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# Supplementary Information for

## The distributional outcomes of rights-based management in fisheries

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## Supporting Information Text

### 1. Fishery background

Commercial crab fisheries in federal waters of Alaska are regulated by the National Marine Fisheries Service (NMFS) and the North Pacific Fishery Management Council (Council) and managed jointly with the Alaska Department of Fish and Game (ADFG) under terms of the Council's Fishery Management Plan (FMP) for Bering Sea and Aleutian Islands King and Tanner Crabs. The Eastern Bering Sea snow crab (BSS) and Bristol Bay red king crab (BBR) have historically represented the two largest of 11 distinct crab fisheries defined in the FMP, in terms of volume, value, and number of vessels.

Since 1996, BSAI crab fisheries have been managed under a limited access regime that functioned initially as a moratorium on entry of new vessels, and then as a License Limitation Program (LLP) implemented in 2000 that imposed vessel size limits and allocated limited-entry permits to harvesters. The limited access regime combined with a buy-back program in 2004 partially mitigated the accumulation of excess harvesting capacity. However, substantial stock and total allowable catch (TAC) declines, combined with the remaining vessel capacity, resulted in fishery seasons lasting just a few days or weeks. These "derby" conditions resulted in gross inefficiencies in harvesting and processing capacity and use of the fishery resource, and excessive occupational hazards to crew members (1).

In response, the Council began development of a "rationalization" program in 2001, for nine of the BSAI crab fisheries. The Crab Rationalization (CR) Program (70 FR 10173) ultimately went into effect with the 2005/06 crab season. Note, as a result of annual spawning cycles and seasonal conditions on the fishing grounds, most CR program fishery seasons are managed on an annual cycle spanning August to July, with the crab fishing year typically denoted by the calendar years spanned. The regulatory season is October 15 to January 15 for the BBR fishery, and October 15 to May 31 for the BSS fishery. Despite the overlap in regulatory seasons, the two fisheries have historically been distinct, with the BBR fishery active during October through November, with only limited activity in the BSS fishery during December, which is primarily fished from January to April/May. As such, the CR program initially implemented for the 2005/06 crab season included the fall 2005 BBR fishery and the spring 2006 BSS fishery.

The CR Program is highly complex relative to most other catch shares programs, with many features designed or subsequently adapted to address social and distributional concerns. Key components include 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, community protection measures, and monitoring and reporting requirements. Given this complexity, our description of the CR program is necessarily brief. CR Program regulations are set forth at 50 CFR 680. For a relatively concise description of the current program structure and requirements for participants, see Crab Rationalization Program Frequently Asked Questions and Small Entity Compliance Guide. A detailed summary and analysis of CR Program management and outcomes and effects of the program over the first ten years of the program are provided in (2).

The CR Program allocates crab resource use privileges in each respective program fishery to qualifying vessel owners, vessel crew members, crab processors, and Western Alaska coastal communities. Harvesting and processing privileges in the CR fisheries are granted as durable, transferable shares, designated as harvest quota share (QS) and processor quota share (PQS), respectively, with annual issuance of pound-denominated individual fishing- and processing quota (IFQ and IPQ) to QS and PQS holders. The harvest component of the respective CR fisheries is divided between Community Development Quota (CDQ), representing 10% of the annual TAC, and the QS/IFQ component comprising the remaining 90% of the TAC. Of the latter, 97% of the QS pool is issued as vessel owner QS (with separate catcher vessel owner (CVO) and catcher-processor owner (CPO) quota pools), and 3% as crab crew QS.

The allocation of purchasing privileges to eligible crab processors for a portion of IFQ crab from delivering vessels is a unique aspect of the CR program. This involves a share matching requirement in which 90% of CVO pounds are issued as A-Class IFQ, which must be sold on a pound-for pound basis to qualified crab buyers holding IPQ pounds, with additional delivery requirements designating a portion of share-matched IFQ for delivery to specified regions within the BSAI. All other IFQ (10% of CVO pounds issued as B-Class IFQ, CPO, and crew-share IFQ) and CDQ landings are exempt from regional delivery and share-matching requirements.

To facilitate coordination of share matching, ex-vessel price setting, and delivery terms between CVO A-Class IFQ and IPQ holders while avoiding anti-trust liabilities, a pre-season arbitration system is required under CR program regulations. The system establishes a procedure for annual negotiations between CVO-A Class IFQ and IPQ holders, requiring that entities in each fishery annually enter into an arbitration organization, select an approved negotiation approach for setting price and delivery terms, and abide by a number of contractual requirements and reporting. CVO IFQ-B and crew share IFQ are exempt from arbitration requirements, but may be included, and qualifying harvesting cooperatives may participate in the system as collective bargaining units under certain conditions. To ensure that the annual arbitration system is in place prior to the crab fishing season, NMFS will not issue any annual IFQ or IPQ pounds in the respective fishery until minimum system thresholds and procedures are satisfied.

The CR program relies substantially on the harvest cooperative structure to achieve operational efficiency and vessel capacity goals of the program. Cooperatives may be voluntarily formed pre-season by QS holders for the purpose of pooling IFQ and in-season coordination of IFQ landings by crab vessels authorized to land the cooperative's IFQ. Once assigned to a cooperative, a QS holder's IFQ pounds are pooled on the cooperative IFQ permit, and any IFQ lease transactions or other contractual arrangements between QS holders, vessel owners, and hired masters inside the cooperative structure are conducted largely without oversight or data collection by NMFS, aside from annual reporting requirements in the EDR (see below). IFQ pounds may be also be transferred between individual IFQ permit holders outside of the cooperative system, but are subject to additional constraints and reporting requirements that act as sufficient disincentives so that as of the 2009/10 season, negligible quantities of IFQ were transferred outside of cooperatives.

While the cooperative structure has been highly effective in facilitating operational efficiencies, the limited reporting requirements applying to IFQ once assigned to a cooperative leaves the IFQ lease market largely unmonitored at the level of individual lease transactions.

## 2. Data description

All monetary values are deflated using the annual US Consumer Price Index for all urban consumers, using 2004 as the base year.

**A. EDR data.** The BSAI Crab Rationalization Economic Data Report (EDR) program is a mandatory annual reporting requirement for all owners and operating leaseholders of active crab harvesting vessels and processors. The EDR program is managed jointly by NOAA Alaska Fisheries Science Center and Pacific States Marine Fisheries Commission, which is designated in EDR regulations as NMFS' EDR Data Collection Agent and responsible for distribution and collection of EDR forms from CR program participants, database management and validation, and verification of EDR data records.

Failures to collect needed cost and earnings data on earlier rationalization programs lead the Council to include data collection as an essential element of the CR program. Concurrent with the Council's work on developing the structure of the CR program during 2001 through 2005, the Council assigned development of the EDR data collection design to an appointed working group of crab industry representatives in collaboration with NMFS Alaska Fisheries Science Center and Council staff economists. This working group designed questionnaires to collect annual fishery-specific data summarizing crab sales and revenues, fixed and variable operating costs (including IFQ leasing costs), employment, and operational information, from the the catcher-vessel, catcher-processor, and shoreside processor sectors of CR program fisheries. Importantly, current participants in the fishery were required to submit retrospective EDR forms in June 2005 for three baseline years (1998, 2001, and 2004), with active operators being required to submit annually thereafter. EDR questionnaires report crab fishery data on a calendar year basis, such that data encompassing operations in the BSS and BBR fisheries are reported in the same EDR submission for distinct crab season-years, e.g., reporting for calendar year 2006 data for the 2005/06 BSS fishery and the 2006/07 BBR fishery.

The initial iterations of the EDR questionnaires were extensive and highly detailed. Upon later review, the Council determined that data quality limitations and submitter burden were excessive under the initial EDR design, and revised the reporting requirements for the 2012 reporting year. Among other changes, the revised EDRs limited vessel and processor cost data reporting to a select set of variable operating costs for each fishery: bait and provisions costs, fuel gallons used, labor costs of (non-captain) crew and captain settlement payments, annual total pounds and cost of each quota type leased by the vessel, and total fuel gallons and purchase cost for the vessel reported at the annual level. Although several of the variable cost items that were discontinued from EDR reporting (including insurance, fishing gear, and vessel repair and maintenance costs) represent substantial annual expenses affecting operating net income, cash flow, and profitability at the vessel-enterprise level, the fuel, bait, provisions, and quota lease costs comprise the principal vessel cost factors that figure in the value of crew settlement payments. The data used in this paper have been collected continuously and consistently in EDRs submitted for all baseline and post-rationalization years – representing an unprecedented panel dataset on vessel costs, revenues and crew compensation straddling the transition to rights-based management. See (3) for a full summary of EDR and other data collected and reported for CR crab fisheries to date.

**B. Crew numbers & days at sea.** Our measures of per-crew compensation rely upon estimates of the number of non-captain crew active for a particular year, vessel and fishery. This is made more complex by the fact that we lack data on the length and intensity (full-time or otherwise) of employment for individual crew members. We desire a "full-time equivalent" measure – a metric of the number of positions (aside from the captain) filled on a full-time basis in a season. This is calculated as the median number of non-captain crew over all fish ticket (landings) records for the vessel during the fishery-year. Fish ticket reporting of vessel crew was inconsistent prior to 2006. To provide estimates for these early years, we use crab vessel EDR data reporting the number of crew paid by settlement in respective crab fisheries.

To convert remuneration to average daily values, we normalize by estimates of the number of days at sea for each vessel and fishery. We do this using three data sources that each capture vessel-level days at sea on fishing trips during the respective fisheries and are available for partially overlapping periods of the time series. EDR data reporting the aggregate number of days at sea by season for each vessel are available for years 1998 through 2011. Two distinct ADFG data sources – trip fish tickets and the Crab Observer Program Confidential Interview Form (CIF) data – each record the number of days at sea at the trip level, and are available beginning 2005 and 2006, respectively. CIF data were originally collected on a partial sample of fishing trips, and increased over time to capture virtually all trips, while fish tickets are captured at every vessel landing. To merge the three data series during the overlapping period, and to compensate for variation in ADFG data collection protocols in the early years of the CR program, the non-zero trip-level days at sea values for a given fishery from the respective ADFG sources are averaged, and then summed over trips to the vessel-level by fishery, and vessel-level estimated counts of days at sea by fishery are calculated as the average of non-zero values from the EDR and ADFG vessel-level totals.

**C. Outside wage estimates.** As a measure of outside wage opportunities for crab crew and captains we utilize median annual "usual weekly earnings" data at the occupation (Standard Occupational Classification, SOC) level from the Current Population Survey as distributed by the Bureau of Labor Statistics. We calculate daily wages on the assumption of a 5 day work week.

Data on outside job alternatives to crab fishing (and fishing in general in the US) are lacking. However, given the typical educational attainment of most non-captain crew members, it is reasonable to expect that they would often engage in semi-skilled manual labor. Another concern is that crab fishing is a physically risky occupation. Many similar risky occupations are either missing from BLS data entirely (fishing, for example, is largely absent) or the data have many missing values and exhibit high degrees of sampling variability (e.g., working on an oil rig). For non-captain crew, we ultimately select two comparison occupations. The first is the "construction and extraction" field, SOC 47-0000, which includes a number of non-management positions in the construction industry – spanning from generic construction labor to more specialized, skilled, or apprenticeship-based roles such as electricians, plumbers, or masons. It therefore serves as a reasonable composite wage for the range of careers that may be selected by crab crew members. The second is "construction laborers," SOC 47-2061, which provides a measure of wage for relatively low-skill, but high-risk, labor. We also utilize an "all industries/all occupations" composite category as well. Because this category mixes occupations across the spectrum of education, training, and management level, the wage is somewhat higher than that of most blue-collar occupations.

For captains, we select comparison occupations that reflect either a captain's operation of complex, specialized machinery, or their direct management of a small team under risky conditions. We therefore select "construction managers," SOC 11-9021, and "operating engineers," SOC 47-2073, where the latter operate heavy construction equipment.

While the trends in captain and crew remuneration relative to outside wages are discussed in the main text, some clarification regarding the overall scale of implied wage premia reported in Figs. S15 and S16 are called for. The implied "wage" for BBR crew is 7 to 10 times outside wages (3 to 5 times for BSS). At first glance these premia are astounding. However, crab fishing is unique in that it involves full time residence for weeks if not months on a ship, with work hours that often go well beyond typical "full time" employment criteria. A vessel owner facing competition from outside employment offers must pay *at least* an individual's opportunity wage for their extended working hours on the vessel *plus* the value of their surrendered leisure time during the voyage and any market premium associated with the morbidity/mortality risk of the work.

**D. Fuel prices.** While total fuel costs for each fishery are obtained from the EDR data, this does not yield a direct estimate of the price per gallon. To obtain an estimate of the average price per gallon, we utilize EFIN Marine Fuel Prices from the Fisheries Economics Data Program of the Pacific States Marine Fisheries Commission. These port-specific monthly survey data provide cash prices (before tax) for #2 marine diesel. We calculate annual averages using data for the dominant regional port of Dutch Harbor, AK.

## 3. Summary of CRP outcomes

This section briefly summarizes effects of the BSAI CR program, as well as trends in important exogenous variables, that are relevant for understanding the context of the distributional results that are the focus of the main text. Detailed analyses, including pre/post-CR comparisons of economic statistics, are available in the official CRP program reviews (2, 4).

**A. Exogenous trends.** Comparisons of economic outcomes over the long time period of this study are complicated by the presence of important volatility and trends in state variables that influence the revenues and costs of vessels but that are minimally, if at all, influenced by the advent of the CRP. Chief among these factors are the abundance of the target species, ex-vessel prices, and fuel prices.

ITQs are unlikely to have influenced stocks, given that TACs were and remain set in a way that is independent of ITQs. Furthermore, despite the pre-ITQ derby fishery, harvest limits were relatively well-enforced. Stock abundance is not directly observed but is proxied based upon stock assessments by the total allowable catch (TAC) that is translated into quota share in each year. Abundance trends in the BBR and BSS fisheries have moved counter to one another since rationalization. After a period of relatively strong stocks, BBR TAC fell after 2010 to less than half of 2005 values, and substantially below the pre-CRP years in our dataset (Fig. 1). BSS TAC increased following rationalization (Fig. S1) and (ignoring vastly higher TACs in 1998) rose well above pre-CRP levels until the final year of the sample.

