Impact of catch shares on diversification of fishers' income and risk

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Many fishers diversify their income by participating in multiple fisheries, which has been shown to significantly reduce year-to-year variation in income. The ability of fishers to diversify has become increasingly constrained in the last few decades, and catch share programs could further reduce diversification as a result of consolidation. This could increase income variation and thus financial risk. However, catch shares can also offer fishers opportunities to enter or increase participation in catch share fisheries by purchasing or leasing quota. Thus, the net effect on diversification is uncertain. We tested whether diversification and variation in fishing revenues changed after implementation of catch shares for 6,782 vessels in 13 US fisheries that account for 20% of US landings revenue. For each of these fisheries, we tested whether diversification levels, trends, and variation in fishing revenues changed after implementation of catch shares, both for fishers that remained in the catch share fishery and for those that exited but remained active in other fisheries. We found that diversification for both groups was nearly always reduced. However, in most cases, we found no significant change in interannual variation of revenues, and, where changes were significant, variation decreased nearly as often as it increased.

diversification | risk | catch shares | fisheries

The income of fishers can be highly variable due to natural variation in the productivity and distribution of fish stocks, variation in prices, and fishers' luck at finding and catching fish. Kasperski and Holland (1) found that fishing vessels on the US West Coast and Alaska had quite high interannual variation in revenue, with an average coefficient of variation (CV) of interannual gross revenue of 0.78. Such large swings in revenues can create risk of business failure and create personal financial crises for fishers who must make loan payments on vessels and permits, as well as cover household expenses with income from fishing. Climate change is likely to shift fisheries spatially and change productivity, which could lead to greater income volatility for fishers and potentially the complete loss of fisheries in areas where they had been present for generations (2, 3). While formal income insurance programs such as crop insurance for farmers do not exist in fisheries, fishers may be able to reduce financial risk by diversifying their fishing activity across a variety of fisheries or areas (1, 4–10). Kasperski and Holland (1) showed that greater diversification can substantially reduce variation in interannual revenue and also the risk of having very low revenues relative to a vessel's own average revenues. Sethi et al. (11) found that Alaskan communities with larger and/or more diverse fishing portfolios experienced lower variability of fishing revenues. Cline et al. (12) found that Alaskan fishing communities with more diversified fishing portfolios were able to maintain or increase fishing revenues in the face of major long-term regime shifts, while those with less diversified portfolios suffered declines in revenues, suggesting that diversification may be a good hedge against climate change-driven shifts in fisheries productivity.

Diversification may also have other advantages. Because many fisheries are seasonal, participating in a suite of fisheries is often necessary to provide year-round employment of capital and labor.

Access to most fisheries in the United States was relatively unrestricted until the 1980s, allowing fishers to assemble a diverse portfolio of fishing activities over the course of a year, but the ability to diversify has become increasingly constrained in the last few decades (13). For the US West Coast and Alaska, the average level of diversification of fishing vessels has generally declined since the mid-1980s (1). The decline appears to be due in part to the inability of new entrants to enter fisheries, since the diversification levels tend to be higher for vessels that have been fishing longer (1). There is anecdotal evidence of declining diversification in some other US regions, but no systematic studies have yet evaluated this. States began restricting access to some nearshore fisheries as early as the 1970s (13–18), but it was not until the 1990s that limited-entry programs and permit moratoriums were implemented in most of the large offshore US fisheries to control or reduce excess capacity (13). License limitation programs and direct catch limits often failed to ensure economic viability due to input stuffing and derbies that increased harvest costs and led to market gluts and poor product quality (18–20). To address these deficiencies, catch shares, which allocate exclusive fishing privileges to individuals or groups, have been implemented in 16 US fisheries since 1990 (21) and in hundreds of other fisheries worldwide (22). Catch shares have largely been

Significance

Catch share programs, which allocate a share of a fishery's annual catch to fishers, are an increasingly popular management approach in the United States and around the world. While catch shares have been shown to increase efficiency, they may reduce diversification of individual fishers, which could increase income variation and financial risk. Shifts in the productivity and distribution of fisheries resulting from climate change may increase the importance of diversification. Our evaluation of 13 US fisheries is a large-scale study to evaluate whether catch shares do in fact lead to reduced diversification. We find that diversification was generally reduced after implementation of catch shares; however, in most cases, we found no significant change in income variation.

