Do Catch Shares End the Race to Fish and Increase Ex Vessel Prices?

Evidence from U.S. Fisheries

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Abstract: *Catch shares appear to lower fishing costs by eliminating redundant capacity. Theory suggests that catch shares may also alter within-season behavior and generate revenue benefits through improved market timing, higher product quality, and changes in the fresh/frozen product mix. Do catch shares alter within-season behavior to end the race to fish? Do catch shares cause ex vessel prices to increase? Despite compelling theory and anecdotal evidence, there is little systematic causal evidence to support these hypotheses. We test both hypotheses for all U.S. catch share fisheries using an individually matched control fishery for each treated fishery and a difference-in-differences estimation approach. We find strong evidence that catch shares cause season decompression consistent with the theory that rights-based management ends the race to fish. However, evidence for price increases is weak, and, on average, our models suggest price decreases. To the extent that catch shares produce benefits on the revenue side, these benefits do not appear to manifest in ex vessel prices. We discuss potential confounding factors in fishing revenues and the need for a richer theoretical understanding of transitions to rights-based management.*

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Introduction

Property rights have long been considered a fundamental prerequisite of economic efficiency in any production system (Grafton, Squires, and Fox, 2000). An absence of property rights and use restrictions is responsible for both the dissipation of economic rents and the degradation of biological sustainability in open-access fisheries (Gordon, 1954). Property rights also remain absent in many tightly managed fisheries, where biological management in the form of effort restrictions or output controls protects stock levels but fails to prevent the rent dissipation caused by competition between fishing vessels (Homans and Wilen, 1997; Wilen, 2006). These two broad categories, open access and biological management, account for the vast majority of the approximately 11,000 fisheries globally (Costello, et al., 2010), resulting in substantial estimated losses in economic value (Kelleher, Willmann and Arnason, 2009).

In contrast to biological management, rights-based fishery management systems directly address the excludability problem of open access resources by limiting access, generally through the use of 'catch-shares' such as individual fishing quotas (IFQs).[1] Catch share systems have grown in prominence since first proposed in the 1970s (Christy, 1973) in part because the establishment of Exclusive Economic Zones made it possible for regulators to enclose common-pool fishery resources. These systems currently represent about 2 percent of fisheries worldwide and roughly a third of fish volumes landed, and they have been

[1] The term 'catch shares-based management' (or simply 'catch shares') is commonly used to refer to any rights-based fisheries management system. These include individual fishing quota (IFQ), individual transferable quota (ITQ), individual vessel quota (IVQ), community fishing quota (CFQ) systems, sectors management (assignment of individual quota to groups of vessels or fishermen in cooperatives), and territorial use rights in fisheries (TURFs). All provide individual entities (individuals, firms, cooperatives, or communities) with some degree of property right (quota) in a total allowable harvest. ITQs are a subset of IFQs and IVQs, which allow for rights to be transferred between individuals (or firms) (Bonzon, et al., 2013). Throughout this paper we use the term 'catch-share' to refer to any quota-based management system (i.e., IFQ, ITQ, IVQ, CFQ, and sector systems). Area-based systems are not included in this analysis.

applied to over 200 species in at least 18 countries (Costello, et al., 2010; Chu, 2009; Tveteras, Paredes and Pena-Torres, 2011). While catch shares do not represent complete privatization of the resource, they provide strengthened property rights (relative to open access and biologically managed fisheries) in the form of a guaranteed right to a proportion of the total allowable catch (TAC). In doing so, they potentially eliminate rent dissipation by aligning individual and collective incentives, attenuating the race to fish, and reducing competition between fishermen and the regulator (Grafton, 1996; Wilen, 2006).

Implementing rights-based management theoretically could increase rents by lowering costs, increasing revenues, or both (Boyce 1992; Grafton, 1996; Homans and Wilen, 2005). Empirical studies of the economic benefits of rights-based policies have focused on costs and show that, mainly by eliminating redundant capacity, catch shares lower costs (Weninger, 1998; Grafton, Squires, and Fox, 2000; Lian, Singh, and Weninger, 2009).[2] Catch shares may also generate benefits on the revenue side through market timing, changes in the product mix across fresh and frozen, or other changes in product quality (Grafton, 1996; Homans and Wilen, 2005). One specific mechanism is that shorter seasons under regulated open access constrain the fresh fish market and encourage development of a lower-value frozen market supplied with fish inventoried during the short season; for a given level of demand, prices are higher and the harvest season is longer under rights-based management (Homans and Wilen, 2005). This revenue benefit to fishermen is *additional* to the reduced costs predicted by Gordon (1954).

Implicitly, there are two hypotheses embedded in the discussion of revenue-side benefits of catch shares: 1) catch shares decompress the season (i.e. end the race to fish), and 2) behavioral changes under catch shares will lead to higher ex vessel[3] prices. Each of these hypotheses has anecdotal support. For example, the Alaska Pacific halibut season extended from 3 to 245 days after forming individual

[2] There is also some evidence that IFQs improve the biological sustainability of fish stocks, although this not conclusive (Costello, Gains, and Lynham, 2008; Bromley, 2009; Essington, et al., 2012).

[3] The ex vessel price is the unit price received by fishing vessels for harvested but unprocessed fish upon landing the catch.

transferable quotas in 1995 (NOAA, 2014). The British Columbia halibut IFQ implementation saw ex vessel prices increase by 22 to 34 percent (Grafton, Squires and Fox, 2000). Price increases were similarly seen after the introduction of the North East Scallop IFQ program (31 percent the following year, relative to the 3 years prior to implementation), Mid-Atlantic Golden Tilefish IFQ program (8 percent), Northeast Multispecies Sector Program (7 percent on average for groundfish), and the Pacific Coast Sablefish Permit Stacking Program (55 percent) (Brinson and Thunberg, 2013). It is possible that these increases were driven by changes in season length, as many fisheries operated under derby conditions prior to program implementation. Another data point comes from the 2009 introduction of catch shares in the Peruvian anchoveta fishery, the largest fishery in the world by volume. Average landing prices increased by 37 percent, the season length increased from approximately 50 days to over 100 days, and the average quality of the anchovy meal improved, all within 1 to 2 years of IFQ introduction (Tveteras, Paredes, and Pena-Torres, 2011). These descriptive examples are consistent with the mechanisms proposed by Homans and Wilen (2005) and suggest that the revenue effects could be causal.

In this paper, we employ rigorous quasi-experimental methods to test the hypotheses that catch shares cause season decompression and ex vessel price increases. Providing causal evidence for these outcomes (or lack thereof) is urgently needed in the current political climate, as the U.S. House of Representatives has included measures to restrict usage of catch shares in its draft bill to reauthorize the Magnuson-Stevens Fishery Conservation and Management Act.[4] We separately test each hypothesis for each U.S. fishery adopting catch shares. To this end, we compare each catch share ('treatment') fishery to a matched ('control') fishery, a domestic or imported fish source that serves the same market as the catch share-managed fishery but did not undergo catch share management reform at the same time. To examine season decompression, we compute a Gini coefficient based on monthly landings; a higher Gini coincides

[4] Strengthening Fishing Communities and Increasing Flexibility in Fisheries Management Act (2013). Section 7. Discussion Draft (House of Representatives). Available online Feb 24, 2015 at < http://naturalresources.house.gov/uploadedfiles/magnusonstevensactdiscussiondraft-113.pdf >

with more landings inequality over time and thus more season compression. So, the hypothesis is that catch share implantation decreases the landings Gini relative to the landings Gini in a counterfactual control fishery. To examine price hypotheses, we simply use ex vessel price as the outcome variable. For both hypotheses, we estimate difference-in-differences models, controlling for a number of fixed effects. We then compute weighted average treatment effects across the fisheries for both outcome variables.

Our empirical strategy is motivated by the nascent economics literature using quasi-experimental methods to evaluate fisheries policies. An early example uses difference-in-differences on detailed panel data to show that marine reserves caused harvest declines in a large-scale, multi-species fishery in the Gulf of Mexico (Smith, Zhang, and Coleman, 2006). A later and particularly notable quasi-experimental fisheries study employs propensity score matching to show that catch shares reduce the likelihood of fishery collapse (Costello, Gaines, and Lynham, 2008). Despite criticism of the identification strategy (Bromley, 2009), the main result qualitatively holds in a follow-up study (Costello et al., 2010). Other quasi-experimental papers have examined the effects of information sharing on bycatch (Abbott and Wilen, 2010), economic effects of a pilot catch share program (Scheld, Anderson, and Uchida, 2012), the effects of catch share formation on spillovers across regional fisheries management boundaries (Cunningham, Bennear, and Smith, 2016), and the effects of catch shares on days at sea (Hsueh, 2014).

Our identification strategy using matched control fisheries significantly improves upon analyses that consider fisheries independently. Quantifying the impact of a management change by examining only the affected fishery (for instance, a before-after comparison of a catch share introduction) is problematic because season length and prices are affected by many factors besides the management regime. Changes in the supply of substitutes, economic conditions, seasonal variation, and technological change are just a few of the factors that can influence season length and prices and may do so concurrently with the change in management in question (Brinson and Thunberg, 2013). Our treatment-control comparison approach is subject to a much smaller set of confounding factors than previous analyses, strengthening our claim of causality. Given the impracticality of randomized controlled trials in catch share implementation, our quasi-experimental approach to observational data provides the most reliable empirical information available on the season length and price effects of catch shares.

Data and Methods

To test our hypothesis, we first identify all federally managed fisheries in the United States that have switched to catch share management and the species included under each (Table 1). We compiled panel data from publicly available records on the National Oceanic and Atmospheric Administration (NOAA) Fisheries Statistics Division's website (NOAA, 2014a). This was supplemented by data sourced directly from the Northwest Fisheries Science Center (NWFSC) which allowed for port disaggregation of select Alaska fisheries data, from Fisheries and Oceans Canada which allowed for price comparisons to Canadian fisheries (pers. comm. Gisele Magnusson, 2015; pers. comm. Barbra Best, 2015), and from NOAA for Chesapeake Bay monthly clam data. Monthly U.S. commercial fisheries landings data are available for the years 1990 to 2012 and include weight in pounds/metric tons and total dollar value of landings by species, state, and management region. Due to confidentiality issues concerning the monthly data, a small number of observations are unavailable in cases where the number of participating vessels was fewer than three. We also obtained annual data that is unaffected by this "rule of three" in the fisheries that we study.

The treated fisheries represent a wide range of species and fishery types (Table A1). The largest fisheries by volume are Alaskan pollock, Pacific whiting, Alaskan Pacific cod, Alaskan Pacific halibut, and Atlantic sea scallop. Pollock is an order of magnitude larger than any of the others. Even setting pollock aside, the remaining fisheries treated with catch shares are vastly different in size, spanning at least five orders of magnitude. So, one of the challenges of this study is developing an identification strategy that plausibly applies both to fisheries like pollock, which lands over 2 billion pounds of fish per year, and small rockfish fisheries landing 1,000 pounds per year. The largest fisheries by value are Atlantic sea scallop, Alaskan pollock, Alaskan king crab, Alaskan Pacific halibut, and Alaskan sablefish. The heterogeneity in value across fisheries is similar to that of volume but not as pronounced. Although the top volume and value lists do not entirely coincide, Alaskan fisheries clearly dominate both. Price per pound paints a slightly different picture from volume and value with Gulf of Mexico species included on the list. The fisheries with the highest prices are Atlantic scallop, Alaskan king crab, Atlantic halibut, Gulf of Mexico gag, and Gulf of Mexico shallow water grouper. Heterogeneity in price spans nearly two orders of magnitude with a pre-treatment price per pound of $3.14 for scallop and $0.04 for Pacific whiting.

For control fisheries, we aimed to select fisheries that served similar markets (and thus were affected by the same shocks in demand) yet are distinctly and independently managed. Our matches are in five categories: A) same species managed by another U.S. management authority that did not implement catch shares at the same time; B) same species in Canada for which Canadian ex vessel prices are available and catch share management reform did not occur at the same time; C) same species that appears in U.S. import data for which the exporting country did not implement catch share reform at the same time; D) similar species/market that did not experience management reform and managed by a different U.S. management authority; and E) a composite of species in the export market (used for just one species). We made decisions hierarchically, choosing an 'A' match where available, then a 'B' match if an 'A' match is unavailable, etc. Most of the matches use the same species (Table 1).

Descriptive Background for a Subset of Species Matches

To illustrate our identification strategy and the matched controls that we select, we provide narrative descriptions of a subset of the fisheries that we analyze.

Pacific halibut *(Hippoglossus stenolepis)* is a large flatfish found in coastal waters between Santa Barbara, California and Nome, Alaska. The Alaskan fishery switched to a catch share system in 1995 with quota allocated to specific areas. Halibut were not overfished at the time, but the fishery had been overcapitalized since the 1970s. Prior to implementation, the season length had shrunk to less than three days. Upon implementation there was a dramatic increase in the length of the season (and, as shown in our results, an increase in ex vessel prices), despite a 21 percent reduction in quota at the same time (Brinson and Thunberg, 2013). Alaskan halibut is regularly cited as an example of the revenue benefits of catch shares (Homans and Wilen, 2005), though the price effects have not previously been subjected to causal inference testing.

The same species is caught in the Canadian halibut fishery, which switched to a catch share system in 1991. Like the Alaskan experience four years later, the Canadian fishery saw dramatically increased season lengths and ex vessel prices following the change. Whereas before catch share management only 40 percent of Canadian halibut was sold fresh, fresh halibut increased to 94 percent within a few years following the policy change (Herrman, 1996). The U.S. West Coast, by contrast, has maintained a derby fishery with fishing period limits and a series of 10-hour seasons (PFMC, 2015). As such, the U.S. West Coast is an ideal matched control for both the Alaskan and Canadian halibut fisheries. The three fisheries serve approximately the same market, primarily U.S. domestic consumption.

