The distributional outcomes of rights-based management in fisheries

Joshua K. Abbott[a,1], Bryan Leonard[a], and Brian Garber-Yonts[b]

[a]School of Sustainability, Arizona State University, Tempe, AZ 85287; and [b]Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA 98115

Edited by Arun Agrawal, School for Environment and Sustainability, University of Michigan-Ann Arbor, Ann Arbor, MI; received May 17, 2021; accepted November 10, 2021

Fisheries managers have increasingly adopted rights-based management (i.e., "catch shares" or "individual transferable quotas" [ITQs]) to address economic and biological management challenges under prior governance regimes. Despite their ability to resolve some of the symptoms of the tragedy of the commons and improve economic efficiency, catch shares remain controversial for their potentially disruptive social effects. One criticism is that the benefits of rights-based reforms are unequally distributed across vessels and between fishery participants (e.g., crew and hired captains) and that stakeholders that do not receive an allocation of harvest rights may see their remuneration decrease. Yet, empirically assessing these claims is difficult in almost all ITQs due to poor availability of longitudinal cost, earnings, and employment data. This paper evaluates these claims using vessel-level data to characterize impacts of a long-established ITQ program for Alaskan crab fisheries on the level and distribution of payments to claimant groups. We find that the share of vessel proceeds accruing to captains, crew, and vessel owners declined under the catch-share regime to make room for new payments to quota owners. Average daily payments to captains, crew, and vessel owners declined, albeit slightly, yet retained their pre-ITQ premia relative to compensation in other sectors. However, inequality in payments to workers and vessel owners declined after ITQs, as did the interseasonal volatility in compensation to workers, a measure of financial risk. Finally, we find that consolidation-induced increases in leasing costs have had little effect on workers' remuneration, but have reduced returns to vessel ownership.

rights-based management | distributional effects | catch shares

Fisheries managers in a growing number of countries have adopted an array of rights-based management reforms—referred to as "catch shares" or "individual transferable quotas" (ITQs)—as a solution to economic and biological losses that plague many fisheries. Catch-shares management defines a fishery-wide total allowable catch (TAC) and then allocates transferable shares of that catch to vessel owners or other fishery participants. This governance approach has a robust record of improving the economic efficiency of fisheries, with economists and fisheries scientists documenting a variety of benefits from catch shares including more cost-efficient harvesting, longer seasons, increases in product quality, safer working conditions, reduced stock variability, and better tracking of management targets (1–6).

Despite these benefits, catch shares are often controversial, both among stakeholders and among scholars—with some social scientists decrying the arguments of ITQ advocates as conceptually flawed (7) or reflecting a "panacea" mindset (8). Much of this opposition stems from the potentially disruptive social and economic effects of catch shares on fishery participants and coastal communities that are excluded from the initial distribution of rights but are nonetheless affected by policy changes (8–10). Critics raise concerns, not only about whether distinct stakeholder groups (e.g., vessel owners, processors, captains, crew, etc.) are left better or worse off in an overall sense from ITQs, but also about whether gains and losses are fairly distributed within and between these groups. Some studies of ITQs have focused on the distribution of benefits across heterogeneous vessel owners (11–13). Others have considered the differential impacts of catch shares on vessel owners, lessors, and lessees of short-term fishing rights, crew (including hired captains), and harvest-dependent operations such as fish processors (14–18). Even among ITQ proponents (16), there is a growing consensus that these distributional consequences must be better understood and, where appropriate, mitigated in the design of catch-share programs. Failure to do so may not only lead to undesirable distributional outcomes but also jeopardize the political feasibility of a class of useful policy instruments (8, 19).

Evaluating the impacts of catch shares to understand and mitigate distributional concerns using the "best available social science" (20) requires thoughtful integration of both qualitative and quantitative data. Unfortunately, quantitative assessments of the impacts of ITQs or other catch-share systems across multiple stakeholder groups are surprisingly scarce due to the sparse and selective availability of cost, earnings, and employment data in most fisheries. Quantitative assessments often focus on only one stakeholder group such as crew (15, 21) or vessel owners (17, 22) to the exclusion of others, or, when performed in the context of more comprehensive assessments of individual catch-shares programs, capture distributional effects at a high level and with a limited set of quantitative metrics (23–25). The overwhelming lack of data prior to the implementation of ITQs requires inferences to be drawn on the basis of a budgetary snapshot

Significance

Rights-based management reforms in fisheries have attracted controversy regarding the unequal distribution of their economic benefits, but systematic quantitative evidence has been lacking due to data limitations. Our research leverages a longitudinal dataset to compare payments to captains, crew, vessel owners, and owners of harvest quota in the Bering Sea crab fisheries both before and after implementing individual transferable quotas (ITQs). This paper provides a fishery-wide accounting of returns to these diverse stakeholder groups at the vessel level. The results underscore the importance of considering the distribution of payments to different stakeholders within each vessel as well as heterogeneity in payments across vessels. Our approach provides a model for collecting and analyzing data on distributional outcomes for other fisheries.

Author contributions: J.K.A., B.L., and B.G.-Y. designed research; J.K.A. and B.L. performed research; J.K.A. analyzed data; and J.K.A., B.L., and B.G.-Y. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission.

[1]To whom correspondence may be addressed. Email: joshua.k.abbott@asu.edu.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2109154119/-/DCSupplemental.

Published January 6, 2022.

for a representative operation (17, 22, 26), missing important longitudinal variation over time as well as heterogeneity across operations (15, 21). As a result, most focused studies of distributional effects either are model-based or rely heavily on ethnographic data (10). While ethnographic data are invaluable as a means to characterize the perceptions and lived experiences of research participants and to develop "thick" understanding of the social–ecological context, even well-executed ethnographies may suffer from shortcomings such as limited longitudinal resolution, potential nonrepresentativeness of respondents, and the informational limitations and possible strategic responses of research participants.