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successful at ending overfishing and promoting rebuilding of fisheries (22) and have generally improved economic performance where this has been evaluated (23–26).

Catch shares are often implemented with an implicit, if not explicit, goal of reducing excess capacity through consolidation. Capacity reduction was an explicit goal for 11 of 13 US catch share programs implemented before 2014, and consolidation did in fact occur in all but one of these programs, often quite rapidly (23). In some cases, vessel or permit buybacks are done in conjunction with catch shares to ensure a rapid and lasting reduction in capacity (24). While consolidation may increase economic efficiency, fishers and communities can face a concomitant loss of access to the fishery, as quota and landings are consolidated in fewer communities (27). Concerns have been raised that the high cost of acquiring quota impedes new entrants, and fisheries become dominated by large firms with access to capital (28–30). Fishers who exit the catch share fishery lose one source of diversification, while those who remain and consolidate quota may become more dependent on the catch share fishery and less diversified, although they may increase their revenue and profit. For this reason, we might expect to see average diversification levels decline after implementation of catch shares. However, purchase of quota can provide opportunities for new fishers to enter catch share fisheries or for fishers with limited previous involvement to increase participation, creating new opportunities for those previously excluded fishers to diversify. The cost of purchasing quota can be very high, creating significant barriers to entry for those who were not gifted quota and do not have access to low-cost financing. However, new entrants often lease quota or fish against quota held by others on contract (for a percentage of the exvessel price), enabling them to enter the fishery without a large capital investment in quota shares (31–35). While leasing and contract fishing may facilitate diversification for new entrants, these fishers are unlikely to share in fishery rents, which would be expected to accrue to the quota share owners as lease fees (34). The emergence of a lease-dependent class of fishers is also considered undesirable in some fisheries and is sometimes actively discouraged with regulations, although this is not always successful (35). Given these countervailing potential drivers of diversification, the net change is uncertain.

If diversification does decline, previous analysis and theory suggest that this could increase variation in revenue, both for those who exit and for those who remain in the fishery. However, since catch shares create a secure privilege to harvest a set share of the total allowable catch, this may help stabilize income. This may offset or partially mitigate increase in financial risk that might otherwise have been caused by a loss of diversification. It is less clear that catch shares would provide a hedge against long-term shifts in the productivity of the catch share fishery (e.g., due to climate change). Furthermore, many of these catch share programs are quite new, and it may take more time to distinguish how the catch share programs ultimately change diversification and financial risk.

We evaluate changes in diversification and income of 6,782 vessels participating in 13 fisheries that implemented catch share programs. The study includes fisheries from different regions of the United States and includes both individual fishing quota (IFQ) and cooperative-based catch share programs (Table 1). These fisheries had landings valued at more than \$1.1 billion in 2013, ∼20% of the total US-landed value (36). For each fishery, we tested whether diversification levels and trends changed after implementation of catch shares, both for those fishers who remained active in the catch share fishery and for those who exited, but remained active in other fisheries. While we suspect that consolidation affects diversity, we did not measure changes in consolidation. We also tested whether the CV of interannual revenues of individual vessels increased (decreased) following implementation of catch shares, indicating increase (decrease) in financial risk. Our analysis shows that, on average, diversification declined significantly in most fisheries, both for those who exited the catch share fishery and those who remained. However, in most cases, we found no significant changes in interannual variation of revenues, and, where changes were significant, variation decreased nearly as often as it increased.

Table 1. US catch share fisheries included in analysis

Fishery	Catch share implemented	2013 revenue from catch share species, \$
Alaska halibut and sablefish	1995	172,059,792
Alaska American Fisheries Act (AFA) pollock	1999	360,423,055
Alaska BSAI king and tanner crab	2005	190,034,267
Alaska BSAI nonpollock (Amendment 80)	2008	220,396,418
Central Gulf of Alaska rockfish	2007	9,827,675
Pacific fixed gear sablefish	2001	5,358,488
Pacific groundfish trawl	2011	26,537,871
Pacific whiting (shoreside and at-sea sectors)	2011	27,329,725
Northeast groundfish	2010	57,236,554
Northeast general category scallops	2010	29,451,902
Mid-Atlantic golden tilefish	2009	5,724,782
Gulf of Mexico red snapper	2007	21,108,505
Gulf of Mexico grouper and tilefish	2010	25,498,029

Source: Ref. 19.