While ex-vessel crab prices are somewhat influenced by BSAI supply, they are likely exogenous to ITQs because the TACs are exogenous and because ITQs did not lead to dramatic shifts in product form or quality as seen in some other ITQ programs. Crab prices are strongly influenced by exogenous developments in both demand – especially income-driven increases in Asian demand – and supply, where Russian crab supply often plays a much larger role in price dynamics than supply from the BSAI. After 5 years of somewhat weak prices after rationalization, BBR prices skyrocketed in 2010 and have remained high (Fig. S3). BSS prices are far less volatile, remaining at or below pre-rationalization levels before increasing somewhat after 2011 (Fig. S3).

Diesel fuel prices in Dutch Harbor, AK closely parallel global markets, continuing along a mild upward trend post-CRP, then falling after 2012 and reaching pre-CRP levels by the end of the sample (Fig. S3).

**B. Economic outcomes.** The initial outcome of the BSAI crab rationalization program was a dramatic consolidation in the number of active vessels (Fig. 1, S1). This reduction in capacity was pivotal to the generation of profits in the fishery through the consolidation of harvest onto a smaller number of more efficient vessels, which reduced redundant fixed costs and encouraged economies of scale on remaining vessels. By contrast, the reduction of "race to fish" incentives were a relatively minor contributor to increased fishery profits from the BBR program (5). The number of vessels in the BBR fishery has subsequently declined as TACs have fallen, although far less than proportionally. Active BSS vessels have remained stable since rationalization, despite increased TACs – filling the increased harvest through longer average seasons rather than by enlisting additional vessels (Fig. 1, S1).

These changes in vessel numbers led to large reductions in the total number of crew positions (Fig. 1, S1), with reductions being initially slightly more than proportional to the exit of vessels from the fishery because vessels generally carried fractionally fewer crew on average in the period immediately after rationalization (although this reduction reflects the continuation of a pre-CRP trend in the case of the BSS). Staffing levels per vessel have slowly recovered to pre-CRP levels (Fig. S4).

Not surprisingly, given the consolidation of quota on fewer vessels, the typical season length for vessels has increased relative to immediately prior to rationalization (Fig. S2), although the variance of trip length is substantial across vessels (particularly in the longer snow crab season) and is often higher in post-CRP years due to the greater degrees of freedom available for vessels in determining their fishing days. Season lengths are tightly related to the available TAC, with the typical season in the BBR fishery now being only a few days longer than in pre-CRP years due to TAC reductions.

To examine the overall economic returns available to claimants, we utilize the contribution margin (CM). The contribution margin is harvester revenues minus variable operating costs *before* payment of crew or quota lease costs. CM is the fund which compensates all claimants to harvester profits, whether vessel owners, quota lessors, captains or crew. It must also compensate vessel owners for any fixed costs they incur.

BSS CM unambiguously increased relative to pre-CRP levels, helped by increases in TACs and supportive product prices. Total BBR CM has been less consistently above pre-CRP levels, as high prices have been counteracted by low TACs. However, it is important to remember that CM must compensate all fixed costs. The reductions in capacity in the fishery have substantially reduced fixed costs and created returns of scale for those that remain by spreading fixed costs over more units of production (5). The implication is that a larger share of CM is available to compensate claimants post-CRP, even at the same level of CM.

Figures S5 and S7 provide additional insight on the post-CRP performance of vessels by focusing only on vessels that are present in post-rationalization years (thereby screening out inefficient vessels that immediately exit) and normalizing CM by either days fished or MT of landings. This normalization removes variation associated with exogenously fluctuating TACs to focus on efficiency gains associated with the CRP itself. BBR CM per day is consistently higher post-CRP (Fig. S5), reflecting improvements in harvest and cost efficiency, as well as strong output prices after 2010. BSS CM per day has generally increased as well, although CM per MT didn't increase relative to pre-CRP levels until 2011 when output prices increased (Fig. S7).

Dividing rates of return by the crab price purges CM trends of exogenous price variability – providing a measure of contribution margin in terms of the physical product of the vessel, in "crab equivalents (6)." By these measures, both daily and per-MT profitability increased for the BBR fishery after rationalization, with per-MT profitability increasing over time (Fig. S6). In other words, profitability, both by day of operation or per ton of harvest, has increased, and this increase is not due purely to an exogenous windfall from higher output prices. The same conclusion can be reached for BSS as well, although crab-equivalent CM per day slid somewhat in the face of falling TACs from 2012 onward (Fig. S8).

Altogether, this analysis suggests that, notwithstanding variations in input and output prices and TACs, contribution margin at the vessel level has remained consistently elevated since rationalization compared to pre-CRP levels.

## 4. Analysis

**A. Crab-equivalent measures of return.** The variability in the price of crab from year to year creates significant volatility in the remuneration of owners, labor and leasors. However, much of this variability is likely exogenous to the CR program itself. There is no evidence that the CR created significant changes in product quality that would affect rents via price increases. Furthermore, while market prices may be influenced by the supply of harvest from the BSAI fisheries, and hence the TACs, there is little reason to think that the TACs have been affected in any appreciable way by the CR program.

It is therefore useful, as a complement to more familiar monetary measures, to utilize metrics for returns that are not affected by exogenous trends in product prices. To this end we calculate "crab-equivalent" remuneration metrics by simply dividing a claimant's remuneration by the (vessel-specific) price of crab in \$/MT. Crab-equivalent metrics therefore report remuneration in terms of the physical product of the vessel (MT of crab) effectively received by a particular claimant.

When employed at the season level, crab-equivalent operating income sidesteps variation in output prices to understand whether the physical size of the "pie" used to reimburse all claimants (after paying operating costs) increased or decreased. When used at the per-day level, crab-equivalents provide a measure of the "wage" in terms of the physical product of the vessel. Finally, when used to normalize "piece-rate" (\$/MT) measures, crab-equivalents have a proportional interpretation – showing the share of each ton of production devoted to the pay of a claimant.

Crab-equivalent metrics deflate monetary measures relative to the rate of output price appreciation. Therefore, if operating costs that are deducted prior to calculating payments to claimants increase at the same rate as output prices (holding constant vessel productivity), then the crab-equivalent remuneration measure will not change. However, if operating costs stay constant or increase more slowly than crab prices, then crab-equivalent metrics will increase (but at a slower rate) to reflect that revenue growth has outpaced costs, yielding more physical product to claimants.

**B. Decomposition of remuneration measures.** While captains and crew are often described as "labor," they are remunerated on the basis of a contracted share of the revenues of the vessel minus certain operating costs (which may vary somewhat from vessel to vessel) and, often, some or all of the costs of leased quota. Therefore, while captains and crew are not full residual claimants in the same way as vessel owners – they cannot receive a negative "wage" and may be guaranteed a minimum payment – they are nonetheless partial claimants to a vessel's profitability.

The "share" paid to captains and crew is typically calculated from revenues after deduction of a range of variable operating costs. While the revised EDR surveys no longer track which costs are deducted, data from shortly after the initiation of the CR program suggests that the majority of vessels deduct fuel, provisions, and bait costs prior to calculating the crew and captain's share (6). These are the vast majority of variable costs faced by vessels, so that claimants are essentially rewarded based on a share of the contribution margin, or "contribution share" of the vessel, which we define as $\textit{Contribution Share} = \frac{CM}{Revenue}$. In this case the effective daily "wage" of a claimant can be written as follows:

$$\underbrace{\text{Wage}}_{\frac{\$}{\text{day}}} \equiv \underbrace{\text{Output price}}_{\frac{\$}{\text{MT}}} \cdot \underbrace{\text{Vessel productivity}}_{\text{MT/day}} \cdot \underbrace{\text{Contribution Share}}_{\frac{\text{Revenue - var. costs}}{\text{Revenue}}} \cdot \text{ Claimant share} \quad [1]$$

The contribution share is the ratio of contribution margin to revenue. The contribution margin is the revenues remaining after payment of variable input costs besides labor (which is a claimant) and the costs of leasing quota. It is the fund which must ultimately reward all claimants (captains, crew, owners, and leasors) as well as cover any fixed costs. The variable costs deducted from revenues to form the contribution margin include the costs of fuel, bait, and provisions from the EDR. The claimant share in Eq. 1 is the realized portion of the contribution margin devoted to the compensation of a claimant. For each vessel, these shares sum to one across crew, captains, owners, and (post-CR) leased quota.

This decomposition may not apply to captains or crew if contribution margin or the contribution share falls to a point where the implied remuneration is below zero or a minimum guaranteed pay. Furthermore, the claimant share need not be a constant across vessels or within a vessel across seasons. Indeed, it is likely that the claimant share adjusts in response to facts on the ground, including the factors on the righthand side of Eq. 1 but also other contextual factors such as the opportunity cost of labor outside the fishery, as a result of an evolving negotiation between owners and other claimants (7).

**C. Measuring volatility.** Our ability to measure the volatility of returns to individual claimants before and after the CRP is limited by two features of the EDR data. First, there are only three pre-CRP years in our dataset for the BBR fishery (four for BSS). Therefore, while there is abundant variability *between* vessels in our data, the ability to examine the variability of returns *within* individual vessels over time is quite limited. Second, due to the three-year spacing of the retrospective EDR between 1998, 2001 and 2004, followed by annual surveys after the CRP, there may be apparent differences in volatility pre and post-CRP that are driven by the change in sampling interval (i.e. due to inter-annual seasonality in biology or prices) rather than a real change in volatility.

The very small pre-CRP sample makes typical variance measures such as the standard deviation or coefficient of variation unattractive due to their dependence on an estimate of the mean, which is itself noisily estimated given the small sample. We therefore adopt a simple approach of calculating the range (the gap between the maximum and minimum return) for each vessel and claimant group over a subset of years and then taking the average of these range measures over all vessels. While individual ranges are heavily prone to outliers, the average range across dozens of vessels is much less so.

In order to control for the change in measurement interval before and after the CRP, we measure the average range across overlapping, sequential three-year intervals (2005/2008/2011, 2006/2009/2012, etc.) to mimic the range for the pre-CRP years of 1998/2001/2004. These "triads" facilitate consistent comparisons of volatility over time by preserving the same three-year sample size and spacing of the pre-CRP years. By comparing the seven post-CRP triads to the pre-CRP triad we can see how volatility of returns compared over time (Fig. S18).* Furthermore, by examining evidence of growth or decline in the mean range over time, we can gain a sense of whether volatility has exhibited any trend since rationalization.

To examine heterogeneity in volatility of returns within claimant groups and how this heterogeneity changed over time, we utilize the vessel-level ranges for the 1998/2001/2004 triad of years to classify each claimant group (all claimants, vessel owners and quota lessors, vessel owners, captains, and crew) into quartiles of pre-CRP volatility. We then calculate the mean range for each quartile group and each triad (Figs. S19, S20).

**D. Leasing effects.** Our objective in this analysis is to recover the effects of variability in the share of fished quota that is leased (as opposed to owned) on the returns to "labor" (captains and crew) vs. owners. Our analysis is based on the structure of Equation 1. As noted in the previous section, the realized (ex-post) claimant share – the final term in Equation 1 – is likely to vary in complex ways across vessels and seasons. The negotiated "share" may vary from season to season and across vessels. Furthermore, even for a given share, vessel owners may retain some flexibility in their final payments to labor due to variations in which costs are deducted prior to calculation of the share – especially the costs of leasing quota.

Suppose that the claimant share can be written as a multiplicative function of the factors on the righthand side of Eq. 1:

$$\text{Claimant share}_{it} = \text{Output price}_{it}^{\beta_1} \times \text{Vessel productivity}_{it}^{\beta_2} \times \text{Contribution share}_{it}^{\beta_3} \times \exp(\alpha_i + \theta_t + \gamma \text{Leased share}_{it} + \epsilon_{it}) \quad [2]$$

where $\alpha_i$ is a vessel-specific, time-invariant effect, $\theta_t$ reflects unobserved annual factors influencing the share (e.g., outside economic conditions), leased share is the share of harvested quota that is leased, and $\epsilon_{it}$ captures unobserved vessel and time-varying heterogeneity. Substituting this expression into the remuneration identity of Eq. 1 yields:

*Due to the calendar year reporting of the EDR and because the CRP came into effect for the October 2005 BBR fishery, 2005 was a pre-CRP year for the BSS. The implication is that 2005/2008/2011 contains both pre and post-CRP years. We nevertheless retain the same triads for both fisheries for the sake of simplicity in comparisons between the two fisheries.

$$\text{Wage}_{it} = \text{Output price}_{it}^{1+\beta_1} \times \text{Vessel productivity}_{it}^{1+\beta_2} \times \text{Contribution share}_{it}^{1+\beta_3} \times \exp(\alpha_i + \theta_t + \gamma \text{Leased share}_{it} + \epsilon_{it}) \quad [3]$$

Taking the natural logarithm of both sides generates a regression equation that is linear in parameters, with output price, productivity, and contribution share entering in logs and the leased share entering in its level. The reduced form coefficients on output price, productivity, and the contribution share are one plus the underlying coefficients of these variables in the claimant share equation.

We estimate the logarithmic regression separately for the two fisheries under three specifications. The first includes only leased share to explore the unconditional, univariate relationship. The second includes all the observed righthand side variables in Eq. 3 while also including indicator (dummy) variables for years, thus capturing the time-varying heterogeneity, $\theta_t$. The third specification includes vessel-specific fixed effects (implemented using the within estimator) as well. This final specification effectively differences out all cross-sectional variability in returns to claimants, so that only *changes* in leased share *within* vessels through time are used to identify its effect. All regressions are estimated using the `lm_robust()` command from the `estimatr` package in R. Cluster-robust standard errors are used to allow for flexible inference under possible heteroskedasticity and serial correlation. Clusters are defined by vessel IDs. To keep our analysis parsimonious, we forego separate analyses for captains and crew, instead summing payments to all labor claimants and dividing by the days fished to produce a single equivalent wage for workers.

