days-at-sea using greenstick gear, and received an additional payment of $60,000. All vessel owners received on-the-water and onshore training on the proper use and maintenance of the gear. Sessions were facilitated by a trainer with extensive experience using the alternative fishing gear. Over the shortened four-month repose, pilot participants took 20 fishing trips, nine of which were observed by at-sea monitors, with an average trip length of 11 days.[18] While the interest among participants in testing these alternative technologies is encouraging, repose participants caught few fish with the greenstick gear compared to the harvest of other fishermen already using the same type of gear along the east coast of the United States. During the period 2007-2015, vessels along the east coast caught a mean of 8.7 fish/day-at-sea (median: 5 fish/day-at-sea), which was significantly higher than preliminary estimates from the 2017 pilot year of the project where a mean of just 0.2 fish/day-at-sea (median: 0.13 fish/day-at-sea) was reported.

During the 2018 repose, nine of the ten vessels −three of them from Florida and the rest from Louisiana− opted to participate in the alternative gear portion of the project. Additional gear options were introduced in 2018 and participants selected two out of three gear options: greenstick, buoy, or deep drop gear. Participants took a total of 50 trips, with an average trip length of 9.8 days. Based on preliminary estimates provided by project participants, trip landings improved slightly with respect to the pilot year (0.25 fish/day-at-sea), but remained significantly below the harvest levels observed from 2007-2015 by fishermen in the east coast of the United States.

4 Lessons Learned

Following the first two years of project implementation, preliminary results suggest the project has been successful at reducing discard mortality. Detailed analyses of the natural resource benefits accrued to-date are currently underway and will aim to evaluate if the project is able to meet restoration targets to reduce discards in the Gulf of Mexico while also minimizing potential economic effects of the repose through the use of alternative gear (DWH-NRDA 2015). In any case, recruiting 60 vessel-years of participation is fundamental

[18]The implementation of incentive payments directly tied to the use of alternative gear requires some means of on-vessel monitoring. Consequently, the project relies on NMFS at-sea observers. Moreover, all vessels permitted for PLL fishing in the Gulf of Mexico are required to possess a satellite-based Vessel Monitoring System (VMS). Vessels participating in the project were required to have their VMS units turned on at all times during the repose.

to achieving the restoration targets, and an efficient and flexible compensation design is critical to attracting sufficient participation.

While reverse auctions and other market mechanisms are commonly used in fisheries (Curtis and Squires 2007; DePiper et al. 2013; Zivin and Mullins 2015), there is no known precedent for using market mechanisms to recruit participation in a temporary fishing repose while also encouraging adoption of low bycatch gear. Following consideration of the advantages and limitations of multiple potential compensation mechanisms, a uniform-price auction was considered the most suitable for this unique application. A key advantage of a uniform-price auction, particularly in multi-period projects like this, is that it provides the opportunity to learn about the reliability of the data used in the estimation of private values, since the optimal strategy is to bid one's own valuation. The first two years of implementation have in fact revealed that applicants employed bidding strategies that were consistent with theory, bidding an amount close to their expected foregone profit during the repose. By implementing a uniform-price auction early in the project, these data become valuable in determining if, and when, future project changes are warranted.

The auction design and implementation process has remained flexible, participatory, and adaptive. Intensive industry outreach during the development and implementation of the compensation design has proved invaluable not only in gaining feedback to help refine the overall design over time, but also in familiarizing potential participants with the main features of a uniform-price auction. Launching the project as a pilot signaled to potential participants that project implementation is flexible and capable of making adjustments based on industry feedback. As a result, the bidding process ran smoothly in 2017 and 2018. The pilot also suggested that the communication and outreach materials developed for the project allowed vessel owners to clearly understand and participate effectively in the repose compensation mechanism. The fact that most vessel owners seem to have bid optimally indicates they understood the compensation design and perceived it as fair. Interestingly, when the project shifted to running separate auctions in the eastern and western Gulf of Mexico for the 2018 repose, comparisons of perceived fairness appeared to be circumscribed within each region of the Gulf. Interest in the project did not seem to be influenced by the possibility that participants in the other region might receive a different payment for joining the repose. Running separate auctions for the two regions effectively expanded participation throughout the entire Gulf in 2018 and helped to prevent the concentration of participants in any one fishing community or region. This was only possible with proactive and regular outreach throughout project implementation.