Results

For each of the 13 catch share fisheries in our study, we first identified all vessels that were active in the fishery in the years leading up to implementation of the catch share program and identified subgroups of vessels that (*i*) continued to be active in the catch share fishery, or (*ii*) exited the catch share fishery, but participated in at least one other fishery. For each fishery subgroup, we evaluated whether vessel-level diversification changed after catch shares and whether that change could be distinguished from preexisting trends. Following Kasperski and Holland (1), we used the Herfindahl–Hirschman Index (HHI) as a metric of fishing revenue diversification for individual vessels. The index takes a maximum value of 10,000 for a vessel that derives revenues from a single fishery and decreases toward zero as revenues are derived from more fisheries or more evenly spread among fisheries. A lower HHI indicates greater diversification.

Comparisons of vessel-level HHI using paired *t* tests and nonparametric Wilcoxon signed-rank tests indicated that HHI levels were significantly higher (i.e., diversification decreased) after implementation of catch share programs in 21 (or 22 using *t* tests) of 28 fishery subgroups (Table 2). Significant decreases in HHI were observed in only one case, for fishers who remained active in the Gulf of Mexico grouper and tilefish IFQ. The results generally indicate decreased diversification, both for vessels that remained in the catch share fishery and for those that exited, but continued fishing in other fisheries. Results were consistent between the paired *t* tests and Wilcox signed-rank tests, with the exception of the Northeast general category scallop fleet that was active pre- and post-catch share, for which the Wilcoxon signed-rank test was not significant, while the paired *t* test was.

In many fisheries, there were preexisting trends in HHI that might have confounded changes related to catch shares (Figs. S1–S3). We used time series panel regressions (Table 3) to test whether there were significant changes in HHI once preexisting trends were controlled for. A significant Wald test statistic (Table 3) indicated that the change in predicted HHI associated with the shift in the regression intercept and slope was significantly different from zero 3 y after catch share implementation (i.e., a change distinguishable from any preexisting trend). The Wald tests were mostly consistent with Wilcoxon signed-rank

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tests, with 16 of 28 fishery subgroups exhibiting significant increases in vessel-level HHI (ranging from 5 to 70% post-catch share) once preexisting trends were accounted for. Only 2 of 28 fishery subgroups showed significant decreases in vessel-level HHI after controlling for preexisting trends. However, for six fisheries where Wilcoxon signed-rank tests showed significant increases in HHI, Wald tests indicated no significant change after controlling for the preexisting trend. While the panel regressions are useful for distinguishing changes in HHI that may have been due to preexisting trends from those related to the catch share programs, they cannot definitively determine whether the remaining changes in HHI were caused by the catch share program. The possibility that factors other than catch shares could have influenced the observed changes in HHI during the post-catch share period cannot be ruled out.

The panel regression results show the importance of accounting for preexisting trends. For example, regression results indicated significant reductions in vessel-level HHI following catch share implementation in the Northeast groundfish fleet that remained active in the catch share fishery and no significant change for those that exited. In contrast, the paired t tests and Wilcoxon signed-rank tests indicated no significant change for the fleet that remained active in the catch share fishery and an increase in HHI for the vessels that exited. Wald tests were not significant for seven fishery subgroups for which paired t tests or Wilcoxon signed-rank tests showed significant increases in HHI. Changes in HHI in those cases appeared to be the continuation of preexisting trends and may not have been a result of the catch share program.

In all but one of the fisheries we studied, there was a statistically significant but noisy relationship between HHI and the CV of interannual revenue indicating that CV decreases on average as HHI decreases. Fitted functions of CV of revenue as a function of HHI are shown in (Fig. 1). Parameter estimates and significance are provided in Table S1. However, despite increases in HHI on average in almost every catch share fishery, tests for changes in income variability (as measured by the CV of annual revenue before and after implementation of catch shares) did not show consistent increases in CV (Table 2). Paired t tests for changes in CV of revenue were not significant at the 10%

Table 2. Vessel-level paired *t* tests and signed rank tests of changes in HHI and CV of revenue