This paper addresses this substantial gap in the literature by examining the long-run changes in the returns to all claimants of harvester revenues—captains, crew, vessel owners, and owners of quota—in two prominent ITQ fisheries for Bristol Bay red king crab (BBR) and Bering Sea snow crab (BSS), managed under the Bering Sea–Aleutian Islands (BSAI) Crab Rationalization Program (CRP). Our longitudinal analysis focuses on the returns to claimants of "persistent" vessels—those that participated in the BBR or BSS fisheries both before and after the CRP program—providing a stable basis for pre/postcomparisons. This analysis is facilitated by an unprecedented vessel-level dataset spanning 3 y prior to and 13 y after ITQs. Using these data, we examine the distribution of returns across a variety of margins.

First, we characterize how the "pie" available to compensate all claimants has evolved by measuring vessels' operating revenues minus variable costs, known as the "contribution margin." Second, we analyze how this income has been distributed over time in an average sense across captains, crew, vessel owners, and quota owners (noting that these categories are not always mutually exclusive). Third, we explore between-vessel heterogeneity in total payments to each group of claimants. Fourth, we group vessels into quartiles of pre-ITQ payments to each claimant and track the relative performance of these quartiles over time. This allows us to determine whether returns for each set of claimants are more evenly distributed since the adoption of the CRP. Finally, we examine the hypothesis that high use of leased quota on a vessel (i.e., "leasing in") explains heterogeneity in returns to workers vs. vessel owners and may suppress their compensation (22).

The CRP presents an attractive setting for studying the distributional implications of rights-based reform for two reasons. First, many aspects of the program were explicitly designed or subsequently adapted to address social and distributional concerns. These features included the initial allocation of crab harvesting quota share and processor quota share, eligibility requirements for program participants, rules for transfers of quota share and pounds, caps on quota holdings and use, rules for harvesting cooperatives, and community protection measures (*SI Appendix*, section 1). Second, excellent data exist to evaluate distributional outcomes due to monitoring and reporting requirements, including mandatory annual economic data reports (EDRs). The crab EDR program is a mandatory annual reporting requirement for all owners and operating leaseholders of active crab harvesting vessels and processors, including retrospective reporting for selected pre-CRP years. These data were previously utilized to study the short-run effects of the CRP on crew in the years immediately following its adoption (15). We expand the scope of this analysis to examine distributional outcomes across all claimants, over 13 y of experience with the Crab Rationalization (CR) Program.

The developments exhibited in the BSAI crab fisheries in the years prior to ITQs mirror those seen in many other fisheries. Despite a limited entry program, large stock and TAC declines, combined with high vessel capacity, resulted in seasons lasting a few days or weeks. These "derby" conditions resulted in gross inefficiencies in harvesting and processing capacity, overuse of the fishery resource, and excessive occupational hazards to crew members (27). In response, the North Pacific Fishery Management Council began development of a "rationalization" program in 2001, for nine of the BSAI crab fisheries. The resulting CR Program went into effect in the 2005/2006 crab season (*SI Appendix*, sections 1 and 3).

The transferability of quota share through sale and lease arrangements facilitated the rapid consolidation of harvest onto a much smaller number of vessels in both the BBR and BSS fisheries (Fig. 1 and *SI Appendix*, Fig. S1). These developments

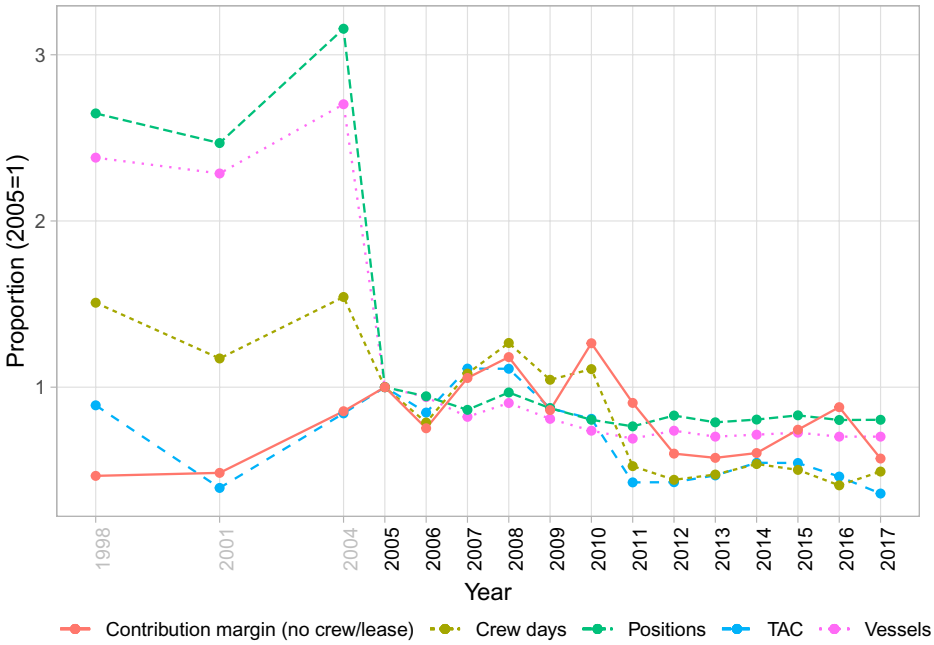

Fig. 1. Trends in the BBR fishery for all active vessels. Variables are scaled proportionally to the first year of the CRP (2005). Shaded years are before the CRP.

led to longer seasons for the vast majority of vessels, given the regulatory TAC (*SI Appendix*, Fig. S2). Fleet consolidation lowered average harvest costs, but also diminished total crew positions in rough proportion to the exit of vessels. However, position losses were partially offset by longer terms of employment for remaining crew, so that total employment, in terms of crew days, has declined less dramatically (Fig. 1 and *SI Appendix*, Fig. S1). Consolidation stabilized about 5 y after CRP implementation, with total employment closely following movements in available TAC in the post-CRP period.