Direct estimation of the regression for owners is impeded by the presence of negative returns for a minority of vessel/year combinations (69 out of 849 for BBR, and 73 of 806 for BSS). To allow estimation of the regressions we add 1+min(Owner return) ($60,772 for BBR and $29,319 for BSS) for each fishery to owner returns before taking the logarithm. While enabling the estimation, this shift does change the interpretation of the coefficients. For example, the percentage change in owner returns from a change in the share of leased quota at a given wage level is $100 \times (exp(\gamma) - 1) \frac{\text{wage + shift}}{\text{wage}} \times \Delta\text{Leased share}$. Furthermore, for variables entering logarithmically, the percentage effect on owner returns for a percentage change in the level of the variable (e.g., vessel productivity) is $\beta \times \frac{\text{wage + shift}}{\text{wage}}$, where $\beta$ is the coefficient from the regression model (not to be confused with the $\beta$ in Eq. 3).

The estimates from these equations are in Tables 1 and S1. Focusing only on the core results relating to leased share, we find for the BBR fishery that vessels with no leased quota offer wages that are 16.4% higher than for those with 100% leased quota (using the regression with controls). However, this relationship loses both its magnitude and statistical significance under the fixed effect model. This implies that whatever relationship exists between higher uses of leased quota on vessels and worker wages, it exists only in the cross section – reflecting fixed differences *between* vessels. The substantial increases of leased quota usage over time for individual vessels have not exerted downward pressure on workers' wages. This does not imply that leasing rates do not affect the remuneration of crew and captains – vessels with higher average leasing rates do offer lower realized wages on average. However, it suggests that the labor contracts offered captains and crew must limit labors' exposure to temporal variability in leasing practices from year to year – perhaps through deducting only a fixed portion of leasing costs prior to calculating the share. Interestingly, the leased-in ratio has no effect on labor returns for BSS. Indeed, there is a statistically *positive* effect of leased ratio under the fixed effects model.

By contrast, the effects of leasing in quota for owner returns are both statistically significant and economically large. Using the fixed effects model for the BBR fishery we find that moving from 0 to 100% leasing reduces owner returns by 74% when evaluated at the mean return. A similar calculation for BSS shows a smaller, but still substantial, 50% effect.

As a robustness check to ensure that our results are not an aberration of our choice of functional form or treatment of negative dependent variables, we estimate the same progression of models using a simple linear specification. These estimates are available in Tables S2 and S3. The core qualitative result – that leased share has no statistically or economically significant effect on worker pay but has a large effect on owner return – is robust.

## 5. Robustness check: accounting for non-fishing time in remuneration

Our analysis has focused on estimates of days at sea, a measure of time engaged in fishing activities, as the divisor for calculation of rates of remuneration. This metric has the virtue of being consistently measurable across time and vessels, while providing for a common per-unit-time basis to compare the remuneration of labor vs. non-labor claimants. However, this choice ignores the fact that both crew and captains are routinely expected to contribute additional labor outside of this active fishing time – labor that is typically compensated through the share payment, rather than through separate wages. For example, many skippers and crew are often expected to contribute several days of labor in a vessel's home port prior to embarking for Dutch Harbor, where they are also expected to be present for a week or more to prepare the boat for departure for the fishing grounds.

Inclusion of this non-fishing time in the calculation of daily remuneration for captains and crew does more than attenuate the mean and quantiles of daily compensation. Consolidation-induced elongation of the fishing season for most vessels (Fig. S2) implies that the *proportion* of non-fishing days out of the total days compensated by crew share has actually *decreased* post-CRP. As a result, failure to account for non-fishing days will tend to provide a pessimistic accounting of the change in average daily compensation rates after rationalization – overestimating "wage" declines or underestimating wage gains. This is only a concern when examining trends of compensation over time (e.g., Figs. 3, S10-S12) or when assessing the share of claimants earning better than the median pre-CR remuneration (Figs. S13, S14). It does not affect analyses of heterogeneity or volatility in remuneration.

No data are available on non-fishing time, and there may be significant variation across vessels in terms of the amount of time entailed or the percent of crew required to contribute to non-fishing activities. However, to assess the potential sensitivity of our results to non-fishing time, we draw upon informal interviews with vessel owners to provide reasonable estimates of non-fishing time and utilize these estimates to examine the implications of failing to account for this time for our analysis of compensation rates.

Specifically, we assume that 80% of crew and the skipper spend 5 days in their home port preparing the vessel to sail to Alaska prior to the BBR season and include these days in our estimates of daily remuneration. These preparatory days are prorated across the BBR and BSS fisheries based on each fishery's respective share of total fishing time.[†] We also assume that 100% of crew and the skipper are required to be present in Dutch Harbor for 8 days prior to embarking for the fishing grounds. These assumptions mirror those used in an earlier analysis of BSAI crew compensation (6), with one exception. The previous analysis counted the time spent steaming from home port to Alaska (assuming 90% of crew travel with the vessel) as work time compensated by the share. We have avoided this assumption here given that crew that do not travel with the vessel are generally required to pay for their own plane ticket to Dutch Harbor. Given the magnitude of this expense, we have elected not to treat steam time as work time – treating it instead as offsetting the cost of personal transportation to Dutch Harbor.

As hypothesized, non-fishing time decreases as a share of total time compensated by the share after rationalization – decreasing from 48% (32%) of days prior to the CRP to 32% (21%) afterward for the BBR (BSS) fishery. In addition to shifting down estimates of daily compensation across all years, accounting for non-fishing time disproportionately decreases pre-CRP remuneration because non-fishing time comprised a larger share of total days pre-CRP. The result for both BBR (compare Figs. 3 and S25) and BSS (compare Figs. S11 and S26) is that the previous finding of small reductions in daily compensation immediately following the CRP no longer holds. Rather, mean and median "wages" fluctuate within, or above, the pre-CRP range. Consideration of non-fishing time likewise leads to more sanguine findings in terms of the share of captain or crew whose post-rationalization compensation exceeds their median pre-CRP rate. Whereas more than half of captains and crew in the BBR fishery between 2006 and 2010 consistently saw lower daily pay when only fishing time was considered (Fig. S13), our sensitivity analysis shows that inclusion of non-fishing time reverses this finding so that well over half (60% or more in most years) of workers received *higher* daily compensation rates in these same years – with 2009 forming the sole exception (Fig. S27).

These results are qualitatively consistent with the findings of a prior study (6), which found that wages remained stable, or even increased for crew on most vessels in the three years following rationalization.

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2. North Pacific Fishery Management Council, Ten-Year Program Review for the Crab Rationalization Management Program in the Bering Sea/ Aleutian Islands, Technical report (2017).
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4. North Pacific Fishery Management Council, Five-Year Review of the Crab Rationalization Management Program for Bering Sea and Aleutian Islands Crab Fisheries, (North Pacific Fishery Management Council), Technical report (2010).
5. M Reimer, J Abbott, J Wilen, Unraveling the multiple margins of rent generation from individual transferable quotas. *Land Econ.* **90** (2014).
6. J Abbott, B Garber-Yonts, J Wilen, Employment and remuneration effects of IFQs in the bering Sea/Aleutian islands crab fisheries. *Mar. Resour. Econ.* **25** (2010).
7. KE McConnell, M Price, The lay system in commercial fisheries: Origin and implications. *J. Environ. Econ. Manag.* **51**, 295–307 (2006).


[†] Recent informal interviews of vessel owners reveal that, prior to approximately 2005, unpaid shipyard work from many crew members were required as a condition of entry to crew employment. At approximately the same time as implementation of the CR Program, crab vessel owners shifted toward direct hourly wage compensation of most shipyard work. This was motivated in part by the relative increase in shipyard work required to prepare the remaining vessels in the consolidated fleet for the lengthened crab seasons, as well as a roughly concurrent shift among PI insurance carriers (unrelated to crab rationalization) to deferring liability for shipyard labor to coverage under payroll-based worker's compensation insurance. Inclusion of this non-fishing time in our estimates would only serve to decrease pre-CRP wages further relative to post-CRP wages.

# Figures

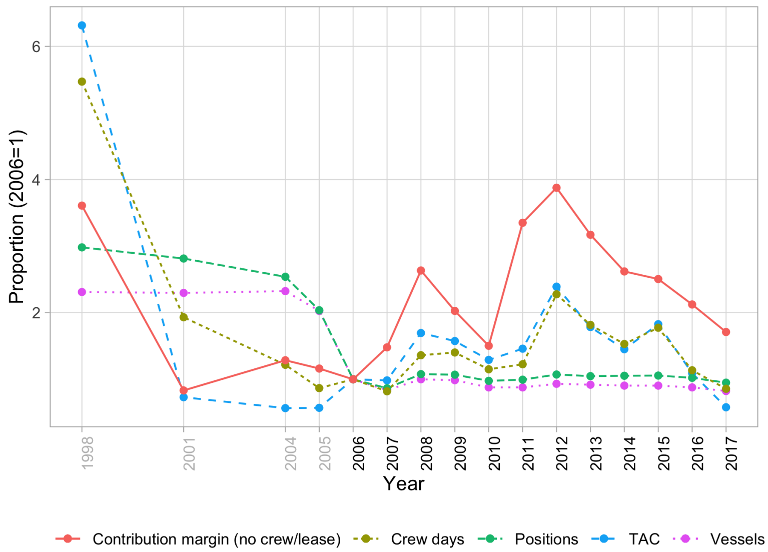


**Fig. S1.** Trends in the BSS fishery for all active vessels. Variables are scaled proportionally to the first year of the catch share (2006) for comparability.

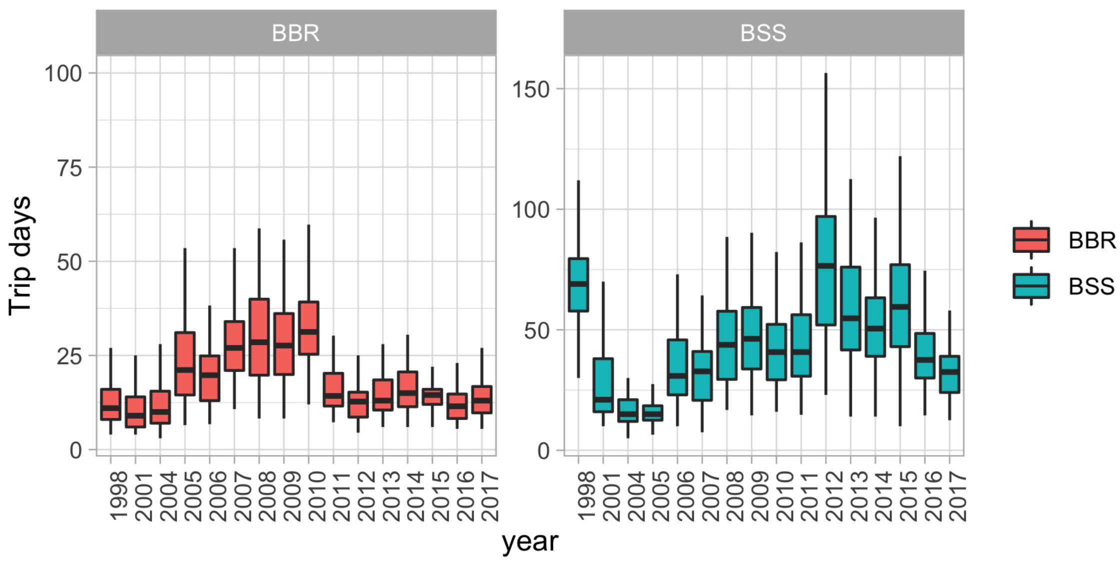


**Fig. S2.** Number of vessel days per vessel in the BBR and BSS fisheries. The box represents the interquartile range (IQR), while the boldface bar is the median. The whiskers are the smaller (in absolute terms) of the max/min or $1.5 \times IQR$.