Ocean quahog *(Arctica islandica)* and Atlantic surf clam *(Spisula solidissima)* are long-lived, bivalve mollusks caught off the Atlantic coast between Maine and Virginia. The U.S. catch is managed primarily by the Mid-Atlantic Fisheries Management Council (MAFMC), with a small portion of the overall TAC managed by individual states. The MAFMC fishery covers larger clams and quahogs, which are used in processed products (Brinson and Thunberg, 2013), while the smaller clams from state fisheries tend to supply fresh markets. Catch share management was introduced into the federal quahog and clam fisheries in 1990, making these the oldest U.S. catch share systems. In the years preceding this change, the surf clam fishery was successfully rebuilding under a tight regime of limited entry, quarterly quotas, and restrictions on fishing time, regulations that were also used to maintain a steady flow of surf clam to processors. Thus, unlike most other fisheries, surf clam was available throughout a long season both before and after catch share implementation (Brinson and Thunberg, 2013). Although not facing overfishing pressures, quahog availability for processors was similarly controlled throughout the year prior to catch share implementation. Consequently, the hypothesized mechanism for a price increase under catch shares—namely, extended season lengths and increased supply of fresh product to the market—was not likely to affect these fisheries.

Our control for both the quahog and surf clam programs is the hard clam *(Mercenaria mercenaria)* fishery in the lower Chesapeake Bay. Hard clams are similarly long-lived bivalves with a distribution from

Canada to Florida. The Chesapeake fishery is a mix of wild-caught and aquacultured product. The larger hard clams are used in processed products, similar to the ITQ-managed surfclam and quahog, while smaller hard clams are sold into the fresh market (Murray and Kirkley, 2005). As sedentary, partially farmed species, clams do not face derby fishing conditions, and prices and quantities are relatively stable throughout the year. As a result, we do not expect to see large treatment effects from catch share implementation in the surf clam and quahog fisheries. We use this comparison to demonstrate a setting in which catch share implementation is unlikely to have ex vessel price impacts.

Wreckfish (*polyprion americanus*) is a large, bass-like predator species that migrates throughout the North Atlantic. The U.S. market is served primarily by deep-water fishing off the South Carolina coast. The fishery, which is managed by the South Atlantic Fishery Management Council (SAFMC), grew rapidly following the discovery of wreckfish off the Georgia coast in the mid-1980s. Permits, a TAC, and a spawning season closure were established in 1990 due to stock level concerns; however, these measures were largely unsuccessful in preventing overfishing and led to derby-fishing conditions. In response, an ITQ system was established in 1992, only the second in the United States (Yandle and Crosson, 2015).

We use red grouper (*Epinephelus morio*) from both the Gulf of Mexico and the South Atlantic as a control for wreckfish. Red grouper is a top predator in reef community food webs throughout the Western Atlantic and is highly valued for its flavor and size. Although red grouper is now under catch share management in the Gulf of Mexico, this change did not occur until January of 2010, thus allowing its use as a control fishery for wreckfish in the early 1990s (NOAA, 2014d; SAFMC, 2014a). Wreckfish is often used as a substitute for grouper in both fresh and frozen markets (GAO, 2002).

Gulf of Mexico red snapper (*Lutjanus campechanus*) has been managed federally since 1976 with the establishment of the Gulf of Mexico Fishery Management Council (GMFMC). Prior to 1991 the fishery was open to commercial fishermen year-round; however, throughout the 1990s, overfishing spurred the imposition of a TAC, size limits, and mandated reductions in shrimp trawl bycatch (Hood, et al. 2007). Under these restrictions, overcapitalization led to sequentially shorter seasons, with derby style fishing conditions and market gluts resulting in reduced ex vessel prices (GMFMC, 2013). An IFQ system was implemented in 2007, with quota grandfathered to commercial fishing vessels (responsible for 51 percent of the total harvest) based on historical catch. The change in policy was accompanied by a one-third reduction in commercial quota. The season length has increased from 121 days to the full year (Brinson and Thunberg, 2013). The stock remains overfished, with stock levels currently estimated to be 37 percent of the target population level, but it shows signs of rebuilding. We match red snapper caught in the Gulf of Mexico to the same species caught in the South Atlantic, where catch shares have not been used.

Grouper and tilefish species in the Gulf of Mexico have been managed under the GMFMCs Reef Fish Fishery Management Plan (FMP) since 1984. The first FMP used gear, size, and catch limits in an effort to reduce the decline in stock populations. Further amendments from 1990 onwards set targets for stock rebuilding and increased restrictions, and, starting in 1992, a moratorium was placed on new fishing permits. However, this did not prevent early closures. A multispecies catch share program managing six species of shallow water grouper, five species of deep water grouper, gag, red grouper, and five species of tilefish was implemented in 2010 following a referendum (note that two species of shallow water grouper, one species of deep water grouper, and two species of tilefish were removed from the program in 2012, leaving a total of thirteen species) (NMFS, 2013). Shares were allocated to existing operators based on historical catch. Shares and associated individual quota are issued in five fish categories (gag, red grouper, other shallow water groupers, deep water groupers, and tilefish) rather than for individual species. The season length for deep water grouper and tilefish has increased from 153 and 124 days, respectively, to the full year, while shallow water grouper did not previously experience season closures (Brinson and Thunberg, 2013). We match Gulf of Mexico reef fish species to the same species caught in the South Atlantic region, where they are managed under the Snapper Grouper Management Complex without the use of catch shares (SAFMC, 2014b; SAFMC, 2014c).

Identification Strategy

To test our hypothesis for each of these fisheries, we create a panel of data for total pounds landed and dollar value. Using monthly landings data (which were available for 37 fish species/species groups and their matched controls) we calculate an annual Gini coefficient, a measure of dispersion, for each fishery and its pair. There are twelve months of landings, which we label m = 1, 2, …, 12. Next, we order the months for a given fishery according to the landings in each month, such that the landings, L^m, form an increasing sequence ($L^1 \leq L^2 \leq \cdots \leq L^{12}$). Given the distribution of landings, {L^1, L^2, …, L^{12}}, the mean landings μ is defined as:

$$\mu = \frac{1}{12}\sum_{m=1}^{12} \mathrm{L}^m$$

The Gini coefficient is represented by:

$$G = 1 - \frac{1}{12^2\mu}\sum_{i=1}^{12}\sum_{j=1}^{12} \min\{\mathrm{L}^i, \mathrm{L}^j\}$$

The Gini coefficient ranges from a minimum value of zero, when landings are equally divided among months of the year, to a maximum of one in cases where all landings for a given year are concentrated in a single month.

In addition, we calculate average per-pound ex vessel price at the observation level, where an observation consists of total landings and value for a given state and region (and in some Alaskan cases, a given port), month/year, and species. In cases where multiple species were grouped together to form a single comparison group, we first summed the total weight and values across species and then calculated an average per-pound ex vessel price at the state-region-month level. Grouping was performed in cases where species are jointly managed and serve a similar or identical market and where relatively small total harvests make individual species-level comparisons difficult (Table 1).

Using the combined landings/imports panel dataset, we perform a series of difference-in-differences (DID) regressions in order to isolate the effect of catch share management on season length and ex vessel prices. DID estimation compares the change in outcome levels over time across treatment and control groups, relying on the assumption that, absent the treatment, the difference between treatment and control outcomes would have remained constant over time. Thus, the change in this difference in the post-treatment period—the ‘difference in differences’—identifies the effect of the treatment on the treated group. In this study, we define the ‘treatment’ as the implementation of a new catch share-based fishery management program, and the ‘post-implementation period’ as the time of the policy change and all subsequent periods. The treatment group is the fishery/region in a given pair that underwent a policy change to catch shares (‘catch share region’), whereas the control group did not undergo such a change.

As the data permit, we run each of our models (described in detail below) with three-year intervals before and after the policy change. Although evidence presented in the next section suggests that price changes can occur relatively quickly, we also wish to capture ex vessel price impacts from new markets that may take several years to materialize while ensuring that the price impact appears persistent. With regard to the pre-implementation period, a longer time period reduces the chance of bias due to "announcement effects" (i.e., when fishermen and others along the seafood supply chain become aware that the policy change would occur some time before the implementation date and change their behavior in response) and possible pilot programs or other partial measures enacted prior to full implementation.

Models: Season Decompression

Our basic model for assessing season decompression following the introduction of catch shares is a relatively simple one that utilizes the annual-level Gini coefficients calculated as described above:

$$G_t = \beta_0 + \beta_1 POST + \beta_2 TREAT + \beta_3 DID_t + \theta_y{}'\boldsymbol{\beta_y} + \varepsilon_t \quad (1)$$

where *G* is the Gini coefficient on landings distribution across months and the *t* subscript refers to year. We include year fixed effects (θ_y) to control for year-specific variation in outcomes that affects both treatment and control fisheries similarly. The idiosyncratic error term is represented by ε_t and is assumed to be normally distributed. The key parameter of interest is the DID estimator, β_3, which is the coefficient on the interaction between the treatment indicator and the post period indicator. As a starting point, we estimate the model above using Ordinary Least Squares (OLS) regression.

From a technical standpoint, however, running OLS regressions on fractional response data such as Gini coefficients can be problematic. When the dependent variable *y* is bounded by the unit interval [0, 1], the effect of any given explanatory variable *x* cannot be constant throughout the variable's range without generating predictions outside the unit interval. Papke and Wooldridge (1996) and Wooldridge (2002) discuss the shortcomings of traditional remedies, such as log-odds transformations (which fail if *y* takes on values of 0 or 1 with positive probability) and two-limit Tobit approaches (which are inappropriate in cases where values beyond the censoring points are infeasible, not merely unobserved). Alternatively, they recommend use of a one-step quasi-maximum likelihood estimation approach that involves nesting a logit function within a more general form. This "fractional logit" model has since been used in several empirical studies to obtain robust estimators of conditional mean parameters in proportional response cases (Papke and Wooldridge, 2008). Thus, as an added check on our OLS results, we also estimate fractional logit models in Stata using a generalized linear model (GLM) with a Bernoulli/binomial distribution and a logit link function.

Models: Price Changes

We begin with a very simple model (Model 1) that uses the most aggregated version of our data, annual landings without state disaggregation:

$$P_t = \beta_0 + \beta_1 POST + \beta_2 TREAT + \beta_3 DID_t + \theta_y{}' \boldsymbol{\beta_y} + \varepsilon_t \tag{2}$$

where *P* is the average ex vessel price per pound and *t* refers to time period (year in this case and month-year in more disaggregated models). We include year fixed effects (θ_y) to control for year-specific variation in outcomes that affects both treatment and control fisheries similarly. The idiosyncratic error term is represented by ε_t and is assumed to be normally distributed. Once again, the primary result of interest in our regressions is the DID estimator, β_3, which is the coefficient on the interaction between the treatment indicator and the post period indicator (note that the right-hand side of this model is the same as that which we used for the Gini coefficient analysis; therefore, we refer to both models as "Model 1").

Model 2 uses annual data that includes observations for each state within the catch share and non-catch share regions, denoted by the subscript *s*. Model 2 includes yearly fixed effects as well as a vector of state indicator variables (θ_s) to account for variation in markets at the state level that stays constant over time:

$$P_{st} = \beta_0 + \beta_1 POST + \beta_2 TREAT + \beta_3 DID_t + \theta_y{}' \boldsymbol{\beta_y} + \theta_s{}' \boldsymbol{\beta_s} + \varepsilon_t \tag{3}$$

For the final model, we move to even further disaggregated data composed of state- and *month*-level observations. Aside from providing more observations, this change allows us to limit the data to the precise 36-month span before and after the month the policy change was implemented. The downside of this improved granularity, however, is an increased likelihood of missing data due to confidentiality rules intended to prevent identification of specific fishermen or fishing vessels in cases where only a few participated in a given time frame and geographic area (this data issue is noticeably problematic in the wreckfish "post" period, for example). Model 3 includes month fixed effects (θ_m) to control for seasonality. Note that year fixed effects will be collinear for one-year windows for all fisheries except for wreckfish (for which the policy change did not occur in January):

$$P_{st} = \beta_0 + \beta_1 POST + \beta_2 TREAT + \beta_3 DID_t + \theta_m{}'\boldsymbol{\beta_m} + \theta_y{}'\boldsymbol{\beta_y} + \theta_s{}'\boldsymbol{\beta_s} + \varepsilon_{st} \quad (1)$$

Ideally, we would have included TAC as a right-side variable in some of our models as a control for simultaneous, exogenous shocks to quantity factors that may be correlated with catch share management change. Unfortunately, TAC data do not exist for a number of control fisheries and do not exist for some treatment fisheries prior to catch share implementation (annual catch limits (ACLs) were not required by federal law until 2011 in some cases). Thus, we cannot separate in our regressions the effect of catch shares alone from possible concurrent reductions in TAC. However, we can qualitatively comment on the circumstances and features of each program's implementation to help interpret correctly the results of the models described above, and a meta-analysis featuring quantitative assessment of TAC changes will be part of future work.