Results

Aggregate Impacts of the CRP. Captains and crew in the BSAI are coclaimants with vessel owners in the economic profitability of the vessel due to the lay share system (28). Lessors of quota—composed of vessel owners, captains and crew members who hold quota and receive lease royalties separate from other fishing income distributions, and owners of inactive vessels that have not permanently sold their quota share—are also claimants due to the connection of lease prices to expected ex-vessel prices and harvest costs at the fishery level (29). Notably, neither Alaska residents nor the US public are claimants under the current system, as no resource royalties are paid by harvesters (although agency management costs are charged to industry through cost recovery). All claimants, as well as any fixed costs, are ultimately paid from the gap between revenues and variable harvest costs (e.g., fuel, bait, and provisions), known as the "contribution margin" (CM) (30). Therefore, it is important to know whether this "pie" has grown postrationalization, so that all claimants could, in principle, be at least as well remunerated as before.

The aggregate fleet-wide CM has not consistently exceeded pre-CRP levels for BBR (Fig. 1), yet it has risen dramatically for BSS (*SI Appendix*, Fig. S1). However, this comparison ignores dramatic and divergent trajectories in the species' TACs and prices that are outside the influence of the CRP. Normalizing CM by day reveals that daily profitability at the vessel level generally increased post-CR, while CM per ton of harvest did not increase until after 2010 in the wake of strong ex-vessel prices (*SI Appendix*, section 3). Purging the exogenous influences of fluctuations in crab prices through the use of "crab-equivalent" metrics that redefine monetary returns in terms of the volume of crab they would buy reveals that the CM has robustly increased for both fisheries post-CRP, whether per day or per ton. This is evident not only at the mean and median, but also across the quantiles of vessel returns (*SI Appendix*, section 3). These improvements occurred despite steadily increasing fuel prices over much of the period (*SI Appendix*, Fig. S3).

Increases in CM actually understate the efficiency gains from rationalization because they do not account for reductions in fixed costs. Consolidation reduced fixed costs through exit of vessels and spreading fixed costs on active vessels across more harvest (25). While EDR data do not measure changes in fixed costs, model-based estimates suggest up to 87% of increases in fishery profits from the CRP may be attributable to consolidation alone, with 65% of this effect coming solely from reduction of excess capacity (31). Altogether, there is ample evidence that the CRP enlarged the economic surplus available to claimants.

Division of CM among Claimants. Next, we assess how these increases in the pie were distributed. Fig. 2 depicts the share of CM paid to different groups in the BBR fishery (*SI Appendix*, Fig. S9 for BSS). This surplus was traditionally shared between captains, crew, and vessel owners (who must pay fixed costs from their share). After rationalization, 43% of this margin was immediately transferred to quota owners that lease their quota, rather than fish it themselves or permanently sell it. Prior to catch shares, the value of access to the fishery was capitalized into ownership of permitted vessels. The CRP transferred some of this value to owners of fishing quota, who earn a "resource rent" (32) (e.g., a payment reflecting the economic scarcity of the crab stock given its management) on their share of harvest rights (13). For leased quota, this rent is explicitly paid to lessors, whereas it is "paid" through the owners' share of the CM for owner-fished quota.

Importantly, while dramatic consolidation did create a substantial group of inactive former owners whose sole income from the fishery is through quota leasing, some owners of active vessels

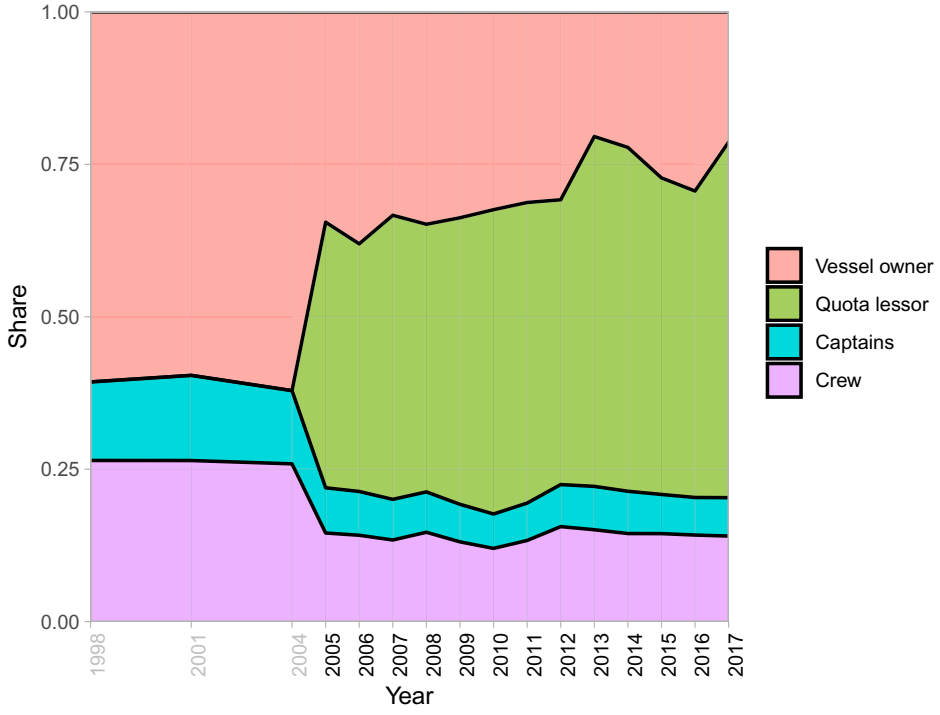

Fig. 2. Share of BBR contribution margin to claimants. Shaded years are before the CRP. Calculated only for vessels that remain at least 1 y after the CRP.

(and captains with crew share) may also earn lease income. This overlap implies that not all gains to lessors are a loss to active vessel owners, and vice versa. In what follows, we report returns over time both for vessel owners and for the union of the sets of vessel and quota owners. The latter grouping allows us to get some sense of how payments to the nonlabor stakeholders in the fishery evolved over time, even as some of those stakeholders transitioned from vessel ownership to quota ownership.