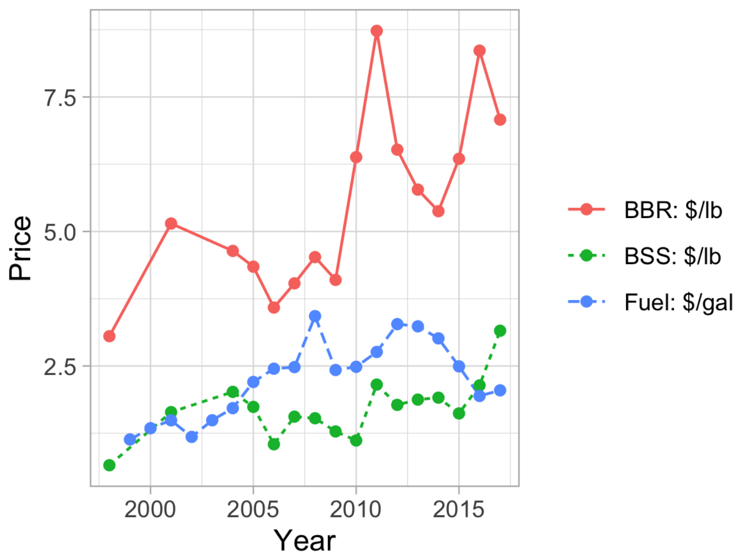


**Fig. S3.** Average ex-vessel prices per lb. and annual average fuel prices in Dutch Harbor, AK.

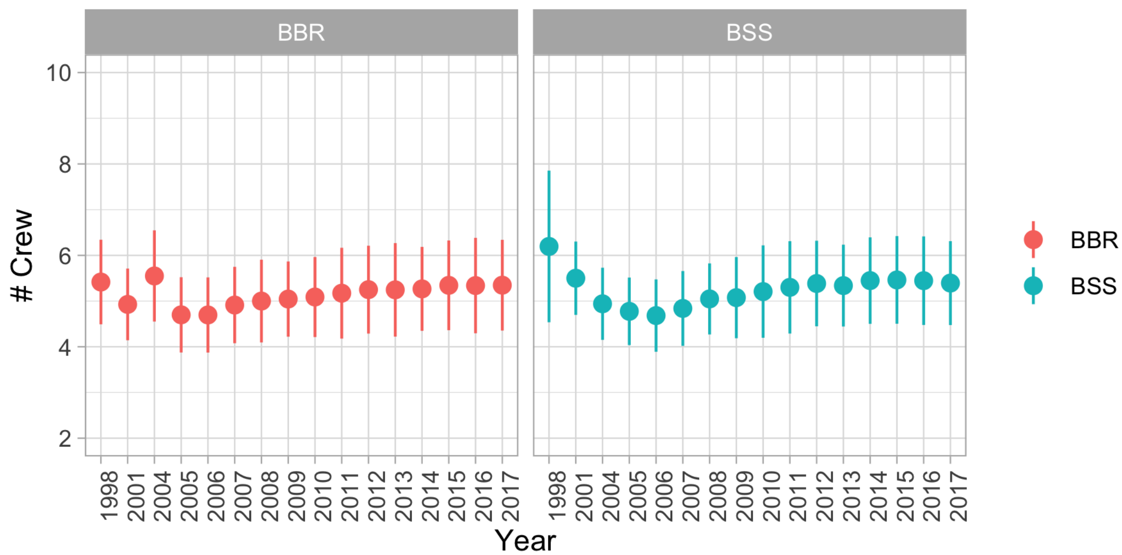


**Fig. S4.** Number of crew per vessel in the BBR and BSS fisheries.

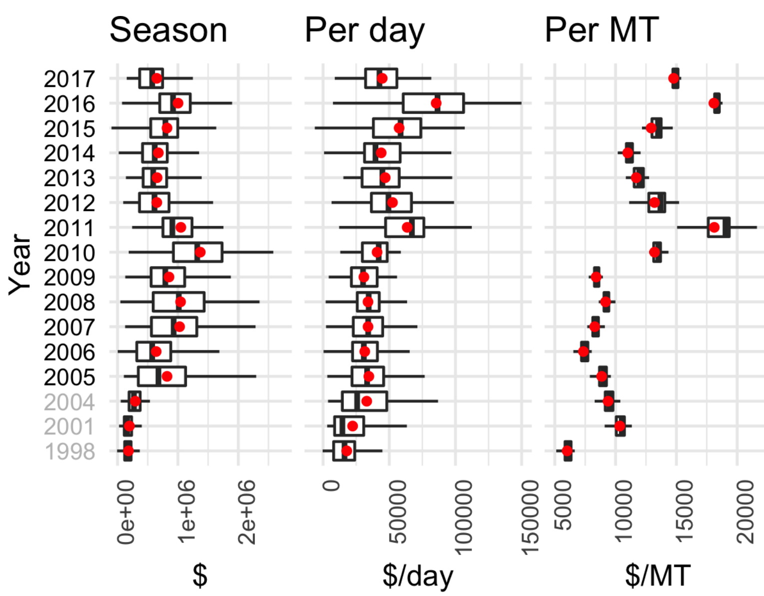


**Fig. S5.** BBR contribution margin per vessel, before crew and quota lease costs. The box represents the interquartile range (IQR), while the boldface bar is the median. The whiskers are the smaller (in absolute terms) of the max/min or $1.5 \times IQR$. The red dots are the mean values. Pre-CR years are shaded in gray.

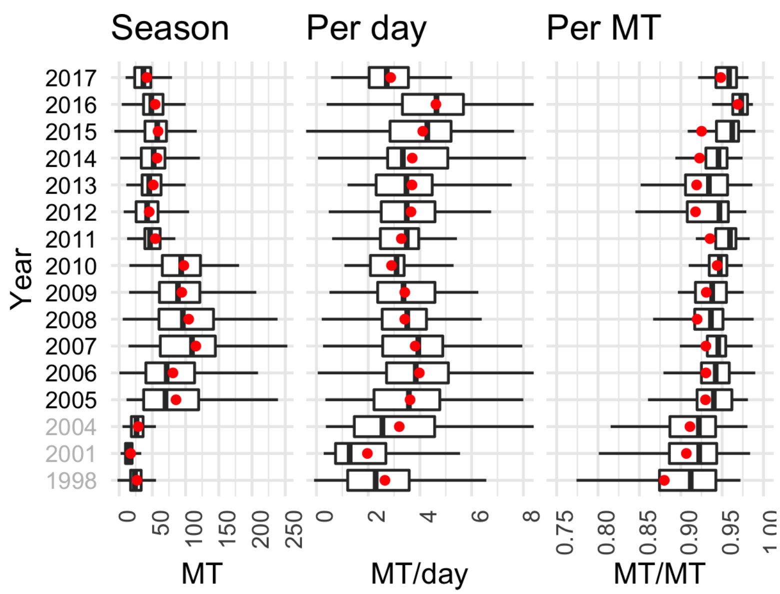


**Fig. S6.** Crab-equivalent BBR contribution margin per vessel, before crew and quota lease costs. Crab-equivalent metrics are found by dividing the monetary contribution margin by the vessel-specific price of crab. The box represents the interquartile range (IQR), while the boldface bar is the median. The whiskers are the smaller (in absolute terms) of the max/min or $1.5 \times IQR$. The red dots are the mean values. Pre-CR years are shaded in gray.

 

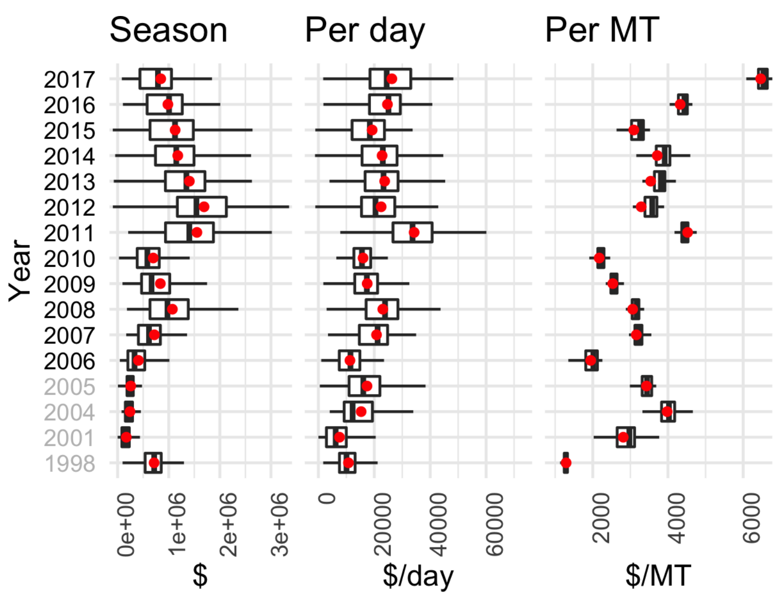


**Fig. S7.** BSS contribution margin per vessel, before crew and quota lease costs. The box represents the interquartile range (IQR), while the boldface bar is the median. The whiskers are the smaller (in absolute terms) of the max/min or $1.5 \times IQR$. The red dots are the mean values. Pre-CR years are shaded in gray.

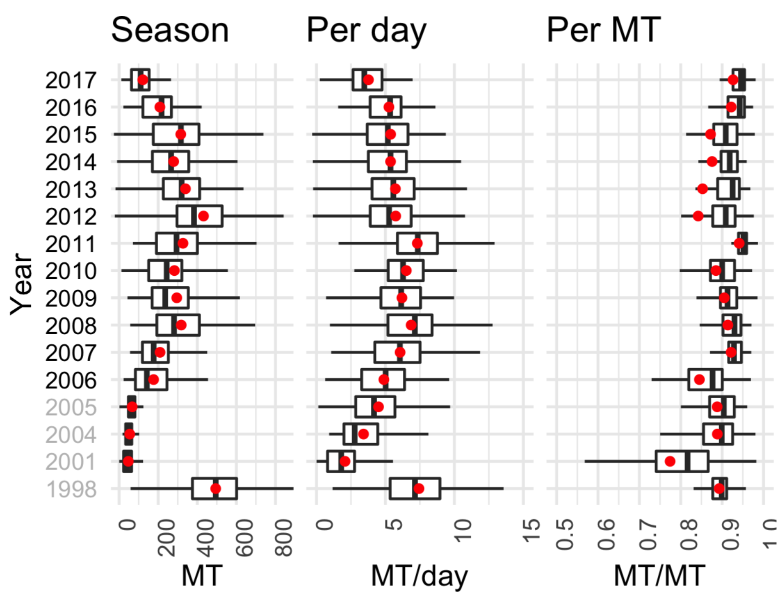


**Fig. S8.** Crab-equivalent BSS contribution margin per vessel, before crew and quota lease costs. Crab-equivalent metrics are found by dividing the monetary contribution margin by the vessel-specific price of crab. The box represents the interquartile range (IQR), while the boldface bar is the median. The whiskers are the smaller (in absolute terms) of the max/min or $1.5 \times IQR$. The red dots are the mean values. Pre-CR years are shaded in gray.

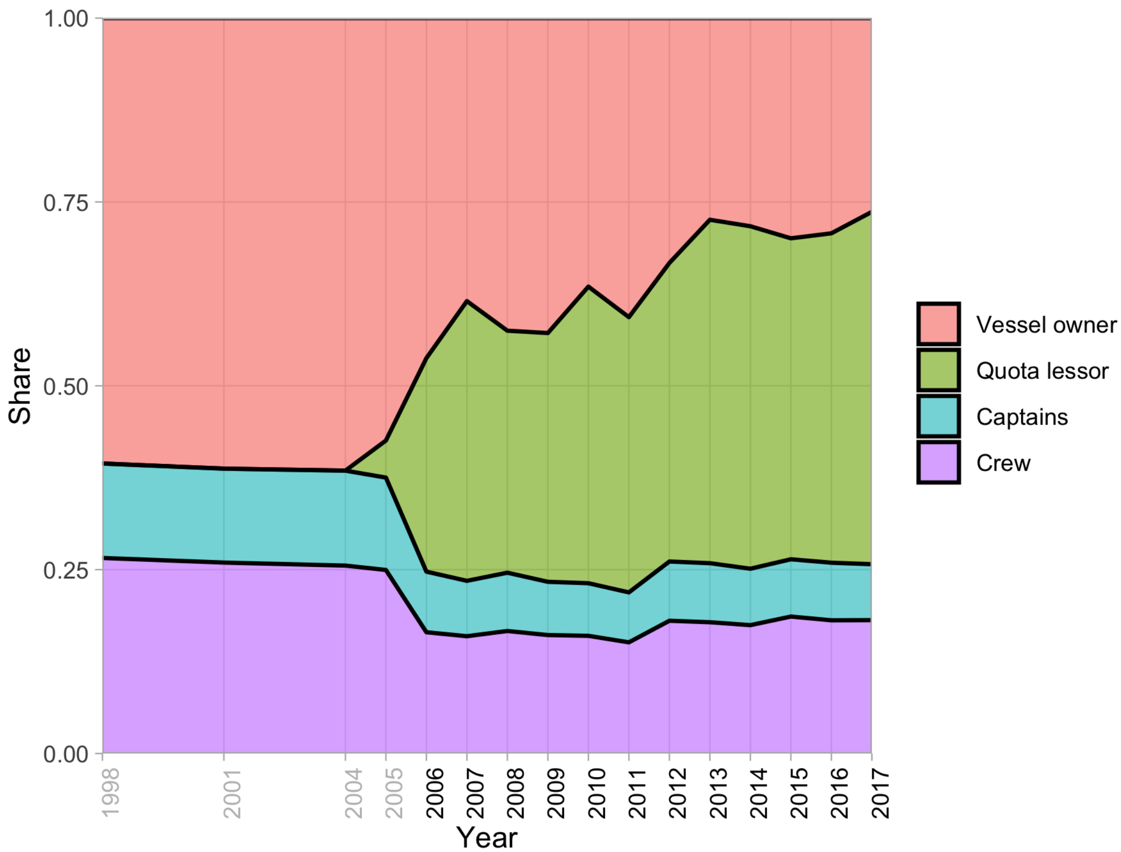


**Fig. S9.** Share of BSS contribution margin to claimants. Shaded years are before the CRP. Calculated only for vessels that persist in the post-CRP fishery.


**Fig. S10.** BBR quantiles and mean of compensation to claimants in crab-equivalent units. Crew compensation is measured as the vessel-level average, with the mean weighted by # of crew members. Returns to vessel owners are measured before fixed costs.