Results

Season Decompression

The majority of the individual treatment effect results on the Gini coefficient are negative, and most of these are significant (Figure 1, Appendix Table 2). Across the fisheries, the results are mostly consistent across OLS and Fractional Logit models with the Fractional Logit models tending to have smaller standard errors. The interpretation is that catch shares caused season decompression for most U.S. fisheries that were treated with this policy. In other words, implementing catch shares attenuated the race to fish. The two most commonly lauded success stories in rights-based fisheries management, Alaskan halibut and Alaskan sablefish, not surprisingly have negative and significant treatment effects. Similarly, all of the Gulf of Mexico catch share fisheries show negative and significant treatment effects on the Gini coefficient. However, there are notable exceptions in other regions. The most valuable fishery in the U.S.—measured by ex vessel revenue—is Atlantic sea scallop (Appendix Table 1). The Atlantic sea scallop Gini treatment effect is actually positive in both OLS and Fractional Logit models, but neither result is statistically significant. For haddock, part of the Northeast groundfish complex, the Gini treatment effect is also positive but in this case statistically significant in both models.

We pool all of the Gini treatment effect results to examine the average treatment effect across fisheries. The results overwhelmingly support the claim that on average catch shares attenuate the race to fish. In both OLS and fractional logit, the average treatment effect is negative in all cases and statistically significant for nearly all weighting schemes (Table 2). The exceptions are two of the OLS models that use revenue in the weighting and are therefore strongly influenced by the positive but insignificant treatment effect for Atlantic scallop in the overall average. Despite the heavy weight attached to sea scallop, the corresponding weighted averaged treatment effects for the fractional logit models are negative and significant.

If the Homans and Wilen (2005) theory is broadly descriptive, a motivation for season decompression is to generate more value from the fresh market through improved timing of the harvest. This in turn suggests that fisheries with a viable fresh market will be more likely to experience season decompression. Assuming that fisheries with fresh markets tend to have higher per-unit prices, then we expect Gini treatment effects to be negatively correlated with prices pre-catch share. We compute this correlation using point estimates of the Gini treatment effects for OLS and Fractional Logit models correlated with a 3-year average ex vessel price pre-treatment. We find that it is indeed negative but insignificant (for OLS, ρ = -0.135, p-value= 0.426, and for Fractional Logit, ρ = -0.117, p-value = 0.490). Given the sampling error on the treatment effects, variation in prices pre-treatment, and the small sample size (just 37 fisheries with monthly landings data), we explore this correlation further in a Monte Carlo analysis. We draw 1,000 sets of 37 draws from the sampling distributions of price and the Gini treatment effect for each fishery and compute the correlation for each set of draws (Figure A1). Despite the insignificant point estimate correlations, the Monte Carlo indicates that the negative correlation is robust.

Price Changes

In contrast to the Gini results on season decompression, the effects of catch shares on ex vessel prices are far more mixed. There are similar numbers of positive and negative treatment effects, most results are statistically insignificant, and the results are not always robust across model specifications (Appendix Table 3). Although treatment effects are positive and significant for the lauded Alaska halibut and sablefish in Model 3, three of the other results are not statistically significant. The Atlantic sea scallop, which did not appear to experience season decompression, has a positive and significant price treatment effect. Gulf of Mexico red grouper did experience season decompression but has a negative and significant price treatment effect. Surprisingly, there are more negative treatment effects than positive ones.

We also pool the price treatment effects to examine the average treatment effect across fisheries. Compared to the Gini analysis, the results are far more equivocal and can reverse signs depending on which weighting scheme and which model is used (Table 3). Nevertheless, the majority of the test statistics suggest that the weighted average treatment effect is negative, a result that directly contradicts the theoretical prediction of Homans and Wilen (2005). The only positive and significant weighted average treatment effect is Model 3 weighted by revenues. This result exactly parallels the lack of significance in the OLS Gini model weighted by revenues. Atlantic sea scallop is the largest revenue-producing fishery in the U.S., so models weighting by revenues place substantial weight on this fishery. In the Gini model, the positive (though not significant) result for sea scallop was enough to make the weighted average insignificant in this one weighting scheme. In a similar manner, the very strong positive treatment effect in the price models for sea scallop is enough to make the overall weighted average treatment effect positive when weighting by revenues (though only significant in Model 3).

Some of the negative treatment effects in the price regressions are Gulf of Mexico reef fish species that adopted catch shares in 2010. These fisheries are matched to fisheries in the South Atlantic that did not adopt catch shares. However, 2010 coincided with the Deepwater Horizon incident in the Gulf of Mexico. It is theoretically possible that South Atlantic reef fish experienced a price premium over the same species in the Gulf in the wake of the oil spill, so we re-run the pooled weighted average price treatment effect dropping Gulf of Mexico fisheries that were treated with catch shares in 2010. The results are similar and still produce mostly negative weighted average treatment effects (Appendix Table 4).

Synthesis

The overarching theoretical prediction for treated fisheries (from Homans and Wilen 2005) is that catch shares will decompress the season (decrease the landings Gini coefficient) and increase ex vessel prices. For each treated fishery, we plot the season decompression and price effects (in percentage terms), using shape markers to distinguish results that are statistically significant from ones that are not (Figure 2). If all treated fisheries perfectly supported the theory, we would see a cluster of red triangles in the lower right quadrant of this figure and empty. Clearly, this pattern does not emerge. Instead, we see a predominance of negative Gini effects (lower two quadrants), but statistically significant price effects appear in all four quadrants. Interestingly, most of the negative and significant price effects have a positive Gini. Overall, the figure suggests that fisheries that did not experience season decompression were not likely to experience price increases. But fisheries that experienced price decreases mostly did not experience season decompression. These results challenge the received wisdom about catch shares and market opportunities to some extent, but they also suggest that season decompression and price effects are more fishery-specific and nuanced than current theory is able to address.

To shed more light on our results, we examine four fisheries in detail (Figure 3). Pacific whiting (hake) experienced neither season decompression nor an ex vessel price increase (Figure 3a, Table A2-A3). Despite these outcomes, the seasonal timing of the fishery did appear to change after treatment, shifting some harvest later in the calendar year. One possibility is that the treatment is confounded with behavior in other fisheries. The fleet that participates in this Pacific whiting also participates in the Alaskan pollock fishery (Hsueh, 2015). It could be that rationalization of the hake fishery freed up opportunities to increase profits in pollock. Furthermore, if those profit changes were on the cost side, we would not expect to find evidence in ex vessel prices for either fishery.

Atlantic sea scallop experienced no season decompression but had substantial gains in ex vessel price after formation of catch shares (Figure 3b, Table A2-A3). Pre-catch share, scallops show a strong seasonal pattern in landings, but the season extends throughout the year. There is no pronounced fishing derby as in the archetypal race to fish. Post-catch shares, we see little change in the seasonal pattern. As such, the sea scallop experience suggests that we may not find evidence of season decompression when the season is already long and decompressed. Nevertheless, prices increased substantially, suggesting that there is another mechanism that triggers revenue gains other than extending the season length. Although we are unable to observe the product mix, it is possible that catch shares allowed more scallops to enter high-end, fresh markets without altering the aggregate landings pattern.

The Gulf of Mexico red grouper fishery experienced the opposite effects of sea scallop, namely season decompression but decreased ex vessel price (Figure 3c, Table A2-A3). Prior to catch shares, the fishery operated year-around but exhibited some seasonal peaks and troughs. After catch shares, landings are more uniform throughout the year. Despite this change, ex vessel price decreases relative to the counterfactual South Atlantic red grouper. As noted above, one possible explanation is that South Atlantic red grouper fetched a premium in the wake of the Deepwater Horizon oil spill, which coincided with the formation of the red grouper catch share in the Gulf. Thus, we cannot separately identify the effect of the policy treatment from the potentially confounding effect of the oil spill.

Alaskan sablefish fits the theoretical story closely with a major derby-style fishery pre-catch share followed by a decompressed season and ex vessel price increases post-catch share (Figure 3d, Table A2-A3). Ex vessel price increases are consistent with findings showing increased bargaining power of fishermen with processors after forming the sablefish IFQ and a model of spatial competition (Fell and Haynie, 2011, 2013). Indeed, the experience of sablefish and Pacific halibut in Alaska motivated the theoretical developments that claim possible revenue-side benefits of catch shares (Homans and Wilen 1997; 2005), so it is not surprising that these effects hold up under rigorous empirical testing. The temporal pattern of prices is worth noting. The difference-in-difference does not appear immediately after treatment but instead appears roughly eighteen months later. This experience suggests that markets do not adapt instantaneously to the new policy even if behavior does (derby-style fishing ended in the first year post-catch share). The sea scallop price difference-in-difference also did not materialize immediately (Figure 3b) but, compared to sablefish, the market appeared to adapt more quickly with changes that were apparent 4-6 months after the policy treatment. Sablefish prices also revert to the control prices at end of the time series, raising questions about the persistence of revenue-side benefits from catch shares. Taken together, these examples suggest that the timing of price changes in response to catch shares may be heterogeneous.

Although there are only a few positive price effects and a larger number of negative ones that are statistically significant and contradict the theory, most price effects—both positive and negative—are simply not statistically significant. An important possibility is that the seafood prices in the matched control fisheries are cointegrated with the seafood prices in the treated fisheries. Even more restrictively, the treated and control markets may be governed by the Law of One Price. If markets in our control fisheries are linked to our treatment fisheries too closely, revenue benefits in the treatment fisheries may contaminate those of the control fisheries, for instance, by increasing ex vessel prices in the control fishery. This concern echoes spatial-dynamic general equilibrium concerns about the use of treatment effects models to evaluate outcomes on the water (Smith et al., 2014). The effects may also be mediated by fishing effort changes in treated and control fisheries; if catch shares reduce effort and capital deployment in one fishery, this effort may be redeployed in the control fishery in some circumstances.

Although our time series are insufficient to test for market integration, market and behavioral interactions across treated and control fisheries raise the question of whether overall ex vessel prices increased relative to some other counterfactual. One could use background inflation (e.g. CPI) as a counterfactual, but this would be a poor proxy for seafood demand growth. Instead, we compare each treated fishery to the capture fishery Fish Price Index (FPI) (Tveteras et al. 2012) and compute difference-in-differences (Table A5). Although the evidence is mixed, there are more examples of positive treatment effects (29 out of 53 fisheries/fishery groups are positive over a 3 year post-treatment window), and the average treatment effect is positive.

Discussion

Our results strongly support season decompression for fisheries that are treated with catch shares. Still, not all fisheries have this result. Why would some fishery seasons fail to decompress in the wake of catch shares? One simple explanation is if the season was not compressed before catch shares, then there would be little room for decompression to happen. A related possibility is that the pre-catch share seasonal pattern already reflects the most profitable way to harvest the fishery. At the extreme would be an annual fishery like shrimp for which optimality requires a strong seasonal pattern. Moreover, optimal management to combat growth overfishing would actually reduce effort early in the season and concentrate more of it at the peak (Huang and Smith, 2014). Although none of the U.S. catch share fisheries are annual species like shrimp, seasonal demand and biological characteristics are plausible limitations on the amount of season decompression we see. Future work should explore these potential explanations of heterogeneity in our Gini treatment effects.

On the price side, there are several possible explanations as to why we observe significant negative treatment effects. The first is that catch shares are, in fact, associated with price depression, either directly or through some process that is correlated with the implementation of catch shares. The mechanisms by which the former might occur are unclear, but this would mean that our hypothesis regarding improved product quality, longer fishing seasons, and enhanced market opportunities is inaccurate or incomplete. Moreover, if price decreases simply reflected increased competition from aquaculture or decreased demand, we would not expect to see so many price increases relative to the Fish Price Index (Table A5).

A second hypothesis is based on the observation that price reductions in the post period sometimes involve groupings of species rather than individual species. With grouped species, it is possible that the mix of more valuable versus less valuable species within that grouping is changing over time in a way that differs across treatment and control groups. If this occurs, the price changes we observe could result from exogenous shifts in species shares within these groupings rather than the catch share programs themselves.

Analyzing deep water grouper landings by species shows that the changes in proportions are very small in both the treatment and control regions, especially right around the policy change in 2010, so this explanation seems implausible. Among the three main shallow water grouper species, scamp is the most valuable, followed by yellowfin and black. From the shallow water grouper data, we see that the pre-period proportions stay essentially constant in the control region, while scamp increases in prominence in the treatment group. This could in fact raise average per-pound prices in the pre-catch shares treatment region and thus make any price increase appear less pronounced in the post-period, particularly as the proportion of the cheaper black grouper seems to rise more in the post-period in the treatment region than in the control region. It should also be noted that price per pound is a function not only of the species, but also of fish size and other quality attributes that are not recorded in our data. We would expect that catch shares improve the ability of fishermen to target quality attributes like fish size, but in multispecies fisheries targeting quality attributes for one species may reduce the ability to target quality attributes for another species.

A third potential explanation for the price decreases is coincidence of other events, which is particularly challenging from an identification standpoint. For example, the Deepwater Horizon oil spill occurred in April 2010, just a few months after the switch to catch share management of all the relevant Gulf of Mexico species except red snapper (which had adopted catch shares in 2008). If, following the spill, consumers were willing to pay a premium for fish *not* caught in the Gulf of Mexico, prices of the South Atlantic species relative to their Gulf of Mexico counterparts would have increased. Still, if this were the case, we would expect to see such results in all of our Gulf fisheries; however, positive and significant DID coefficients are observed for tilefish.[5] When we drop the 2010 Gulf of Mexico catch share fisheries from the meta-analysis, the weighted average price treatment effect is still negative for most models. Thus, if other events explain negative price treatment effects, there would have to be explanations for other fisheries beyond those affected by Deepwater Horizon.

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[5] We are unable to test for a drop in red snapper prices in the Gulf of Mexico relative to the South Atlantic in 2010, as the fishery was closed in the South Atlantic in 2010 and 2011.

A fourth explanation for price decreases (or null results) is related to market integration. We found that some of the catch share treated fisheries saw ex vessel prices increases relative to the FPI despite decreasing relative to the matched control. These results hint that ‘a rising tide lifts all boats’ in the sense that catch share implementation improves market outcomes for the treated and the control fishery. Still, the evidence is far from conclusive, and degrees of market integration likely vary substantially by fishery. Future work that integrates seafood market studies with the analysis of regulatory impacts can help to clarify this issue.