The alternative gear portion of the project helped to attract interest in participation. This portion of the project keeps fishing vessels and upstream markets active throughout the repose by continuing to bring yellowfin tuna and swordfish to market, and provides potential vessel owners with additional incentives to participate in the repose. Participants' vessels are outfitted with up to two different alternative gear types at no cost to the vessel owner, offering participants a low-risk opportunity to experiment with these low-bycatch gear types, to fish in closed areas, and to identify opportunities to diversify harvest by utilizing multiple gear types on a single trip.

Detailed analyses on catch and discard rates using the alternative gear are currently underway, but the interest among vessel owners in the use of alternative gear is encouraging. However, preliminary estimates suggest catch rates on alternative gear are low and opportunities remain to improve product quality. While adoption of experimental technologies may be rapid, perfecting their use requires training and practice, which often takes time (Haasnoot et al. 2016). Currently it is difficult to determine whether meager catch rates are due to shrinking and weak incentives, a steep learning curve associated with operating new gear, or the possibility that the gear may be unsuitable for commercial use in the Gulf of Mexico. Thus, to assess the effectiveness of a given set of economic incentives, those incentives need to remain in place unmodified longer than a season. For this reason, the flat payment per day-at-sea was continued in the second year of the project. However, since moral hazard may be at play here (Vestergaard 2010, Jensen et al. 2017), in future years other mechanisms may be explored to help improve target catch rates on alternative gear.[19] These options include additional training opportunities, increased observer coverage (i.e., making fishing effort more observable), or a rank-order tournament (i.e. performance related pay that provides a financial reward to agents who put in enough

[19]Moral hazard is a pervasive phenomenon in fisheries. For example, it is critical for understanding the share contracts that characterize the lay system (McConnell and Price 2006), and for the analysis of discards and illegal landings (Jensen and Vestergaard 2002).

effort to finish in one of the top positions; see Lazear and Rosen 1981).

5 Conclusion

Bycatch mitigation strategies are important to sustainable fisheries management (Komoroske and Lewison 2015; Dunn et al. 1989; Little et al. 2015). The *Deepwater Horizon* Oceanic Fish Restoration Project offers a novel approach to bycatch reduction through a voluntary and temporary reduction in pelagic longline fishing effort to help compensate for injuries sustained during a major oil spill. Responses to other disasters have led to large-scale efforts to reduce fishing mortality though vessel buy-back programs that permanently remove vessels from a fishery to limit overall effort (Upton 2010). However, unlike these permanent measures, the *Deepwater Horizon* Oceanic Fish Restoration Project sought to recruit participation in a fishing repose, where vessels would remain active in the fishery, but would abstain from pelagic longline fishing for a portion of the year in order to reduce fishing effort. By instituting a temporary, voluntary, and non-regulatory repose, the project appears to be able to achieve natural resource benefits while still allowing for flexibility in the long-term management of highly migratory species.