Fishery	Matched vessels	Change in HHI paired *t* test	Change in HHI Wilcoxon signed rank	CV revenue paired *t* test	CV revenue Wilcoxon signed rank
Alaska halibut and sablefish					
Active pre and post	1,849	Increase***	Increase***	Not significant	Not significant
Exited	1,689	Increase***	Increase***	Not significant	Not significant
Alaska AFA pollock					
Catcher vessels	111	Increase***	Increase***	Decrease***	Decrease***
Catcher/processors	19	Increase***	Increase***	Decrease***	Decrease***
Alaska BSAI crab					
Active pre and post	125	Increase***	Increase***	Increase*	Not significant
Exited	108	Increase***	Increase***	Increase*	Not significant
Alaska BSAI nonpollock (Amendment 80)	23	Increase**	Increase**	Increase***	Increase***
Central Gulf of Alaska rockfish					
Active catcher vessels	35	Not significant	Not significant	Not significant	Not significant
Exited catcher vessels	6	Increase**	Increase*	Not significant	Not significant
Active catcher/processors	9	Not significant	Not significant	Not significant	Not significant
Exited catcher/processors	3	Not significant	Not significant	Not significant	Not significant
Pacific groundfish trawl					
Active pre and post	91	Increase***	Increase***	Not significant	Not significant
Exited	96	Increase**	Increase***	Not significant	Not significant
Pacific at-sea whiting					
Active pre and post	27	Increase***	Increase***	Decrease*	Decrease*
Exited	28	Increase***	Increase***	Not significant	Not significant
Pacific shoreside whiting					
Active pre and post	26	Increase***	Increase***	Decrease**	Decrease**
Exited	90	Increase***	Increase**	Not significant	Not significant
Pacific fixed gear sablefish					
Active pre and post	118	Increase**	Increase**	Not significant	Not significant
Exited	58	Increase***	Increase***	Not significant	Not significant
Northeast groundfish					
Active pre and post	454	Not significant	Not significant	Increase***	Increase***
Exited	271	Increase***	Increase***	Not significant	Not significant
Northeast general category scallop					
Active pre and post	222	Increase**	Not significant	Not significant	Not significant
Exited	55	Increase***	Increase***	Increase*	Increase*
Mid-Atlantic tilefish					
All	18	Not significant	Not significant	Decrease*	Decrease**
Gulf of Mexico red snapper					
Active pre and post	444	Increase***	Increase***	Increase***	Increase***
Exited	97	Increase***	Increase***	Not significant	Not significant
Gulf of Mexico grouper and tilefish					
Active pre and post	561	Decrease***	Decrease***	Increase**	Increase**
Exited	149	Increase***	Increase***	Decrease***	Decrease***

*10% significance level; **5% significance level; ***1% significance level.

Table 3. Time-series regression result for trends and shifts in HHI after implementation of catch shares

Fishery	Intercept	Trend	Post-CS intercept shift	Post-CS trend shift	Wald test F 3 y post-CS	Change in predicted HHI 3 years post-CS, %
Alaska halibut and sablefish						
Active pre and post	8.342***	−0.0027	−0.0681***	0.0286***	101.89***	17
Exited	8.629***	0.0261***	0.0885***	−0.0048	9.03***	5
Alaska AFA pollock						
Catcher vessels	8.502***	−0.0001	0.1814***	0.0040	52.23***	27
Catcher/processors	8.932***	−0.0022	0.1563	−0.0014	2.98*	15
Alaska BSAI crab						
Active pre and post	8.528***	−0.0155***	−0.0501	0.0226***	60.74***	28
Exited	8.463***	0.0079	0.4920***	−0.0147*	12.91***	35
Alaska BSAI nonpollock (Amendment 80)	8.236***	−0.0027	0.3917***	−0.0194	5.95**	22
Central Gulf of Alaska rockfish						
Active catcher vessels	8.103***	−0.0025	−0.4683***	0.0422**	0.00	0
Exited catcher vessels	8.264***	0.0468**	0.2944	−0.0386	1.16	−12
Active catcher/processors	8.494***	−0.0737**	−0.1552	0.0626	29.64***	70
Exited catcher/processors	8.385***	−0.0172	0.4185	−0.0167	4.92	26
Pacific groundfish trawl						
Active pre and post	8.407***	−0.0024	0.0040	0.0093	4.16**	10
Exited	8.597***	0.0185***	0.2798**	−0.0282*	—	0
Pacific at-sea whiting						
Active pre and post	8.535***	−0.0002	0.0033	0.0162	5.70**	18
Exited	8.391***	0.0046	−0.2090	0.0366	3.87*	17
Pacific shoreside whiting						
Active pre and post	8.229***	−0.0059	−0.2394**	0.0466***	10.59***	25
Exited	8.488***	0.0085	0.2580*	−0.0237	0.19	2
Pacific fixed gear sablefish						
Active pre and post	8.491***	−0.0035	−0.2692***	0.0299***	2.59	6
Exited	8.553***	0.0076	0.1134	0.0026	8.24***	15
Northeast groundfish						
Active pre and post	8.676***	0.0047***	−0.0955	0.0028	6.29**	−5
Exited	8.688***	0.0098***	0.0268	0.0013	1.46	5
Northeast general category scallop						
Active pre and post	8.631***	0.0134***	0.0533	−0.0050	1.31	−3
Exited	8.719***	0.0085	0.0002	0.0043	1.59	8
Mid-Atlantic tilefish						
All	8.895***	0.0110	0.0261	−0.0064	0.13	–
Gulf of Mexico red snapper						
Active pre and post	8.448***	−0.0060	−0.1234*	0.0217***	24.26***	12
Exited	8.517***	0.0001	−0.3151**	0.0509***	23.41***	28
Gulf of Mexico grouper and tilefish						
Active pre and post	8.798***	0.0017	−0.2402***	0.0085*	26.88***	−8
Exited	8.704***	0.0180***	0.1980	−0.0073	3.35 *	6