The initial effects of lease payments on the share of CM to labor (captain and crew) vs. owners were in proportion to the claimants' pre-CRP share. Labor absorbed approximately one-third of lease payments, with labor's share falling from 38% in 2004 to 22% in 2005, whereas owners' share fell from 62 to 34%. In contrast to the continued decline in owners' share (reaching 21% by 2017), captain and crew's shares have remained relatively stable since rationalization.

Real Payments to Claimants. How did these reductions in the share of surplus to labor and vessel owners affect their absolute compensation? Fig. 3 explores this question by plotting the annual fleet-wide quantiles and means of payments to crew, captains, vessel owners, and a combined cohort of both lessors and vessel owners in the BBR fishery (*SI Appendix*, Fig. S11 for BSS). We report daily earnings to facilitate comparisons of remuneration across seasons of variable duration (15). For captains and crew, this approximates a daily wage. For owners of vessels and/or quota, it can be thought of as a rental rate.

Focusing on the BBR fishery, we see that mean and median remuneration to captains and crew initially fell after rationalization before rising to levels at or above pre-CRP levels beginning in 2011 (Fig. 3). These swings were heavily influenced by volatility in output prices (*SI Appendix*, Fig. S3). Remuneration in crab-equivalent units exhibited less variability in terms of the physical output of the vessel, yet remained at or just below the pre-CRP range (*SI Appendix*, Fig. S10). Average daily returns to vessel owners also declined initially postrationalization, before beginning to climb in 2010. Daily mean returns to the combined cohort of lessors and vessel owners increased more steadily post-CRP. Mean compensation in the BSS has exhibited similar trends (*SI Appendix*, Fig. S11). Furthermore, returns to vessel owners have seen less of a "squeeze" over time, remaining above pre-CRP means in both monetary and crab-equivalent terms (*SI Appendix*, Fig. S12).

Changes in the mean and median fleet-wide returns may not be representative indicators of compensation change due to heterogeneity in within-vessel changes over time. Comparing annual vessel-level returns to each vessel's pre-CRP median suggests that less than half of BBR captains and crew persisting on a vessel would have seen their compensation increase, although this trend had reversed by 2011 (*SI Appendix*, Fig. S13). By contrast, vessel/quota owners' returns consistently improved compared to before rationalization. Even so, the share of vessel owners with returns exceeding their pre-CRP median fell to levels comparable to that of labor since 2011. Trends in the BSS are similar, albeit less extreme, with captain and crew reporting improved compensation relative to the pre-CRP median in 8 of 12 y and consistently higher returns to the majority of vessel/quota owners (*SI Appendix*, Fig. S14).

While many BSAI crab captains and crew may have seen lower daily pay in the first 5 y after the CRP, this finding is contingent on normalizing pay over active fishing days. In practice, the share also compensates labor for several days spent on obligatory nonfishing activities (15). Including nonfishing time in the "wage" calculation tends to decrease pre-CRP compensation relative to post-CRP compensation since nonfishing days represent a larger share of total labor days during short derby seasons than in the rationalized fishery. Sensitivity analyses based on representative estimates of nonfishing days suggest that most captains and crew are likely to have seen stable, and in many cases increasing, compensation after ITQs once the totality of their time commitment is accounted for (*SI Appendix*, section 5).

Compensation is not determined in isolation; the expected wage in a small resource industry is also influenced by prevailing wages outside of the sector (28). Therefore, it is important to understand how laborers fared relative to their likely "opportunity wage" in other industries. Comparing median postrationalization compensation to median wages in common alternative occupations suggests that captains and crew earned a similar

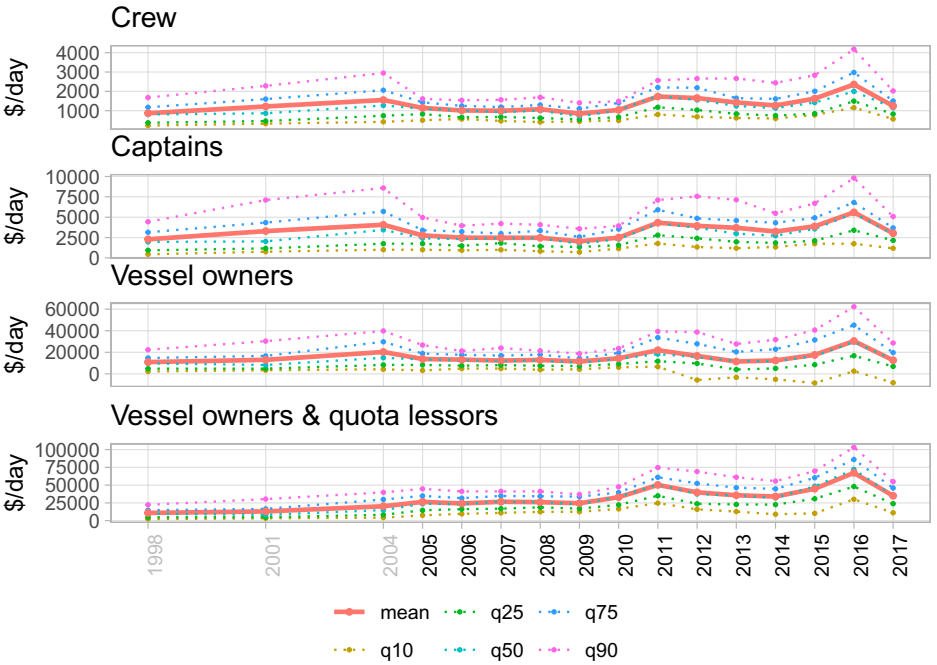

Fig. 3. BBR quantiles and mean of compensation to claimants. Crew compensation is measured as the vessel-level average, with the mean weighted by number of crew members. Returns to vessel owners are measured before fixed costs. Shaded years are before the CRP.

premium for their labor to that in the years before rationalization (*SI Appendix*, Figs. S15 and S16). Indeed, this premium has widened since 2010.