Considering both season decompression and price effects, product markets are an essential consideration. Some fisheries target species that are have viable fresh markets, while others target species that are directed into frozen or canned products. The theoretical model of channeling more of the product into the fresh market (Homans and Wilen 2005) presumes the existence of both fresh and frozen markets. Some markets appear to be exclusively frozen, such as the high-value Alaskan crab. This could partly reflect the ability to maintain high-quality product with flash freezing technology, something that may apply less to finfish. Moreover, freezing technology has improved in recent decades, so the incentives to move product into fresh markets may be less pronounced than they once were.

It is also important to remain cognizant of differences in how catch share interventions are implemented across affected fisheries. Not all rights-based fishery management systems are exactly alike; in some cases, for example, pilot programs occurred ahead of full implementation, and in many cases the change to rights-based management was accompanied by a sharp drop in TAC. The latter case makes it particularly difficult to tell whether the effects we see are due to rights-based management or reductions in supply, as we are unable to control directly for TAC.

A related issue is that of selection. It is possible that the political climate that makes a particular region amenable to rights-based management is also conducive to other interventions that affect seasons or prices. It might also be the case that catch share programs are disproportionately implemented in fisheries at risk of collapse, fisheries facing certain types of market conditions, or other unobserved characteristics that might be related to ex vessel prices. In future work we will categorize our final results according to these types of characteristics to get a broad sense of whether or not the impacts of catch share management on prices appear to depend on them, according to our analysis. Accounting for possible selection bias would also be a useful direction for future research on this topic.

Another caveat is the variability in the quality of our treatment-control matches. In some cases (including most fisheries in the South Atlantic and Gulf of Mexico), finding a match is straightforward, as the same species is caught in two adjacent regions, one of which switched to catch shares while the other did not. In other cases, however, this process requires expert input, grouping of species, use of import products, and some degree of judgment and guesswork as to what might be plausibly considered a market substitute for the species in question. Recognizing that some of our matches will be "better" than others in this regard, we intend to conduct a meta-analysis at a later stage of the project which will weight our results according to some measure of match quality.

The treatment effects literature in the social sciences acknowledges a tension between external and internal validity (Shadish, Cook, and Campbell, 2002). External validity suggests that a study is generalizable to many different situations; the causal mechanisms in the particular treatment and control groups are likely present elsewhere. Internal validity is a measure of how well-identified the causal effect is in the study itself. By aiming to evaluate *all* U.S. catch share fisheries in our study, we ultimately prioritized external validity over internal validity. We developed empirical specifications that can be applied across all of the fisheries adopting catch shares, fisheries that are vastly different from one another in many respects. But in doing so, we necessarily sacrificed some attention to idiosyncratic circumstances of each fishery analyzed. Future research that digs deeper into the details of each fishery individually would be complementary and allow for a more thorough examination of internal validity.

Finally, our analysis is a first attempt to quantify causal links between catch shares and market outcomes. As capture fisheries face increased competition from aquaculture, they face greater incentives to generate more economic value from the same harvest (Anderson, 2002). There is near consensus in fisheries economics that catch shares generate cost savings relative to biological forms of management, but lower costs are only part of economic value. The revenue-side effects we seek to quantify are not well understood.

Our results are urgently needed in current policy debates. Particularly salient now is the debate about catch shares in the reauthorization of Magnuson-Stevens and whether Congress ultimately will limit the ability of fishery management councils to use this policy instrument. Our results, suggest that limiting the use of this policy instrument could hinder the ability of U.S. fisheries to end the race to fish and gain more control over market outcomes, but this control does not obviously translate into revenue-side benefits.

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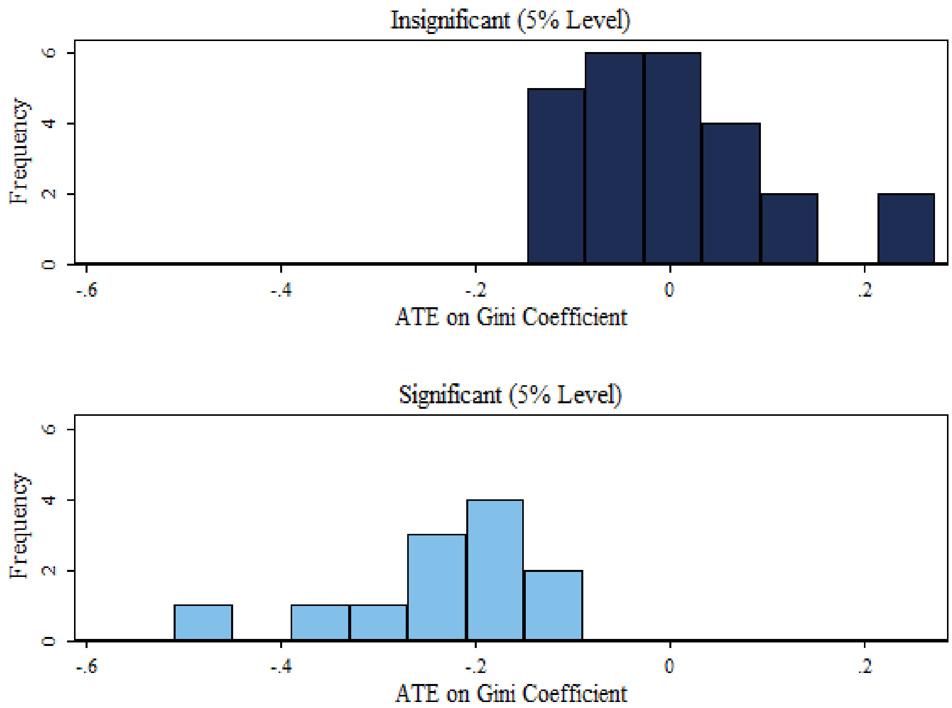
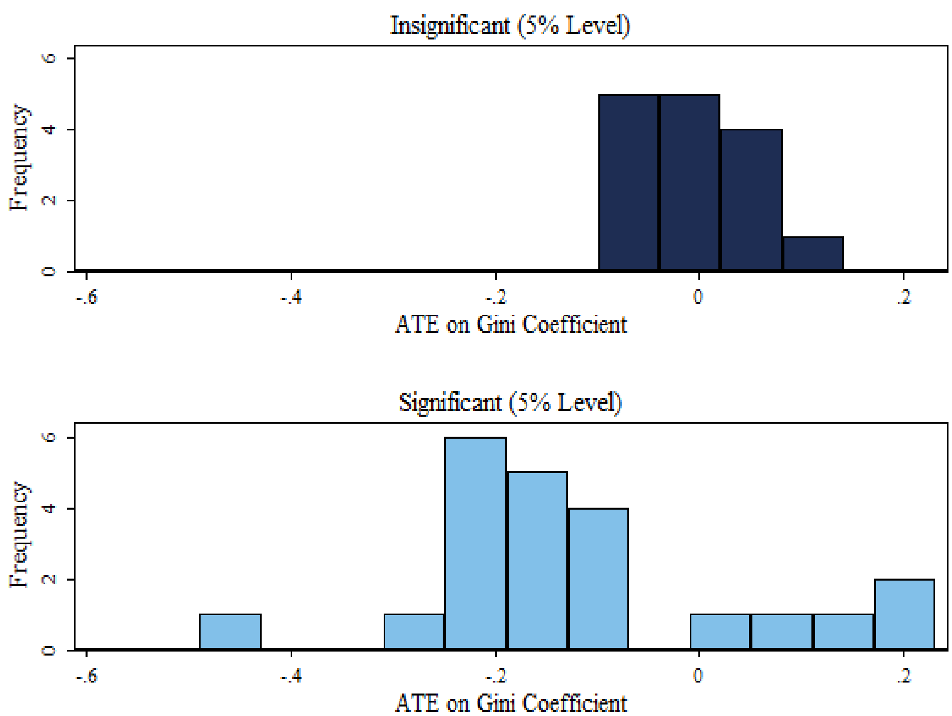


a. Unweighted Gini Results (OLS)



b. Unweighted Gini Results (Fractional Logit)

Figure 1. Summary of Individual Fishery Season Decompression.

Histograms of the individual landings Gini coefficient treatment effects across all fisheries/fishery groups for which data was sufficient to perform the season decompression analysis (37 fisheries/fishery groups). Treatment effects shown along the x-axis; counts of fisheries shown on the y-axis. All histograms are unweighted, meaning each fishery is counted once, regardless of size or economic importance. Panel (a) gives the results for the Ordinary Least Squares (OLS) analysis, and Panel (b) gives results for the fractional logit analysis, which corrects for the bounded nature of the dependent variable (Gini coefficient) in the difference-in-differences regressions. In each panel, the top histogram shows only treatment effects that are insignificant at the five percent level—predictably clustered around zero—and the bottom histogram shows only significant treatment effects. In Panel (a), significant treatment effects clearly fall below zero, ranging from roughly -0.1 to -0.5, meaning that Gini coefficients on landings decreased (i.e., the fishing season became more spread out) following the introduction of catch shares in the treatment fisheries. In Panel (b), we see that there are some significant and positive treatment effects; however, the majority of the significant treatment effects still fall below zero, indicating an overall trend toward season decompression post-catch shares. The difference between Panels (a) and (b) can be explained by the smaller standard errors resulting from the fractional logit analysis; some positive treatment effects that were not significant in the OLS regressions therefore became significant in the fractional logit regressions.

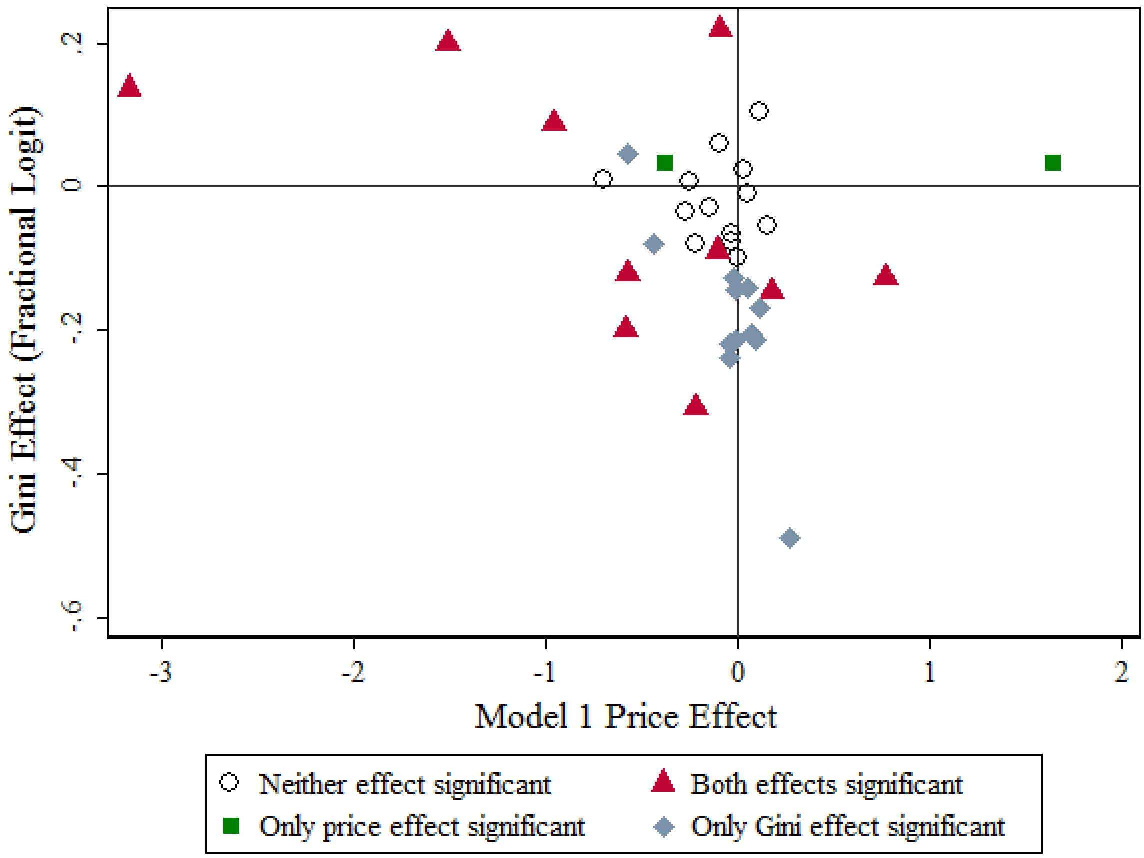
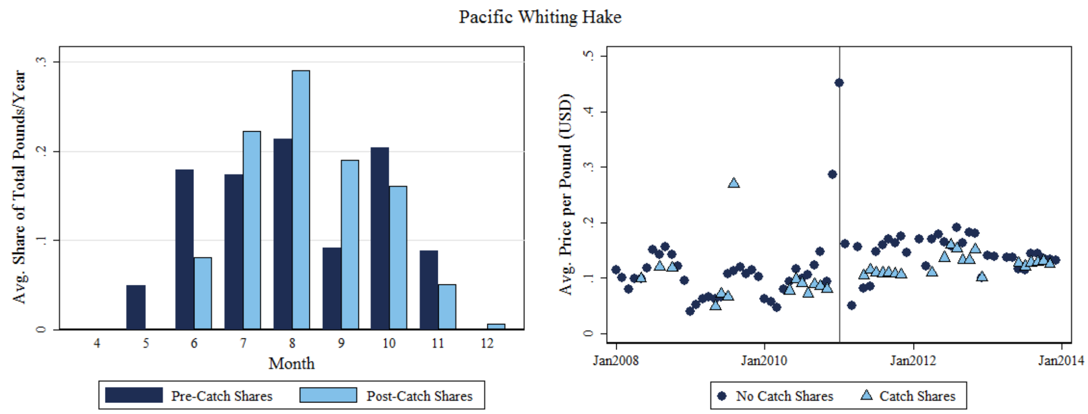


