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Authors
Strabo, Frederik
Reimer, Matthew N
Sanchirico, James N

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Who benefits from capacity reduction programs? Insights from the U.S. Pacific Coast groundfish fishery

Frederik Strabo[†*], Matthew N. Reimer[†‡], and James Sanchirico[‡]

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Abstract

Overextraction and excess capacity are longstanding challenges in natural resource industries. Capacity-reduction programs are increasingly common policy responses designed to reduce capacity, reallocate access rights, and improve environmental and economic outcomes. Yet little is known about how such programs distribute benefits and costs among participants who remain in the industry. This paper estimates the benefits accruing from the U.S. Pacific Coast Groundfish Buyback Program, which retired over one-third of its vessel capacity through a voluntary $46 million reverse auction. Exploiting spatial variation in capacity reductions across ports within a difference-in-differences design, we find that active vessels operating in ports with larger relative reductions realized substantial revenue gains, while those elsewhere saw small or negligible gains. Conservative estimates suggest the program generated approximately $23.9 million in additional revenues net of variable costs and program fees over the first seven years, yielding approximately $4.66 in private net benefits per dollar of fees paid during this period. However, returns varied widely depending on the degree of local capacity reduction. These findings demonstrate that while capacity reduction programs can yield significant economic gains for remaining industry participants, their uneven impacts raise important questions about program design and the balance between efficiency and equity.

JEL Codes: Q20, Q22, Q28

Keywords: buyback, fisheries, capacity reduction, distributional effects

[*] *Corresponding Author*, `ftstrabo@ucdavis.edu`

[†] Department of Agricultural and Resource Economics, University of California, Davis

[‡] Department of Environmental Science and Policy, University of California, Davis

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1 Introduction

Across natural resource sectors, governments are increasingly turning to capacity reduction programs to manage overcapacity, ease transitions away from extractive industries, and balance environmental and economic objectives. Examples include the voluntary retirement of coal-fired power plants (Srivastav and Zaehringer, 2024), the buyout of water rights (Grafton and Wheeler, 2018), the retirement of grazing permits on public lands (PEER, 2024), and the payment for converting agricultural land to vegetative cover (Parks and Schorr, 1997; Hellerstein, 2017). These programs aim to permanently reduce extractive activity in targeted sectors while compensating participants who leave and providing benefits to those who remain. Yet despite their growing prevalence, we know relatively little about their economic effectiveness or how the benefits and costs are distributed among those who remain active in the industry.

In fisheries, vessel buyback programs have been widely adopted to reduce fleet capacity and promote the recovery of depleted stocks (Holland et al., 1999; Squires, 2010). The U.S. Pacific Coast groundfish fishery provides a prominent example. Declared a disaster in 2000, the fishery subsequently rebounded and was certified as sustainable by the Marine Stewardship Council in 2014. A pivotal step in this turnaround was the 2003 Pacific Coast Groundfish Buyback Program, a voluntary, industry-financed vessel retirement program that permanently removed approximately one-third of the active trawl vessel fleet. While the buyback program was one of several components leading to the biological recovery of the fishery (Warlick et al., 2018), the economic consequences of the program are less understood.

Theoretical work highlights several design challenges for buyback programs, including "effort creep"—improvements in gear, technology, or fishing practices that raise effective capacity—and incentives for capital reinvestment in anticipation of future buybacks, both of which may erode the intended efficiency gains (Holland et al., 1999; Clark et al., 2005, 2007; Weninger and McConnell, 2000). Other researchers have also raised concerns regarding the distributional impacts of buybacks (Watson and Johnson, 2012; Holland et al., 2017). For example, in some ports, more than 60% of the vessels were retired under the groundfish buyback program. Moreover, the cost of the program was repaid through a uniform landings fee collected on revenues from remaining trawl vessels, raising concerns that the burden of financing the program might not align with those who benefited most from the program.

These issues motivate our two research questions: To what extent did the buyback generate economic benefits for vessels that remained in the fishery, and how were those benefits distributed among them? To answer these questions, we draw on vessel-level data from 1994 to 2010 to evaluate the economic benefits and distributional impacts of the Pacific Coast Groundfish Buyback Program. We focus on vessels that remained active after the buyback and compare revenue outcomes according to the extent of capacity reduction at each vessel's main port. Our empirical strategy employs a continuous two-way fixed effects framework, which controls for time-invariant vessel characteristics and fishery-wide shocks, allowing us to isolate the relationship between localized capacity reductions and subsequent economic performance. We estimate the program's private net benefits by comparing observed outcomes with those that would have occurred in the absence of any capacity reduction. We then evaluate these benefits relative to the program fees paid by remaining vessels during our study period, providing a measure of the private returns to industry participants.

We find that vessels based in ports with larger buyback-induced capacity reductions experienced significantly greater revenue gains than those in less affected ports, averaging a 1.4% increase in revenues for each percentage-point reduction in capacity. These benefits were concentrated among trawl vessels that were active participants in the fishery and primarily driven by increased productivity in the groundfish fishery. Overall, conservative estimates suggest the buyback program generated positive aggregate benefits, producing revenue gains net of program fees of approximately $60 million over the first seven years. Using industry-reported estimates of variable costs, this amounts to $24 million—roughly half of the cost of the program—or $4.66 in net revenues for every one dollar paid in program fees. However, these benefits vary widely depending on the degree of local capacity reduction experienced. Indeed, our results suggest that vessels in ports with roughly no capacity reduction realized negligible gains after accounting for program fees, while vessels in ports with the largest capacity reduction gained an estimated $0.6 million, on average, over seven years. Together, these results reveal how spatially concentrated capacity reductions can yield localized efficiency gains, but also cause regional disparities.

Although vessels in ports with the largest capacity reductions experienced the greatest aggregate gains, their benefits per dollar of capacity retired were smaller, suggesting diminishing returns to geographically concentrated reductions. This pattern indicates that, all else equal, a more even spatial allocation of capacity reductions could generate greater aggregate gains and more balanced regional outcomes. At the same time, the persistence of localized gains and the absence of vessel relocation across ports after the buyback suggest that high port-switching costs and limited stock dispersal constrain the diffusion of benefits. Together, these findings imply that the efficiency and equity of capacity reduction programs depend not only on the overall scale of reductions, but also on their spatial distribution and the economic and ecological linkages that connect participants across space.

This paper contributes to the environmental policy literature by providing new evidence for designing policies that aim to promote conservation while supporting regional economic adaptation. While vessel buybacks have long been used in fisheries to reduce overcapacity, similar approaches—often structured as reverse auctions—are increasingly central to managing extractive activity across natural resource sectors (Srivastav and Zaehringer, 2024; Grafton and Wheeler, 2018; PEER, 2024; Parks and Schorr, 1997; Hellerstein, 2017). Yet empirical evidence on the economic, distributional, and spatial impacts of such transitions remains limited (for an exception, see Edwards, 2016). Our results show that concentrating effort reductions in specific locations can generate substantial localized gains for those who remain in the industry, but can also bring about regional disparities. These findings suggest that capacity reduction programs may entail significant distributional trade-offs, depending on how the reductions are allocated. Furthermore, our results suggest that incorporating considerations of the economic and ecological connectivity across ports into both the design and financing of capacity reduction programs may improve efficiency while reducing disparities in outcomes. As governments grapple with the need for managed transitions in the face of climate change, our study offers new evidence of how the spatial allocation of capacity reductions shapes both efficiency and distributional outcomes—patterns that may also emerge in other managed transition programs.

Our study also contributes to the growing literature on the design and evaluation of fishery buyback programs. Much of the existing research has focused on the theoretical foundations of buyback programs and their potential to improve efficiency and resource rents by reducing excess capacity (e.g., Clark et al., 2005, 2007; Squires, 2010). The literature emphasizes that capacity reductions alone are not guaranteed to lead to long-term efficiency gains without simultaneously addressing the incentives of remaining vessel owners to reinvest in unregulated dimensions of fishing capacity (e.g., Holland et al., 1999; Weninger and McConnell, 2000). However, relatively few empirical studies have tested these theoretical predictions or assessed whether buyback programs have delivered lasting economic benefits in practice (for exceptions, see Fox et al., 2006; Pascoe et al., 2012; Holland et al., 2017). The Pacific Coast Groundfish Buyback provides a rare opportunity to evaluate a program that was intentionally designed to mitigate these concerns: by simultaneously announcing a future catch share program with quota allocations based on pre-buyback catch histories, the policy limited incentives for capital reinvestment and strategic behavior. We show that under such conditions, capacity reduction programs can yield substantial and persistent efficiency gains among remaining industry participants.

The paper is organized as follows. We first discuss previous evaluations of fishery buyback programs and provide background on the Pacific Coast Groundfish Buyback Program (Section 2). We then present a conceptual framework that motivates how buyback programs are expected to generate economic benefits with spatially heterogeneous capacity reductions (Section 3), followed by a description of our empirical design (Section 4). Section 5 presents the estimates the heterogeneous impacts of the buyback program and its distribution of benefits across ports, and Section 6 concludes the paper.

2 Background

Fishery buyback programs

Fishery buyback programs have been implemented worldwide to reduce excess capacity, improve economic performance, and facilitate transitions to rights-based management systems such as individual transferable quotas (ITQs). In the United States, examples include the Pacific Coast Groundfish Buyback Program, the New England groundfish buyback (Walden et al., 2003), the Gulf of Mexico shrimp buyback (Mamula, 2009), and the Bering Sea pollock program (Felthoven, 2002). In Canada, large-scale buybacks were introduced following the 1992 cod moratorium (Schrank, 2005) and through the Pacific Salmon Revitalization Plan in British Columbia (Weninger and McConnell, 2000). Australia has pursued repeated decommissioning rounds in the Northern Prawn and South East Trawl fisheries since the late 1980s (Pascoe et al., 2012; Fox et al., 2006), while New Zealand paired a vessel buyback with the 1986 introduction of its Quota Management System to align fleet capacity with total allowable catches (Dewees, 1998). More recently, China has used buybacks to absorb excess capacity in domestic fisheries as part of its transition away from fuel subsidies (Wang et al., 2023). These experiences illustrate both the widespread adoption of buyback programs and the diversity of institutional contexts in which they have been applied.

While buyback programs have the potential to increase efficiency and reduce fishing pressure on depleted stocks in the short run, critics point out that they can unintentionally incentivize additional investment along unregulated dimensions of capacity, undermining initial efficiency gains (Campbell, 1989; Holland et al., 1999; Weninger and McConnell, 2000; Squires, 2010). The problem can be compounded when participants expect governments to offer future buyouts, since the possibility of being compensated later increases the incentive to expand present capacity (Clark et al., 2005, 2007). Sustaining long-term efficiency, therefore, requires institutional arrangements that remove these incentives. Pairing buybacks with an ITQ system is often viewed as one way to achieve this. However, even if ITQs are anticipated, excessive investment may still take place in the period preceding quota implementation, dissipating rents and offsetting many of the intended benefits (Clark et al., 2007).

Despite a substantial theoretical literature, relatively few studies provide empirical ex post evaluations of whether buyback programs yield durable economic benefits. Existing empirical work has examined improvements in technical efficiency and profitability following capacity reductions (Fox et al., 2006; Pascoe et al., 2012; Mamula and Collier, 2015), changes in the spatial distribution of landings and effort (Watson and Johnson, 2012), and the design and performance of the auctions used to remove capacity (DePiper, 2015). Our analysis extends this literature by evaluating both the cost-effectiveness and the distributional consequences of a large-scale buyback program resulting from heterogeneous capacity reductions across ports.

Several studies have examined the Pacific Coast Groundfish Buyback Program, most notably Holland et al. (2017), which provides one of the few quantitative assessments of a buyback's cost-effectiveness. Leveraging the fishery's transition to an individual fishing quota (IFQ) system eight years after the buyback, the authors estimate the value of the "buyback quota"—the catch shares that would have been allocated to retired vessels but were instead redistributed among the remaining participants. They find that the aggregate value of these quotas exceeded the costs of repaying the loan used to finance the buyback, implying an overall economic gain. However, they note that not all vessels may have benefited from the program, as all remaining participants were required to fund the loan through landings fees, regardless of the capacity reduction in their own ports. Importantly, by valuing buyback quotas in the post-ITQ period, their analysis captures the combined effects of both the buyback and the subsequent catch share program. In contrast, we estimate the direct, near-term effects of the 2003 buyback, isolating its immediate impact on revenues and participation before the ITQ program was introduced. Moreover, we examine the distributional consequences of the buyback itself, showing that the benefits were uneven across vessels and ports.

A related study by Watson and Johnson (2012) analyzes the spatial distribution of landings before and after the groundfish buyback program. The authors find that the program reduced the geographic dispersion of landings and that ports more heavily affected by vessel retirements experienced higher landings in subsequent years. This finding motivates one of our core hypotheses: that vessels based in ports where capacity reductions were most pronounced benefited disproportionately from the buyback's implementation.

Setting

The West Coast groundfish fishery is among the most ecologically and economically significant fisheries in the United States, encompassing over 90 species of rockfish, flatfish, and roundfish harvested across the coastal waters of California, Oregon, and Washington. Key commercial species include Pacific whiting, Dover and petrale sole, sablefish, lingcod, and multiple rockfish species such as widow, canary, and bocaccio (Warlick et al., 2018). These species support both trawl and fixed-gear fleets and have long played a central role in coastal economies throughout the region.

The modern groundfish fishery expanded rapidly following the passage of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) in 1976. The MSA created a 200-mile fishery conservation zone, which later became part of the exclusive economic zone, and established the Pacific Fishery Management Council (PFMC) to set science-based catch limits (Dell'Apa et al., 2012). The exclusion of foreign fleets and expanded federal support spurred a rapid expansion in the domestic trawl fleet, tripling in size between 1976 and 1979 and more than doubling groundfish landings by 1982.[1] However, scientific understanding of the exploited fish stocks lagged behind this growth: many groundfish species are long-lived and slow to reproduce, and early catch limits proved unsustainable. By the mid-1980s, landings of key species such as canary and widow rockfish had declined by more than 60%, and by the 1990s, the fishery suffered from persistent overcapacity, declining stocks, and poor economic performance (Holland et al., 2017). In response, managers implemented a limited entry program in 1994 that restricted participation in the groundfish trawl fishery (Warlick et al., 2018). Yet despite permit restrictions and trip limits on harvests, overfishing continued. In 2000, the fishery was declared a federal disaster, citing stock depletions and widespread economic hardship.