 

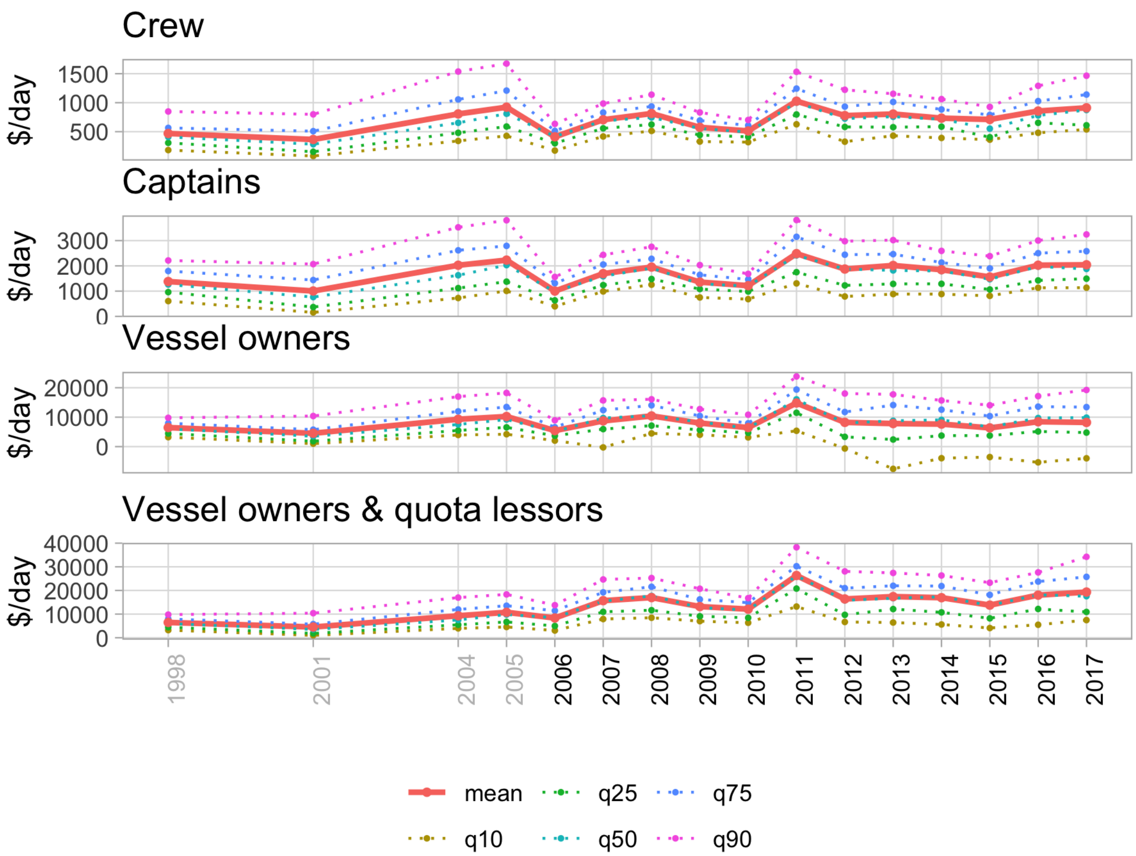


**Fig. S11.** BSS quantiles and mean of compensation to claimants. Crew compensation is measured as the vessel-level average, with the mean weighted by # of crew members. Returns to vessel owners are measured before fixed costs.

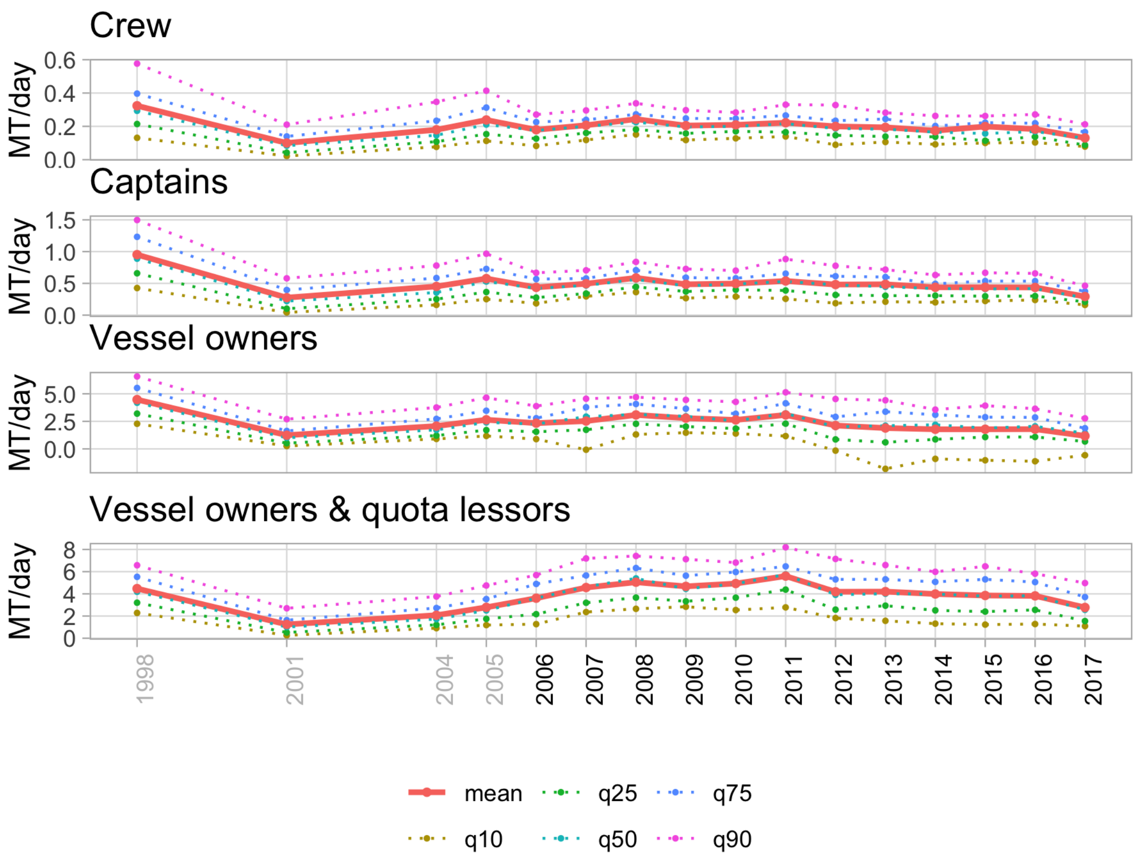


**Fig. S12.** BSS quantiles and mean of compensation to claimants in crab-equivalent units. Crew compensation is measured as the vessel-level average, with the mean weighted by # of crew members. Returns to vessel owners are measured before fixed costs.

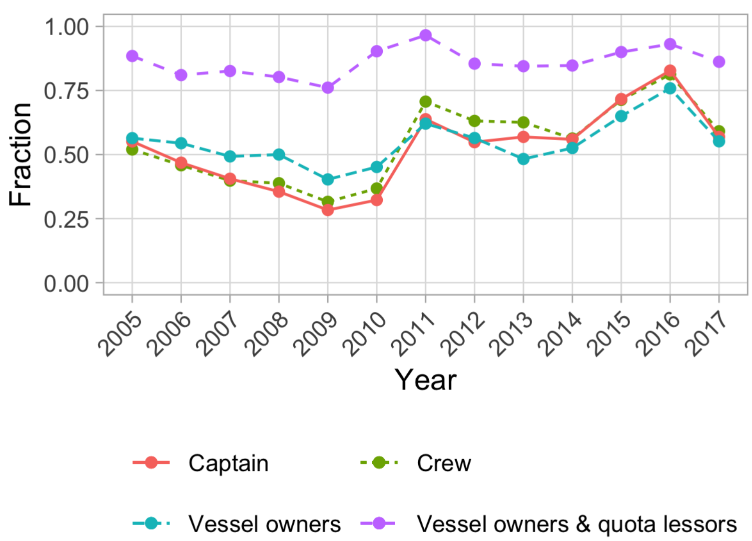


**Fig. S13.** Share of BBR claimants earning better than the median pre-CR daily remuneration (captains and crew) or seasonal return (vessel owners and quota lessors).

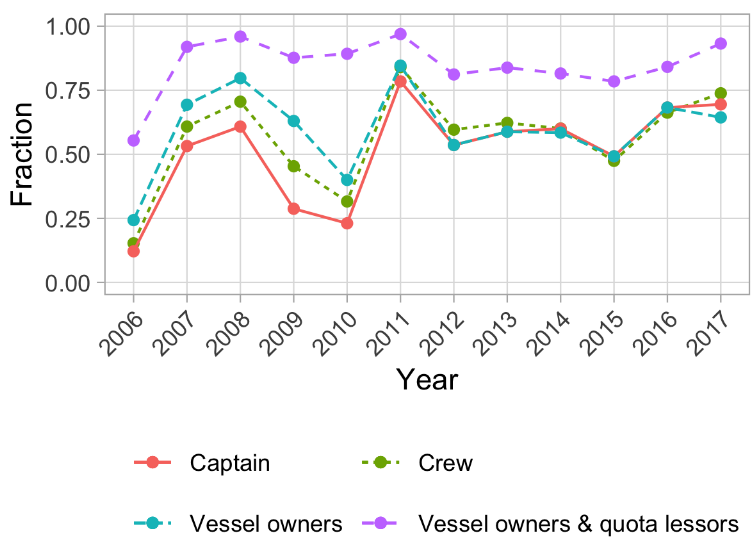


**Fig. S14.** Share of BSS claimants earning better than the median pre-CR daily remuneration (captains and crew) or seasonal return (vessel owners and quota lessors).