Heterogeneity and Distributional Implications. How has the heterogeneity of compensation changed within and between each claimant group? Fig. 3 suggests that heterogeneity across the fleet in payments to captains, crew, and vessel owners has generally fallen over time—especially in the years directly following the introduction of catch shares—whereas heterogeneity in payments to the combined group of vessel/quota owners has remained high postrationalization or even increased. However, comparisons of annual quantiles mask potential "churn" in the cross-vessel distribution of returns over years, making it difficult to assess whether these changes are associated primarily with high-earning claimants, low-earning claimants, or both. Fig. 4 explores the changing composition of earnings for each claimant group by tracking returns for cohorts defined by their pre-CRP quartiles of compensation.

Fig. 4 tells a striking story. The aforementioned reduction in the average wages of captains and crew after CRP was the mixture of two qualitatively different trends—a dramatic reduction in labor compensation for vessels paying above-median wages prior to the CRP, paired with mild increases in compensation for vessels in the lower quartiles of pre-CRP average wages. These countervailing effects compressed returns to labor across vessels in a durable fashion, suggesting that rationalization undermined persistent hierarchies of worker compensation across vessels based on efficiency of harvest under derby conditions. The BSS exhibits comparable results (*SI Appendix*, Fig. S17).

The story is quite similar for daily returns to vessel owners and to vessel/quota owners. Notably, it appears that the top two quartiles of vessel owners are worse off than prior to rationalization, whereas every quartile of overall vessel/quota ownership appears to be at least as well off (with the bottom two quartiles improving considerably). The pre-CRP rank ordering of returns to vessel/quota ownership across quartiles remains largely unchanged after rationalization (Fig. 4) so that the relative distribution of payments to vessel/quota owners has been compressed, but not substantially reshuffled. Strikingly, though, the returns to vessel owners in the highest pre-CRP quartile have slid dramatically over time. The BSS tells a similar story for captains and crew, but vessel and quota owners appear to have fared better there (*SI Appendix*, Fig. S17).

Volatility. The dispersion around mean returns exhibited in Fig. 4 is a function of not only between-vessel heterogeneity in returns, but also temporal fluctuations around these averages. Such volatility is undesirable for risk-averse claimants and is shared between labor and nonlabor claimants through the share system. We examine whether volatility has increased or decreased after rationalization for each claimant group by comparing the average range of vessel-level returns for claimants across "triads" of post-CRP years to the three sampled years preceding the CRP (*SI Appendix*, section 4.C). We find that overall returns are more volatile since catch shares, with no post-CRP triad falling below the 1998/2001/2004 range (*SI Appendix*, Fig. S18), although it is impossible to parse whether this change is exogenously or endogenously driven given the very small sample of pre-CRP years. This increase in volatility is mirrored in increased volatility to vessel/quota ownership (*SI Appendix*, Fig. S18). However, there is some evidence that volatility borne by labor remained steady or even declined, with five of seven post-CRP triads exhibiting lower ranges than before rationalization. Intriguingly, labor has been partially sheltered from financial risk, even as overall risk has grown since implementation of catch shares.

SI Appendix, Figs. S19 and S20 mimic the analysis in Fig. 4 by examining claimant groups' trends in volatility (defined as the within-vessel range over triads of years) within cohorts defined by each claimant's pre-CRP volatility (arranged in quartiles). *SI Appendix*, Fig. S19 demonstrates that cross-vessel heterogeneity in the volatility of overall returns has fallen since the adoption of catch shares. Returns are noticeably less volatile since rationalization for claimants in the highest quartile of variability in 1998 to 2004, while overall returns became more volatile for vessels previously in the lowest quartile of volatility. This homogenization of volatility after catch shares applies not only to overall returns, but also to labor and vessel/quota ownership.

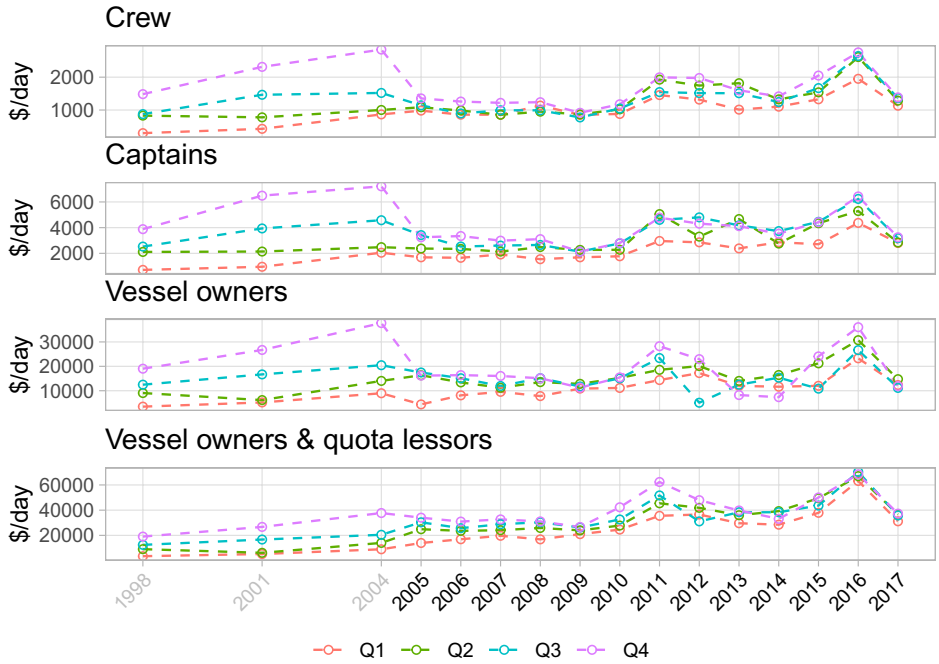

Fig. 4. Comparisons of mean returns by claimant in the BBR fishery by quartile of prerationalization returns. Quartiles are determined based on the median return in the pre-CR period.

Indeed, captains and crew that were previously exposed to the most variable returns before the CRP now have a much more reliable income stream.