The disaster in the groundfish fishery prompted a series of structural reforms aimed at improving both ecological sustainability and economic viability, including the Pacific Coast Groundfish Buyback Program, enacted by Congress in 2003. The program sought to reduce fleet overcapacity through a reverse-auction mechanism that permanently retired trawl vessels and their permits. Vessel owners submitted bids to the National Marine Fisheries Service (NMFS), which ranked them based on the ratio of historical ex-vessel revenue (from groundfish, Dungeness crab, and pink shrimp) to the bid amount.[2] This metric aimed to maximize the expected capacity reduction per dollar spent. The program accepted all bids until the available \$46 million budget was exhausted, resulting in the retirement of 91 out of 108 bidding vessels (NMFS and NOAA, 2003) that were responsible for 40% of ex-vessel revenue from all trawlers in 2002 (Warlick et al., 2018). The program was financed by a combination of \$10 million in public funds and a \$36 million loan to be repaid over 30 years via landings fees on ex-vessel revenues from groundfish, Dungeness crab, and pink shrimp. For example, the trawl sector was originally responsible for repaying \$28.4 million through a 5% fee on ex-vessel revenues, with a 6.97% interest rate. Notably, this fee also applied to groundfish caught with fixed gear under the subsequent IFQ program.

The buyback was implemented over a relatively short time window. NMFS issued a formal invitation for bids on July 18, 2003. The bidding period closed on August 29, and accepted bids were announced shortly thereafter. A referendum on program implementation passed in October 2003 with 85% approval, and by December 4, all accepted vessels were permanently removed from the fishery and were not permitted to be used for commercial fishing in any other fishery in the future.

These reforms laid the foundation for the 2011 transition to the IFQ program in the groundfish trawl sector, which further sought to align economic incentives with sustainable harvest. Managers established a control date for determining future catch share allocations at the time of the buyback, setting quota allocations based on catch history only up to 2003. The control date was intended to

[1] Historical account based on information from https://www.westcoastgroundfish.com.

[2] Revenues were calculated as the average of the vessel's three highest annual totals from 1998–2001.

discourage vessels from expanding fishing effort in anticipation of the catch share program and to ensure that future allocations to the remaining permit holder would not be diluted if other vessels increased their catch. The quota that would have been issued to the retired vessels was instead allocated to those that remained in the fishery. The buyback thus marked a pivotal institutional turning-point in the governance of the fishery—reducing overcapacity, improving profitability, and paving the way for long-term ecological and economic recovery in the fishery.

3 Conceptual Framework

In this section, we outline the mechanisms through which a buyback program with spatially uneven capacity reductions can generate heterogeneous benefits. Local capacity reductions can affect remaining participants both on the water, by reducing fishing congestion and allowing local biomass to recover, and at the port, by easing congestion in processing and service facilities and altering local market conditions. Spatial heterogeneity in fish stocks, local markets for buyers and sellers, and port-switching costs jointly determine whether and how these local benefits persist over time.

Baseline bioeconomic system

Consider a coastline partitioned into spatially distinct ports, $p \in \mathcal{P}$, each with access to a nearby fishing ground (or patch). For simplicity, assume that the fishery consists of a single spatially distributed stock and operates under limited entry, with a fixed number of vessels. Following the spatiotemporal bioeconomics literature (e.g., Sanchirico and Wilen, 1999), biomass dynamics in each patch evolve according to the following difference equation:

$$X_{p,t+1} = X_{p,t} + g_p(X_{p,t}) - h(X_{p,t}, N_{p,t})N_{p,t} + \sum_{k \in \mathcal{P}} d_{kp} X_{k,t},$$

where $X_{p,t}$ and $N_{p,t}$ denote biomass and the number of vessels, respectively, in port p and period t, $g_p(\cdot)$ represents local biological growth, and d_{kp} captures dispersal of biomass from one patch to another. Harvest per vessel, $h(\cdot)$, depends positively on local biomass and negatively on local vessel density, reflecting on-the-water congestion (Brown Jr, 1974). We assume vessels choose where to fish but not how much effort to exert, implicitly assuming that vessels do not race for fish along unregulated dimensions of effort.

Each vessel chooses its home port to maximize expected profits net of switching costs:

$$Y_{i,p,t} = \begin{cases} 1 & \text{if} \quad \pi_{i,p,t} - c_p(Y_{i,t-1}) > \pi_{i,k,t} - c_k(Y_{i,t-1}) \quad \forall p \neq k \\ 0 & \text{otherwise,} \end{cases}$$

where $\pi_{i,p,t}$ is profit from operating out of port p, and $c_p(\cdot)$ denotes the cost of switching to port p from the vessel's previous home port. The number of vessels operating from each port is therefore $N_{p,t} = \sum_i Y_{i,p,t}$. Fishing profits are given by

$$\pi_{i,p,t} = \rho \cdot h(X_{p,t}, N_{p,t}),$$

where ρ denotes the ex-vessel price net of variable fishing costs.

Spatial equilibrium and buyback effects

In equilibrium, vessels will distribute across ports such that no vessel can unilaterally improve their expected profit by switching ports, given switching costs. With homogeneous vessels and zero switching costs, the equimarginal principle requires that expected profits are equalized across ports. In this frictionless benchmark, spatial differences in local stock abundance and congestion dissipate through vessel mobility.

A buyback program that removes capacity unevenly across ports disrupts this spatial equilibrium. Ports that experience greater vessel reductions will initially enjoy higher per-vessel harvests and profits due to lower congestion and local stock recovery. These localized gains are expected to persist if vessel mobility is limited or fish stocks are weakly connected across space. In contrast, when dispersal is high and switching costs are low, we expect vessels to reallocate toward the most profitable ports and stocks to diffuse, eroding spatial differences in benefits over time. In the extreme of perfect mobility and full stock connectivity, post-buyback profits will equalize across ports, and local benefits will dissipate.

This stylized framework yields the following two predictions. First, vessels operating in ports with greater relative capacity reductions should experience larger immediate post-buyback increases in revenues relative to those in less-affected ports. Second, the persistence of these gains depends on spatial frictions: the benefits will last longer when vessel mobility is limited or when local stocks are weakly linked to adjacent areas. This second prediction also raises a potential empirical challenge: if vessels are mobile or local stocks are strongly connected through dispersal, then the benefits of capacity reduction in one port will spill over into other ports, violating the stable unit treatment assumption (SUTVA). We return to this issue in our empirical framework.

4 Empirical Design

Our empirical design exploits the removal of vessels under the Pacific Coast Groundfish Buyback Program to estimate how reductions in fishing capacity affected the performance of vessels that remained in the fishery. A key feature of our empirical strategy is the spatial heterogeneity in capacity reductions: vessels removed under the buyback program were unevenly distributed across ports, resulting in differential exposure to capacity reductions for the remaining fleet. We measure treatment intensity as the share of pre-buyback revenues purchased under the program in each port, providing a relative measure of local capacity reduction at a vessel's home port. Using this continuous measure in a difference-in-differences framework, we estimate how local capacity reductions affected vessel performance over time.

We estimate a vessel's performance under the observed reduction in capacity relative to a counterfactual scenario with no capacity reduction. Because treatment intensity varies continuously across space, we estimate the dose-response relationship between capacity reduction and vessel performance. Our parameters of interest are the average level treatment effect (ATT), defined as the average effect of experiencing a given level of capacity reduction relative to receiving no capacity reduction, and the average level treatment effect per unit of capacity reduction (ATT/d, Callaway et al., 2024).[3] Under the assumption that port-level capacity reductions are independent of future trends in vessel performance, we interpret our estimates as causal effects of the buyback program and use them to assess both its aggregate and distributional consequences for remaining participants.[4]

Data

Our primary dataset combines commercial landings data, limited entry permit records, and vessel registration data for vessels participating in the Pacific Coast groundfish fishery from 1994 to 2010—the final year before the introduction of IFQs. These data are compiled and maintained by

[3]Formally, let $Y_t(d)$ denote the potential outcome in period t under treatment dosage (or capacity reduction) $D = d$, and assume vessels are exposed to the treatment for all $t \geq T_0$. The level treatment effect is defined as the difference in potential outcomes from switching treatment from zero to dose d, $Y_t(d) - Y_t(0)$, referred to as the dose-response function. The average level treatment effect,

$$ATT(d|d') = E[Y_t(d) - Y_t(0)|D = d'],$$

represents the average effect of dose d relative to zero dosage for units that actually experienced dose d'. Thus, the per-unit effect of dose d for those who received dose d is $ATT(d|d)/d$ and the total effect of the assigned doses across all units is $\sum_d N_d ATT(d|d)$, where N_d is the number of units that received dose d.

[4]Callaway et al. (2024) show that the average level treatment effect is identified under two key assumptions: (i) no anticipation and (ii) parallel trends in the absence of treatment. The latter requires that the average change in untreated potential outcomes for units with dose d equals that for untreated units. These assumptions are sufficient to identify the causal effect of the program as implemented.

the Pacific Fisheries Information Network (PacFIN) of the Pacific States Marine Fisheries Commission. The commercial landings database provides comprehensive records of the value and volume of all shoreside commercial landings, reported at the vessel-day-species level.

We define groundfish vessels as those that held a limited-entry groundfish permit at any point during the sample period. Permit and vessel information are drawn from a publicly available database (NOAA, 2025). We link vessels across data sources using unique U.S. Coast Guard vessel identifiers. We identify vessels removed under the buyback program using Federal Register documents listing all retired vessels along with their associated permits and Coast Guard numbers (United States, Department of Commerce, 2003). We are able to match all 91 vessels that participated in the program to our dataset.

Samples

We focus our analysis on two samples of groundfish vessels. The first (full) sample is an unbalanced panel of all vessels that held a groundfish permit in 2003—the year the program was implemented—but were not retired as part of the program. While these vessels had the potential to benefit from the reduction in capacity, the sample includes many that were intermittently active or did not hold permits consistently throughout the study period, complicating the interpretation of treatment effects over time (Miller, 2023). To address this, our second (balanced) sample is restricted to vessels that held permits and participated in the groundfish fishery every year from 1994 to 2010. This more stable sample allows us to estimate the impact of the buyback program on continuously active participants—those most likely to benefit from reductions in fishing capacity.

One potential concern with our balanced sample is the possibility of attrition bias. For example, if low-performing vessels exposed to less capacity reduction are more likely to exit the fishery, the remaining vessels in our balanced sample would disproportionately consist of higher-performing vessels in low-exposure ports. In this case, selective attrition would bias our estimated effects of treatment exposure downward. However, as long as our identifying assumptions hold within the balanced sample, we are still able to consistently estimate an average treatment effect for vessels in the balanced sample (i.e., active groundfish participants), as opposed to the entire groundfish fleet (Ghanem et al., 2023). To assess whether the impacts of capacity reduction in the balanced sample are driven by attrition, we examine whether attrition through post-buyback exit and participation vary systematically with treatment intensity in the full sample.

Because the buyback program retired only trawl vessels, which generally operate in different fishing grounds than fixed-gear vessels, we expect trawl vessels to benefit most from reductions in on-the-water congestion.[5] However, if capacity reduction also affects port-level congestion,

[5]For example, Wang et al. (2024) use high-resolution Vessel Monitoring System (VMS) data to show that limited-

infrastructure, or services, fixed-gear vessels may also experience indirect benefits. To account for these possibilities, we estimate treatment effects separately by gear type, restricting the analysis to either trawl or fixed-gear vessels.

Finally, we exclude vessels whose home ports experienced zero capacity reduction under the buyback program. These ports—typically located in Southern California—differ systematically from treated ports in terms of species composition, regulatory context, and market conditions. Thus, we exclude them from the main analysis to enhance comparability among vessels exposed to different levels of treatment. As a result, our estimated average treatment effects are interpreted relative to the lowest nonzero level of treatment exposure, rather than to no exposure at all (Callaway et al., 2024).

The balanced sample of trawl vessels includes 70 vessels (Table S.1), representing approximately one-half of the vessels and three-quarters of groundfish revenues in the full sample (Figure A1). Similarly, the balanced sample of fixed-gear vessels is comprised of 27 vessels, representing one-quarter of the vessels and one-half of the groundfish revenues in the full sample. On average, vessels are comparable in size and their specialization in groundfish fisheries across samples, although vessels in the balanced sample tend to have higher total revenues across all fisheries in the years prior to the buyback program (Table S.2).

Defining Treatment

We define a vessel's treatment exposure, $Treat_i$, as the percentage of groundfish ex-vessel revenues retired through the buyback program in vessel i's main port, p. Formally:

$$Treat_i = 100 \times \frac{\textit{Buyback Revenues}_{p(i)}}{\textit{Total Revenues}_{p(i)}}, \tag{1}$$

where $p(i)$ is vessel i's main port, defined as the port where it landed the highest cumulative revenue during 1998–2001. $Buyback\ Revenues_{p(i)}$ represents the total groundfish revenues landed by vessels retired through the buyback program in port $p(i)$ during this period, while $Total\ Revenues_{p(i)}$ is the total groundfish revenues landed by all vessels in the same port over the same timeframe. This period corresponds to the base years NMFS used to rank vessels for buyback eligibility.[6]

We use a relative measure of capacity reduction rather than an absolute count of vessels retired for three reasons. First, ports differ greatly in baseline fleet size, infrastructure, and market capacity, so a proportional measure better captures the relevance of the local shock. Second, conditional

entry fixed-gear and trawl vessels fish in distinct areas. Differences in trip limits and other pre-ITQ regulations further suggest limited overlap between these gear types.

[6] We select 1998–2001 to align with the NMFS buyback ranking criteria. We also test alternative timeframes—including shorter, longer, and different periods—and find our results to be generally robust to these choices (Table A7).

on baseline port characteristics, relative reductions are more plausibly exogenous to future vessel performance because the buyback's reverse-auction mechanism determined participation based on vessel-specific bids rather than port-level factors. Finally, a proportional measure provides a common scale for comparing treatment intensity across ports, facilitating interpretation of the estimated effects as the impact per percentage-point reduction in local capacity.