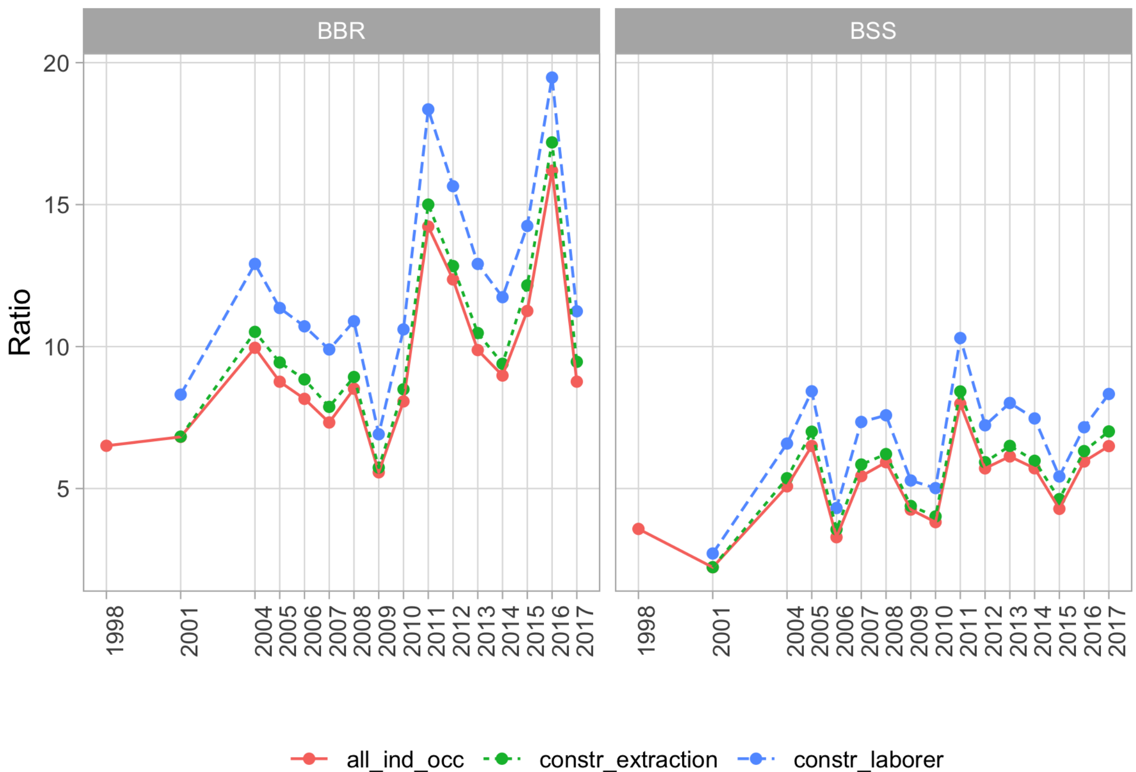


**Fig. S15.** Median ratio between crew pay ($/day) and outside pay rates.

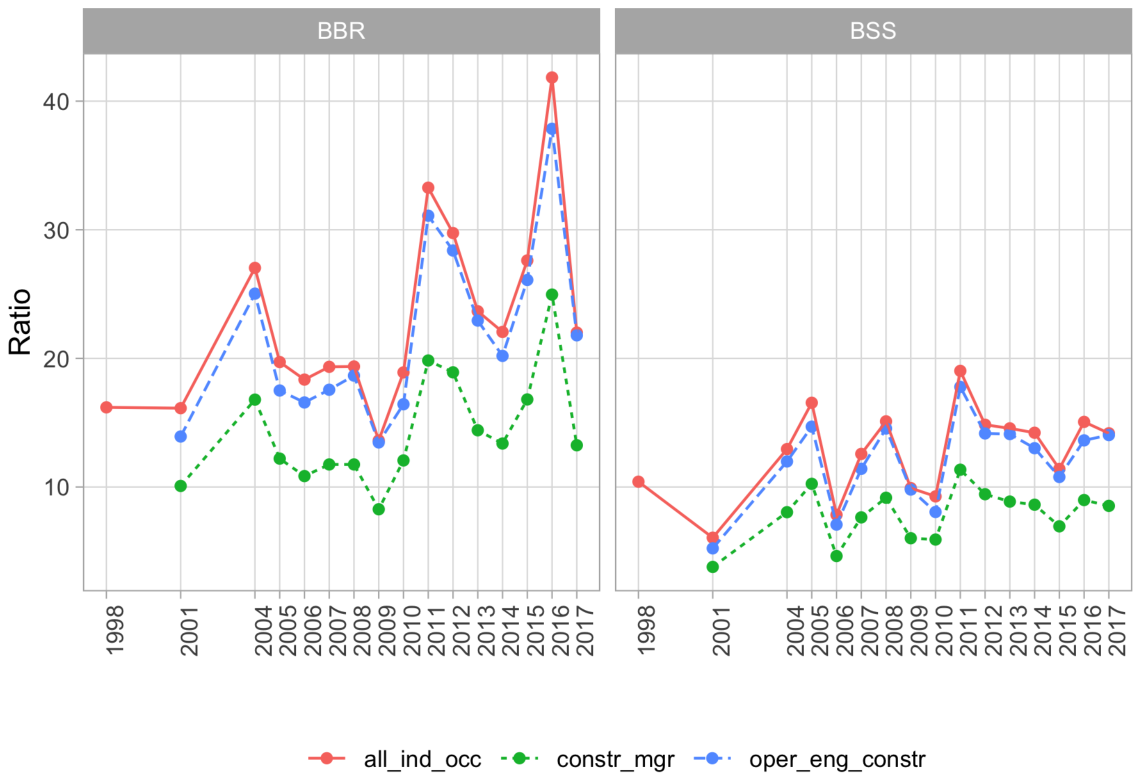


**Fig. S16.** Median ratio between captain pay ($/day) and outside pay rates.

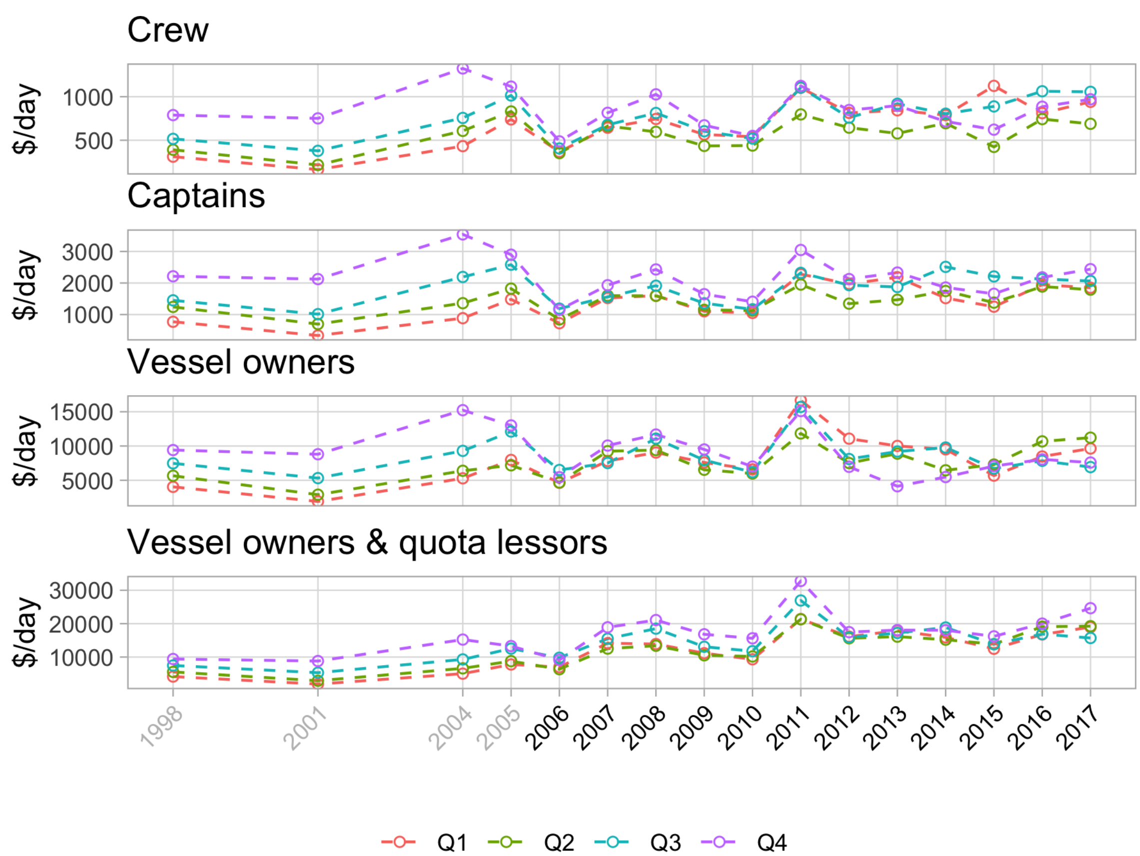


**Fig. S17.** Comparisons of mean returns by claimant in the BSS fishery by quartile of pre-rationalization returns. Quartiles are determined based on the median return in the pre-CR period.

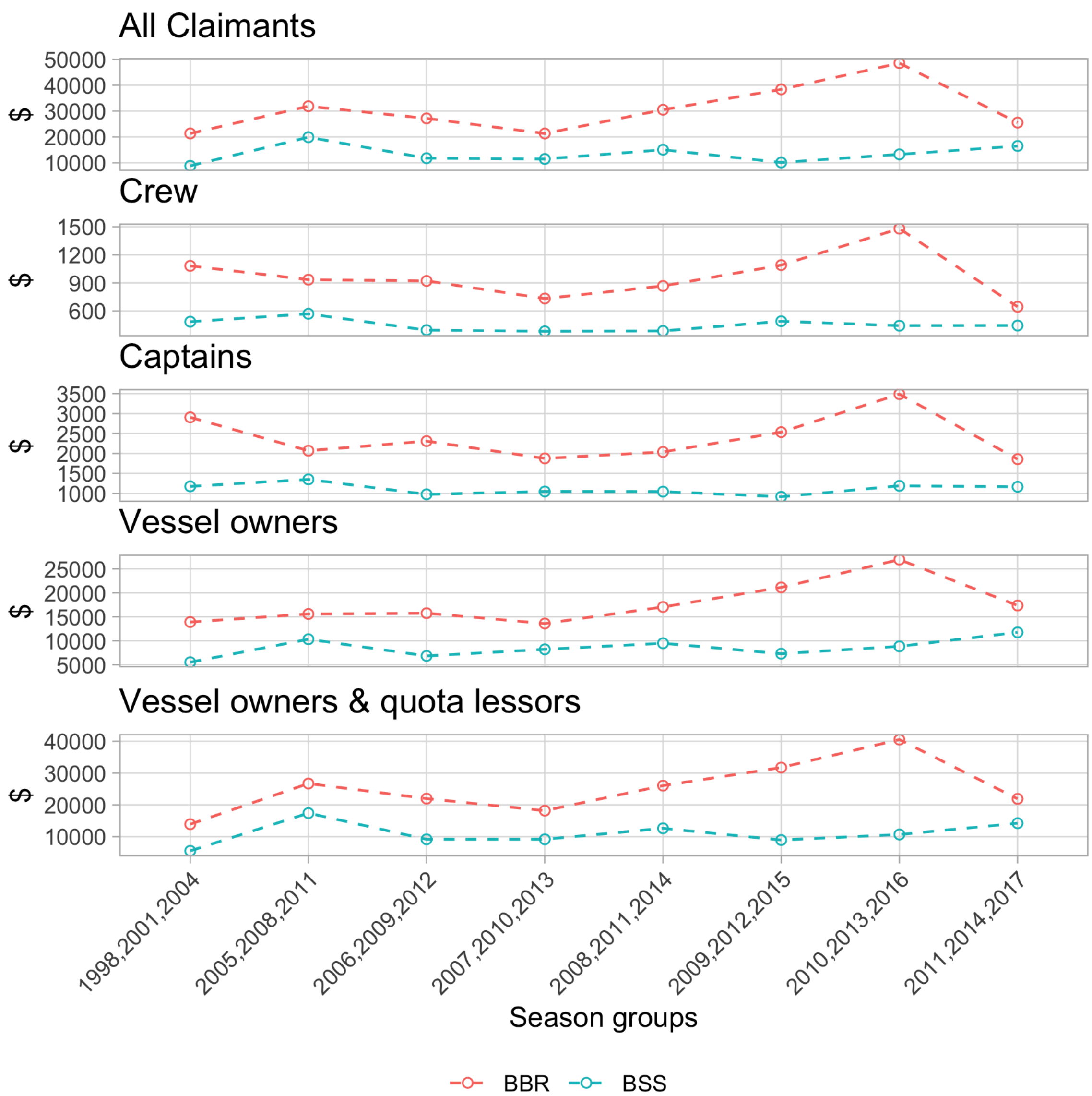


**Fig. S18.** Volatility of daily returns to claimants over seasons as measured by the mean range of daily returns at the vessel level across "triads" of years.

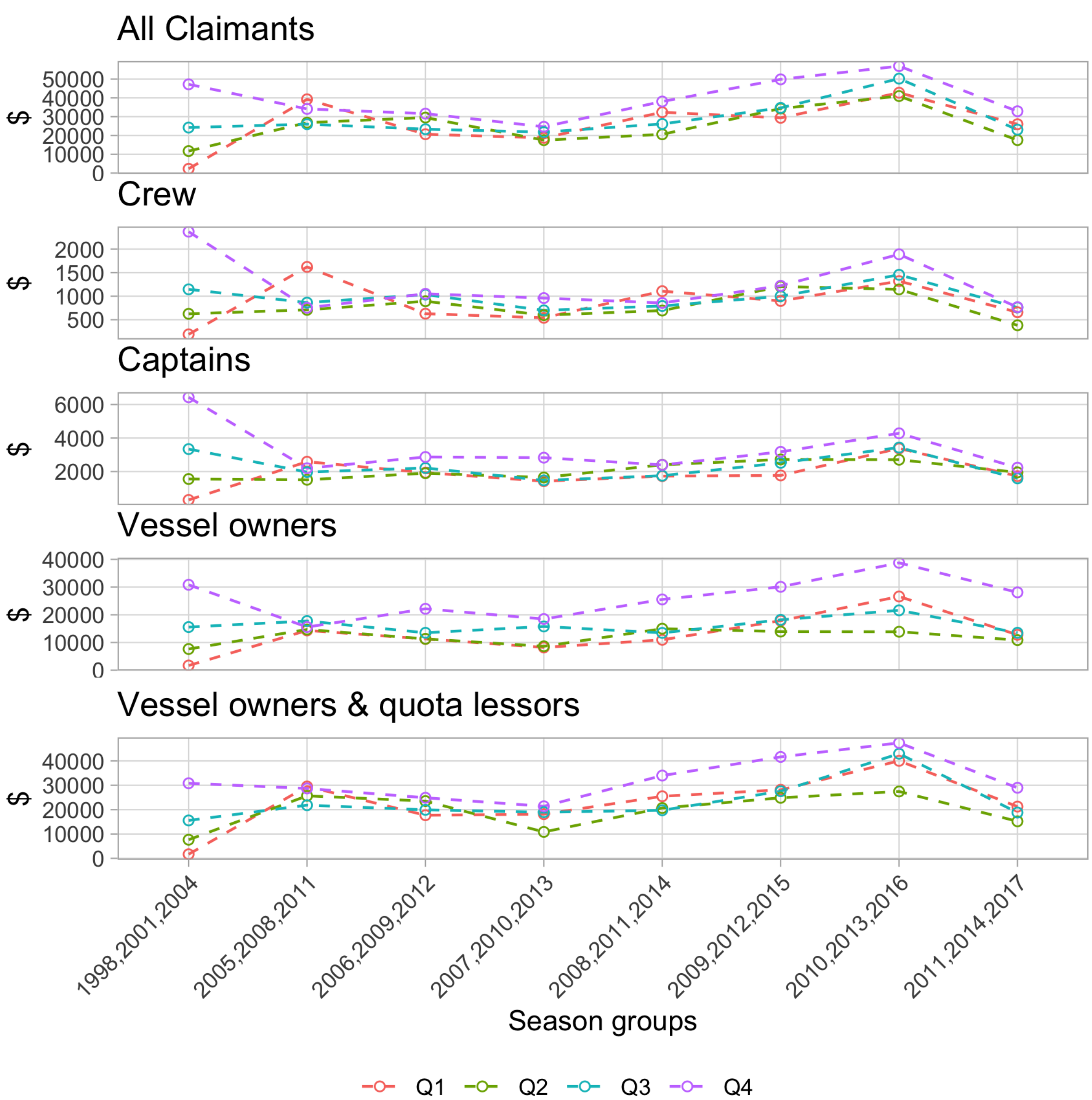


**Fig. S19.** Volatility of BBR daily returns to claimants over seasons as measured by the mean range of daily returns at the vessel level across "triads" of years. Q1-Q4 refer to the quartiles of returns, defined for each claimant group, in the pre-ITQ triad 1998/2001/2004.

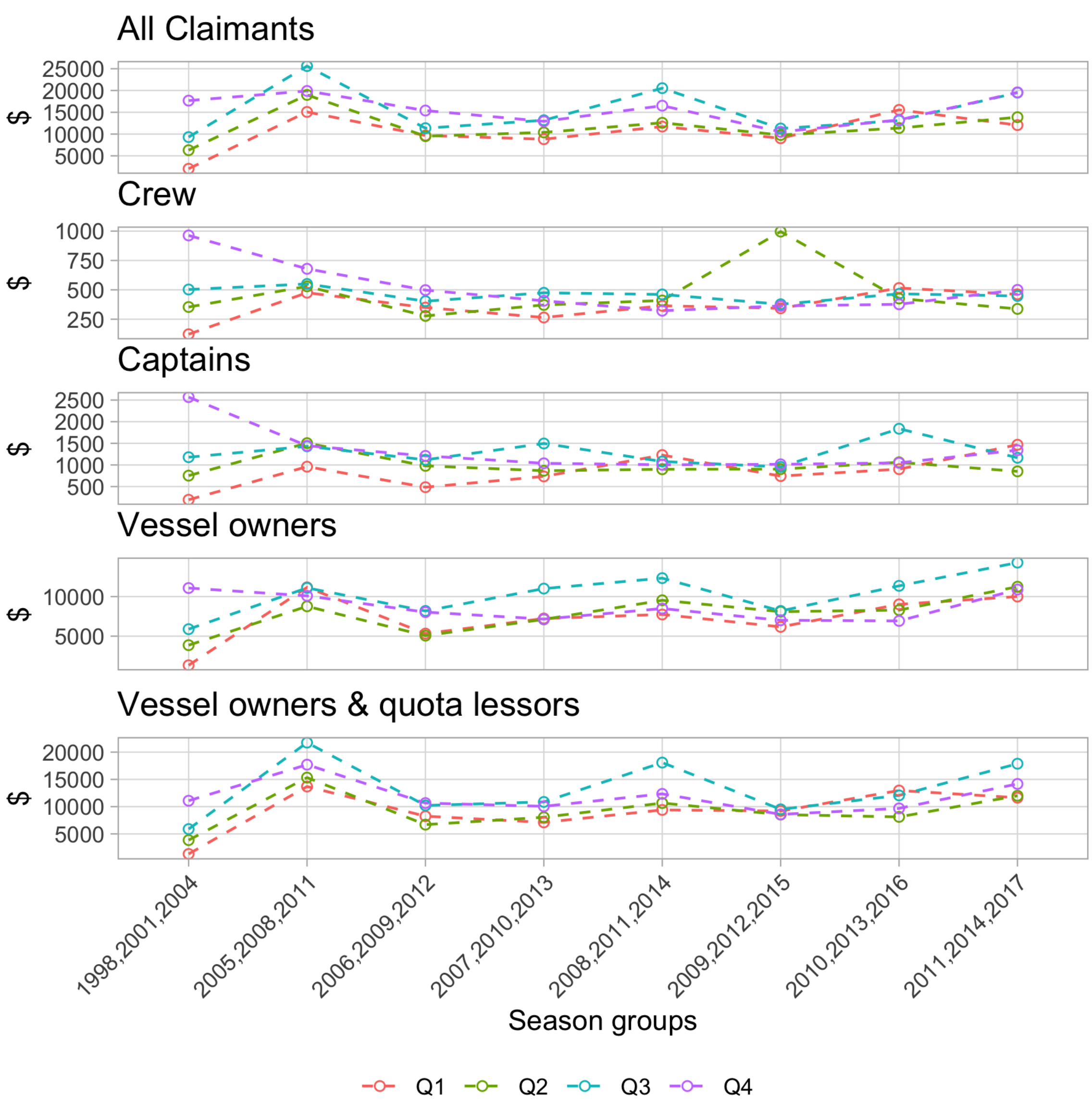


**Fig. S20.** Volatility of BSS daily returns to claimants over seasons as measured by the mean range of daily returns at the vessel level across "triads" of years. Q1-Q4 refer to the quartiles of returns, defined for each claimant group, in the pre-ITQ triad 1998/2001/2004.