The Role of Lease Costs. Parsing the mechanisms through which ITQs affect heterogeneity and volatility in claimants' compensation across vessels and through time is an ongoing topic of research. However, one of the most significant and frequently discussed impacts of ITQs on industry cost structure is the need to cover each ton of catch with an equivalent amount of quota. In the BSAI fisheries, consolidation has caused many former vessel owners who still own quota to lease a large portion of their quota out to other vessels. In a typical year the average vessel leases in well over half its quota, with the overall share rising from 69 to 87% in 2017 (*SI Appendix*, Fig. S21). Lease costs per ton of harvest have risen over time, buoyed by increases in economic efficiency and the growth of crab prices after 2010 (*SI Appendix*, Figs. S22 and S23) (29). Nevertheless, lease prices have remained a relatively constant share of ex-vessel prices, so that the large increase in the share of surplus accruing to lessors (Fig. 2) is primarily due to additional leasing rather than a disproportionate increase in lease prices.

The implications of increased quota leasing for compensation of labor vs. vessel owners are explored in Table 1 for the BBR fishery (*SI Appendix*, Table S1 for BSS). We regress the log of returns per day for labor (captains and crew) (Table 1, columns 1 to 3) and owners (Table 1, columns 4 to 6) at the vessel level on the ratio of quota on a vessel that is leased in (*SI Appendix*, section 4.D). We estimate the unconditional relationship (Table 1, columns 1 and 4), as well as models that control for other determinants of claimants' compensation (Table 1, columns 2 and 5) and vessel fixed effects (Table 1, columns 3 and 6). The results suggest that a weak relationship exists between leasing costs and compensation to labor—∼16% lower wages for a vessel with 100% leased-in quota vs. fully owned quota. However, this relationship is driven solely by cross-sectional variation in contracts between vessels. Focusing solely on variability in leasing share within vessels over time (Table 1, column 3), we find no significant effect of increased leasing on the daily wage of labor. In contrast, leasing in quota has a large, significant effect on the returns of vessel owners. Increasing the share of leased quota from 0 to 100% is predicted to reduce returns to vessel owners by 74%.

Discussion

We provide insight into the distributional effects of catch shares by examining payments to captains, crew, and owners of vessels and quota for each vessel in the Bering Sea crab fisheries. Despite increasing concern about how the benefits and costs of rights-based fisheries policy are borne by different stakeholder groups, previous studies lacked the detailed data necessary to simultaneously compare outcomes both within and between vessels.

The transition from limited entry to catch shares led to a marked increase in vessel productivity with more modest effects on contribution margins due to exogenous and offsetting changes in TACs and prices. Rationalization also impacted how vessel net revenues are distributed to different participants. The share of net revenues going to captains, crew, and vessel owners all declined under the new catch-share regime to make room for payments to quota owners, even though a larger share of CM now goes to vessel owners rather than to fixed costs due to efficiency gains from consolidation. The capture of fishery rents in many rights-based programs by a narrow group frequently dominated by vessel owners, as opposed to the broader public or a wider swath of fisheries stakeholders, is an ongoing source of contention in both current and proposed catch-share programs. Many policy proposals exist for addressing these concerns (33). Nevertheless, redistribution of rents will likely prove politically challenging in established programs—emphasizing the importance of broadening the base of initial allocation of quota and considering the case for resource royalties before implementing new ITQ systems.

Given the newfound sharing of net revenues with owners of harvest quota, captains and crew earned slightly less compensation per day fishing than they did prior to catch shares—although this difference erodes after accounting for nonfishing time compensated by crew share. Nevertheless, laborers' earnings maintained their historic premium compared to alternative occupations. There is also evidence that payments to captains and crew became more equitable across vessels and less variable over time in the wake of catch shares. Payments to vessel and quota owners also became more equitable across vessels. For vessel owners, this convergence is driven by a decline in returns for the highest-earning vessels. For the combined measure of vessel and quota owners, the convergence is due to improvements in the lower quartiles.

We also find that leasing costs—especially those accrued as a result of ongoing consolidation after the initial downsizing under the CRP—are passed through to vessel owners, but not to crew. This finding suggests that payments to quota owners may be directly "squeezing" payments to vessel owners. This is consistent with previous vessel-level studies of inframarginal rents and rationalization (13) that emphasize the conversion of skill-based

Table 1. Regressions of daily remuneration to all workers (crew and captains) and vessel owners on the share of leased quota for the BBR fishery

	log(labor cost/d)			log(owner return/d)		
	Base	Controls	Fixed effects	Base	Controls	Fixed effects
(Intercept)	9.13***	−2.13		11.40***	11.05***	
	(0.06)	(2.85)		(0.03)	(2.76)	
Leased ratio	−0.15**	−0.18**	−0.00	−0.29***	−0.30***	−0.16**
	(0.05)	(0.06)	(0.04)	(0.06)	(0.08)	(0.06)
log(production)		0.62***	0.49***		0.27***	0.30***
		(0.09)	(0.10)		(0.07)	(0.06)
log(price)		1.13***	0.44*		−0.00	−0.08
		(0.31)	(0.22)		(0.30)	(0.47)
log(contribshare)		−0.41	−0.38		−0.44	−0.85
		(0.27)	(0.20)		(0.48)	(0.84)
R^2	0.02	0.50	0.82	0.18	0.26	0.43
Observations	849	849	849	849	849	849

All regressions with controls also include year dummy variables. The minimum daily return to vessel owners (−60,771), plus one, is added to owner return prior to the log transformation to ensure positivity. ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$. Cluster-robust SEs (cluster = vessel ID) are reported.

rents previously earned by vessel owners into "resource rents" that get priced into quota costs. Indeed, we find that vessels in the top quartile of pre-CRP returns to capital consistently have higher lease costs after rationalization (*SI Appendix*, Fig. S24). Our ability to separately characterize payments to vessel owners vs. quota for each quartile of vessels reveals the importance of considering how resource rents get distributed postrationalization, not just between vessels, but across different stakeholders within each vessel. Specifically, we find that the relative impact of the CRP on each quartile of vessels differs across crew, captains, and vessel/quota owners.