A potential concern is whether our definition of a vessel's main port accurately reflects where it lands the majority of its catch over time. If vessels regularly distribute their landings across multiple ports, assigning treatment exposure based solely on the main port may result in an inaccurate measure of actual exposure.[7] However, we find that a vessel's main port is a strong predictor of where it lands the majority of its revenue: over 50% of vessels receive more than 93% of their revenues from a single port between 1998 and 2001, and over 90% receive more than 50% (Figure A2). These findings support the validity of our main port treatment exposure measure. As a robustness check, we also consider an alternative treatment measure that accounts for vessels with multi-port landing patterns by using a weighted average of buyback exposure across all ports.[8]

Figure 1 demonstrates the heterogeneity in treatment exposure across ports and vessels. We categorize ports and vessels into four exposure groups: very low (0–10%), low (10–20%), medium (20–40%), and high (>40%). We choose these cutoffs so that each group represents roughly equal variation in treatment intensity. In general, there is considerable heterogeneity in treatment exposure. For example, vessels in Eureka experienced a 61% capacity reduction in groundfish revenues, while those in San Francisco experienced only a 15% reduction (Table S.1). There is also considerable heterogeneity in vessel characteristics across treatment exposure groups (Table S.2). For example, vessels in high treatment-exposure groups tend to earn less total revenue, specialize less in groundfish fisheries, and spread landings across more ports in the pre-buyback years than those in low and medium exposure groups. We account for these differences across vessels in our empirical strategy by including vessel-level fixed effects and allowing trends in vessel performance to vary across vessels based on their observed characteristics.

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[7] For instance, consider two vessels with the same designated main port: one lands all of its revenue there, while the other lands half of its revenue there and the other half across two other ports. Our measure would assign both vessels the same level of treatment exposure, despite meaningful differences in where they operate. Such misclassification could introduce measurement error and attenuate estimated treatment effects.

[8] Specifically, we compute this alternative treatment measure as:

$$Treat_i = 100 \times \sum_p w_{i,p} \frac{\textit{Buyback Revenues}_p}{\textit{Total Revenues}_p},$$

where $w_{i,p}$ is the percent of revenues landed in port p by vessel i, $Buyback\ Revenues_p$ is the total groundfish revenues landed by vessels retired through the buyback program in port p, and $Total\ Revenues_p$ is the total groundfish revenues landed by all vessels in port p, from 1998-2001.

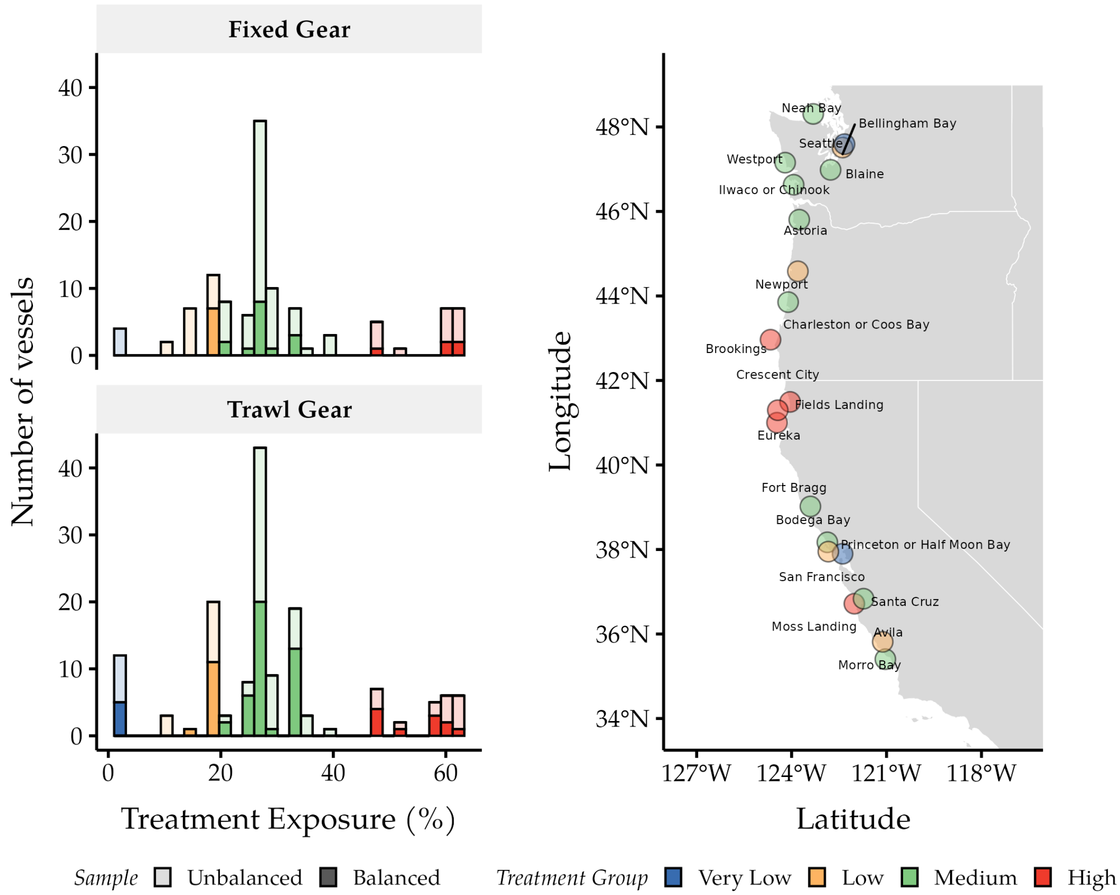

Figure 1: Distribution of treatment exposures across ports and vessels. *Left panel:* the distribution of the treatment exposure across vessels, by sample (Unbalanced and Balanced) and gear (Trawl and Fixed Gear). Dark-shaded bars represent vessels in the balanced sample, while light-shaded bars represent vessels unique to the unbalanced sample. The full sample is the sum of the dark- and light-shaded bars. *Right panel:* the spatial distribution of the treatment exposure across ports. Vessels and ports are categorized by exposure bins, measured as the percentage of groundfish revenues corresponding to the bought-out vessels between 1998 and 2001: Very Low (0–10%), Low (10–20%), Medium (20–40%), and High (40–62%).

Estimation

Our baseline specification is the two-way fixed effects (TWFE) model,

$$Y_{it} = \beta \cdot Treat_i \cdot Post_t + \mu_i + X_i' \gamma_t + \epsilon_{it}, \tag{2}$$

where Y_{it} denotes the outcome of interest for vessel i in year t, $Post_t$ is an indicator equal to one for years following the buyback (2004 onward), and $Treat_i$ is the treatment exposure (defined in Eq. 1). Fixed effects, μ_i, control for vessel-specific, time-invariant unobserved heterogeneity, such as skipper skill. The interactive fixed effects $X_i'\gamma_t$ include year fixed effects and allow for year-specific factors, such as trip limits and market conditions, to affect vessels differentially based on observed characteristics X_i, such as vessel length and specialization in groundfish fisheries prior to the buyback program.

Our primary outcome variable is the natural log of total fishing revenues earned across all fisheries, which captures both potential improvements in groundfish performance and substitution across fisheries in response to treatment exposure. To explore mechanisms through which benefits from the buyback program may arise, we estimate additional models using alternative outcomes, including log groundfish-specific revenues and harvests, the number of trips taken, and average harvest per trip.

As shown by Callaway et al. (2024), the TWFE coefficient β from Eq. 2 represents a weighted average of the level treatment effect per unit of exposure across all observed levels of treatment exposure, ATT/d. For our primary outcome, this effect is interpreted as the difference (in logs) in total revenues per percentage-point reduction in capacity at a vessel's home port. While the difference in logs approximates the percentage difference for small differences, we report exact percentage differences using the formula $100 \cdot (e^{\beta} - 1)$. We compute an aggregate measure of capacity reduction impacts as $\bar{d} \cdot \beta$, where $\bar{d}$ is the average treatment exposure across all vessels.

While the TWFE coefficient β provides an aggregate measure of the ATT/d, it suffers from the fact that the weights used to average over treatment exposure levels are not intuitive and can take on negative values (Callaway et al., 2024). This is not problematic if the per-unit level treatment effects are homogeneous across treatment exposure. However, if treatment effects vary with the level of exposure, the presence of negative and unintuitive weights can complicate interpretation and obscure the underlying dose-response relationship.

To address the limitations of the TWFE specification with continuous treatment, we estimate an alternative model that allows for heterogeneous treatment effects across exposure levels and facilitates the construction of average level treatment effects using non-negative, interpretable weights based on the distribution of treatment exposure. We divide vessels into one of four discrete exposure groups, as shown in Figure 1, and replace the linear term $\beta \cdot Treat_i$ in Eq. 2 with a saturated set of treatment exposure indicators, with the lowest-exposure group as the omitted category:

$$Y_{it} = \sum_{j=1}^{J} \theta_j \cdot \mathbf{1}\{Group_i = j\} \cdot Post_t + \mu_i + X_i'\gamma_t + \epsilon_{it}. \tag{3}$$

In this specification, θ_j represents the average level treatment effect, $ATT(d_j|d_j)$, for exposure group j. Thus, $\theta_j/\bar{d}_j$ represents the per-unit average level treatment effect, $ATT(d_j|d_j)/d_j$, where $\bar{d}_j$ denotes the average treatment exposure in group j. To recover an aggregate treatment effect across all exposure levels analogous to the TWFE estimate, we compute a weighted average using group-specific sample shares:

$$ATT^{Bin} = \sum_{j=1}^{J} w_j \theta_j \quad \text{and} \quad ATT/d^{Bin} = \sum_{j=1}^{J} w_j \frac{\theta_j}{\bar{d}_j}, \tag{4}$$

where w_j is the proportion of all vessels in exposure group j.

To test the validity of the parallel trends assumption and to allow for dynamic treatment effects, we estimate an event study version of the TWFE model:

$$Y_{it} = \sum_{\substack{y=-10 \\ y \neq -1}}^{7} \beta_y \cdot \mathbf{1}\{Year_t = y\} \cdot Treat_i + \mu_i + X_i' \gamma_t + \epsilon_{it}, \tag{5}$$

where $Year_t$ denotes the year relative to the first full calendar year following implementation of the buyback year (2004), and β_y captures the treatment effect in event time y. Coefficients with $y < -1$ correspond to pre-buyback years and allow us to assess whether trends in outcomes were parallel across different levels of treatment exposure prior to the buyback program. Coefficients with $y \geq 0$ capture post-buyback dynamics, enabling us to examine the evolution of treatment effects over time. We omit $y = -1$, so all β_y coefficients are interpreted relative to 2003, the year in which the buyback program was implemented. In addition, we estimate an event study version of our nonparametric dose-response function in Eq. 3, allowing for heterogeneous dynamic treatment effects across exposure groups.[9]

5 Results

Capacity reduction improves total revenues for active trawlers only. Table 1 reports estimates of the average level effect per unit of exposure, ATT/d, from the TWFE specification in Eq. 2 using the natural log of total revenues as the outcome variable. We report estimates for the full and balanced samples, as well as the trawl and fixed-gear fleets. We find that higher local capacity reductions are associated with improved revenue performance for the balanced panel of trawl vessels (column 3), equal to a 1.4% increase in total revenues per percentage-point reduction in capacity (p-value = 0.0023). With an average capacity reduction of 27.7%, this equates to a 47% increase in annual revenues, on average, for active trawlers.[10] We do not find any evidence that

[9]Estimation is conducted using the `fixest` package in R (Bergé, 2018).

[10]The ATT/d estimate from the TWFE model is measured as the difference in logs. Evaluating program impacts on total revenue at the average level of capacity reduction (27.7%) amounts to a difference in logs of $0.014 \cdot 27.7 = 0.39$. Converting this to an exact percentage change, we obtain $100 \times (e^{0.39} - 1) = 47.4\%$.

Table 1: TWFE Baseline Results: Total Revenues

	Full		Balanced	
	Trawl (1)	Fixed (2)	Trawl (3)	Fixed (4)
$Post_t \cdot Treat_i$	0.005	0.003	0.014**	-0.002
	(0.005)	(0.005)	(0.005)	(0.005)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	2,193	1,686	1,190	408
R^2	0.64	0.64	0.66	0.81

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
This table reports the TWFE results with the natural log of total revenues as the dependent variable using four different samples: (1) full sample of trawl vessels, (2) full sample of fixed-gear vessels, (3) balanced panel of trawl vessels, and (4) balanced panel of fixed-gear vessels. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

capacity reduction improves revenue performance when we include non-active trawl vessels in the sample (column 1), nor do we find evidence of an effect for fixed-gear vessels (columns 2 and 4). Estimates of ATT/d using the nonparametric approach in Eq. 3 provide similar results (Table S.3).

Our results suggest that reductions in local fleet capacity increased revenues for only active remaining vessels. Moreover, the lack of a statistically significant effect for fixed-gear vessels suggests that revenue gains from capacity reductions were largely confined to trawl vessels. This is consistent with prior evidence that fixed-gear and trawl vessels operate in largely non-overlapping grounds and target different species, limiting the extent to which the removal of trawl vessels would provide spillover benefits into the fixed-gear fleet.

Capacity reduction provides sustained total revenue increases for active trawlers. Estimates of the event study coefficients in Eq. 5 demonstrate that the revenues of active trawlers increased from the capacity reduction immediately after the onset of the buyback program, and these gains persisted until the catch share program was implemented in 2011 (Figure 2).[11] The sustained revenue gains from capacity reduction indicate that the program was successful in preventing effort creep over time and that local benefits did not dissipate with vessel mobility or stock connectivity, as suggested by our conceptual framework.

Event study coefficients demonstrate a moderate decline prior to the buyback program, sug-

[11] Event-study coefficients for all samples are presented in Figure A3.