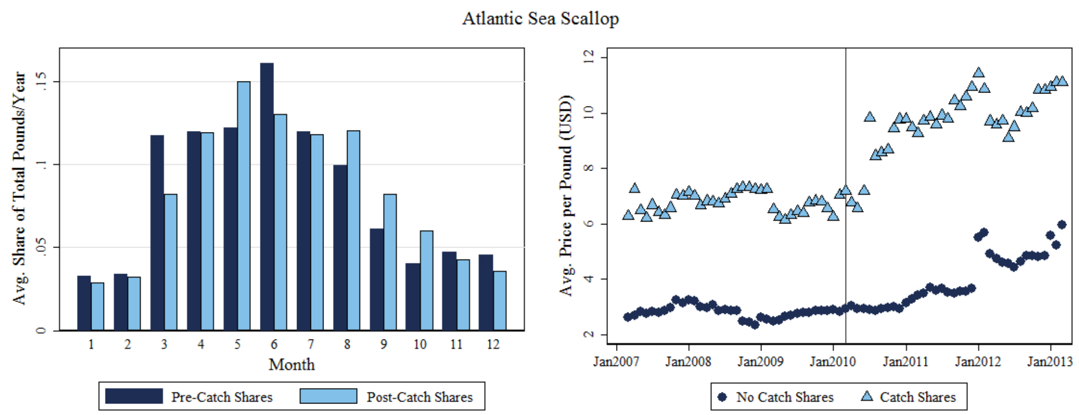
Figure 2. Season Decompression and Ex Vessel Price Treatment Effects by Fishery

Treatment effects for individual fisheries/fishery groups on two dimensions: season decompression (y-axis) and ex vessel price effects (results from Model 1, x-axis). Results were available for both analyses for 37 fisheries in total. Fisheries for which the distribution of landings across the season was significantly affected but not price are indicated by light blue diamonds (count = 12), fisheries whose season length did not change significantly but whose price effect was significant are indicated by green squares (count = 2), and fisheries for which both effects were significant are shown as pink triangles (count = 10). Fisheries for which neither effect was significant (count = 13) are marked by empty circles; numbers are used to label all other fisheries according to the legend below.

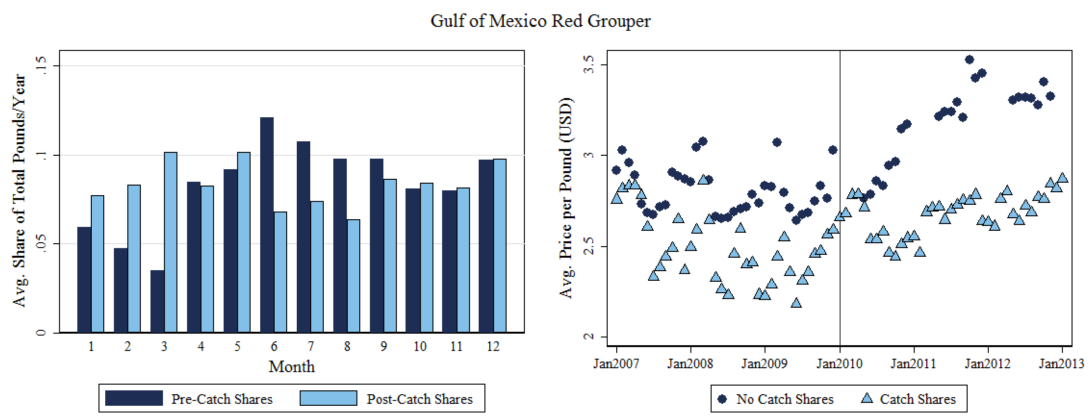
(a)



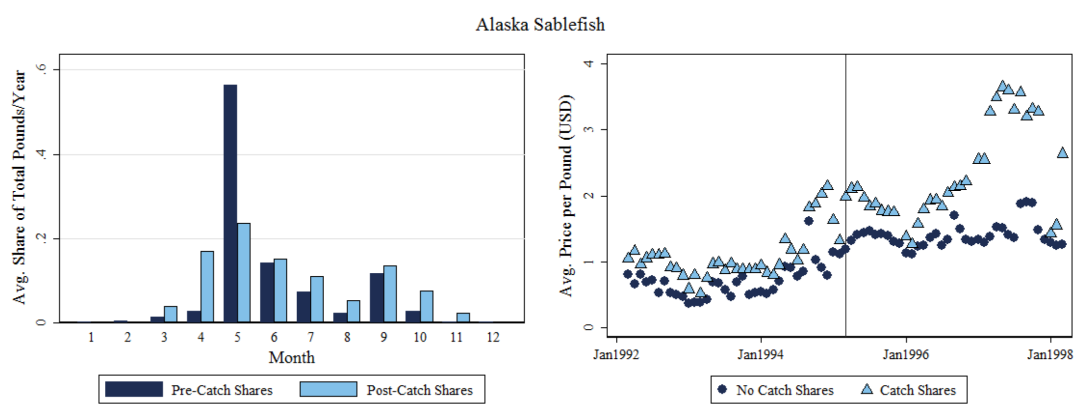
(b)



(c)



(d)



Notes: In right panels, vertical line marks implementation of catch share program in treatment fishery. Points represent average prices across states, weighted by volume.

Figure 3. Selected examples of price and season decompression outcomes

Right panels show ex vessel prices for four fishery pairs in the 3-year period pre- and 3-year period post- catch share implementation. Left panels show the distribution of landings averaged across months during the same periods for only treatment fisheries. The four fisheries were selected to highlight the four potential outcomes of the two dimensions analyzed: price increase and season decompression (Alaskan sablefish), price increase without season decompression (Atlantic sea scallop), no price increase with season decompression (Red grouper), and no price increase and no season decompression (Pacific whiting hake). Ex vessel prices are average price per pound, adjusted for exchange-rates when Canadian control fisheries are used, and weighted by volume.

Region	Program Name	Species	Commencement Date	Grouping	Comparison Region	Comparison Species/Product
Northeast	Mid-Atlantic Ocean Quahog ITQ Program	Ocean quahog	October, 1990	Ocean quahog	Chesapeake	Inshore hard clam
	Mid-Atlantic Surfclam ITQ Program	Atlantic surfclam	October, 1990	Atlantic surfclam	Chesapeake	Inshore hard clam
	Mid-Atlantic Golden Tilefish IFQ Program	Golden tilefish	November, 2009	Golden tilefish	South Atlantic	Golden tilefish
	Northeast General Category Atlantic Sea Scallop IFQ Program	Sea scallop	March, 2010	Sea scallop	Canada	Sea scallop
	Northeast Multispecies Sectors Program	Atlantic cod	May, 2010	Atlantic cod	Canada	Atlantic cod
		Pollock		Pollock	Canada	Pollock
		Haddock		Haddock	Canada	Haddock
		Redfish		Redfish	Canada	Acadian redfish
		White hake		White hake	Canada	White hake
		Witch flounder		Witch flounder	Canada	Witch flounder
		Winter flounder		Winter flounder	Canada	Winter flounder
		Windowpane flounder		Windowpane flounder	Canada	Windowpane flounder
		Yellowtail flounder		Yellowtail flounder	Mid-Atlantic	Yellowtail flounder
		American plaice		American plaice	Canada	Atlantic plaice flounder
		Atlantic halibut		Atlantic halibut	Canada	Atlantic halibut
Southeast	South Atlantic Wreckfish ITQ Program	Wreckfish	March, 1992	Wreckfish[1]	South Atlantic Gulf of Mexico	Red grouper
	Gulf of Mexico Red Snapper IFQ Program	Red snapper	January, 2007	Red snapper[2]	South Atlantic	Red snapper

Region	**Program Name**	**Species**	**Commencement Date**	**Grouping**	**Comparison Region**	**Comparison Species/Product**
	Gulf of Mexico Grouper-Tilefish IFQ Program	Snowy grouper	January, 2010	Deep-water grouper	South Atlantic	Deep-water grouper
		Speckled hind				
		Warsaw grouper				
		Yellowedge grouper				
		Gag		Gag	South Atlantic	Gag
		Black grouper		Shallow-water grouper	South Atlantic	Shallow-water grouper
		Scamp				
		Yellowfin grouper				
		Yellowmouth grouper				
		Red grouper		Red grouper	South Atlantic	Red grouper
		Blueline (grey) tilefish		Tilefish	South Atlantic	Tilefish
		Golden Tilefish				
		Goldface Tilefish[3]				
Northwest	Pacific Coast Sablefish Permit Stacking Program	Sablefish	August, 2001	Sablefish	Canada	Sablefish
	Pacific Groundfish Trawl Rationalization Program	Pacific cod	January, 2011	Pacific cod	Canada	Pacific cod
		Lingcod		Lingcod	Canada	Lingcod
		Pacific hake (whiting)		Pacific hake (whiting)	Canada	Pacific hake (whiting)
		Sablefish		Sablefish	Canada	Sablefish
		Pacific Ocean perch		Pacific Ocean perch	Canada	Pacific Ocean perch
		Widow rockfish		Widow rockfish	Canada	Widow rockfish
		Canary rockfish		Canary rockfish	Canada	Canary rockfish
		Splitnose rockfish		Splitnose rockfish	Canada	Splitnose rockfish
		Yellowtail rockfish		Yellowtail rockfish	Canada	Yellowtail rockfish
		Shortspine thornyhead		Shortspine thornyhead	Canada	Shortspine thornyhead

Region	Program Name	Species	Commencement Date	Grouping	Comparison Region	Comparison Species/Product
		Darkblotched rockfish		Darkblotched rockfish	Canada	Darkblotched rockfish
		Yelloweye rockfish		Yelloweye rockfish	Canada	Yelloweye rockfish
		Dover sole		Dover sole	Canada	Dover sole
		Petrale sole		Petrale sole	Canada	Petrale sole
		Arrowtooth flounder		Arrowtooth flounder	Canada	Arrowtooth flounder
		Starry flounder		Starry flounder	Canada	Starry flounder
Alaska	Alaska Halibut IFQ Program	Pacific Halibut	March, 1995	Pacific halibut	Canada Pacific	Pacific halibut imports (fresh) Pacific halibut
	Alaska Sablefish IFQ Program	Sablefish	March, 1995	Sablefish	Pacific	Sablefish
	American Fisheries Act (AFA) Pollock Cooperatives	Pollock	January, 1999	Pollock	Pacific	Pacific hake (whiting)
	Bering Sea and Aleutian Islands Crab Rationalization Program	Red King crab	August, 2005	King crab	Russian Federation	King crab imports (frozen)
		Golden King crab				
		Snow crab		Snow crab	Canada	Snow crab imports (frozen)
	Non-Pollock Trawl Catcher/Processor Groundfish Cooperatives (Amendment 80)	Atka mackerel	January, 2008	Atka Mackerel	Japanese export index created from top 5 fish exports (minimal processing) from Alaska to Japan (annual)	
		Aleutian Islands Pacific Ocean perch		Pacific Ocean perch	Pacific	Pacific Ocean perch
		Pacific cod		Pacific cod	Pacific	Pacific cod
		Flathead sole		Sole	Pacific	Sole (weighted average of Dover and Petrale)
		Rock sole				
		Yellowfin sole				
	Central Gulf of Alaska Rockfish Cooperatives Program	Pacific Ocean perch	May, 2007	Pacific Ocean perch	Pacific	Pacific Ocean perch
		Pacific cod		Pacific cod	Pacific	Pacific cod
		Sablefish		Sablefish	Pacific	Sablefish

Region	Program Name	Species	Commencement Date	Grouping	Comparison Region	Comparison Species/Product
		Shortspine thornyhead		Shortspine thornyhead	Pacific	Shortspine thornyhead
		Northern rockfish		Rockfishes	Pacific	Rockfishes (Widow, Canary, Splitnose, Yellowtail, Shortspine thornyhead, Chilipepper, Longspine, Cowcod, Darkblotched, Yelloweye, Other)
		Dusky rockfish				
		Shortraker rockfish				
		Rougheye rockfish				

Notes: Fisheries with insufficient data for differences-in-differences analysis not shown. In cases where a pilot program or partial implementation took place before the full catch share program went into effect, the implementation date used in our analysis is shown.

[1] Collapsed four years after ITQ introduction. Now only fished by a few vessels, and only 10 percent of the quota is typically caught.
[2] Moratorium in South Atlantic, 2010-11.
[3] No landings in 2010.

Table 1. Summary of Treated Fisheries and Matched Controls

All U.S. fisheries that underwent conversion to catch share management are included in our analysis, with the exception of those with insufficient data around the time period of catch share implementation. We selected comparison fisheries which serve approximately the same market (and thus are affected by the same shocks in demand) yet are distinctly and independently managed. Regions are defined by the U.S. regional fishery management councils. Commencement date indicates the time of catch share management implementation. Grouping indicates comparisons made on the basis of grouped fisheries, which is done in cases where the grouped fisheries do not serve distinct markets (and may not even be properly differentiated from one another when landed) and sometimes where an exact match (same species) does not exist.