CS, catch share. *10% significance level; **5% significance level; ***1% significance level.

level for 15 of 28 fishery subgroups (17 of 28 using the Wilcoxon signed-rank test). Paired *t* tests indicated CV of revenue decreased in six fishery subgroups, while seven showed significant increases in CV (only five showed significant increases in CV with Wilcoxon signed-rank test).

Discussion

One explanation for the decrease in vessel diversification generally found in this study is that catch shares tend to incentivize consolidation and specialization. Catch share programs are often implemented in fisheries with excess capacity with an expectation that they will result in consolidation. Some consolidation is often intended as a means of increasing efficiency, although catch share programs in the United States typically limit how much quota individuals or companies can control to limit market power and for social reasons (23). Consolidation did occur in all but one of the fisheries in this study (23). Catch share programs may also create incentives for vessels to specialize in fisheries according to their comparative advantage if quota is transferable. Quota must be purchased or leased at a competitive price, providing the incentive and means for less efficient boats to exit and sell or lease their quota to more efficient vessels, which can generate more profit with it and thus bid more for it. If fishing operations with a low proportion of income from catch share fisheries opt to exit and sell their access privileges to vessels with a high proportion of income in the catch share fishery, we would generally expect income diversification to fall for both groups.

The consistency of this result across a wide range of US fisheries is nevertheless surprising, given that many catch share fisheries were not the primary source of fishing income for many participants. If vessels with a low proportion of income from the catch share fishery ex ante increased participation in the catch share fishery, this would increase their diversification. Also, in a number of cases, anecdotal evidence suggested that the catch share system provided the opportunity for some fishers to increase participation in other fisheries. For example, the Pacific groundfish trawl IFQ enabled some vessels to increase their participation in crab and shrimp fisheries without reducing their groundfish catch. Many of the vessels in the Pacific whiting IFQ derived a majority of their income from Alaska pollock, so

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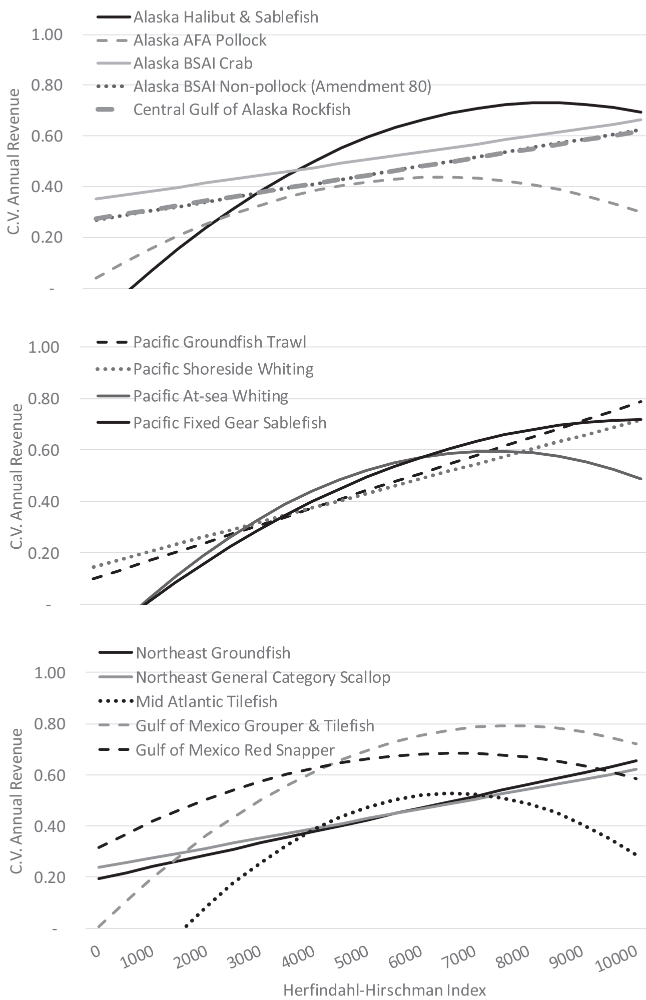