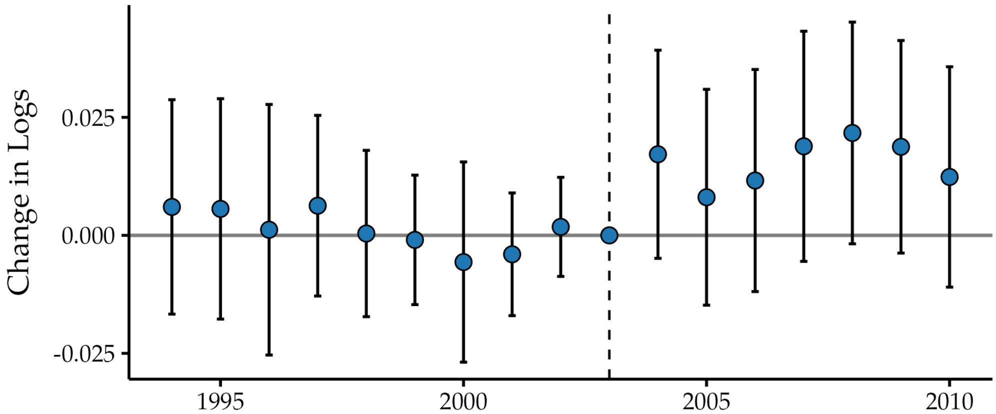

Figure 2: Event-study coefficients: balanced trawl sample. Estimates of the annual average level treatment effect on total revenue, per one percent reduction in capacity. Treatment effects estimated using the TWFE model in Eq. 5. Error bars represent 95% confidence intervals using standard errors clustered at the vessel level. Treatment exposure is measured as the percentage of groundfish revenues corresponding to the bought-out vessels between 1998 and 2001. The reference year is 2003.

gesting that capacity reduction may have been more concentrated in ports where revenues of active groundfish trawlers were declining. A joint test of the null hypothesis that all pre-treatment coefficients are equal to zero is easily rejected (p-value = 0.002), raising doubt over the validity of the parallel trends assumption. However, violation of the parallel trends assumption would result in attenuation bias toward zero if the declining differential pre-trend had persisted in the post-treatment years in the absence of the buyback program. Indeed, a partial identification approach that allows for violations of parallel trends (Rambachan and Roth, 2023) shows that our estimates are robust and more pronounced using extrapolations of differential pre-trends into the post-treatment period.[12]

Revenue gains from capacity reduction are heterogeneous. Nonparametric estimates of ATT and ATT/d reveal heterogeneous revenue gains from the buyback program across exposure level groups (Table S.3, Fig. A4). Relative to the baseline group (with capacity reductions below 10%), vessels whose home ports experienced the largest capacity reductions (greater than 40%) saw the greatest overall gains, with average annual revenues rising by 137%, compared to 27% for vessels in medium-exposure ports (20–40%) and 45% for vessels in low-exposure ports (10–20%). When scaled by treatment intensity, however, revenue gains per percentage point of capacity reduction are largest for vessels in low-exposure ports (2.0%), followed by those in high-exposure (1.6%) and medium-exposure ports (0.8%). This pattern indicates a non-monotonic dose–response function,

[12] Specifically, under the assumption that the post-treatment violation of parallel trends is a linear extrapolation of the pre-trend, we calculate robust 95% confidence intervals from the TWFE specification in Eq. 2 to be [0.010,0.031] using the `HonestDiD` package (Rambachan and Roth, 2025), compared to [0.004,0.024] from our baseline specification.

with large capacity reductions experiencing diminishing returns.

We also examine whether the revenue gains of local capacity reductions varied by vessel characteristics, testing for heterogeneity based on a vessel's length, its pre-buyback revenue performance, its pre-buyback specialization in groundfish fishing, and its pre-buyback concentration of revenues in its main port (Table 2). We find no evidence that larger vessels experienced significantly greater post-buyback revenue gains, nor do we observe a substantial difference in revenue gains based on the degree of concentration in a vessel's pre-buyback revenues at its homeport. However, we do find evidence that vessels with larger revenues prior to the buyback program experience fewer revenue gains per unit of capacity reduction. For example, vessels in the bottom quartile of pre-buyback total revenues gained 3.6% in total revenues per unit of capacity reduction, compared to just 0.7% for vessels in the top quartile. In contrast, we find evidence that vessels with more groundfish specialization in the pre-buyback years experienced larger revenue gains per unit of capacity reduction, with vessels in the bottom quartile of groundfish specialization experiencing only 0.2% in total revenue gains per unit of capacity reduction, compared to 1.5% for vessels in the top quartile. This heterogeneity likely reflects the comparative advantage of groundfish specialists in exploiting newly available opportunities following capacity reduction, while vessels operating at a smaller scale prior to the buyback may have had a greater ability to expand operations more readily than larger vessels already operating near capacity.[13]

Revenue gains stem from improved productivity in the groundfish fishery, not substitution from other fisheries. To explore potential mechanisms underlying the positive program impacts on active trawl vessels, we estimate the TWFE model (Eq. 2) for the balanced trawl sample using several alternative dependent variables (Table 3). We find that the program led to a 2.4 percent increase in groundfish revenues (p-value = 0.0001) and a 2.9 percent increase in groundfish landings (p-value = 0.0000) per unit of capacity reduction, equating to an average annual increase of 94% and 123%, respectively. Revenue gains in the groundfish fishery, however, did not come at the expense of revenues from other fisheries in which active trawlers participate. Indeed, we do not detect any meaningful change in annual revenues or landings coming from non-groundfish fisheries associated with capacity reduction in the groundfish fleet, nor do we observe a change in the annual number of fishing trips taken in the groundfish fishery. Instead, we find a 1.9% and 2.9% increase in groundfish landings and revenue per trip, respectively, per unit of capacity reduction, equating to 69% and 123% overall increases, on average. Together, this suggests that total revenue gains

[13] We corroborate the latter point by estimating heterogeneous treatment effects across quartiles of pre-buyback capacity utilization, finding similar results to those for pre-buyback total revenues in column 1 of Table 2. Capacity utilization is defined as a vessel's observed output relative to its maximum potential output (Walden and Atwood, 2025). We impute a vessel's maximum potential output using the largest average revenue observed in its vessel class (based on deciles of vessel length) during the pre-buyback years. Dividing each vessel's annual average revenue by this imputed maximum potential output yields a capacity utilization measure for each vessel, ranging from 0 to 1.

Table 2: TWFE heterogeneous treatment effects across observable characteristics.

	(1)	(2)	(3)	(4)
$Post_t \cdot Treat_i$	0.036**	0.002	0.009**	0.012***
	(0.012)	(0.003)	(0.003)	(0.002)
$Post_t \cdot Treat_i \cdot Q2_i$	-0.025	0.015*	0.012*	0.010
	(0.014)	(0.006)	(0.005)	(0.008)
$Post_t \cdot Treat_i \cdot Q3_i$	-0.027*	0.010**	0.004	-0.002
	(0.012)	(0.003)	(0.003)	(0.002)
$Post_t \cdot Treat_i \cdot Q4_i$	-0.029*	0.013***	0.004	-0.001
	(0.012)	(0.003)	(0.003)	(0.002)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Heterogeneity	Pre-buyback Total Revenues	Pre-buyback GF Specialization	Pre-buyback Main Port Pct.	Vessel Length
Observations	1,190	1,190	1,190	1,190
R^2	0.69	0.67	0.67	0.67

Notes: *p < 0.05; **p < 0.01; ***p < 0.001.
This table reports the results of four separate TWFE regressions with the natural log of annual total revenues as the dependent variable, interacting $Post \cdot Treat$ with quartile indicators of (1) average annual pre-buyback total revenues (1994-2002), (2) average annual pre-buyback percentage of total revenues in the groundfish fishery (1994-2002), (3) average annual pre-buyback percentage of total revenues in a vessel's main port, and (4) vessel length. The first quartile ($Q1$) serves as the reference group. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

do not stem from substitution away from other fisheries toward the groundfish fishery; rather, they appear to come from productivity gains in the groundfish fishery itself.

Productivity gains are offset by expansion of harvests toward lower-valued species. While total revenue gains appear to be driven by improved productivity in the groundfish fishery, improvements in groundfish revenues per trip are smaller than improvements in groundfish landings per trip due to a small decrease in the per-unit value of groundfish landings of 1.0% (p-value = 0.0000, Table 3). To understand the source of this decrease, we estimate the TWFE model on a monthly vessel-level panel using species-specific prices as outcomes, focusing on three commonly landed groundfish species: Sablefish, Petrale Sole, and Dover Sole. We do not find a significant relationship between treatment exposure and the per-pound landings value of these individual species (Table S.4), suggesting that the small decline in the average per-unit value in groundfish landings is unlikely to reflect market-level price depression from an increased supply of landings. Instead, the decrease is likely driven by changes in the species composition of landed catch, as vessels expand production by harvesting lower-valued species.

Capacity reduction does not influence vessel participation or exit rates. The results thus far have focused on a balanced panel of trawl vessels that participate in the groundfish fishery every year of our sample. It is possible that capacity reduction differentially influenced the rate at which vessels participate or exit the fishery. Using the full sample of vessels, where participation varies on an annual basis, we estimate the TWFE model in Eq. 2 using a binary variable indicating a vessel's participation as the dependent variable, conditional on a vessel holding a limited entry groundfish permit. We do not find any evidence that capacity reduction influenced participation among trawl or fixed gear vessels (Table S.5). To investigate whether capacity reduction influenced exit rates, we regress a binary variable indicating whether a vessel exited the groundfish fishery during the post-buyback years on treatment exposure groups, including year fixed effects, where exit is defined as whether a vessel relinquished its limited-entry permit.[14] Again, we do not find any meaningful evidence that capacity reduction differentially influences exit rates among trawl or fixed gear vessels (Table S.6). Thus, we conclude that capacity reduction did not result in differential participation and exit rates, and therefore, productivity gains identified among active trawlers are driven by improved productivity in the groundfish fishery, rather than sample selection of more productive vessels participating in every year.

[14] By definition of our sample, there is no exit prior to the buyback program, since our full sample consists of vessels that held a groundfish permit in 2003, the last year before implementation of the program. Thus, we can only investigate the relationship between capacity reduction and exit rates in the post-buyback years.

Table 3: Mechanisms for the balanced sample of trawl vessels.

	Groundfish Revenues (1)	Groundfish Landings (2)	Non-Groundfish Revenues (3)	Non-Groundfish Landings (4)
$Post_t \cdot Treat_i$	0.024***	0.034***	0.014	0.016
	(0.006)	(0.006)	(0.023)	(0.023)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	1,190	1,190	1,190	1,190
R^2	0.66	0.53	0.75	0.58

	Groundfish Trips (5)	Groundfish Revenues/Trip (6)	Groundfish Landings/Trip (7)	Groundfish Price (8)
$Post_t \cdot Treat_i$	0.005	0.019**	0.029***	-0.010***
	(0.003)	(0.006)	(0.006)	(0.002)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	1,190	1,190	1,190	1,190
R^2	0.60	0.69	0.89	0.87

Notes: *p < 0.05; **p < 0.01; ***p < 0.001.
This table reports the results of eight separate TWFE regressions with the following dependent variables (all measured in the natural log): (1) annual total revenues, (2) annual groundfish revenues, (3) annual groundfish landings, (4) the percent of annual revenues from the groundfish fishery, (5) the number of groundfish trips (per year), (6) the average groundfish revenues per trip, (7) the average groundfish landings per trip, and (8) average price of landed groundfish for the balanced sample of trawl vessels. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Robustness Checks

We conduct a variety of robustness checks to ensure that our results do not reflect spurious correlations between ports and vessel performance or are not driven by researcher degrees of freedom. These include exploiting alternative variation in capacity reduction and exploring the sensitivity of our results to the inclusion of additional fixed effects, allowing for differential trends, and using different definitions of treatment.

One concern with our empirical strategy is that reductions in groundfish capacity resulting from the buyback program may have been more likely to occur in ports that would have seen improvements in groundfish vessel performance even in the absence of the buyback program. From a design-based perspective, an ideal test of this hypothesis would be to randomly reallocate groundfish capacity reduction across ports and evaluate whether similar results are obtained to those that we observe. Unfortunately, given that we can only observe the actual groundfish capacity reduction that occurred, this exercise is not possible. However, several vessels that were bought out under the program historically participated in other sectors—most notably, the Dungeness crab fishery. Since the groundfish buyback program removed all permits associated with the bought-out vessels, the program indirectly removed capacity from the Dungeness crab fishery as well. Importantly, capacity reductions in the Dungeness crab fishery differ considerably across ports from capacity reductions in the groundfish fishery (Fig. A5), allowing us to explore whether similar revenue gains accrue from capacity reductions with a different allocation across ports.

Following our analysis of the groundfish capacity reductions, we construct a balanced panel of Dungeness crab vessels from 1994 to 2010 and define port-level treatment exposure as the share of Dungeness crab revenues retired through the buyback program in each vessel's main port. Estimating the TWFE model in Eq. 2 with this alternative sample, we find strikingly similar patterns (Table S.7): higher capacity reduction in the Dungeness crab fishery is associated with a 0.9% increase in total revenues (p-value = 0.015), 1.7% increase in crab revenues (p-value = 0.001), and 1.9% increase in crab landings (p-value = 0.001), per unit of capacity reduction. In addition, vessels exhibit greater specialization in the crab fishery following local capacity reductions. These results support our findings on groundfish capacity reduction and suggest that the benefits of buybacks may extend across fisheries when vessels participate in multiple markets, highlighting broader gains from targeted capacity reductions.

As highlighted by our conceptual framework, another concern with our empirical strategy is the possibility that capacity reduction in one port incentivized vessels to move to another port. For example, ports with high capacity reduction and less congested fishing grounds may attract other vessels from ports with low capacity reduction. Alternatively, if capacity reduction strains local port infrastructure, vessels from high-capacity reduction ports may be induced to move to low-capacity reduction ports. In either case, the effects of capacity reduction in one port depend on the capacity reduction in other ports, which violates the stable unit treatment value assumption (SUTVA). In fact, we observe limited port switching after the buyback program (Fig. A6). For instance, of the 70 vessels comprising our balanced trawl sample, only 11 had a main port after the buyback program that differed from their main port before the buyback program. Moreover, any observed port switching primarily consisted of vessels moving to neighboring ports for which they had a history of use prior to the buyback program and experienced similar amounts of capacity reduction. Thus, there is little evidence to suggest that vessels switching between ports is driving our results.

Differences in vessel characteristics across treatment exposure groups (Table S.2) may also raise concerns that our results are picking up differences in trends that would have occurred even in the absence of the buyback program. To address this concern, we allow trends in vessel performance to vary across vessels based on their pre-buyback characteristics, such as their total revenues, groundfish specialization, concentration of revenues in their main port, and vessel length.[15] The inclusion of these interactive fixed effects has minimal influence on our results (Table S.8).

Finally, we assess the sensitivity of our results to alternative definitions of treatment exposure. Using a vessel's main port to assign capacity reduction may raise concerns of measurement error if vessels land harvests across multiple ports. Another concern is that treatment exposure may depend on the specific years used to define port-level capacity reduction and to determine a vessel's main port. To address the first concern, we re-estimate the TWFE model using an alternative definition of treatment exposure: a weighted average of capacity reduction across all ports, where the weights reflect each vessel's port-level revenue shares. To address the second concern, we re-estimate the TWFE model using alternative four-year pre-buyback periods for both the main port and weighted definitions of treatment exposure. Our findings are robust across both alternative exposure measures and time windows (Fig. A7). The one notable exception arises when treatment definitions include the year 2003—the year in which the buyback was both announced and implemented. In those cases, estimated effects are smaller and statistically indistinguishable from zero. This attenuation appears to be driven not by changes in the main ports of remaining vessels, but by changes in the revenue shares of vessels that were subsequently bought out. Since the buyback may have influenced the fishing behavior of these vessels prior to their exit, we do not think that 2003 is an accurate measure of pre-buyback port capacity. The consistency of results across all other periods supports the validity that our treatment exposure reflects pre-buyback capacity conditions.