While the first two years of the *Deepwater Horizon* Oceanic Fish Restoration Project has applied a compensation approach that has successfully attracted participation throughout the Gulf, more research is needed to fully evaluate the natural resource benefits gained through the repose. Additionally, more work is needed to identify and implement opportunities to improve the participants' proficiency with the alternative gear in order to increase both the quantity and quality of fish caught. This will be critical to evaluating whether the alternative gear can prove profitable in the Gulf of Mexico. As additional information is gathered and analyzed through the continued implementation of the project, consideration should be given to project adjustments. This may include, for example, the possibility of multiple-year participant commitments, which would limit participant turnover and eliminate the need to run yearly auctions. Likewise, alternative auction formats may be considered in future years. For instance, strategies that aim to minimize the cost per pound of bycatch removed through participation in the repose were initially considered but were later discarded because they could be perceived as rewarding vessels with high historical bycatch rates. Indeed, while such arrangements may appear more cost-effective in achieving restoration targets than the current approach, they could backfire by undermining overall voluntary participation if harvesters perceive they are being unjustly treated in favor of high-bycatch offenders. Voluntary initiatives for environmental protection, such as the *Deepwater Horizon* Oceanic Fish Restoration Project, need to be mindful of the dynamic incentives for renewed participation that alternative compensation designs may generate. For this reason, in the original project it was assumed that each vessel-year would be treated identically, regardless of historical bycatch rates of individual vessel owners. However, it may be prudent to reconsider this assumption in future years as additional data is gathered to evaluate progress towards restoration targets.

Although there is still much to learn, the lessons gathered through the first two years of implementation may help inform the design of similar initiatives in different conservation settings. Currently, the *Deepwater Horizon* trustees responsible for the Open Ocean Restoration Area are developing restoration plans for other resources that were injured by the oil spill.[20] This project will serve as an important case study for restoring pelagic resources for which traditional habitat restoration efforts may not be feasible. More broadly, payments for ecosystem services as a policy approach have gathered considerable interest in recent years (Ferraro 2011). This project adds to the existing evidence (e.g. Langpap 2006) that payment schemes can be effective in promoting conservation.

[20]For details see `http://www.gulfspillrestoration.noaa.gov/restoration-areas/open-ocean`.