Model Type	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	One-sided p-value
OLS	Unweighted	-0.0773	0.0001	-6.7830	0.0000
	1/Variance	-0.0814	0.0001	-10.7036	0.0000
	Fishery Size (Pounds)	-0.0891	0.0007	-3.3083	0.0010
	Fishery Size (Dollars)	-0.0358	0.0007	-1.3800	0.0879
	Pounds/Variance	-0.0757	0.0002	-5.3256	0.0000
	Dollars/Variance	-0.0315	0.0006	-1.2994	0.1009
Fractional Logit	Unweighted	-0.0735	0.0000	-10.8620	0.0000
	1/Variance	-0.0837	0.0000	-18.0712	0.0000
	Fishery Size (Pounds)	-0.0930	0.0003	-5.0935	0.0000
	Fishery Size (Dollars)	-0.0384	0.0003	-2.2961	0.0137
	Pounds/Variance	-0.0774	0.0001	-8.6993	0.0000
	Dollars/Variance	-0.0356	0.0002	-2.3424	0.0123

Table 2. Meta-analysis of Season Decompression Based on Landings Gini Coefficient

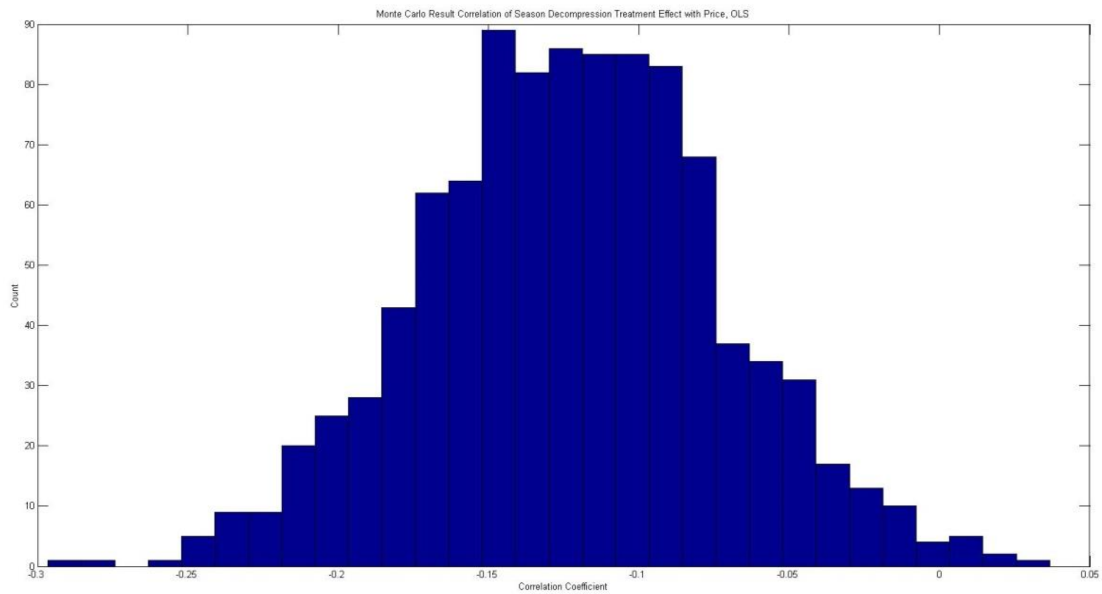
Average of treatment effects (season decompression) for all fisheries with monthly landings data (37 fisheries) (see table A2 for individual fisheries results). Weighting is by variance, and/or by fishery size (pounds landed) and fishery value (total ex vessel revenues).

Model	Weighting Scheme	Weighted Average Treatment Effect (%)	Weighted Variance	t-statistic	One-sided p-value
1	Unweighted	-0.3253	0.0011	-10.0177	1.0000
	1/Variance	0.0034	0.0000	0.5671	0.2865
	Fishery Size (Pounds)	-0.1409	0.0005	-6.3576	1.0000
	Fishery Size (Dollars)	0.1456	0.0172	1.1085	0.1363
	Pounds/Variance	-0.1081	0.0002	-7.2968	1.0000
	Dollars/Variance	-0.0653	0.0002	-4.9893	1.0000
2	Unweighted	-0.4003	0.0008	-13.8272	1.0000
	1/Variance	-0.0649	0.0000	-10.3801	1.0000
	Fishery Size (Pounds)	-0.1478	0.0004	-7.8801	1.0000
	Fishery Size (Dollars)	0.1237	0.0132	1.0783	0.1429
	Pounds/Variance	-0.1485	0.0002	-10.7507	1.0000
	Dollars/Variance	-0.1198	0.0002	-9.3037	1.0000
3	Unweighted	-0.2886	0.0002	-20.8617	1.0000
	1/Variance	-0.2131	0.0000	-32.3401	1.0000
	Fishery Size (Pounds)	0.0143	0.0001	1.6210	0.0555
	Fishery Size (Dollars)	0.2514	0.0028	4.7610	0.0000
	Pounds/Variance	-0.4059	0.0001	-34.0934	1.0000
	Dollars/Variance	-0.0329	0.0004	-1.7351	0.9557

Table 3. Meta-analysis of Ex Vessel Price Treatment Effects

Average of treatment effects (ex vessel price) for all fisheries/fishery groups included in analysis (53 fisheries) (see table A3 for individual fishery/fishery group results). Weighting is by variance, and/or by fishery size (pounds landed) and fishery value (total revenue).

Appendix



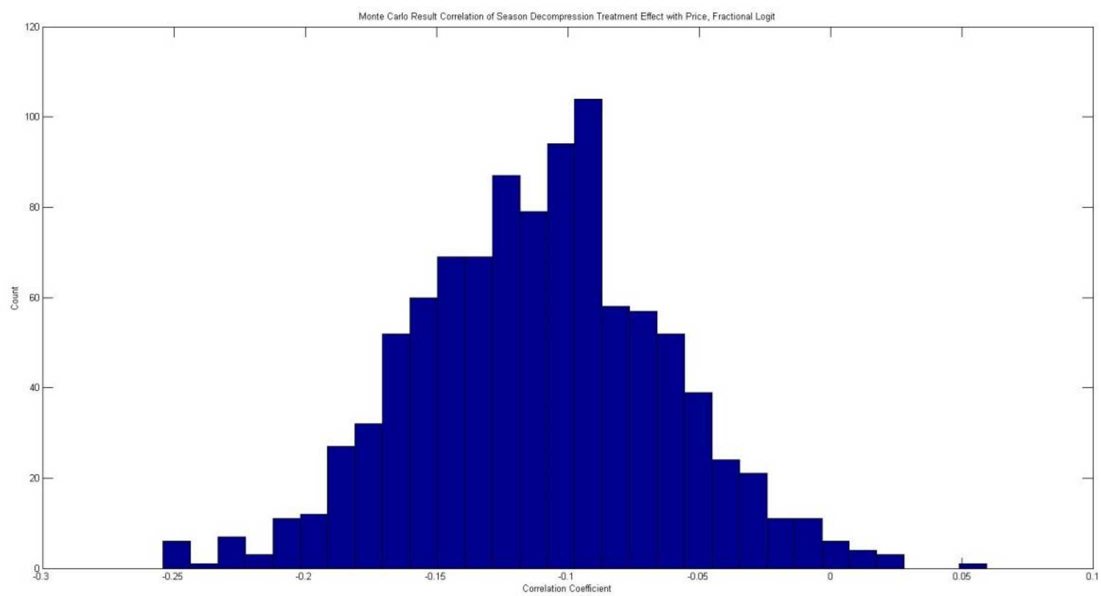


Figure A1. Incentives for Season Decompression. Base (pre-treatment) ex vessel price is negatively correlated with the Gini treatment effect.

Monte Carlo result of correlation between season decompression treatment effect and average price (weighted by volume) in the three years preceding catch share management. Top panel: treatment effect based on OLS regression; lower panel: treatment effect based on fractional logit regression.

Program	Species/Group	Yearly Landings		Yearly Value (millions of 2015 dollars) (mean/sd)		Average Price/lb (2015 dollars) (mean/sd)	
		Pre-CS	**Post-CS**	**Pre-CS**	**Post-CS**	**Pre-CS**	**Post-CS**
Alaska Crab	King Crab	18,936	23,419	47.777	46.335	$ 2.52	$ 1.98
		4,065	2,387	6.937	9.617	$ 0.30	$ 0.24
Alaska Crab	Snow Crab	23,537	46,272	23.737	32.603	$ 1.01	$ 0.70
		4,050	12,638	5.018	11.873	$ 0.08	$ 0.10
Alaska Halibut	Pacific Halibut	63,662	58,184	45.120	52.022	$ 0.71	$ 0.89
		5,116	13,284	11.183	12.024	$ 0.24	$ 0.22
Alaska Non-Pollock	Atka Mackerel	2,922	7,733	0.600	1.412	$ 0.21	$ 0.18
		2,410	3,000	0.405	0.708	$ 0.13	$ 0.02
Alaska Non-Pollock	Pacific Cod	77,765	70,930	12.586	10.204	$ 0.16	$ 0.14
		3,753	9,520	3.001	5.553	$ 0.04	$ 0.07
Alaska Non-Pollock	Pacific Ocean Perch Rockfish	11,776	19,853	6.709	11.032	$ 0.57	$ 0.56
		3,568	4,376	1.116	6.261	$ 0.09	$ 0.18
Alaska Non-Pollock	Sole	47,297	34,499	11.759	7.679	$ 0.25	$ 0.22
		3,414	3,732	0.631	1.612	$ 0.01	$ 0.03
Alaska Pollock	Pollock	1,227,744	1,736,289	93.963	110.239	$ 0.08	$ 0.06
		105,974	288,268	32.850	6.336	$ 0.03	$ 0.01
Alaska Rockfish	Pacific Cod	20,615	22,698	2.991	3.902	$ 0.15	$ 0.17
		8,619	6,648	0.874	1.680	$ 0.02	$ 0.07
Alaska Rockfish	Pacific Ocean Perch Rockfish	10,373	11,450	0.542	0.676	$ 0.05	$ 0.06
		612	1,863	0.223	0.239	$ 0.02	$ 0.02
Alaska Rockfish	Rockfishes	7,071	6,941	0.361	0.475	$ 0.05	$ 0.07
		948	1,374	0.112	0.176	$ 0.02	$ 0.01
Alaska Rockfish	Sablefish	1,095	1,004	0.819	1.004	$ 0.75	$ 1.00

Program	Species/Group	Yearly Landings		Yearly Value (millions of 2015 dollars) (mean/sd)		Average Price/lb (2015 dollars) (mean/sd)	
		Pre-CS	Post-CS	Pre-CS	Post-CS	Pre-CS	Post-CS
		180	59	0.079	0.197	$ 0.07	$ 0.20
Alaska Rockfish	Shortspine Thornyhead	104	125	0.017	0.026	$ 0.17	$ 0.20
		12	16	0.003	0.005	$ 0.02	$ 0.03
Alaska Sablefish	Sablefish	33,880	26,788	29.566	34.599	$ 0.87	$ 1.29
		2,020	4,561	5.159	8.642	$ 0.15	$ 0.21
Atlantic Sea Scallop	Sea Scallop	56,489	53,416	177.354	227.289	$ 3.14	$ 4.26
		2,719	8,352	7.717	28.012	$ 0.11	$ 0.52
Gulf of Mexico Grouper-Tilefish	Deep Water Grouper	1,393	983	1.927	1.453	$ 1.38	$ 1.48
		41	184	0.134	0.333	$ 0.07	$ 0.08
Gulf of Mexico Grouper-Tilefish	Gag	1,239	565	1.920	0.974	$ 1.55	$ 1.72
		345	136	0.532	0.244	$ 0.01	$ 0.05
Gulf of Mexico Grouper-Tilefish	Red Grouper	4,791	5,170	5.508	6.272	$ 1.15	$ 1.21
		726	1,161	0.731	1.451	$ 0.06	$ 0.05
Gulf of Mexico Grouper-Tilefish	Shallow Water Grouper	456	317	0.684	0.509	$ 1.50	$ 1.61
		90	85	0.131	0.144	$ 0.02	$ 0.03
Gulf of Mexico Grouper-Tilefish	Tilefish	519	411	0.335	0.385	$ 0.65	$ 0.94
		48	99	0.022	0.109	$ 0.05	$ 0.05
Gulf of Mexico Red Snapper	Red Snapper	4,474	2,624	6.173	4.013	$ 1.38	$ 1.53
		317	331	0.364	0.522	$ 0.05	$ 0.04
Mid-Atlantic Golden Tilefish	Golden Tilefish	1,682	1,876	2.013	2.418	$ 1.20	$ 1.29
		179	75	0.130	0.076	$ 0.15	$ 0.08
Mid-Atlantic Quahog	Ocean Quahog Clam	25,667	40,586	6.117	10.156	$ 0.24	$ 0.25
		7,532	3,366	1.772	1.024	$ -	$ 0.01