[15] All characteristics are time-invariant and measured in the first year of the sample (1994).

Who Benefited from the Buyback Program?

The results thus far show that vessels whose home ports experienced larger capacity reductions under the buyback program gained more in fishing revenues. However, higher revenues do not necessarily imply greater net benefits, since remaining vessels were required to repay the portion of the program that was not publicly funded through landings fees. Thus, it's possible that vessels that experienced the greatest capacity reduction in their home port also incurred the greatest cost of repaying the loan.

To quantify the net benefits of the buyback program for the remaining vessels, including the cost of the landings fees, we answer the following question: how much do the remaining vessels benefit from their observed capacity reduction under the buyback program relative to a counterfactual scenario in which there is no capacity reduction or landings fee? The answer to this question can be interpreted as the private net benefits realized by remaining vessels during the first seven years following the buyback program, thus capturing the private gains accruing to a subset of industry participants rather than overall social welfare.

We estimate a vessel's revenue gains from the program as its level treatment effect—i.e., the difference between its observed total revenues in the post-buyback period (2004–2010) under its realized treatment exposure and its predicted revenues under a zero-treatment counterfactual:

$$\Delta\widehat{Y}_i = \sum_{t=2004}^{2010} \left[Y_{it}(Treat_i) - \widehat{Y}_{it}(0) \right],$$

where $\widehat{Y}_{it}(0)$ is the predicted total revenues (in levels) from our TWFE specification in Eq. (2) after setting $Treat_i = 0$. This difference represents the estimated revenue gains a vessel received from the program, relative to a scenario in which no capacity reductions occurred. The costs of the buyback program consist of the landings fees on the revenues of trawl vessels, which began in 2006.[16] Accordingly, we define vessel-specific program costs as:

$$C_i = \sum_{t=2006}^{2010} \sum_{f \in F} \tau_f \cdot Y_{it}^f(Treat_i),$$

where $Y_{it}^f(Treat_i)$ and τ_f denote the vessel revenues and landings fee rate, respectively, for fishery $f \in F = \{$groundfish, Dungeness crab, pink shrimp$\}$. The net benefits, NB_i, for each vessel are

[16] The applicable landings fee rates were 5% for groundfish; for coastal Dungeness crab: 1.24% in California, 0.55% in Oregon, and 0.16% in Washington; and for pink shrimp: 5.00% in California, 3.75% in Oregon, and 1.50% in Washington (NOAA, 2005).

thus:

$$NB_i = \Delta \widehat{Y}_i - C_i.$$

We estimate that the total revenue gains from the buyback program between 2004 and 2010 across all active trawl vessels in our balanced sample are equal to $61.2 million (95% CI = [31.5, 95.4]), or $10.36 in benefits for every one dollar of landings fees paid (95% CI = [5.84, 15.46]).[17] Because we only observe fishing revenues, our estimate ignores any additional variable costs associated with increasing harvests in response to the program (e.g., crew wages, fuel, etc.). However, assuming that variable costs are proportional to revenues, the net benefits from the program would still be positive so long as variable costs are less than 78.5% of revenues.[18] Using estimates from a survey of trawl vessel owners with limited-entry groundfish permits in 2004, which found variable costs to be approximately 55% of revenues (Lian, 2010), net benefits from the buyback program would be $23.9 million, or $4.66 in benefits for every one dollar of landings fees paid during the study period.

Figure 3 demonstrates that, while most vessels in our balanced trawl sample benefited from the program, such benefits are not equally distributed: vessels whose home ports experienced more capacity reduction also benefited the most from the buyback program, even after accounting for the landings fees on groundfish revenues. Assuming a uniform variable-cost share of 55%, each vessel in the High treatment exposure group gained, on average, $0.596 million in net benefits over the seven-year post-buyback period, compared to $0.299, $0.432, and $-0.010 million for vessels in the Medium, Low, and Very Low treatment groups, respectively. Thus, vessels receiving higher capacity reductions disproportionately benefited from the program, while vessels with little to no capacity reduction were made slightly worse off after accounting for the program fees.

Notably, our estimated gains capture only the benefits from capacity reductions in one's home port and do not capture other program elements that benefited all vessels regardless of capacity reduction in their home port, such as increased trip limits, which are absorbed by our year fixed effects. Moreover, these estimates do not capture any gains from capacity reductions in the Dungeness crab and pink shrimp fisheries resulting from the buyback program. Thus, our estimates should be interpreted as conservative.

Our estimates reflect the private net benefits to vessels during the seven years following the buyback and do not capture the full lifetime costs and benefits of the program. We view this as the most appropriate measure for several reasons. First, the buyback was followed by the introduction

[17] Specifically, revenue gains, $\Delta \widehat{Y}$, and program costs, C, are estimated to be $67.7 million and $6.5 million, respectively. Confidence intervals computed using a clustered bootstrap procedure.

[18] The variable cost share, S, that would result in zero net benefits can be found by solving for the value of S such that $(1 - S) \cdot \Delta \widehat{Y} = C$.

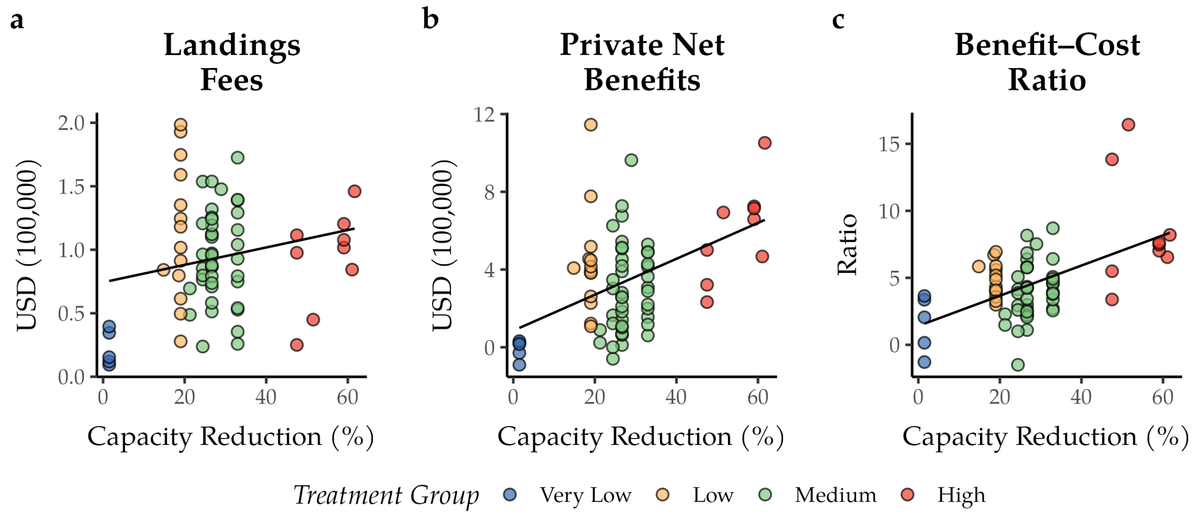

Figure 3: Private net benefits from the buyback program for the balanced trawl sample. (a) Landings fees paid on groundfish revenues (2006-2010), (b) estimated private net benefits (net revenues minus landings fees) from the buyback program (2004-2010), (c) estimated benefit-cost ratio (net revenues over landings fees) from the buyback program (2004-2010). Net revenues calculated as $(1 - S)Revenues$, where $S = 0.55$ is the assumed variable-cost share (Lian, 2010).

of an IFQ program in 2011. Extending our study beyond 2010 would therefore confound gains from capacity reduction under the buyback with the additional gains generated under the IFQ program (Holland et al., 2017). Second, while loans for the Dungeness crab and pink shrimp fisheries have been repaid, vessels are still repaying the groundfish fishery loan. Thus, projecting future benefits would require strong assumptions, particularly given that groundfish landings fees have been reduced in recent years to address financial hardships following the COVID-19 pandemic.

One concern with our approach, however, is that it doesn't account for the fact that landings fees were not collected during the first two years of the program and, during the study period, were insufficient to fully cover interest and principal on the buyback loan. To address this, we provide two complementary benefit-cost ratios that capture a more complete, longer-run accounting of program financing costs. First, we include counterfactual landings fees in 2004–2005, when fees were not yet collected, using observed fee rates and revenues. Under this adjustment, the benefit–cost ratio declines from 4.66 to 3.42. If the program's costs and benefits remained proportional over time, the benefit–cost ratio would remain similar as the repayment period continued. Second, following Holland et al. (2017), we compare the estimated average annual net revenue gains from the program to the fixed annual payments required to fully amortize the buyback loan over 30 years, which yields a more conservative benefit-cost ratio of 1.52.[19] Notably, the benefit–cost ratio remains above one (1.19) even if the industry had been required to finance the full $46 million cost of the program instead of financing the program with $10 million in public funds, indicating that early economic gains to the industry were large relative to the scale of public support.[20]

6 Conclusion

Capacity reduction programs are emerging as a central policy tool for addressing overinvestment, overextraction, and economic inefficiency across a range of natural resource sectors. Whether in fisheries, agriculture, water markets, or nonrenewable energy sectors, policymakers are increasingly turning to buyout or retirement programs as they address the need for managed transitions in the face of climate change. While reducing excess capacity can alleviate pressure on depleted resources and raise average productivity, the realized benefits depend on how reductions are implemented, particularly their spatial distribution, the incentives for reinvestment, and the institutional context that determines who bears the cost and who captures the benefits of the program. Despite their growing prominence, empirical evidence on the economic consequences and distributional effects of capacity reduction programs remains limited.

Our study contributes to this broader literature by providing causal evidence on the distributional effects of a large-scale buyback program with spatial heterogeneity in capacity reduction. Using seventeen years of vessel-level data, we evaluate the U.S. Pacific Coast Groundfish Buyback Program, which permanently retired one-third of the active trawl fleet. We find that ports experiencing greater local capacity reductions experienced significantly higher post-intervention benefits among active remaining vessels, while those with smaller reductions experienced negligible gains. These results imply that spatially concentrated capacity reduction can generate large localized efficiency gains, but at the cost of creating disparities between ports.

Conservative estimates suggest that capacity reduction under the buyback program generated net benefits to remaining vessels totaling $23.9 million over the seven years following implemen-

[19]Following Holland et al. (2017), we compute benefit–cost ratios for three loan repayment scenarios: 1) a $35.7 million loan repaid over 30 years beginning in 2004, 2) a $40.6 million loan repaid over 28 years beginning in 2006, and 3) a $45.7 million loan repaid over 30 years beginning in 2004. The first scenario assumes remaining participants began paying off the loan immediately after the buyback in 2004. The second scenario accounts for the absence of payments in 2004–2005, with accrued interest increasing the loan balance to $40.6 million by 2006. The third scenario assumes the full $45.7 million program cost (including public funding) is financed by the industry. Using standard loan amortization formulas with an interest rate of 6.97%, the fixed annual payments for the three scenarios are $2.87, $3.34, and $3.67 million, respectively. Comparing these fixed annual payments to the estimated average annual net revenue gains of $4.46 million over the study period yields benefit–cost ratios of 1.52, 1.31, and 1.19.

[20]Note that these benefit-cost ratios assume that our balanced sample of vessels finances the entire loan, despite representing only one-half of the groundfish trawl fleet and three-quarters of groundfish revenues. Furthermore, it does not account for the gains experienced by vessels participating in the crab and shrimp fisheries, which also benefited from capacity reductions in their respective fisheries.

tation, or about \$4.66 in benefits for every dollar paid in program fees during this period. These gains were concentrated among vessels that remained active in the groundfish fishery before and after the buyback and were driven primarily by productivity improvements and expanded landings of lower-valued groundfish species, rather than by increased trip frequency or the reallocation of effort from other fisheries.

This benefit–cost ratio should be interpreted in light of several considerations. First, our estimate reflects the private returns to a subset of industry participants rather than overall social welfare. A full welfare analysis would additionally require accounting for changes in consumer surplus, ecological outcomes, and impacts on participants outside the trawl fleet, including fixed-gear fishermen and vessels operating in other fisheries. Second, because program fees were collected beyond our study period, our estimate reflects the gains accruing to remaining vessels during the early years of the program rather than a full accounting of the program's lifetime costs. Third, the buyback program included a \$10 million public contribution used to finance vessel retirements. While our analysis focuses on private gains to remaining vessels, the estimated gains during the first seven years alone exceed this public contribution, suggesting that the program generated substantial returns relative to the scale of public support.

The sustained gains from the program indicate that effort creep was successfully prevented from eroding the rents generated by capacity reduction—a common concern in the buyback literature (e.g., Holland et al., 1999; Squires, 2010; Weninger and McConnell, 2000; Clark et al., 2007). The absence of such rent dissipation was likely due to the contemporaneous announcement of the forthcoming catch share program and the establishment of a control date for quota allocation, which reduced incentives to race for catch history. Together, these complementary policies suggest that buyback programs may be effective when paired with regulations that address the underlying drivers of overcapitalization.

While the private gains from the buyback program were likely influenced by the existence of a forthcoming catch share program, our estimates do not include the additional gains that may have arisen following implementation of the catch share program in 2011, when quotas associated with the retired permits were redistributed to the remaining vessels. Holland et al. (2017) demonstrate additional profits arose from increased quota allocations under the catch share system, suggesting that the total economic impacts of the buyback extend beyond the gains measured here. Importantly, vessels experiencing minimal gains from capacity reduction under the buyback program may have still benefited from the catch share program by selling quota to vessels that expanded their post-buyback catch volumes. Nevertheless, Holland et al. (2017) document a wide distribution of net revenues after the catch share program, with some vessels remaining unprofitable after accounting for the buyback landings fees.

Our estimates suggest that the buyback program was successful in generating aggregate private benefits; however, these benefits varied widely across ports, reflecting differences in the magnitude of local capacity reductions. These findings are consistent with evidence from non-fishery research on place-based policies and the uneven regional impacts of structural change (e.g., Autor et al., 2013; Kline and Moretti, 2014; Bartik, 2020). The persistence of localized gains, along with limited vessel mobility after the buyback, suggests that high port switching costs and localized fish dispersal both limit the diffusion of benefits across space. Consequently, the initial geographic distribution of buyback intensity—and the alignment between who pays and who benefits—plays a critical role in determining the overall equity and efficiency outcomes of capacity-reduction programs. In settings with strong spatial frictions, policymakers may need mechanisms to offset these disparities and align program costs and benefits, particularly when regional equity is a central policy objective.