Fig. 1. Fitted CV-HHI relationships for case study fisheries.

increased whiting revenues might be expected to increase their diversification. After implementation of the Gulf red snapper IFQ, fishers were forced to diversify into other fisheries, such as vermilion snapper and shallow water groupers, to offset the forgone revenue due to a sharp reduction in the red snapper quota. All of these examples suggest the possibility of increased diversification for those that continued fishing in the catch share fishery. However, in almost every case, vessels that increased diversification were apparently outnumbered by vessels that became more specialized.

A primary reason for being concerned about reduced diversification is an expectation that diversification serves to reduce variation in annual fishing revenues, thereby reducing financial risk. This relationship was demonstrated empirically for West Coast and Alaskan vessels for a variety of vessel groupings by size, revenue, and fishery participation (1), and we found a similar relationship between HHI and CV in the fisheries we studied. We did not, however, find a significant increase in CV of revenue after catch share implementation in most cases, despite reductions in diversification. Of the cases with significant changes, a decrease in CV of revenue was nearly as common as an increase. Catch shares provide fishers with a secure share of the total allowable catch. This might be expected to stabilize vessels' catch and revenue and offset increases in income variation that might otherwise have occurred as vessels became less diversified. Owning a secure share of the total allowable catch may allow for better business planning (e.g., scheduling trips to take advantage of higher prices or better information on fish abundance), so stabilization of revenues under catch shares might be particularly pronounced in fisheries where the catch share programs ended derbies, making it more likely that the CV of revenue would decline. This could occur for vessels that did not participate in the catch share fishery as well, if the pre-catch share fishery had been a source of volatility in revenues. In the Bering Sea and Aleutian Islands (BSAI) pollock fishery, Pacific whiting, and Gulf of Mexico grouper and tilefish fisheries (all of which had derbies before catch shares), we did see significant decreases in the CV of revenues. However, CV in other fisheries that had derbies before catch shares did not change significantly (Alaska halibut and sablefish fishery and Pacific fixed gear sablefish fishery) or increased (Alaska BSAI crab and Gulf of Mexico red snapper).

Our analysis supports the conclusion that catch shares tend to reduce diversification, both for vessels that remain in these fisheries and those that exit and continue fishing in other fisheries. In some cases, these reductions in diversification appear to be associated with preexisting trends, but in others, there were additional reductions in diversification following implementation of the catch share program. Although average levels of diversification were lower after catch share implementation in almost every case, we did not find a concomitant systematic increase in revenue volatility. This could be because catch shares have a stabilizing effect on vessels' revenues, although it may be that we were simply unable to differentiate the impact of changes in diversification from other factors that affected income variation. The noisy relationship between CV and HHI can make it difficult to identify the effect of changes in HHI on CV, even if they did have an impact. In several cases with statistically significant decreases in diversification, the average change was not large and might not be expected to have a noticeable impact on revenue variation on average. However, there was substantial heterogeneity in changes in HHI across fishers within a fishery. Even when the average change in HHI was small, some fishers experienced large shifts in diversification that may have influenced the risk of their specific operations, despite only a moderate effect on much of the fleet. While catch shares may decrease diversification as a result of consolidation, they can also increase economic efficiency by increasing fishery value and decreasing costs, which may compensate for increased revenue volatility if it does occur. Nevertheless, the trend toward reduced diversification both in catch share fisheries and others is concerning. Interannual income variation is only one potential risk that diversification can help mitigate. As noted earlier, diversification may help mitigate the risk of longer-term shifts in fishery productivity and spatial distributions associated with longer climate cycles, regime shifts, and climate change. Fishers who can move into other fisheries in response to these changes may be better able to weather these changes.