Our findings suggest that vessel-level heterogeneity in returns does not imply analogous heterogeneity in payments to distinct claimant groups across vessels. In fact, catch shares had modest effects on average crew and captain compensation, but made payments more equitable across vessels and less volatile over time. One interpretation is that rationalization has made labor a more uniform input to vessel productivity and therefore made labor compensation more like a wage than a traditional share payment designed to incentivize performance under conditions of production risk and possible moral hazard (28). This is consistent with the finding that annual variability in leasing costs is not passed on to crew. Nevertheless, there is no evidence of share payments actually being replaced by wages, as has been noted in some ITQ fisheries (10). While some may lament these developments as a disintegration of the historic relationship of crew as "coventurers," the normative interpretation is not so clearcut. Indeed, if crew are risk averse, then reduced exposure to financial volatility—combined with relatively stable wages, longer employment periods, and reduced physical risk (27)—may adequately compensate for the loss of "motherlode" outcomes under the derby.

Several caveats to our results are necessary. First, despite our attempts to account for the effects of exogenous time-varying factors such as crab prices and abundance, longitudinal comparisons alone are not sufficient to establish a robust causal link between the CRP and distributional outcomes. Rigorous causal inference approaches that have been used to address some effects of catch shares (2, 4) should ideally be used to address their distributional outcomes as well. However, the potential for this analysis is limited given the sparsity of longitudinal employment and remuneration data in most fisheries, with credible analysis also being challenged by tight socioeconomic and biological couplings across fisheries that undermine the validity of empirical counterfactuals for ITQ "treated" fisheries (34).

Second, our data are limited to vessels, captains, and crew that remained in the fishery. Therefore, we are unable to address the impacts of catch shares on the large number of participants who exited the crab fisheries after the CRP was adopted (15). Nor are we able to assess the impacts of the CRP on processors and other stakeholders that are not compensated by the ex-vessel revenue of harvesting vessels. The focus on active vessels in fishery regulation creates severe biases in social and economic data collection. Concerted efforts are needed to develop longitudinal data collection programs for captains, crew, and processors (35), regardless of current participation, to mitigate this myopia. In many cases, developing these data will first require significant upgrades in reporting requirements for both employers and employees (e.g., crew license registries) to properly characterize and sample the relevant population.

Finally, while we have primarily treated captains, crew, vessel owners, and lessors as distinct claimant groups, they are commingled in practice—with some claimants earning returns as both labor and vessel/quota owners. For example, some active captains or crew may possess an ownership interest in a vessel, while others may earn returns from quota share—either due to their ownership interest in a vessel prior to the introduction of ITQs or, as in the CRP, through a dedicated allocation of quota to crew. Measuring the extent of this overlap and its impacts for the distributional outcomes of the CRP pushes the bounds of available data and is a topic of ongoing research. However, the potential for overlap in claimant groups highlights the need for robust and transparent accounting. This need will grow even more acute if, in the pursuit of distributional equity, the basis for allocation of quota share in future catch-share programs extends beyond the ownership of physical capital.

Despite these limitations, our analysis reveals the many insights that can be gained from the deployment of rigorous, ongoing quantitative data collection programs before rights-based reforms are implemented. It also suggests that fisheries managers in even relatively well-monitored systems should significantly expand the scope of socioeconomic data collection to credibly assess the social and economic effects of major policy changes. These quantitative data, in combination with complementary ethnographic and other qualitative data, represent a critical investment in the capacity of policy makers to understand a much wider range of distributional impacts than currently exists. This knowledge can facilitate a more careful and transparent examination of tradeoffs across policy alternatives—undermining panacea thinking and helping to foster consensus among social scientists about the distributional properties of alternative fishery management approaches.

Materials and Methods

The principal data source for this analysis is the BSAI Crab Rationalization EDR program, with additional data from Alaska Department of Fish and Game's (ADFG) fish ticket system and the Crab Observer Program Confidential Interview Form (CIF) database. These confidential data sources were accessed via the Alaska Fisheries Information Network (AKFIN) data warehouse.

The Crab EDR program is a mandatory, ongoing annual reporting requirement for all owners and operating leaseholders of active crab harvesting vessels and processors. Participants in the pre-CR 2005 fishery were required to submit retrospective EDR forms for three pre-CR baseline years (1998, 2001, and 2004). The EDR elicits fishery-specific, temporally comparable data on crab sales and revenues, operating costs, employment, and operational information. EDR cost data include crew and captain settlement payments, bait and provisions costs, annual total pounds and cost of each quota type leased by the vessel, and fuel use and cost.

Numbers of crew per vessel are estimated as the vessel-level median value of crew onboard from ADFG fish ticket records captured at each vessel landing, less one (to deduct the captain from the rest of the fishing crew). Prior to 2006, this number was estimated from EDR data reporting the number of crew paid by settlement in respective crab fisheries (*SI Appendix*, *Data description*).

Total days at sea estimates are from two distinct ADFG sources reporting the number of days at sea in each vessel fishing trip, summed over all fishing trips by the vessel during the associated target fishery (*SI Appendix*, section 2).

As a measure of outside wage opportunities we utilize median annual "usual weekly earnings" data at the occupation level from the Current Population Survey distributed by the Bureau of Labor Statistics. We calculate daily earnings on the assumption of a 5-d work week (*SI Appendix*, section 2).

All monetary values are deflated using the annual US Consumer Price Index for all urban consumers (base = 2004). To examine monetary remuneration measures relative to the price of output, we divide by the vessel-specific price of crab output. These "crab-equivalent" metrics compare remuneration relative to crab price appreciation, providing a measure of compensation in megatons of harvest (15).

Data Availability. All code and publicly available data for reproducing the analysis have been posted in GitHub: https://github.com/joshuakabbott/BSAICrabPNAS. Confidential data used for this analysis cannot be publicly shared.

ACKNOWLEDGMENTS. We thank seminar participants at the Property and Environment Research Center (PERC) and two anonymous reviewers for their comments. Funding for this research was provided by National Oceanic and Atmospheric Administration Fisheries and a PERC Lone Mountain Fellowship.