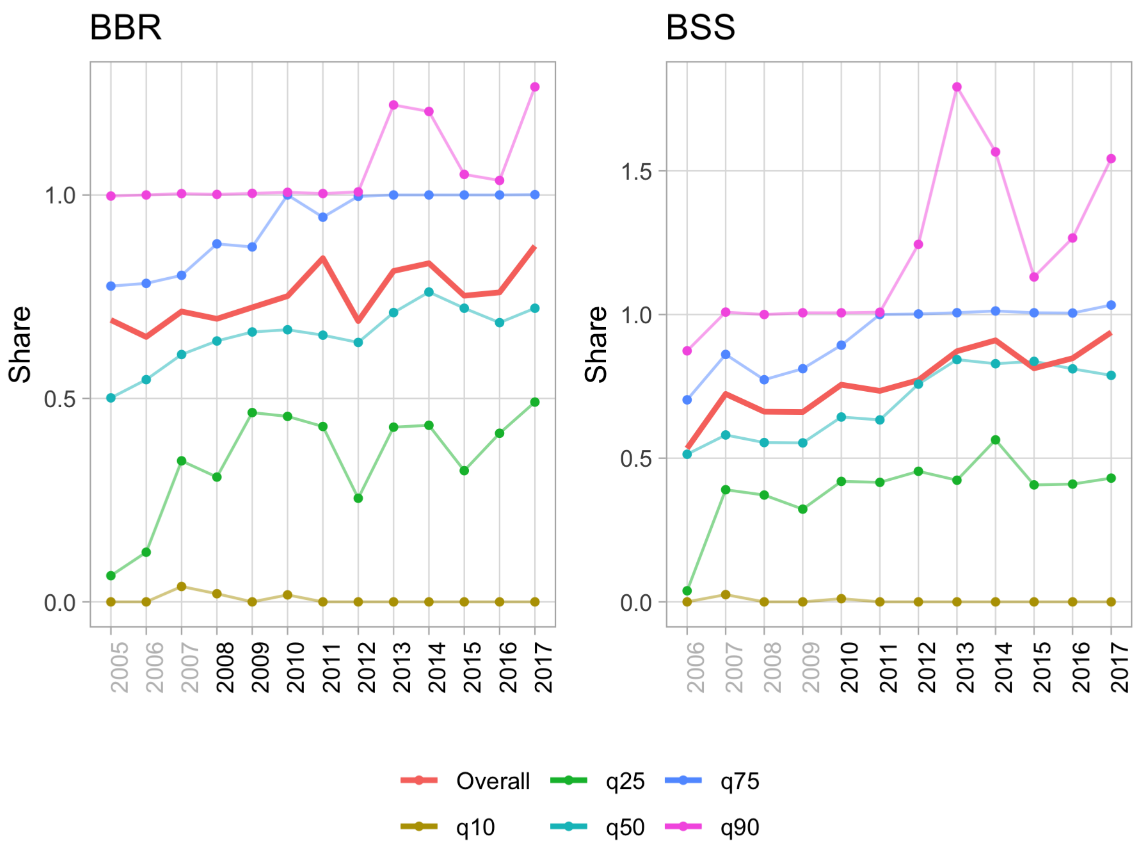


**Fig. S21.** Share of harvest caught using leased quota.

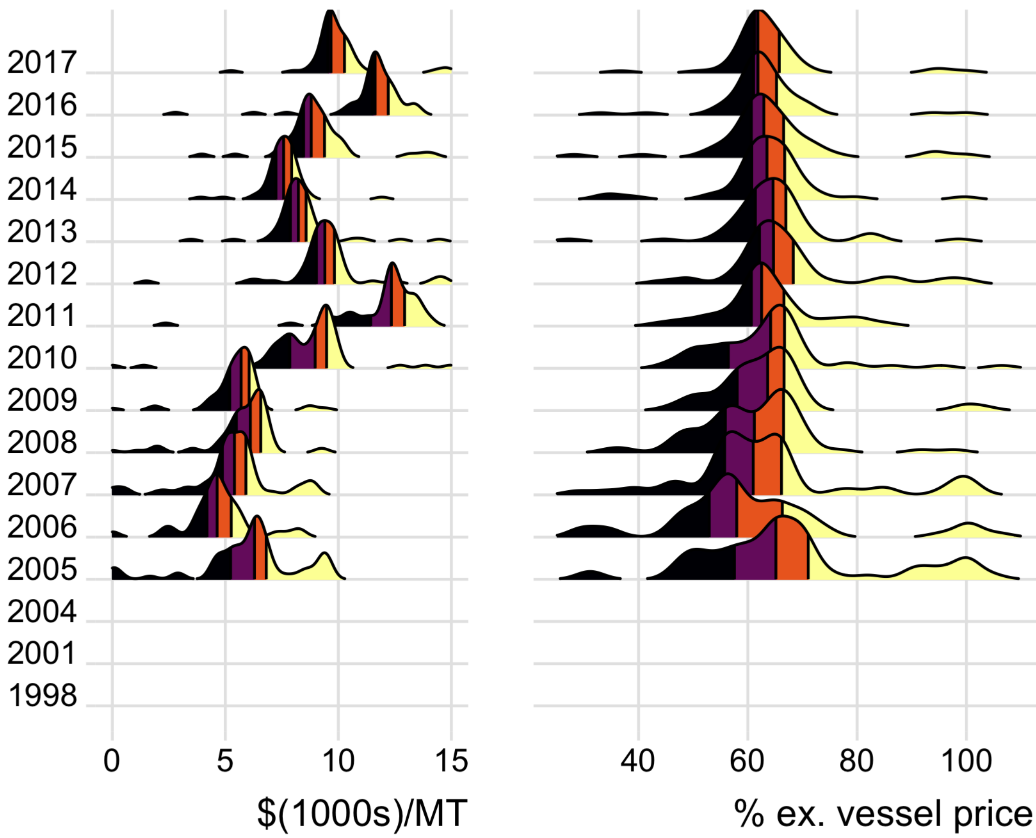


**Fig. S22.** Distribution of lease payments for BBR in absolute terms and in percentage of ex-vessel price.

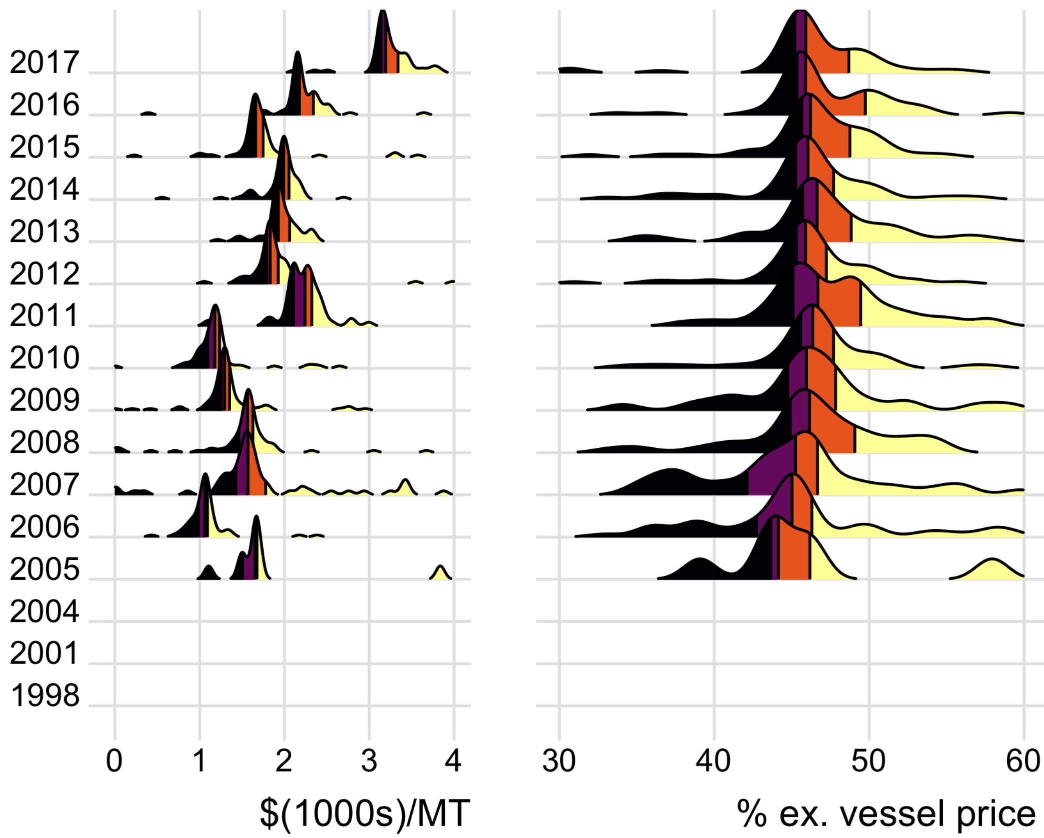


**Fig. S23.** Distribution of lease payments for BSS in absolute terms and in percentage of ex-vessel price.

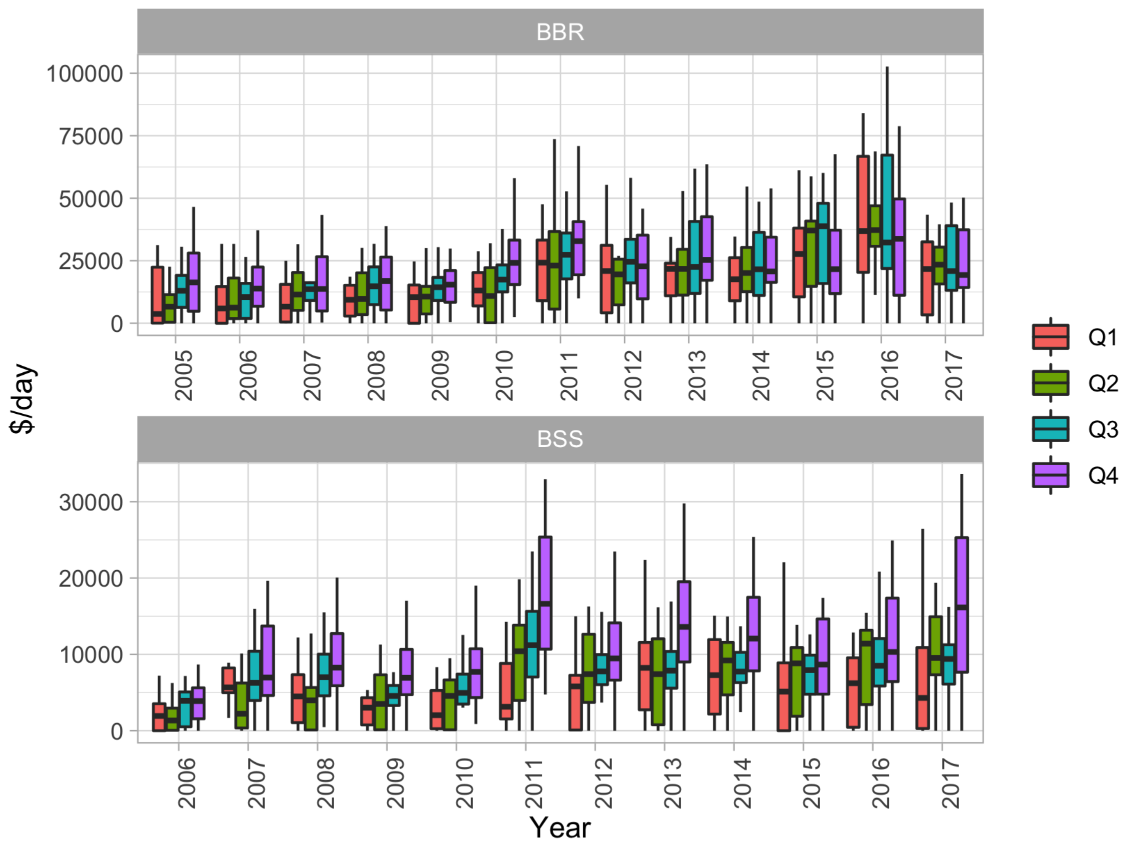


**Fig. S24.** Lease costs per day by quartile of median daily return to vessel owners in the pre-CR period.

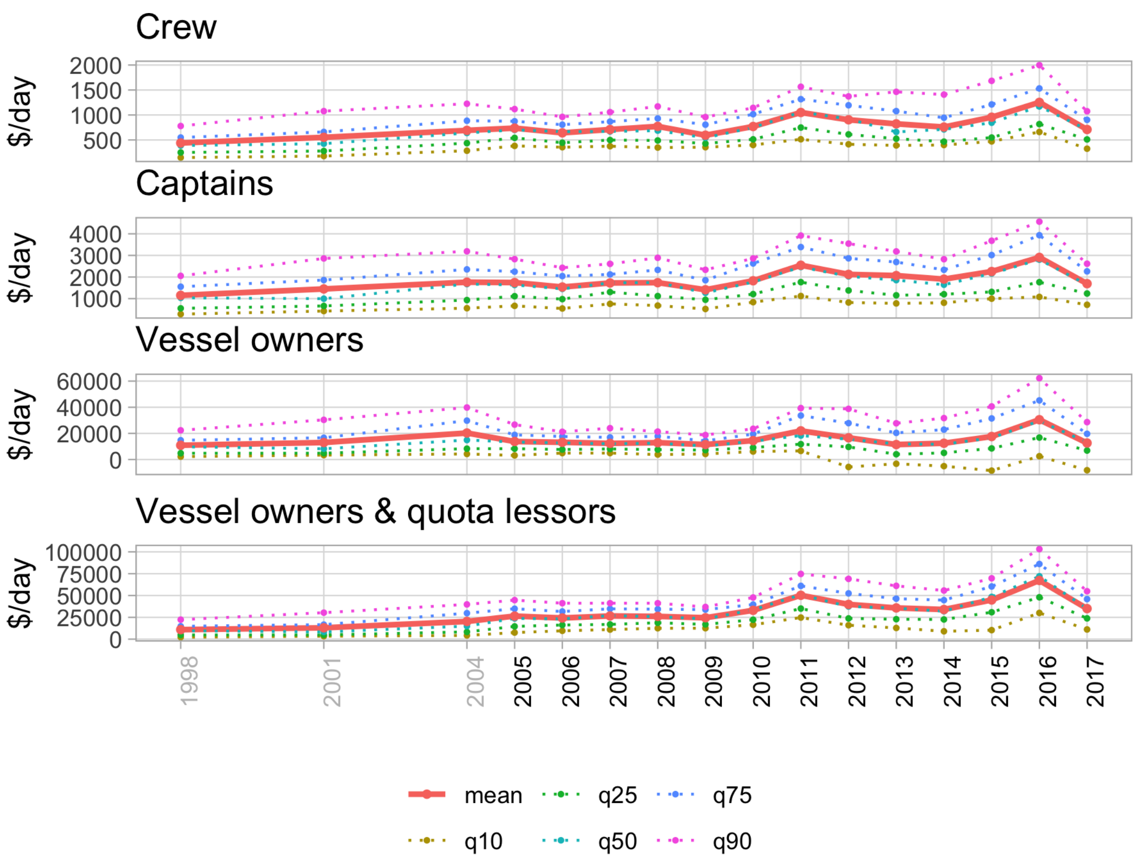


**Fig. S25.** BBR quantiles and mean of compensation to claimants, including non-fishing days in calculations for captain and crew pay (compare Fig. 3).

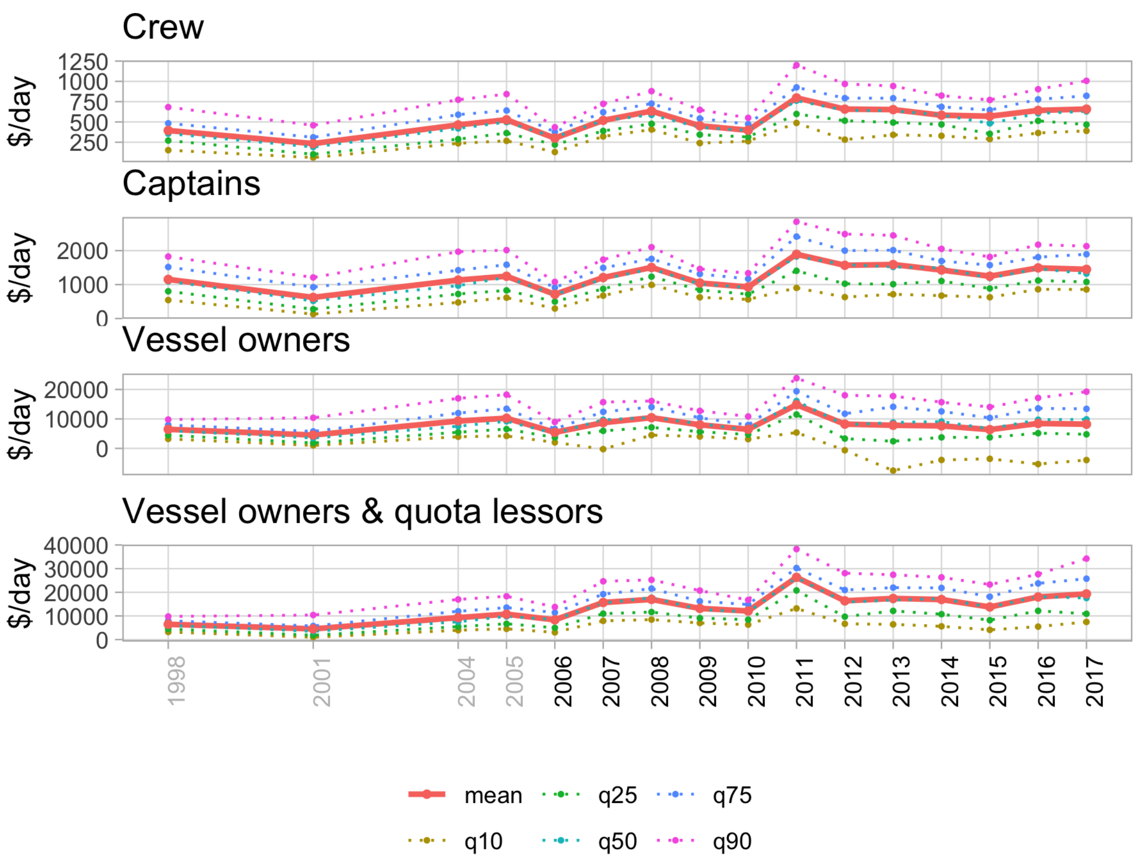


**Fig. S26.** BSS quantiles and mean of compensation to claimants, including non-fishing days in calculations for captain and crew pay (compare Fig. S11).

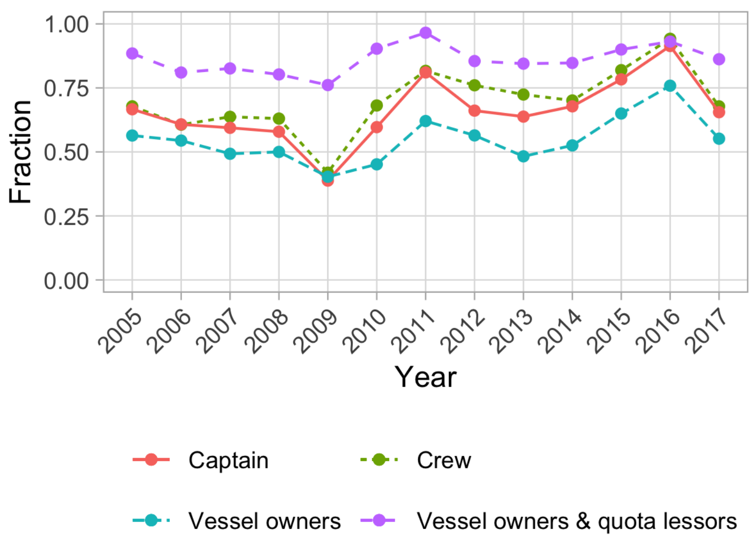


**Fig. S27.** Share of BBR claimants earning better than the median pre-CR daily remuneration (captains and crew) or seasonal return (vessel owners and quota lessors). Captain and crew pay is calculated to include non-fishing days (compare Fig. S13).

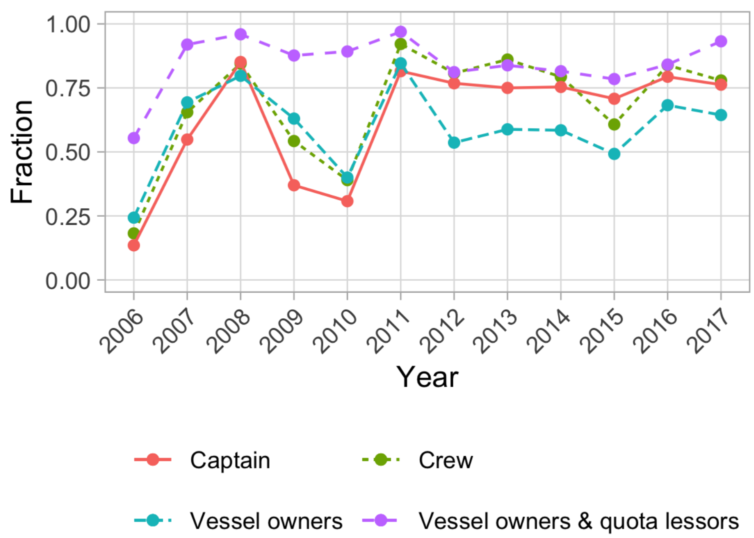


**Fig. S28.** Share of BSS claimants earning better than the median pre-CR daily remuneration (captains and crew) or seasonal return (vessel owners and quota lessors). Captain and crew pay is calculated to include non-fishing days (compare Fig. S14).

## Tables

| | log(labor cost/day) | | | log(owner return/day) | | |
|---|---|---|---|---|---|---|
| | Base | Controls | FEs | Base | Controls | FEs |
| (Intercept) | 8.54*** | 2.47 | | 10.64*** | 7.75*** | |
| | (0.04) | (1.32) | | (0.04) | (0.99) | |
| leasedratio | -0.04 | -0.02 | 0.11** | -0.20*** | -0.15** | -0.12* |
| | (0.04) | (0.06) | (0.04) | (0.03) | (0.05) | (0.05) |
| log(vprod) | | 0.64*** | 0.67*** | | 0.27*** | 0.27*** |
| | | (0.06) | (0.06) | | (0.03) | (0.03) |
| log(price) | | 0.56** | 0.39** | | 0.30* | 0.40** |
| | | (0.17) | (0.14) | | (0.12) | (0.13) |
| log(contribshare) | | -0.16 | -0.16 | | 0.14 | 0.24 |
| | | (0.30) | (0.16) | | (0.35) | (0.51) |
| $R^2$ | 0.00 | 0.55 | 0.82 | 0.09 | 0.21 | 0.30 |
| Num. obs. | 806 | 806 | 806 | 806 | 806 | 806 |

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. Cluster-robust SEs (cluster=vessel ID) are reported.