Program	Species/Group	Yearly Landings		Yearly Value (millions of 2015 dollars) (mean/sd)		Average Price/lb (2015 dollars) (mean/sd)	
		Pre-CS	Post-CS	Pre-CS	Post-CS	Pre-CS	Post-CS
Mid-Atlantic Surfclam	Atlantic Surf Clam	48,861	60,784	17.635	19.425	$ 0.36	$ 0.32
		8,661	3,651	2.048	0.878	$ 0.02	$ 0.02
Northeast Groundfish	Acadian Redfish	2,489	6,203	0.621	1.632	$ 0.25	$ 0.26
		720	2,569	0.125	0.737	$ 0.03	$ 0.02
Northeast Groundfish	Atlantic Cod	18,542	12,647	12.995	10.343	$ 0.70	$ 0.82
		1,476	6,123	1.282	4.398	$ 0.10	$ 0.09
Northeast Groundfish	Atlantic Halibut	72	65	0.161	0.189	$ 2.25	$ 2.89
		24	12	0.047	0.038	$ 0.09	$ 0.10
Northeast Groundfish	Atlantic Plaice Flounder	2,564	3,082	1.818	2.043	$ 0.71	$ 0.66
		459	149	0.109	0.124	$ 0.12	$ 0.03
Northeast Groundfish	Haddock	11,608	10,664	6.650	5.800	$ 0.57	$ 0.54
		3,187	8,307	0.898	3.440	$ 0.13	$ 0.14
Northeast Groundfish	Pollock	18,957	13,310	4.674	5.117	$ 0.25	$ 0.38
		2,770	2,403	0.571	0.612	$ 0.03	$ 0.04
Northeast Groundfish	White Hake	3,284	5,351	1.698	2.571	$ 0.52	$ 0.48
		406	1,123	0.144	0.490	$ 0.06	$ 0.06
Northeast Groundfish	Windowpane Flounder	177	8	0.035	0.002	$ 0.20	$ 0.27
		102	3	0.019	0.001	$ 0.01	$ 0.04
Northeast Groundfish	Winter Flounder	4,831	4,780	4.291	3.816	$ 0.89	$ 0.80
		220	1,050	0.765	0.603	$ 0.12	$ 0.09
Northeast Groundfish	Witch Flounder	2,203	1,846	2.329	1.734	$ 1.06	$ 0.94
		123	339	0.422	0.104	$ 0.14	$ 0.12
Northeast Groundfish	Yellowtail Flounder	3,636	3,359	2.702	1.998	$ 0.74	$ 0.59

Program	Species/Group	Yearly Landings		Yearly Value (millions of 2015 dollars) (mean/sd)		Average Price/lb (2015 dollars) (mean/sd)	
		Pre-CS	Post-CS	Pre-CS	Post-CS	Pre-CS	Post-CS
		170	704	0.650	0.271	$ 0.14	$ 0.06
Pacific Groundfish	Arrowtooth Flounder	7,013	4,652	0.324	0.230	$ 0.05	$ 0.05
		1,259	309	0.058	0.030	$ -	$ 0.01
Pacific Groundfish	Canary Rockfish	15	22	0.004	0.005	$ 0.24	$ 0.23
		4	6	0.001	0.001	$ 0.02	$ 0.01
Pacific Groundfish	Darkblotched Rockfish	284	207	0.065	0.044	$ 0.23	$ 0.21
		68	36	0.014	0.007	$ 0.01	$ -
Pacific Groundfish	Dover Sole	24,054	16,411	3.835	3.082	$ 0.16	$ 0.19
		1,468	922	0.573	0.238	$ 0.02	$ 0.01
Pacific Groundfish	Lingcod	277	773	0.096	0.251	$ 0.35	$ 0.32
		57	117	0.015	0.034	$ 0.02	$ 0.01
Pacific Groundfish	Pacific Cod	526	1,175	0.117	0.281	$ 0.22	$ 0.24
		359	292	0.068	0.081	$ 0.06	$ 0.01
Pacific Groundfish	Pacific Ocean Perch Rockfish	132	68	0.029	0.015	$ 0.22	$ 0.22
		6	5	0.001	0.001	$ -	$ 0.01
Pacific Groundfish	Pacific Whiting Hake	116,142	191,852	4.846	10.473	$ 0.04	$ 0.05
		20,301	43,917	2.065	1.517	$ 0.01	$ 0.01
Pacific Groundfish	Petrale Sole	3,510	3,108	1.628	1.821	$ 0.46	$ 0.59
		1,593	1,565	0.696	0.727	$ 0.05	$ 0.06
Pacific Groundfish	Sablefish	6,202	3,404	5.367	2.984	$ 0.87	$ 0.88
		569	351	0.417	1.120	$ 0.03	$ 0.23
Pacific Groundfish	Shortspine Thornyhead	2,619	1,623	0.820	0.559	$ 0.31	$ 0.34
		257	153	0.101	0.084	$ 0.03	$ 0.03

Program	Species/Group	Yearly Landings		Yearly Value (millions of 2015 dollars) (mean/sd)		Average Price/lb (2015 dollars) (mean/sd)	
		Pre-CS	Post-CS	Pre-CS	Post-CS	Pre-CS	Post-CS
Pacific Groundfish	Splitnose Rockfish	151	30	0.026	0.004	$ 0.17	$ 0.13
		33	12	0.007	0.001	$ 0.01	$ 0.01
Pacific Groundfish	Starry Flounder	95	25	0.021	0.007	$ 0.22	$ 0.28
		65	9	0.013	0.002	$ 0.04	$ 0.03
Pacific Groundfish	Widow Rockfish	245	572	0.048	0.114	$ 0.20	$ 0.20
		51	327	0.009	0.064	$ 0.01	$ -
Pacific Groundfish	Yelloweye Rockfish	0	0	0.000	0.000	$ 0.24	$ 0.24
		0	0	0.000	0.000	$ -	$ 0.02
Pacific Groundfish	Yellowtail Rockfish	1,133	2,760	0.264	0.618	$ 0.23	$ 0.22
		519	427	0.119	0.111	$ 0.01	$ 0.01
Pacific Sablefish	Sablefish	7,150	6,676	6.285	6.087	$ 0.88	$ 0.91
		1,656	1,062	2.017	0.927	$ 0.11	$ 0.06
South Atlantic Wreckfish	Wreckfish	2,556	627	2.480	0.663	$ 0.97	$ 1.06
		1,109	399	1.013	0.399	$ 0.03	$ 0.03

Table A1. Summary Statistics

Volume, value, and average price of each fishery/fishery group included in analysis, in the 3-year period pre- and 3-year period post-catch share implementation.

Program	Species/Group	OLS (b/se)	Fractional Logit (b/se)
Alaska Halibut	Pacific Halibut	-0.1957***	-0.2055***
		(0.0423)	*(0.0305)*
Alaska Sablefish	Sablefish	-0.2108**	-0.2136***
		(0.0404)	*(0.0245)*
Atlantic Sea Scallop	Sea Scallop	0.03	0.0316
		(0.0430)	*(0.0277)*
Gulf of Mexico Grouper-Tilefish	Deep Water Grouper	-0.2493**	-0.2381***
		(0.0380)	*(0.0218)*
Gulf of Mexico Grouper-Tilefish	Gag	-0.2002*	-0.1688***
		(0.0689)	*(0.0428)*
Gulf of Mexico Grouper-Tilefish	Red Grouper	-0.3544***	-0.3069***
		(0.0478)	*(0.0267)*
Gulf of Mexico Grouper-Tilefish	Shallow Water Grouper	-0.2909**	-0.2182***
		(0.0538)	*(0.0294)*
Gulf of Mexico Grouper-Tilefish	Tilefish	-0.5095**	-0.4885***
		(0.1026)	*(0.0549)*
Gulf of Mexico Red Snapper	Red Snapper	-0.1446*	-0.1407***
		(0.0381)	*(0.0232)*
Mid-Atlantic Golden Tilefish	Golden Tilefish	-0.2398**	-0.2132***
		(0.0398)	*(0.0197)*
Northeast Groundfish	Acadian Redfish	-0.08	-0.0812*
		(0.0682)	*(0.0394)*
Northeast Groundfish	Atlantic Cod	-0.0878+	-0.1265***
		(0.0376)	*(0.0224)*
Northeast Groundfish	Atlantic Halibut	0.14	0.1368**
		(0.0737)	*(0.0450)*
Northeast Groundfish	Atlantic Plaice Flounder	-0.1786*	-0.1984***
		(0.0655)	*(0.0386)*
Northeast Groundfish	Haddock	0.0451+	0.0467***
		(0.0213)	*(0.0129)*
Northeast Groundfish	Pollock	0.00	-0.0286
		(0.0516)	*(0.0294)*
Northeast Groundfish	White Hake	-0.0770+	-0.1216***
		(0.0312)	*(0.0204)*
Northeast Groundfish	Windowpane Flounder	0.23	0.1988***
		(0.1206)	*(0.0551)*
Northeast Groundfish	Winter Flounder	0.09	0.0876**
		(0.0489)	*(0.0302)*
Northeast Groundfish	Witch Flounder	0.00	-0.0366
		(0.0442)	*(0.0308)*

Program	**Species/Group**	**OLS (b/se)**	**Fractional Logit (b/se)**
Northeast Groundfish	Yellowtail Flounder	-0.06	-0.0542
		(0.1092)	*(0.0664)*
Pacific Groundfish	Arrowtooth Flounder	-0.08	-0.0648+
		(0.0551)	*(0.0366)*
Pacific Groundfish	Canary Rockfish	-0.11	-0.0808
		(0.0881)	*(0.0542)*
Pacific Groundfish	Darkblotched Rockfish	-0.08	-0.0771+
		(0.0698)	*(0.0422)*
Pacific Groundfish	Dover Sole	-0.01	0.0237
		(0.0352)	*(0.0275)*
Pacific Groundfish	Lingcod	0.03	0.0322
		(0.0608)	*(0.0362)*
Pacific Groundfish	Pacific Cod	-0.14	-0.1429**
		(0.0757)	*(0.0450)*
Pacific Groundfish	Pacific Ocean Perch Rockfish	0.2494+	0.2202***
		(0.0955)	*(0.0490)*
Pacific Groundfish	Pacific Whiting Hake	-0.09	-0.0985+
		(0.0852)	*(0.0578)*
Pacific Groundfish	Petrale Sole	-0.1523*	-0.1457***
		(0.0433)	*(0.0280)*
Pacific Groundfish	Sablefish	0.01	0.0091
		(0.0398)	*(0.0238)*
Pacific Groundfish	Shortspine Thornyhead	-0.03	-0.0093
		(0.0357)	*(0.0257)*
Pacific Groundfish	Splitnose Rockfish	0.02	0.0061
		(0.1049)	*(0.0635)*
Pacific Groundfish	Starry Flounder	0.11	0.1043
		(0.1550)	*(0.0960)*
Pacific Groundfish	Widow Rockfish	-0.15	-0.1286**
		(0.0756)	*(0.0419)*
Pacific Groundfish	Yelloweye Rockfish	0.04	0.0591
		(0.0911)	*(0.0568)*
Pacific Groundfish	Yellowtail Rockfish	-0.1052**	-0.0888***
		(0.0228)	*(0.0131)*

+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Note: Three-year time windows before and after implementation used for both models.

Table A2. DID Treatment Effects by Individual Fishery/Fishery Group: Gini Coefficient for Season Compression

Program	Species/Group	Model 1 (b/se)	Model 2 (b/se)	Model 3 (b/se)
Alaska Crab	King Crab	0.48	0.36	
		(0.36)	*(0.44)*	
Alaska Crab	Snow Crab	-0.26	-0.24	
		(0.24)	*(0.18)*	
Alaska Halibut	Pacific Halibut	0.07	0.13	0.39***
		(0.09)	*(0.08)*	(0.10)
Alaska Non-Pollock	Atka Mackerel	-0.17	-0.16	
		(0.16)	*(0.15)*	
Alaska Non-Pollock	Pacific Cod	-0.04	-0.02	
		(0.04)	*(0.04)*	
Alaska Non-Pollock	Pacific Ocean Perch Rockfish	-0.04	-0.04	
		(0.23)	*(0.23)*	
Alaska Non-Pollock	Sole	0.07**	0.08*	
		(0.02)	*(0.03)*	
Alaska Pollock	Pollock	-0.02	-0.01	
		(0.02)	*(0.02)*	
Alaska Rockfish	Pacific Cod	0.02	0.07	
		(0.04)	*(0.07)*	
Alaska Rockfish	Pacific Ocean Perch Rockfish	0	0	
		(0.03)	*(0.03)*	
Alaska Rockfish	Rockfishes	0.03	0.08+	
		(0.03)	*(0.04)*	
Alaska Rockfish	Sablefish	0.05	0.01	
		(0.14)	*(0.17)*	
Alaska Rockfish	Shortspine Thornyhead	0.31*	0.08	
		(0.10)	*(0.36)*	
Alaska Sablefish	Sablefish	0.09	0.11*	0.53***
		(0.09)	*(0.05)*	*(0.10)*
Atlantic Sea Scallop	Sea Scallop	1.65**	1.61***	1.76***
		(0.35)	*(0.30)*	*(0.14)*
Gulf of Mexico Grouper-Tilefish	Deep Water Grouper	-0.04	-0.23+	-0.16**
		(0.06)	*(0.13)*	*(0.06)*
Gulf of Mexico Grouper-Tilefish	Gag	0.12+	-0.29*	0
		(0.06)	*(0.11)*	*(0.05)*
Gulf of Mexico Grouper-Tilefish	Red Grouper	-0.22*	-0.24**	-0.22***
		(0.09)	*(0.07)*	*(0.04)*
Gulf of Mexico Grouper-Tilefish	Shallow Water Grouper	-0.04	-0.19*	-0.19***