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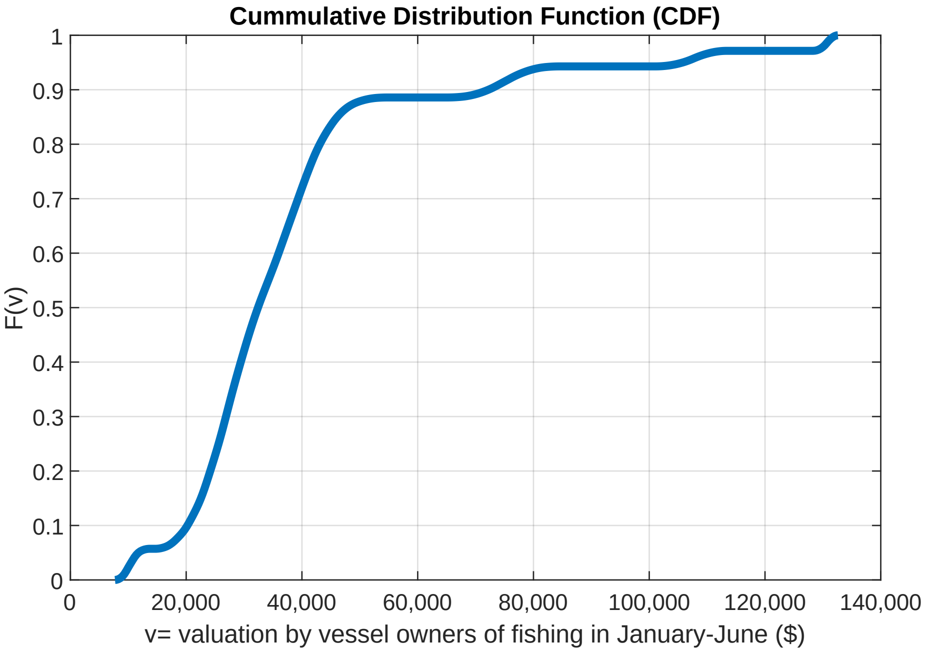