At the same time, we find evidence of diminishing returns to spatially concentrated reductions: while ports with greater buyback intensity experienced the largest total gains, the benefits per dollar of capacity retired were smaller. Holding other factors constant, this suggests that spreading reductions more evenly across space could yield larger aggregate benefits and more balanced regional outcomes. These results underscore the importance of considering not just the scale, but also the spatial allocation of capacity reductions in program design.

Together, these findings suggest policymakers may wish to consider how buyback programs allocate reductions across locations. For example, program rules could discourage excessive concentration of buyback participation in a small number of ports, or incorporate mechanisms that better align program financing with the geographic distribution of benefits—such as fee structures linked to the magnitude of local capacity reductions. The simultaneous introduction of catch shares based on pre-buyback catch history could also offer a market-based approach to compensate vessels that experience a disproportionately low capacity reduction by those that experience more. More broadly, our results suggest that careful attention to both the spatial design and financing of buyback programs may improve efficiency while reducing disparities among remaining participants.

In sum, this study demonstrates that capacity-reduction programs, when carefully designed, can yield meaningful economic and environmental benefits. Yet their success for the remaining industry participants hinges on both the spatial distribution of capacity reductions and the mechanisms that govern how resulting rents are shared. As governments confront the challenge of managing transitions in overcapitalized and resource-intensive sectors, our findings offer guidance for designing policies that balance efficiency, regional equity, and long-term sustainability.

References

Autor, D. H., Dorn, D., and Hanson, G. H. (2013). The China Syndrome: Local Labor Market Effects of Import Competition in the United States. *American Economic Review*, 103(6):2121–2168.

Bartik, T. J. (2020). Using Place-Based Jobs Policies to Help Distressed Communities. *Journal of Economic Perspectives*, 34(3):99–127.

Bergé, L. (2018). *fixest: Fast Fixed-Effects Estimations*. R package version 0.13.3.

Brown Jr, G. (1974). An optimal program for managing common property resources with congestion externalities. *Journal of Political Economy*, 82(1):163–173.

Callaway, B., Goodman-Bacon, A., and Sant'Anna, P. H. C. (2024). *Difference-in-Differences with a Continuous Treatment*. Number no. w32117 in NBER Working Paper Series. National Bureau of Economic Research, Cambridge, Mass.

Campbell, H. F. (1989). Fishery Buy-Back Programmes and Economic Welfare. *Australian Journal of Agricultural Economics*, 33(1):20–31.

Clark, C. W., Munro, G. R., and Sumaila, U. R. (2005). Subsidies, buybacks, and sustainable fisheries. *Journal of Environmental Economics and Management*, 50(1):47–58.

Clark, C. W., Munro, G. R., Sumaila, U. R., and Sutinen, J. G. (2007). Buyback Subsidies, the Time Consistency Problem, and the ITQ Alternative. *Land Economics*, 83(1):50–58.

Dell'Apa, A., Schiavinato, L., and Rulifson, R. A. (2012). The magnuson–stevens act (1976) and its reauthorizations: Failure or success for the implementation of fishery sustainability and management in the us? *Marine Policy*, 36(3):673–680.

DePiper, G. S. (2015). To bid or not to bid: The role of participation rates in conservation auction outcomes. *American Journal of Agricultural Economics*, 97(4):1157–1174.

Dewees, C. M. (1998). Effects of individual quota systems on new zealand and british columbia fisheries. *Ecological Applications*, 8(sp1):S133–S138.

Edwards, E. C. (2016). What Lies Beneath? Aquifer Heterogeneity and the Economics of Groundwater Management. *Journal of the Association of Environmental and Resource Economists*, 3(2):453–491.

Felthoven, R. G. (2002). Effects of the american fisheries act on capacity, utilization and technical efficiency. *Marine Resource Economics*, 17(3):181–205.

Fox, K. J., Grafton, R. Q., Kompas, T., and Che, T. N. (2006). Capacity reduction, quota trading and productivity: the case of a fishery. *Australian Journal of Agricultural and Resource Economics*, 50(2):189–206.

Ghanem, D., Hirshleifer, S., and Ortiz-Beccera, K. (2023). Testing Attrition Bias in Field Experiments. *Journal of Human Resources*.

Grafton, R. Q. and Wheeler, S. A. (2018). Economics of water recovery in the murray-darling basin, australia. *Annual Review of Resource Economics*, 10(1):487–510.

Hellerstein, D. M. (2017). The US Conservation Reserve Program: The evolution of an enrollment mechanism. *Land Use Policy*, 63:601–610.

Holland, D., Gudmundsson, E., and Gates, J. (1999). Do fishing vessel buyback programs work: A survey of the evidence. *Marine Policy*, 23(1):47–69.

Holland, D. S., Steiner, E., and Warlick, A. (2017). Can vessel buybacks pay off: An evaluation of an industry funded fishing vessel buyback. *Marine Policy*, 82:8–15.

Kline, P. and Moretti, E. (2014). People, Places, and Public Policy: Some Simple Welfare Economics of Local Economic Development Programs. *Annual Review of Economics*, 6(1):629–662.

Lian, C. E. (2010). West coast limited entry groundfish trawl cost earnings survey protocols and results for 2004. NOAA Technical Memorandum NMFS-NWFSC-107, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA. 35 p.

Mamula, A. and Collier, T. (2015). Multifactor productivity, environmental change, and regulatory impacts in the us west coast groundfish trawl fishery, 1994–2013. *Marine Policy*, 62:326–336.

Mamula, A. T. (2009). *License buyback programs in commercial fisheries: An application to the shrimp fishery in the Gulf of Mexico*. Texas A&M University.

Miller, D. L. (2023). An Introductory Guide to Event Study Models. *Journal of Economic Perspectives*, 37(2):203–30.

NMFS and NOAA (2003). Magnuson-stevens act provisions; fishing capacity reduction program; pacific coast groundfish fishery; california, washington, and oregon fisheries for coastal dungeness crab and pink shrimp. Federal Register, 68(213), 62435-62440. National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA).

NOAA (2005). Magnuson-stevens act provisions; fishing capacity reduction program; pacific coast groundfish fishery; industry fee system for fishing capacity reduction loan. Federal Register, 70(133), 40225–40231. National Oceanic and Atmospheric Administration (NOAA).

NOAA (2025). Pacific coast groundfish permit applications. Accessed: 2025-10-02, `https://www.webapps.nwfsc.noaa.gov/apex/ifq/f?p=109:23`.

Parks, P. J. and Schorr, J. P. (1997). Sustaining Open Space Benefits in the Northeast: An Evaluation of the Conservation Reserve Program. *Journal of Environmental Economics and Management*, 32(1):85–94.

Pascoe, S., Coglan, L., Punt, A. E., and Dichmont, C. M. (2012). Impacts of Vessel Capacity Reduction Programmes on Efficiency in Fisheries: The Case of Australia's Multispecies Northern Prawn Fishery. *Journal of Agricultural Economics*, 63(2):425–443.

PEER (2024). Voluntary grazing permit retirement on public lands. Technical report, Public Employees for Environmental Responsibility. Accessed: 2025-06-16.

Rambachan, A. and Roth, J. (2023). A More Credible Approach to Parallel Trends. *Review of Economic Studies*, 90(5):2555–2591.

Rambachan, A. and Roth, J. (2025). *HonestDiD: Robust Inference in Difference-in-Differences and Event Study Designs*. R package version 0.2.6.

Sanchirico, J. N. and Wilen, J. E. (1999). Bioeconomics of Spatial Exploitation in a Patchy Environment. *Journal of Environmental Economics and Management*, 37(2):129–150.

Schrank, W. E. (2005). The newfoundland fishery: Ten years after the moratorium. *Marine Policy*, 29(5):407–420.

Squires, D. (2010). Fisheries buybacks: A review and guidelines. *Fish and Fisheries*, 11(4):366–387.

Srivastav, S. and Zaehringer, M. (2024). The economics of coal phaseouts: auctions as a novel policy instrument for the energy transition. *Climate Policy*, 24(6):754–765.

United States, Department of Commerce (2003). Magnuson-stevens act provisions; fishing capacity reduction program; pacific coast groundfish fishery; california, washington, and oregon fisheries for coastal dungeness crab and pink shrimp. *Federal Register*, 68(213):62435–62440. Accessed 2025-10-02, `https://www.govinfo.gov/content/pkg/FR-2003-11-04/pdf/03-27712.pdf`.

Walden, J. B. and Atwood, J. (2025). Comparing economic and physical measures of capacity utilization in fisheries. *Marine Resource Economics*, 40(4):253–273.

Walden, J. B., Kirkley, J. E., and Kitts, A. W. (2003). A limited economic assessment of the northeast groundfish fishery buyout program. *Land Economics*, 79(3):426–439.

Wang, K., Reimer, M. N., and Wilen, J. E. (2023). Fisheries subsidies reform in China. *Proceedings of the National Academy of Sciences*, 120(26):e2300688120.

Wang, Y.-H., Ruttenberg, B. I., Walter, R. K., Pendleton, F., Samhouri, J. F., Liu, O. R., and White, C. (2024). High resolution assessment of commercial fisheries activity along the US West Coast using Vessel Monitoring System data with a case study using California groundfish fisheries. *PLOS ONE*, 19(6):e0298868.

Warlick, A., Steiner, E., and Guldin, M. (2018). History of the West Coast groundfish trawl fishery: Tracking socioeconomic characteristics across different management policies in a multispecies fishery. *Marine Policy*, 93:9–21.

Watson, P. and Johnson, T. (2012). Federal Fishery Policy and the Geographic Distribution of Commercial U.S. West Coast Fish Landings: Insights from the 2003 Federal Groundfish Permit Buyback. *Marine Resource Economics*, 27(4):289–301.

Weninger, Q. and McConnell, K. E. (2000). Buyback programs in commercial fisheries: effciency versus transfers. *Canadian Journal of Economics/Revue canadienne d'économique*, 33(2):394–412. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/0008-4085.00021.

Appendix

A Supplementary Figures

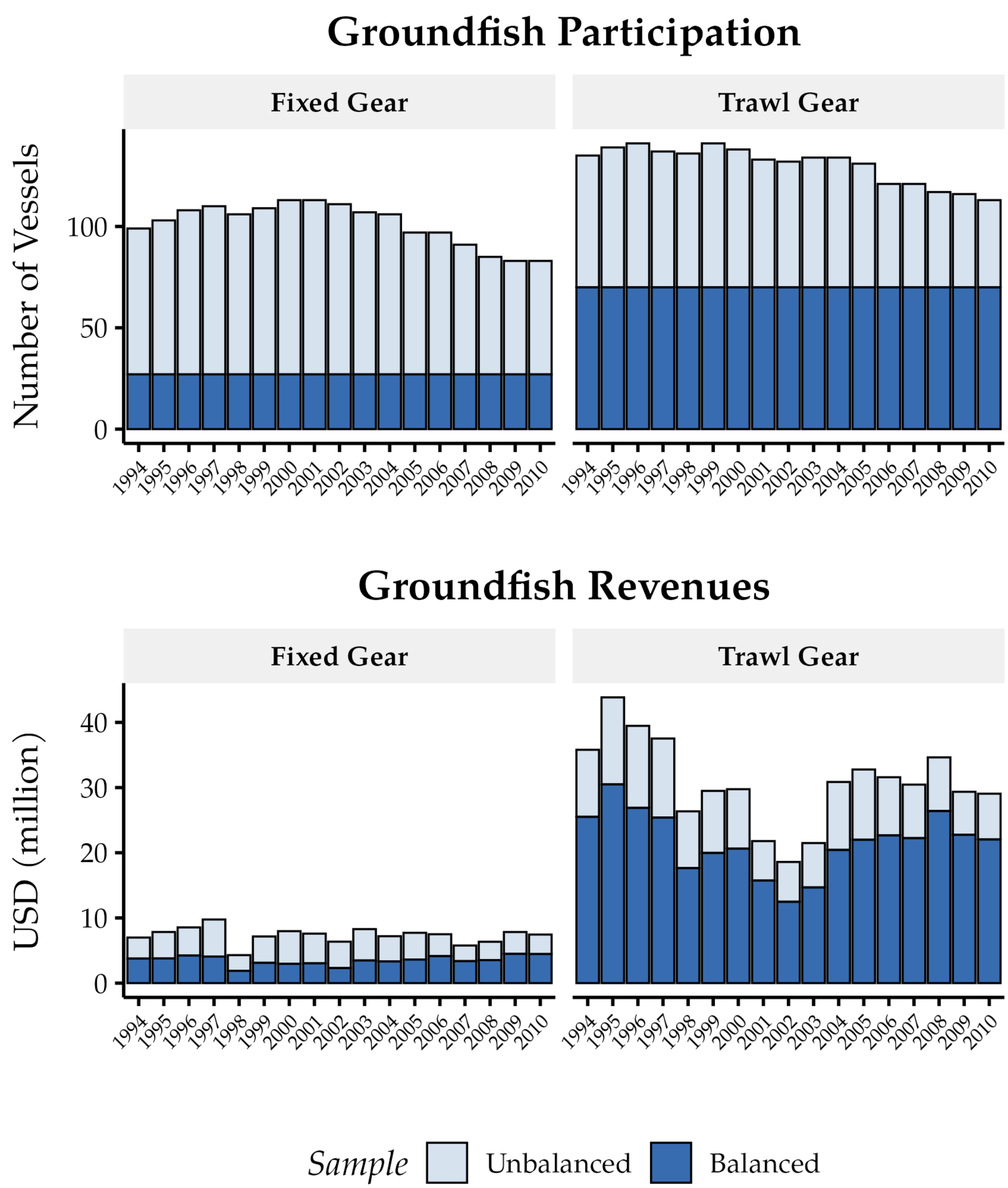

Figure A1: Composition of vessels across samples. The number of vessels (top row) and groundfish revenues (bottom row) in the balanced and unbalanced samples, by year and gear. The balanced sample is represented by the dark blue bars. Vessels unique to the unbalanced sample are represented by the light blue bars. The full sample is represented by the sum of the dark and light blue bars.