Materials and Methods

We measured diversification and variation in revenue at the individual vessel level. It might be preferable to use the owning entity rather than the vessel as the unit of analysis since some individuals or firms own multiple vessels and may diversify fishing across vessels. However, comprehensive ownership information was not available, which made this approach infeasible. The great majority of vessels are thought to be independently owned in most of the fisheries we studied, so we expect that this would not greatly change our results. It would also be desirable to include nonfishery sources of income in the diversification analysis, since some fishers supplement income from nonfishery sources. However, data on nonfishery income is rarely collected and could not be considered for this analysis. To measure diversification of a fishing vessel's gross revenues, we used the HHI, which was calculated by summing the squares of the percentages of gross annual revenues derived from groups of jointly targeted or managed species that are considered to be distinct fisheries. These groupings are listed in *SI Materials and Methods*. The index takes a maximum value of 10,000 for a vessel that derives revenues from a single fishery and decreases toward zero as revenues are spread among more fisheries or spread more evenly among a given set of fisheries. The HHI is defined as:

$$H = \sum_{i=1}^{S_j} p_i^2 \quad [1]$$

where p_i represents percent (ranging from 0 to 100) of an individual's total gross revenues derived from fishery i. In addition to diversification, we also calculated the CV of year-to-year variation in fishing revenues for each vessel for an equal number of years before and after implementation of the catch share program. Average HHI and CV were calculated over periods of between 6 and 10 y before and after the implementation of the catch share program. The years used for each fishery depended on the implementation years and the number of years of data available before and after (Table S2).

Distributions of vessel-level HHI values tend to be bimodal with an interior mode and another near the maximum value of 10,000 associated with vessels whose revenue was dominated by or limited to a single fishery. Distributions of CV may also be nonnormal. We therefore used both parametric and nonparametric tests that compared the vessel-level change in HHI before and after catch share program implementation. We ran paired *t* tests, but we also used the nonparametric analog, the Wilcoxon signed-rank test (on matched pairs), which tests the null hypothesis that individual changes in HHI are symmetrically distributed around zero (or that the median difference between pairs of observations is zero). The signed-rank test was performed by using the ranks of the differences in average HHI scores for equal periods pre- and post-catch share for individual vessels.

Evaluating whether changes in diversification can be ascribed to the catch share program was further complicated by the fact that changes may represent preexisting trends that would have continued whether or not the catch share program was implemented. For this reason, we tested for changes in trends and tried to identify structural breaks in those trends. For each fishery and subgroup, we estimated the following model:

$$\ln(HHI_{it}) = \alpha + \beta * trend + \gamma D_{it} + \delta * trend * D_{it} + e_{it} + \mu_i$$

where *trend* is the time trend variable and D_{it} is an indicator that takes the value of 1 if an observation occurs in the post-catch share period. We accounted for the panel structure of the data by estimating vessel fixed-effects models (e.g., with μ_i capturing the fixed heterogeneity in HHI across vessels). To determine both the sign and significance of the change coincident with catch shares, we calculated the predicted change in HHI 3 y after the implementation of catch shares (i.e., associated with γ and δ, but not the preexisting trend, β) and used a Wald test to determine the significance of the change.

We also fitted the relationship between CV of annual revenue and HHI for each of the catch share fisheries to determine whether C (a proxy for financial risk) tends to be lower for vessels that are more diversified. Average HHI and CV of annual revenue were calculated for the entire pre- and post-catch share period for each vessel. Ordinary least squares regressions with quadratic or linear specifications (with CV of annual revenue as the dependent variable and HHI as the explanatory variable) were run for each fishery, and the results are shown in Table S1. Linear specifications were used if the coefficient on HHI squared in the quadratic specification was insignificant. These regressions used observations of all vessels involved in the catch share fishery leading up to implementation that also continued fishing any time after implementation. The risk of having very low revenues relative to a vessel's own average revenue for those who continued to fish was decreased by diversification in the catch share fishery.

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