1. R. Q. Grafton *et al.*, Incentive-based approaches to sustainable fisheries. *Can. J. Fish. Aquat. Sci.* **63**, 699–710 (2006).
2. A. M. Birkenbach, D. J. Kaczan, M. D. Smith, Catch shares slow the race to fish. *Nature* **544**, 223–226 (2017).
3. F. R. Homans, J. E. Wilen, Markets and rent dissipation in regulated open access fisheries. *J. Environ. Econ. Manage.* **49**, 381–404 (2005).
4. L. Pfeiffer, T. Gratz, The effect of rights-based fisheries management on risk taking and fishing safety. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 2615–2620 (2016).
5. T. E. Essington, Ecological indicators display reduced variation in North American catch share fisheries. *Proc. Natl. Acad. Sci. U.S.A.* **107**, 754–759 (2010).
6. M. C. Melnychuk *et al.*, Can catch share fisheries better track management targets? *Fish Fish.* **13**, 267–290 (2012).
7. D. W. Bromley, Abdicating responsibility: The deceits of fisheries policy. *Fisheries (Bethesda, Md.)* **34**, 280–290 (2009).
8. O. R. Young *et al.*, Moving beyond panaceas in fisheries governance. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 9065–9073 (2018).
9. C. Carothers, C. Chambers, Fisheries privatization and the remaking of fishery systems. *Environ. Soc.* **3**, 39–59 (2012).
10. J. Olson, Understanding and contextualizing social impacts from the privatization of fisheries: An overview. *Ocean Coast. Manage.* **54**, 353–363 (2011).
11. T. Heaps, The effects on welfare of the imposition of individual transferable quotas on a heterogeneous fishing fleet. *J. Environ. Econ. Manage.* **46**, 557–576 (2003).
12. J. C. Péreau, L. Doyen, L. Little, O. Thébaud, The triple bottom line: Meeting ecological, economic and social goals with individual transferable quotas. *J. Environ. Econ. Manage.* **63**, 419–434 (2012).
13. C. A. Grainger, C. Costello, Distributional effects of the transition to property rights for a common-pool resource. *Mar. Resour. Econ.* **31**, 1–26 (2016).
14. B. J. McCay, ITQs and community: An essay on environmental governance. *Agric. Resour. Econ. Rev.* **33**, 162–170 (2004).
15. J. K. Abbott, B. Garber-Yonts, J. E. Wilen, Employment and remuneration effects of IFQs in the Bering Sea/Aleutian Islands crab fisheries. *Mar. Resour. Econ.* **25**, 333–354 (2010).
16. C. A. Grainger, D. P. Parker, The political economy of fishery reform. *Annu. Rev. Resour. Econ.* **5**, 369333–386354 (2013).
17. E. Pinkerton, D. N. Edwards, The elephant in the room: The hidden costs of leasing individual transferable fishing quotas. *Mar. Policy* **33**, 707–713 (2009).
18. S. C. Matulich, R. C. Mittelhammer, C. Reberte, Toward a more complete model of individual transferable fishing quotas: Implications of incorporating the processing sector. *J. Environ. Econ. Manage.* **31**, 112–128 (1996).
19. J. R. Boyce, Instrument choice in a fishery. *J. Environ. Econ. Manage.* **47**, 183–206 (2004).
20. S. Charnley *et al.*, Evaluating the best available social science for natural resource management decision-making. *Environ. Sci. Policy* **73**, 80–88 (2017).
21. E. Steiner, S. Russell, A. Vizek, A. Warlick, Crew in the west coast groundfish catch share program: Changes in compensation and job satisfaction. *Coast. Manage.* **46**, 656–676 (2018).
22. D. N. Edwards, E. Pinkerton, Priced out of ownership: Quota leasing impacts on the financial performance of owner-operators. *Mar. Policy* **111**, 103718 (2020).
23. A. A. Brinson, E. M. Thunberg, Performance of federally managed catch share fisheries in the United States. *Fish. Res.* **179**, 213–223 (2016).
24. Pacific Fishery Management Council and National Marine Fisheries Service, *West Coast Groundfish Trawl Catch Share Program: Five-Year Review* (Pacific Fishery Management Council, Costa Mesa, CA, 2017).
25. North Pacific Fishery Management Council, *Ten-Year Program Review for the Crab Rationalization Management Program in the Bering Sea/Aleutian Islands* (North Pacific Fishery Management Council, Anchorage, AK, 2017).
26. A. Davidson, The cost-benefit ledger of quota leasing. *Mar. Policy* **34**, 1115–1116 (2010).
27. D. Lucas, S. Case, T. Teske, A. DeLeon, D. Kloczko, "Assessment of safety in the Bering Sea/Aleutian Island Crab Fleet" (NIOSH Publication No. 2016–112, US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, 2016).
28. K. E. McConnell, M. Price, The lay system in commercial fisheries: Origin and implications. *J. Environ. Econ. Manage.* **51**, 295–307 (2006).
29. R. G. Newell, J. N. Sanchirico, S. Kerr, Fishing quota markets. *J. Environ. Econ. Manage.* **49**, 437–462 (2005).
30. A. Gallo, Contribution margin: What it is, how to calculate it, and why you need it. *Harv. Bus. Rev.* **10**, 1–3 (2017).
31. M. Reimer, J. Abbott, J. Wilen, Unraveling the multiple margins of rent generation from individual transferable quotas. *Land Econ.* **90**, 538–559 (2014).
32. J. A. Krautkraemer, Nonrenewable resource scarcity. *J. Econ. Lit.* **36**, 2065583–2107559 (1998).
33. National Academies of Science Engineering and Medicine, *The Use of Limited Access Privilege Programs in Mixed-Use Fisheries* (National Academies of Sciences, Engineering, and Medicine, 2021).
34. P. J. Ferraro, J. N. Sanchirico, M. D. Smith, Causal inference in coupled human and natural systems. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 5311–5318 (2019).
35. M. Guldin, C. M. Anderson, Catch shares and shoreside processors: A costs and earnings exploration into the downstream sector. *Mar. Resour. Econ.* **33**, 289–307 (2018).