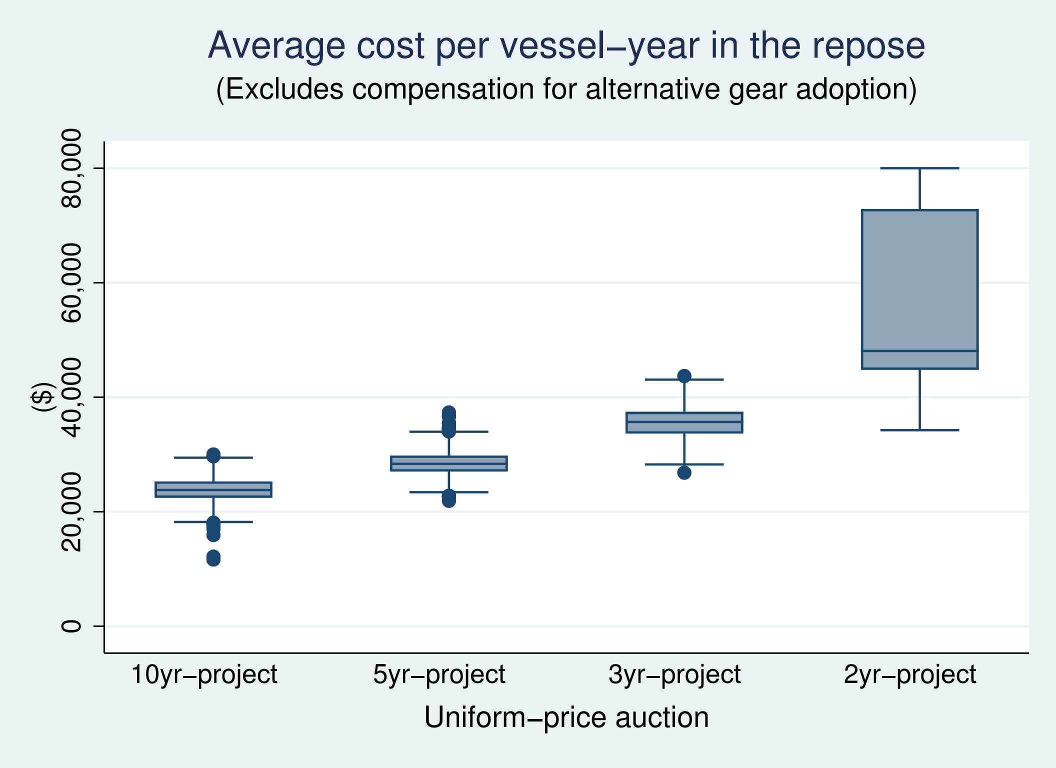
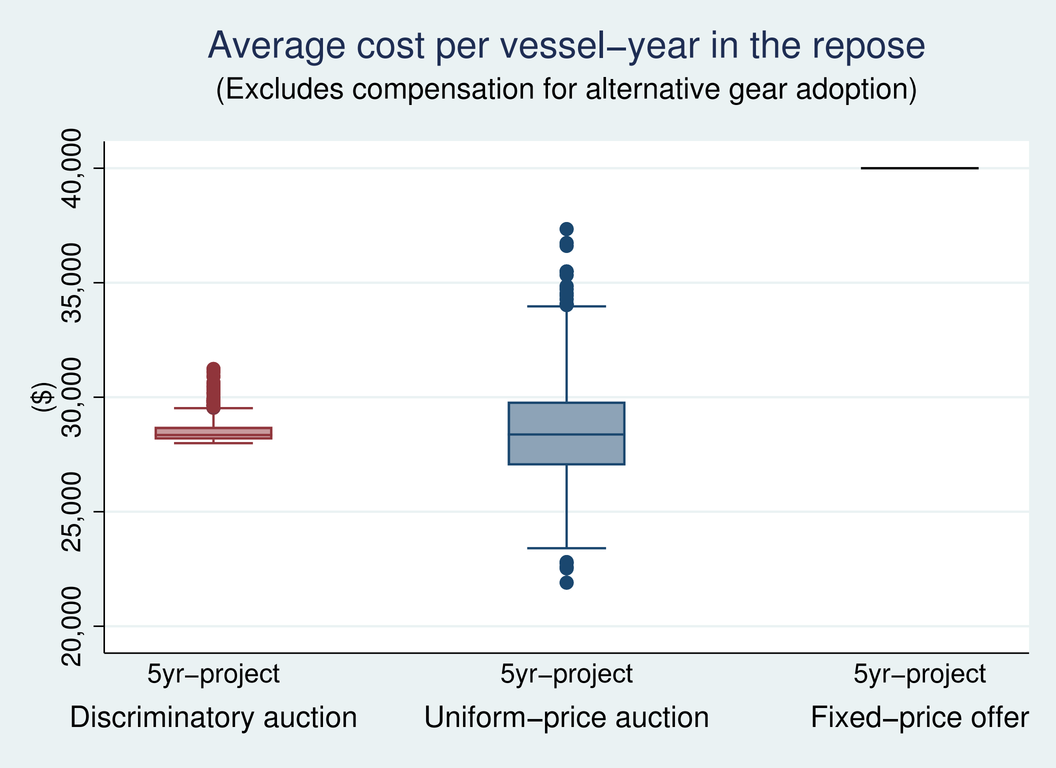
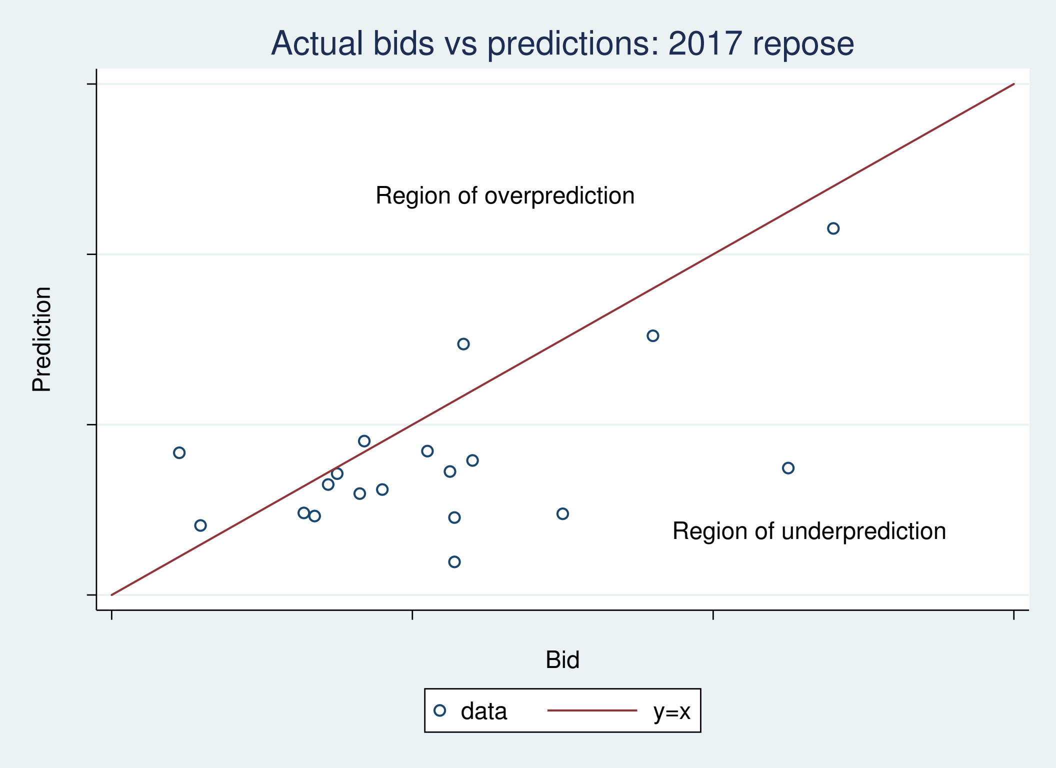