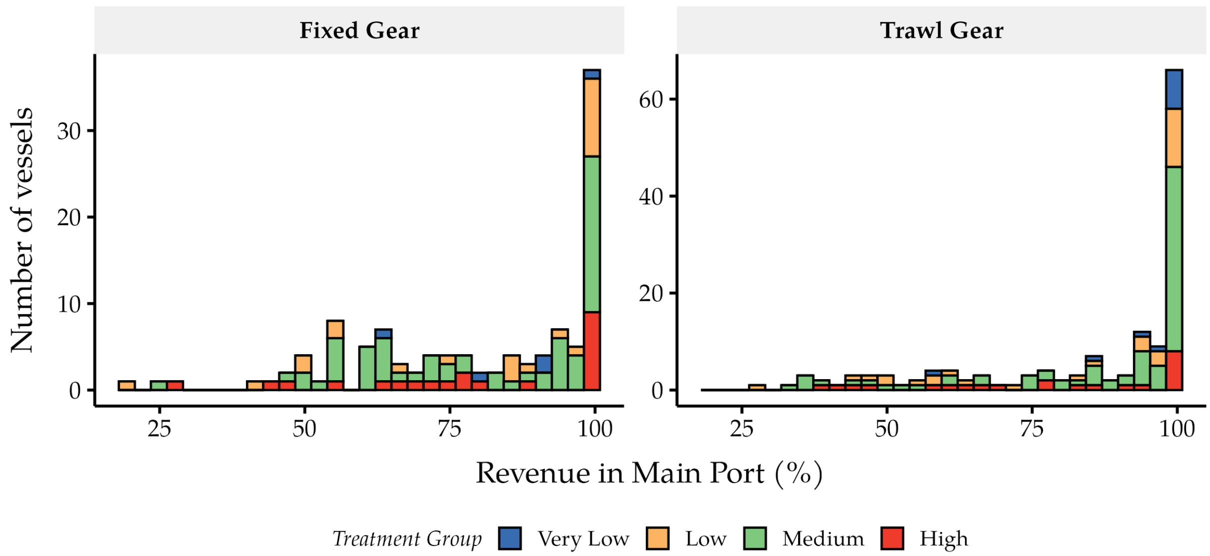

Figure A2: Distribution of main port revenues concentration. The distribution of the percentage of revenues attributable to a vessel's home port between 1998 and 2001, by gear and treatment exposure group.

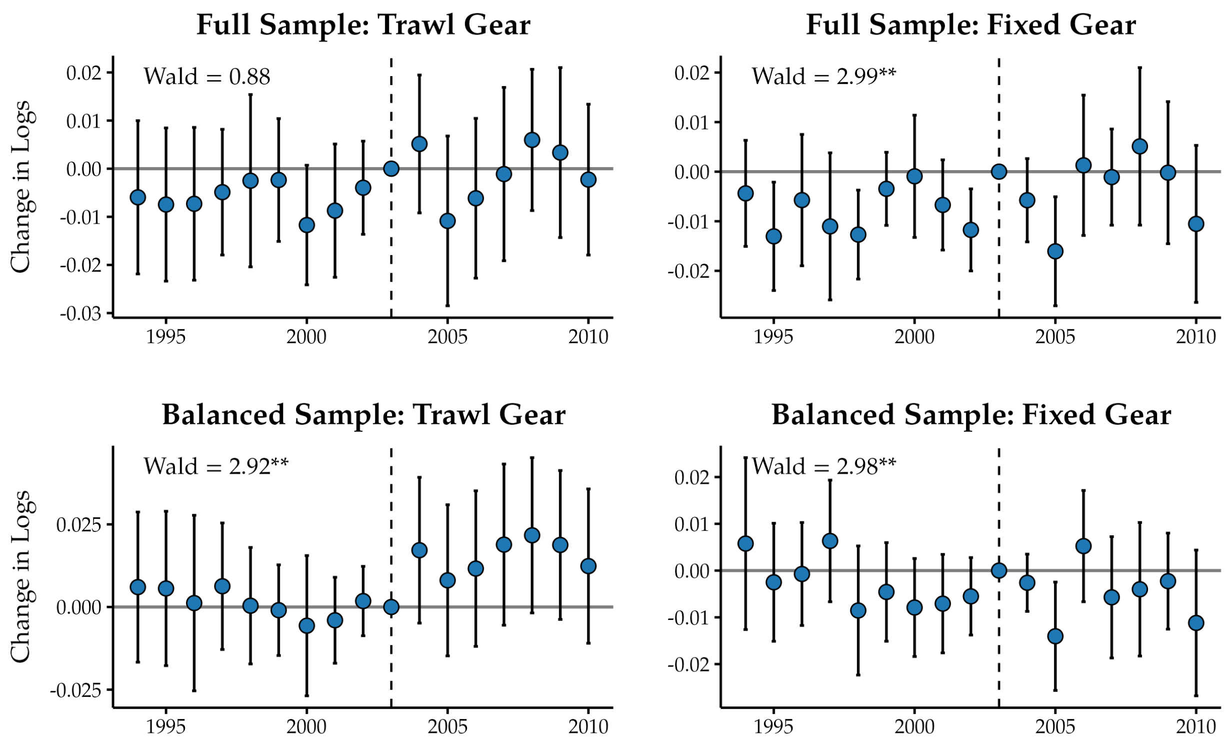

Figure A3: Event-study coefficient estimates for all samples. Blue dots represent estimates of the annual average level treatment effect (in percentage points) on total revenue per one-percent reduction in capacity, relative to 2003, using the TWFE model in Eq. 5. Error bars represent 95% confidence intervals using standard errors clustered at the vessel level. The Wald statistic represents a test of the joint null hypothesis that all pre-treatment event study coefficients are equal to zero (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

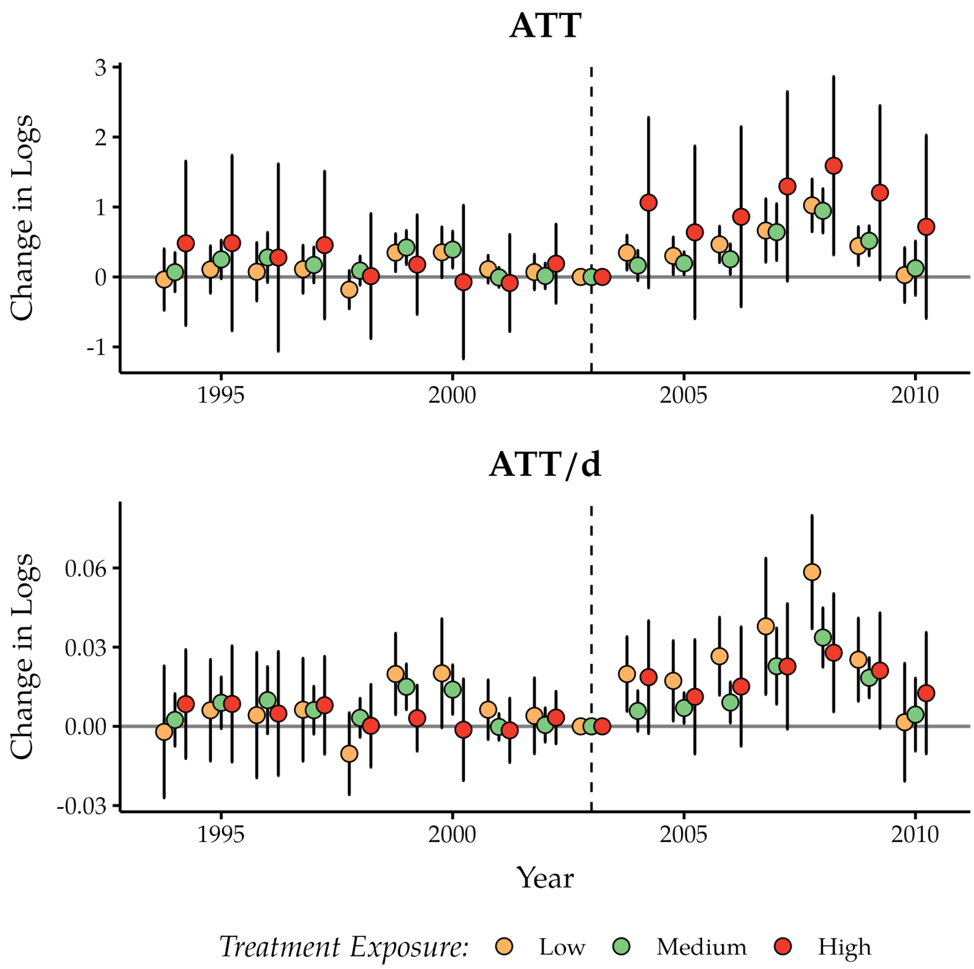

Figure A4: Treatment group event-study coefficients: balanced trawl sample. Nonparametric estimates of the annual average level treatment effect (ATT) and annual average level treatment effect per one-percent reduction in capacity (ATT/d) on total revenue. Treatment effects estimated using discrete bins of treatment exposure groups (Eq. 3). Error bars represent 95% confidence intervals using standard errors clustered at the vessel level. Treatment exposure is measured as the percentage of groundfish revenues corresponding to the bought-out vessels between 1998 and 2001: Very Low (0–10%), Low (10–20%), Medium (20–40%), and High (40–62%). The reference year is 2003, and the reference group is Very Low.

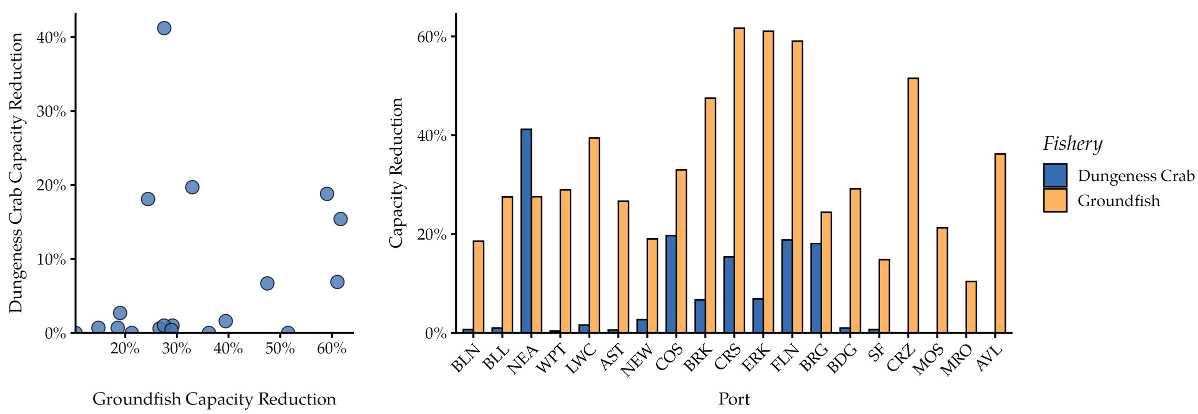

Figure A5: Capacity reductions for the Groundfish and Dungeness crab fisheries, by port. Capacity reduction is measured as the percentage of groundfish revenues corresponding to the bought-out vessels between 1998 and 2001. Ports ordered from North (left) to South (right).

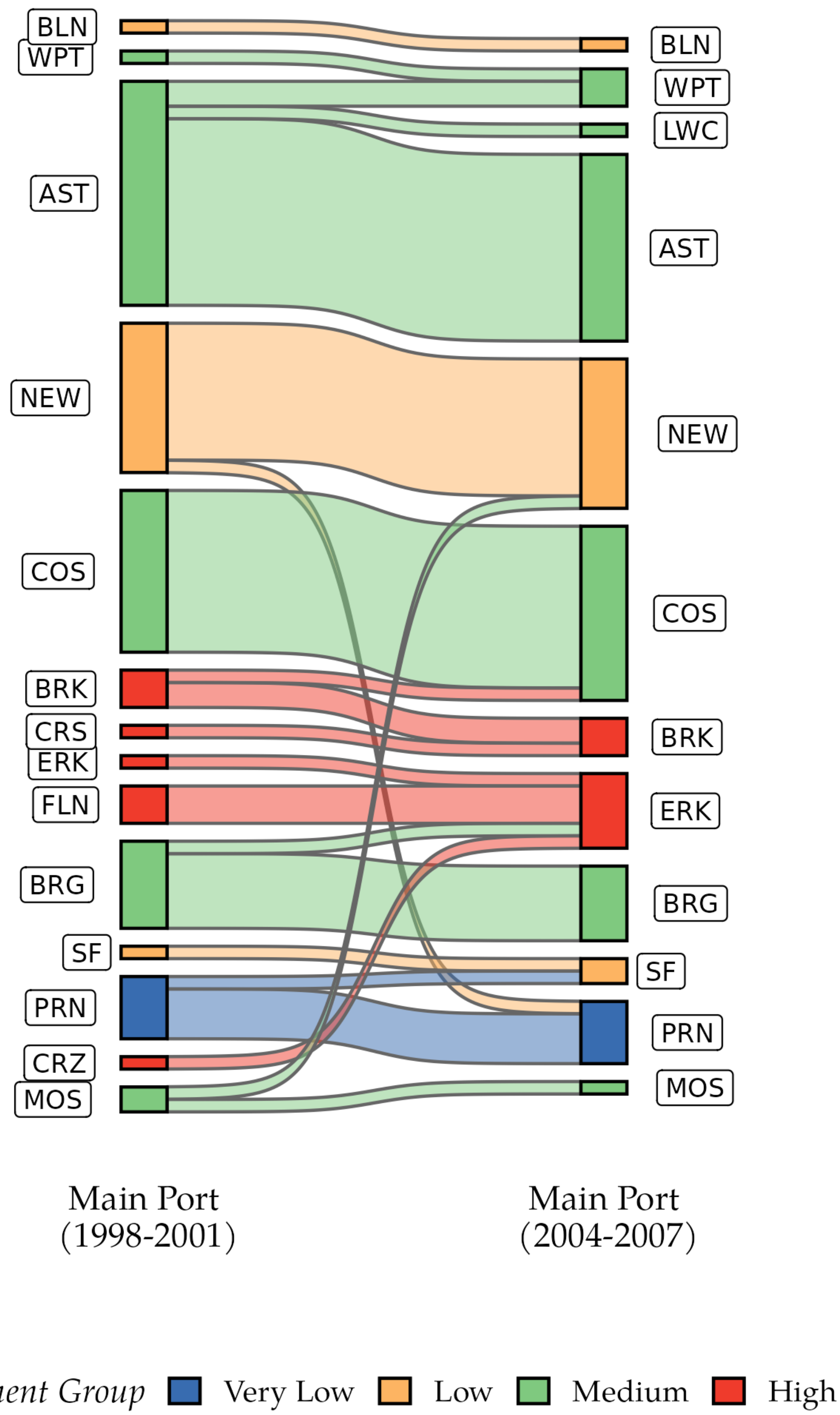

Figure A6: Main port switching for the balanced sample of trawl vessels. Nodes represent ports, and their size represents the number of vessels claiming a port as their main port. Edges represent the number of vessels that use a port on the left as their main port before the buyback program (1998-2001) and a port on the right as their main port after the buyback program (2004-2007). Edges connecting different ports represent port switching. Ports are ordered from North (top) to South (bottom).