**Table S1. Regressions of daily remuneration to workers (crew and captains) and owners on the share of leased quota for the BSS fishery. All regressions with controls also include year dummy variables. The minimum daily return to owners (-29,318), plus one, is added to owner return prior to the log transformation to ensure positivity.**

| | labor cost/day | | | owner return/day | | |
|---|---|---|---|---|---|---|
| | Base | Controls | FEs | Base | Controls | FEs |
| (Intercept) | 10765.75*** | 2434.90 | | 23880.16*** | -7515.12 | |
| | (602.02) | (3573.18) | | (1642.30) | (14957.87) | |
| leasedratio | -1237.44* | -2040.03*** | -235.84 | -12767.20*** | -13190.79*** | -9717.88*** |
| | (519.12) | (566.64) | (407.97) | (1768.95) | (1846.72) | (2537.13) |
| vprod | | 1904.06*** | 1655.18*** | | 4651.82*** | 5582.22*** |
| | | (215.28) | (276.23) | | (532.34) | (682.63) |
| price | | 1.03*** | 0.67** | | 1.24 | 1.25 |
| | | (0.22) | (0.20) | | (0.69) | (0.87) |
| contribshare | | -10963.12** | -8560.84* | | -547.21 | 3993.31 |
| | | (3916.15) | (3995.54) | | (18603.38) | (23610.85) |
| $R^2$ | 0.02 | 0.53 | 0.77 | 0.26 | 0.59 | 0.72 |
| Num. obs. | 849 | 849 | 849 | 849 | 849 | 849 |

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. Cluster-robust SEs (cluster=vessel ID) are reported.

**Table S2. Regressions of daily remuneration to all workers (crew and captains) and vessel owners on the share of leased quota for the BBR fishery. All regressions with controls also include year dummy variables.**

| | labor cost/day | | | owner return/day | | |
|---|---|---|---|---|---|---|
| | Base | Controls | FEs | Base | Controls | FEs |
| (Intercept) | 5861.53*** | 2936.15 | | 12763.29*** | -9617.84* | |
| | (252.04) | (2148.72) | | (773.12) | (4016.80) | |
| leasedratio | -375.57 | -705.37* | -62.01 | -6143.32*** | -5737.45*** | -4232.92*** |
| | (210.57) | (321.52) | (216.65) | (890.62) | (1002.21) | (1117.39) |
| vprod | | 627.23*** | 660.14*** | | 1631.06*** | 1903.53*** |
| | | (62.17) | (61.56) | | (88.57) | (137.60) |
| price | | 0.29* | 0.33** | | 2.23** | 2.69*** |
| | | (0.14) | (0.11) | | (0.67) | (0.70) |
| contribshare | | -4637.23 | -4292.16 | | 3758.17 | 4192.70 |
| | | (2591.31) | (2981.93) | | (5168.26) | (6774.52) |
| $R^2$ | 0.01 | 0.43 | 0.64 | 0.29 | 0.70 | 0.80 |
| Num. obs. | 806 | 806 | 806 | 806 | 806 | 806 |

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. Cluster-robust SEs (cluster=vessel ID) are reported.

**Table S3. Regressions of daily remuneration to workers (crew and captains) and vessel owners on the share of leased quota for the BSS fishery. All regressions with controls also include year dummy variables.**