Program	**Species/Group**	**Model 1 (b/se)**	**Model 2 (b/se)**	**Model 3 (b/se)**
		(0.07)	*(0.08)*	*(0.04)*
Gulf of Mexico Grouper-Tilefish	Tilefish	0.27+	0.03	0.20*
		(0.11)	*(0.16)*	*(0.09)*
Gulf of Mexico Red Snapper	Red Snapper	0.05	0.08	0.07*
		(0.08)	*(0.08)*	*(0.04)*
Mid-Atlantic Golden Tilefish	Golden Tilefish	-0.01	-0.03	-0.14
		(0.16)	*(0.25)*	*(0.12)*
Mid-Atlantic Quahog	Ocean Quahog Clam	-0.08	-0.56	0.14
		(0.44)	*(0.44)*	*(0.26)*
Mid-Atlantic Surfclam	Atlantic Surf Clam	-0.13	-0.15	0.24
		(0.43)	*(0.34)*	*(0.22)*
Northeast Groundfish	Acadian Redfish	-0.44	-0.63*	-0.44***
		(0.25)	*(0.31)*	*(0.09)*
Northeast Groundfish	Atlantic Cod	0.77*	0.38+	0.40***
		(0.27)	*(0.19)*	*(0.10)*
Northeast Groundfish	Atlantic Halibut	-3.17*	-2.84***	-2.74***
		(1.02)	*(0.58)*	*(0.31)*
Northeast Groundfish	Atlantic Plaice Flounder	-0.59*	-0.34	-0.35**
		(0.20)	*(0.24)*	*(0.12)*
Northeast Groundfish	Haddock	-0.57	-0.5	-0.31*
		(0.34)	*(0.34)*	*(0.12)*
Northeast Groundfish	Pollock	-0.15	-0.14+	-0.15**
		(0.08)	*(0.07)*	*(0.06)*
Northeast Groundfish	White Hake	-0.57*	-0.55**	-0.55***
		(0.22)	*(0.16)*	*(0.11)*
Northeast Groundfish	Windowpane Flounder	-1.51*	-1.53**	-1.43***
		(0.52)	*(0.39)*	*(0.20)*
Northeast Groundfish	Winter Flounder	-0.96*	-0.69**	-0.68***
		(0.26)	*(0.24)*	*(0.11)*
Northeast Groundfish	Witch Flounder	-0.27	-0.21	-0.19
		(0.28)	*(0.25)*	*(0.12)*
Northeast Groundfish	Yellowtail Flounder	0.16	-0.36	0.09
		(0.14)	*(0.40)*	*(0.11)*
Pacific Groundfish	Arrowtooth Flounder	-0.03	-0.03	-0.05
		(0.02)	*(0.02)*	*(0.04)*
Pacific Groundfish	Canary Rockfish	-0.21+	-0.22**	-0.16*
		(0.08)	*(0.07)*	*(0.06)*
Pacific Groundfish	Darkblotched Rockfish	-0.03	-0.01	-0.01
		(0.07)	*(0.06)*	*(0.03)*

Program	Species/Group	Model 1 (b/se)	Model 2 (b/se)	Model 3 (b/se)
Pacific Groundfish	Dover Sole	0.03	0.02	0.01
		(0.02)	*(0.02)*	*(0.01)*
Pacific Groundfish	Lingcod	-0.37*	-0.38**	-0.26**
		(0.12)	*(0.11)*	*(0.09)*
Pacific Groundfish	Pacific Cod	-0.01	0.01	-0.01
		(0.05)	*(0.05)*	*(0.02)*
Pacific Groundfish	Pacific Ocean Perch Rockfish	-0.09*	-0.09*	-0.06**
		(0.03)	*(0.03)*	*(0.02)*
Pacific Groundfish	Pacific Whiting Hake	0.01	0	-0.03
		(0.01)	*(0.01)*	*(0.02)*
Pacific Groundfish	Petrale Sole	0.18*	0.16**	0.16***
		(0.05)	*(0.04)*	*(0.04)*
Pacific Groundfish	Sablefish	-0.70+	-0.65*	-0.60***
		(0.31)	*(0.24)*	*(0.15)*
Pacific Groundfish	Shortspine Thornyhead	0.06	-0.01	-0.04
		(0.29)	*(0.25)*	*(0.10)*
Pacific Groundfish	Splitnose Rockfish	-0.25+	-0.25+	-0.23***
		(0.10)	*(0.10)*	*(0.06)*
Pacific Groundfish	Starry Flounder	0.12	0.06	0.30+
		(0.13)	*(0.19)*	*(0.16)*
Pacific Groundfish	Widow Rockfish	-0.02	0.03	-0.09
		(0.04)	*(0.06)*	*(0.05)*
Pacific Groundfish	Yelloweye Rockfish	-0.1	-0.07	-0.08
		(0.09)	*(0.10)*	*(0.11)*
Pacific Groundfish	Yellowtail Rockfish	-0.10*	-0.1	-0.12***
		(0.03)	*(0.08)*	*(0.03)*
Pacific Sablefish	Sablefish	-0.09	-0.08	
		(0.12)	*(0.13)*	
South Atlantic Wreckfish	Wreckfish	0.30***	0.25***	0.21*
		(0.06)	*(0.05)*	*(0.10)*
Annual/Monthly		Annual	Annual	Monthly
Fixed Effects		Year	Year, State	Year, State

+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Notes: Three-year time windows before and after implementation used for all models. Units for coefficients and standard errors are U.S. dollars. Per-pound prices have been converted using spot exchange rates where needed.

Table A3. DID Treatment Effects by Individual Fishery/Fishery Group: Change in Price per Pound

Model	Weighting Scheme	Weighted Average Treatment Effect (%)	Weighted Variance	t-statistic	One-sided p-value
1	Unweighted	-0.3644	0.0013	-10.2185	1.0000
	1/Variance	0.0027	0.0000	0.4467	0.3286
	Fishery Size (Pounds)	-0.1411	0.0005	-6.3427	1.0000
	Fishery Size (Dollars)	0.1505	0.0180	1.1216	0.1338
	Pounds/Variance	-0.1081	0.0002	-7.2953	1.0000
	Dollars/Variance	-0.0653	0.0002	-4.9606	1.0000
2	Unweighted	-0.4287	0.0010	-13.6042	1.0000
	1/Variance	-0.0630	0.0000	-9.9659	1.0000
	Fishery Size (Pounds)	-0.1477	0.0004	-7.8396	1.0000
	Fishery Size (Dollars)	0.1303	0.0137	1.1120	0.1358
	Pounds/Variance	-0.1484	0.0002	-10.7477	1.0000
	Dollars/Variance	-0.1195	0.0002	-9.2415	1.0000
3	Unweighted	-0.3161	0.0002	-21.0555	1.0000
	1/Variance	-0.2251	0.0000	-32.5972	1.0000
	Fishery Size (Pounds)	0.0149	0.0001	1.6777	0.0499
	Fishery Size (Dollars)	0.2594	0.0029	4.8096	0.0000
	Pounds/Variance	-0.4077	0.0001	-34.0160	1.0000
	Dollars/Variance	-0.0250	0.0004	-1.2392	0.8894

Table A4. Meta-analysis of Ex Vessel Prices Excluding 2010 Gulf of Mexico Catch Shares

Average of treatment effects (ex vessel price) for all fisheries excluding Gulf of Mexico fisheries (48 fisheries/fishery groups) (see table A3 for individual fisheries results). Weighting is by variance, and/or by fishery size (pounds landed) and fishery value (total revenue).

Program	Species/Group	Percent Changes						Difference-in-Differences			Summary
		Ex-Vessel Prices			FPI						
		1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	
Mean								***0.01***	***0.03***	***0.03***	
Min								***-0.60***	***-0.43***	***-0.46***	
Max								***0.64***	***0.60***	***0.57***	
Alaska Crab	King Crab	-13%	-15%	-13%	9%	17%	27%	-0.22	-0.32	-0.40	-
	Snow Crab	-25%	-22%	-22%	12%	21%	25%	-0.37	-0.43	-0.46	-
Alaska Halibut	Pacific Halibut	10%	36%	38%	6%	6%	4%	0.05	0.29	0.34	+
Alaska Non-Pollock	Atka Mackerel	-54%	-18%	-3%	6%	10%	20%	-0.60	-0.28	-0.24	-
	Pacific Cod	-8%	-12%	-4%	6%	10%	18%	-0.14	-0.22	-0.22	-
	Pacific Ocean Perch Rockfish	-14%	-14%	6%	6%	10%	18%	-0.20	-0.24	-0.12	-
	Sole	-4%	-10%	-3%	6%	10%	18%	-0.10	-0.20	-0.21	-
Alaska Pollock	Pollock	66%	3%	-9%	2%	0%	-1%	0.64	0.04	-0.08	ambiguous
Alaska Rockfish	Pacific Cod	36%	39%	30%	18%	19%	22%	0.18	0.20	0.09	+
	Pacific Ocean Perch Rockfish	4%	2%	23%	18%	19%	22%	-0.14	-0.16	0.01	ambiguous
	Rockfishes	9%	20%	45%	18%	19%	22%	-0.08	0.02	0.24	ambiguous
	Sablefish	10%	24%	47%	18%	19%	22%	-0.08	0.05	0.25	ambiguous
	Shortspine Thornyhead	13%	35%	35%	18%	19%	22%	-0.05	0.16	0.13	ambiguous
Alaska Sablefish	Sablefish	35%	66%	61%	6%	6%	4%	0.29	0.60	0.57	+
Atlantic Sea Scallop	Sea Scallop	38%	38%	45%	12%	7%	9%	0.25	0.30	0.35	+
Gulf Of Mexico Grouper-Tilefish	Deep Water Grouper	12%	12%	15%	12%	7%	10%	0.00	0.05	0.05	ambiguous
	Gag	12%	15%	19%	9%	6%	9%	0.03	0.09	0.10	+
	Red Grouper	10%	11%	13%	12%	9%	11%	-0.02	0.02	0.02	ambiguous
	Shallow Water Grouper	7%	11%	15%	11%	7%	9%	-0.04	0.04	0.06	ambiguous
	Tilefish	55%	52%	56%	12%	7%	10%	0.43	0.45	0.46	+
Gulf Of Mexico Red Snapper	Red Snapper	15%	16%	20%	18%	19%	22%	-0.03	-0.03	-0.02	-
Mid-Atlantic Golden Tilefish	Golden Tilefish	24%	17%	15%	14%	9%	10%	0.10	0.08	0.05	+

Program	Species/Group	Percent Changes						Difference-in-Differences			Summary
		Ex-Vessel Prices			FPI						
		1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	
Mid-Atlantic Quahog	Ocean Quahog Clam	8%	16%	19%	8%	6%	6%	0.01	0.10	0.13	+
Mid-Atlantic Surf Clam	Atlantic Surf Clam	-3%	-3%	1%	8%	6%	6%	-0.10	-0.10	-0.05	-
New England Groundfish	Acadian Redfish	19%	21%	13%	11%	7%	10%	0.08	0.13	0.03	+
	Atlantic Cod	35%	26%	23%	12%	7%	10%	0.23	0.18	0.14	+
	Atlantic Halibut	36%	37%	37%	9%	6%	8%	0.27	0.31	0.28	+
	Atlantic Plaice Flounder	12%	0%	0%	12%	7%	9%	0.00	-0.06	-0.10	ambiguous
	Haddock	4%	6%	0%	12%	8%	10%	-0.08	-0.02	-0.10	-
	Pollock	32%	50%	66%	12%	8%	10%	0.20	0.42	0.56	+
	White Hake	0%	-3%	0%	11%	7%	9%	-0.11	-0.10	-0.09	-
	Windowpane Flounder	36%	37%	46%	11%	7%	9%	0.26	0.30	0.37	+
	Winter Flounder	11%	7%	-4%	12%	7%	10%	-0.01	0.00	-0.14	-
	Witch Flounder	11%	-5%	-5%	12%	7%	10%	-0.01	-0.12	-0.15	-
	Yellowtail Flounder	-4%	-8%	-14%	12%	7%	10%	-0.16	-0.15	-0.24	-
Pacific Groundfish	Arrowtooth Flounder	14%	14%	13%	15%	16%	12%	-0.01	-0.02	0.02	ambiguous
	Canary Rockfish	4%	7%	4%	15%	16%	12%	-0.11	-0.09	-0.08	-
	Darkblotched Rockfish	2%	-1%	-1%	15%	16%	12%	-0.13	-0.17	-0.13	-
	Dover Sole	36%	32%	25%	15%	16%	12%	0.21	0.16	0.13	+
	Lingcod	-7%	-3%	0%	15%	16%	12%	-0.22	-0.19	-0.12	-
	Pacific Cod	22%	18%	13%	15%	16%	12%	0.07	0.02	0.02	+
	Pacific Ocean Perch Rockfish	4%	4%	4%	15%	16%	12%	-0.10	-0.12	-0.08	-
	Pacific Whiting Hake	51%	66%	39%	15%	16%	11%	0.36	0.50	0.27	+
	Petrale Sole	28%	37%	35%	15%	16%	12%	0.13	0.21	0.23	+
	Sablefish	12%	5%	7%	15%	16%	12%	-0.03	-0.11	-0.05	-
	Shortspine Thornyhead	17%	23%	17%	15%	16%	12%	0.02	0.07	0.05	+
	Splitnose Rockfish	-15%	-16%	-20%	15%	16%	12%	-0.30	-0.32	-0.32	-
	Starry Flounder	37%	41%	35%	15%	16%	12%	0.22	0.24	0.23	+

Program	Species/Group	Percent Changes						Difference-in-Differences			Summary
		Ex-Vessel Prices			FPI						
		1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years	
	Widow Rockfish	0%	7%	8%	15%	16%	12%	-0.15	-0.09	-0.04	-
	Yelloweye Rockfish	10%	7%	7%	15%	16%	12%	-0.05	-0.09	-0.04	-
	Yellowtail Rockfish	4%	1%	2%	15%	16%	12%	-0.11	-0.15	-0.10	-
Pacific Sablefish	Sablefish	-3%	10%	13%	0%	1%	5%	-0.03	0.09	0.08	ambiguous
South Atlantic Wreckfish	Wreckfish	12%	20%	21%	1%	4%	5%	0.11	0.15	0.16	+

Table A5. Comparison of Price Changes in Treated Fisheries to the Fish Price Index for Capture Fisheries

Difference-in-differences between treated fisheries and the fish price index, for 1-, 2-, and 3-year intervals before and after catch share implementation. The summary column indicates the extent of agreement (sign on difference-in-differences) among time windows.