Cummulative Distribution Function (CDF)
F(v)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
v= valuation by vessel owners of fishing in January-June ($)



Average cost per vessel–year in the repose
(Excludes compensation for alternative gear adoption)
($)
0
20,000
40,000
60,000
80,000
10yr–project
5yr–project
3yr–project
2yr–project
Uniform–price auction


Average cost per vessel–year in the repose
(Excludes compensation for alternative gear adoption)
($)
40,000
35,000
30,000
25,000
20,000
5yr–project
Discriminatory auction
5yr–project
Uniform–price auction
5yr–project
Fixed–price offer



Actual bids vs predictions: 2017 repose
Region of overprediction
Region of underprediction
Prediction
Bid
data
y=x

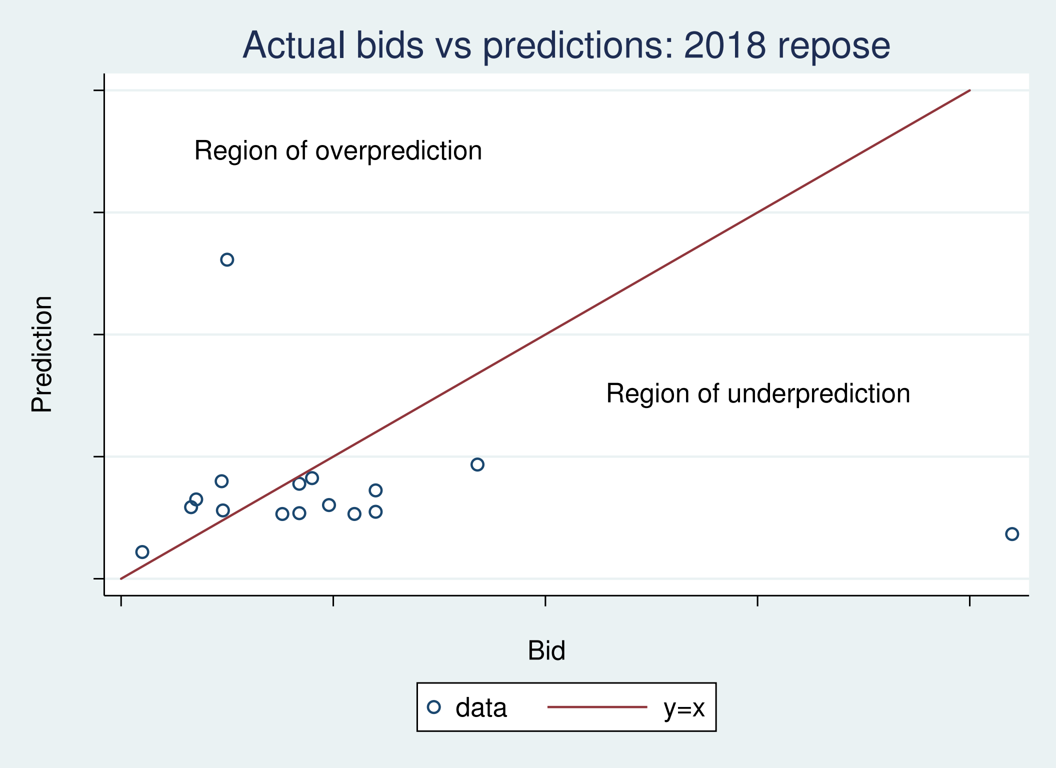

Actual bids vs predictions: 2018 repose
Region of overprediction
Region of underprediction
Prediction
Bid
data
y=x

Table 1: 2017 Pilot repose: bids vs. predictions

Variable	Obs.	Mean	SD	Median	[1 pctl, 99 pctl]
Bids ($)	22	51,215	28,389	46,500	[10,500, 120,000]
Predictions ($)	19	39,584	23,242	35,625	[9,708, 107,599]

Notes: (a) In the first year of the project, there were three bidders for whom not enough information was available in order to estimate their valuation; (b) pctl denotes percentile.

Table 2: 2018 repose: bids vs. predictions

Variable	Obs.	Mean	SD	Median	[1 pctl, 99 pctl]
Bids ($)	16	49,806	47,231	42,000	[5,000, 210,000]
Predictions ($)	16	36,911	26,524	29,789	[10,957, 130,678]

Notes: pctl denotes percentile.