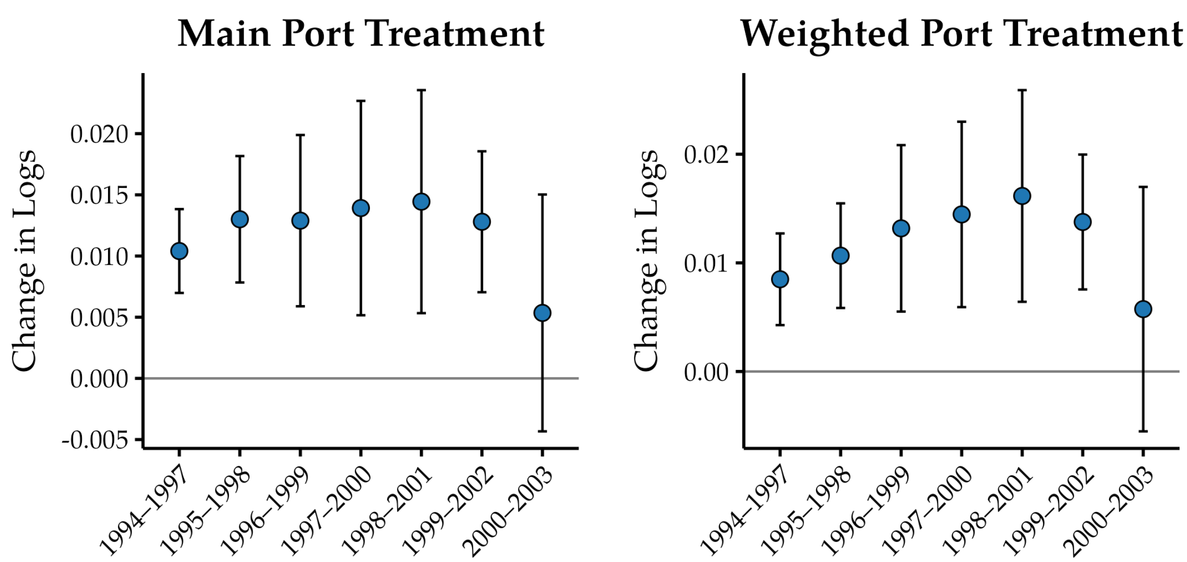

Figure A7: Robustness to different treatment definitions. Estimates of the TWFE model using the log of total revenues as the dependent variable across different treatment definitions and exposure years. The left panel uses a vessel's main port to determine treatment exposure, while the right panel uses a weighted average of ports, with the weights determined by the proportion of a vessel's revenues attributable to a port. The x-axis represented different four-year periods used to calculate (1) the proportion of revenues at each port attributable to the vessels bought out under the program, and (2) a vessel's main port (left panel) or vessel's port-specific weights (right panel). Our baseline results use the "Main Port" treatment and the years 1998-2001.

B Supplementary Tables

Table S.1: Number of vessels and treatment exposure, by ports

Port Group	State	Treatment Exposure	No. Vessels	No. Trawlers	No. Fixed Gear
Bellingham Bay	WA	0.28	6	0	6
Blaine	WA	0.19	1	1	0
La Push	WA	0	3	0	3
Neah Bay	WA	0.28	1	0	1
Westport	WA	0.29	2	1	1
Astoria	OR	0.27	21	20	1
Brookings	OR	0.48	5	4	1
Charleston or Coos Bay	OR	0.33	16	13	3
Newport	OR	0.19	17	10	7
Port Orford	OR	0	3	0	3
Tillamook or Garibaldi	OR	0	1	1	0
Crescent City	CA	0.62	3	1	2
Eureka	CA	0.61	4	2	2
Fields Landing	CA	0.59	3	3	0
Fort Bragg	CA	0.24	7	6	1
Monterey	CA	0.01	1	1	0
Moss Landing	CA	0.21	4	2	2
Newport Beach	CA	0	1	0	1
Oxnard	CA	0	1	0	1
Princeton or Half Moon Bay	CA	0.01	5	5	0
San Francisco	CA	0.15	1	1	0
Santa Cruz	CA	0.52	1	1	0
Terminal Island	CA	0	1	0	1

The following table shows the ports, treatment exposure in each ports along with the number of vessels in each port along with their associated gear types in our fully balanced sample.

Table S.2: Observable pre-buyback characteristics across treatment exposure groups.

	Trawl Gear							
	Full				Balanced			
	Total Revenues ($1,000) (1)	Percent Groundfish (2)	Vessel Length (m) (3)	Percentage Main Port (4)	Total Revenues ($1,000) (5)	Percent Groundfish (6)	Vessel Length (m) (7)	Percentage Main Port (8)
Treatment = Very Low	-87.47*	-0.13	-3.69	0.12***	-89.03	-0.11	-14.71**	0.17***
	(46.19)	(0.11)	(5.12)	(0.03)	(71.87)	(0.15)	(5.64)	(0.04)
Treatment = Low	94.86**	0.30***	17.59***	0.08**	176.68**	0.11	8.55	0.09*
	(47.49)	(0.07)	(3.56)	(0.03)	(80.08)	(0.08)	(5.15)	(0.05)
Treatment = Medium	79.45**	0.23***	9.23***	0.06**	112.04*	0.09	2.74	0.06
	(37.20)	(0.07)	(3.12)	(0.03)	(62.17)	(0.07)	(4.62)	(0.04)
Constant	250.65***	0.51***	56.93***	0.84***	300.43***	0.69***	65.36***	0.82***
	(31.31)	(0.06)	(2.65)	(0.03)	(57.13)	(0.07)	(4.30)	(0.04)
Observations	146	146	146	146	70	70	70	70
R^2	0.09	0.19	0.18	0.07	0.16	0.08	0.21	0.10

	Fixed Gear							
	Full				Balanced			
	Total Revenues ($1,000) (1)	Percent Groundfish (2)	Vessel Length (m) (3)	Percentage Main Port (4)	Total Revenues ($1,000) (5)	Percent Groundfish (6)	Vessel Length (m) (7)	Percentage Main Port (8)
Treatment = Very Low	27.74	0.08	8.44	0.09***				
	(55.34)	(0.13)	(8.47)	(0.03)				
Treatment = Low	79.66*	0.14*	4.59**	-0.01	301.70***	-0.10	10.81**	0.06
	(46.08)	(0.08)	(2.30)	(0.04)	(92.92)	(0.08)	(4.20)	(0.07)
Treatment = Medium	46.44	0.24***	5.58***	-0.01	101.86*	0.16	10.94**	-0.02
	(30.15)	(0.06)	(1.93)	(0.03)	(51.21)	(0.10)	(3.93)	(0.06)
Constant	128.24***	0.30***	41.52***	0.86***	119.02***	0.49***	39.45***	0.86***
	(18.06)	(0.05)	(1.34)	(0.03)	(10.59)	(0.07)	(2.38)	(0.05)
Observations	113	113	113	113	24	24	24	24
R^2	0.02	0.10	0.05	0.03	0.30	0.27	0.20	0.10

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

This table reports differences in pre-buyback characteristics of vessels across treatment exposure groups. Each column represents the results of a separate regression of our binned exposure group on (1) average annual total revenues (1994-2002), (2) average annual percent of revenues attributable to the groundfish fishery (1994-2002), (3) vessel length (meters), and (4) average annual percent of revenues attributable to a vessel's main port (1994-2002). The "High" treatment exposure group serves as the reference group.

Table S.3: Nonparametric estimates of the average level treatment effects for the balanced trawl sample

	Log Total Revenues (1)	Log GF Revenues (2)	Log GF Landings (3)	% GF Revenues (4)
ATT^{Bin}	0.353***	0.870**	1.142***	0.122
	(0.057)	(0.280)	(0.300)	(0.074)
ATT/d^{Bin}	0.012***	0.031**	0.040***	0.004
	(0.002)	(0.010)	(0.011)	(0.003)
Group specific ATT^{Bin}				
Low	0.372***	0.842**	0.960**	0.106
	(0.056)	(0.297)	(0.326)	(0.086)
$Medium$	0.238***	0.741*	1.027**	0.119
	(0.053)	(0.280)	(0.299)	(0.074)
$High$	0.861**	1.515***	1.961***	0.165
	(0.253)	(0.380)	(0.395)	(0.109)
Group specific ATT/d^{Bin}				
Low	0.020***	0.045**	0.051**	0.006
	(0.003)	(0.016)	(0.017)	(0.005)
$Medium$	0.008***	0.026*	0.037**	0.004
	(0.002)	(0.010)	(0.011)	(0.003)
$High$	0.016**	0.028***	0.036***	0.003
	(0.005)	(0.007)	(0.007)	(0.002)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	1,190	1,190	1,190	1,190

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
This table reports the nonparametric estimation results of the average level treatment effect (ATT) and the average level treatment effect per unit of treatment exposure (ATT/d) for (1) the natural log of total revenues, (2) the natural log of groundfish revenues, (3) the natural log of groundfish landings, and (4) the percent of annual revenues from the groundfish fishery, for the balanced sample of trawl vessels. Group-specific ATT are estimated from Eq. 3 and aggregated following Eq. 4. Treatment exposure is measured as the percentage of groundfish revenues corresponding to the bought-out vessels between 1998 and 2001: Very Low (0–10%), Low (10–20%), Medium (20–40%), and High (40–62%). Very Low serves as the reference group. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Table S.4: TWFE Price Effects for the balanced trawl sample

	Price/lb		
	Sablefish	Petrale Sole	Dover Sole
	(1)	(2)	(3)
$POST_t \cdot Treat_i$	-0.0014	0.0027	0.0007
	(0.0014)	(0.0018)	(0.0008)
Vessel FEs	Yes	Yes	Yes
Month-Year FEs	Yes	Yes	Yes
Observations	9,113	7,425	7,205
R^2	0.57	0.35	0.40

Notes: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.
This table reports the results of three separate TWFE regressions on the price per pound landed in a given month for different subsamples of Sablefish, Petrale Sole and Dover Sole. Vessel and year-month fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Table S.5: TWFE estimates of participation for the full sample of vessels.

	Participate in any fishery		Participate in groundfish fishery	
	Trawl	Fixed	Trawl	Fixed
	(1)	(2)	(3)	(4)
$Post_t \cdot Treat_i$	0.000	0.000	-0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.002)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	2,241	1,367	2,241	1,367
R^2	0.41	0.28	0.44	0.41

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
This table reports the estimation results of four separate TWFE regressions on annual participation in any fishery (1 and 2) or the groundfish fishery (3 and 4) using the full sample of vessels for the years 1994-2010, by gear. Participation is conditional on having a limited-entry groundfish permit. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Table S.6: Post-buyback exit rate by treatment exposure group.

	Trawl Gear (1)	Fixed Gear (2)
Low	-0.069	0.007
	(0.038)	(0.098)
Medium	-0.049	-0.043
	(0.038)	(0.092)
High	-0.050	-0.044
	(0.041)	(0.095)
Year FEs	Yes	Yes
Observations	898	531
R^2	0.008	0.03

Notes: $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
This table reports the estimation results of two separate linear probability models of the exit hazard rate in the post-buyback years across treatment exposure groups using the full sample of vessels for the years 2004-2010, by gear type. Year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Table S.7: TWFE estimates for the balanced Dungeness crab vessels.

	Log Total Revenues (1)	Log Crab Revenues (2)	Log Crab Landings (3)	% Crab Revenues (4)
$Post_t \cdot Treat_i$	0.009^{*}	0.017^{***}	0.019^{***}	0.006^{***}
	(0.004)	(0.004)	(0.004)	(0.001)
Vessel FEs	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Observations	6,307	6,307	6,307	6,307
R^2	0.76	0.67	0.68	0.59

Notes: $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.
This table reports the results of four separate TWFE regressions on the natural log of total revenues, crab revenues, groundfish landings, and the percent of annual revenues from the Dungeness crab fishery for a balanced sample of crab vessels. Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level.

Table S.8: Robustness checks using interactive fixed effects.

	(1)	(2)	(3)	(4)	(5)	(6)
TWFE						
$Post_t \cdot Treat_i$	0.014**	0.014**	0.015***	0.015**	0.014***	0.013***
	(0.005)	(0.004)	(0.004)	(0.005)	(0.003)	(0.003)
Binned						
$Post_t \cdot Treat_i =$ Low	0.372***	0.501***	0.346***	0.476***	0.356***	0.477***
	(0.056)	(0.074)	(0.086)	(0.137)	(0.062)	(0.109)
$Post_t \cdot Treat_i =$ Medium	0.238***	0.346***	0.211*	0.315**	0.182*	0.284***
	(0.053)	(0.064)	(0.094)	(0.102)	(0.091)	(0.078)
$Post_t \cdot Treat_i =$ High	0.861**	0.923***	0.834***	0.926**	0.788***	0.845***
	(0.253)	(0.238)	(0.208)	(0.294)	(0.188)	(0.179)
Vessel FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Total Revenue$_{1994}$ $\times$ Year	No	Yes	No	No	No	Yes
% Groundfish$_{1994}$ $\times$ Year	No	No	Yes	No	No	Yes
Vessel Length$_{1994}$ $\times$ Year	No	No	No	Yes	No	Yes
% Main Port$_{1994}$ $\times$ Year	No	No	No	No	Yes	Yes
Observations	1,190	1,190	1,190	1,190	1,190	1,190
R^2	0.66	0.69	0.67	0.67	0.67	0.71

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
This table reports the results of six separate TWFE and binned treatment exposure regressions on the natural log of total revenues, including year fixed effect interactions with baseline (2) total revenues, (3) percentage of revenues from the groundfish fishery, (4) vessel length, (5) percentage of revenues from a vessel's main port, and (6) all baseline variables. Baseline variables are measured in the first year of the sample (1994). Vessel and year fixed effects are included in each regression. Standard errors are clustered at the vessel level. The "Very Low" treatment exposure group serves as a reference group for the binned regression specification.