WORKING PAPER · NO. 2023-63

Regulating Biological Resources: Lessons from Marine Fisheries in the United States

Eyal Frank and Kimberly Oremus

MAY 2023 (UPDATED JUNE 2026)

EPIC
ENERGY POLICY INSTITUTE
AT THE UNIVERSITY OF CHICAGO

An Affiliated Center of
Becker Friedman Institute

5757 S. University Ave.
Chicago, IL 60637
Main: 773.702.5599
bfi.uchicago.edu

Regulating Biological Resources: Lessons From Marine Fisheries in the United States*

Eyal Frank† Kimberly Oremus‡

6/2/2026

Abstract

In 1996, with United States fish populations in decline, Congress overhauled fishing laws with scientific thresholds for rebuilding overfished stocks. The law's impact is contested, and lawmakers have spent over a decade debating its reauthorization while countries around the world consider similar policies. We develop the first causally interpretable evaluation of this law, exploiting the European Union's comparable fisheries and later adoption of similar laws. Compiling comprehensive data on US and EU fishery status and management, we examine depleted fisheries and measure the effect of a policy that aims to rebuild their population levels. We find treated populations increase by 52 percent relative to these counterfactuals, with both catch and revenue rebounding to baseline levels or greater. For at least 69 percent of successfully rebuilt stocks, the net present value of revenue exceeds simulated counterfactuals over the rebuilding and post-rebuilding period, indicating that longer-term revenue gains offset short-term losses.

Keywords: natural resources, resource management, common-pool resources, fisheries.

*We are grateful for helpful comments from Maximilian Auffhammer, Chris Costello, Michael Greenstone, Koichiro Ito, Amir Jina, Kailin Kroetz, Ryan Kellogg, Chris Legault, Kyle Meng, Jennifer Raynor, James Rising, Jeffrey Shrader, and Cody Szuwalski. We would like to thank Jesse Adelman, Sushant Banjara, Jennifer Boughton, David Foote, Miriam Gold, Alessandra Guerrero, Ben Hurley, Stephanie Klunk, Chong An Ong, Pete Rodrigue, Ruby Roty, Daniel Tropper, and Vanessa Zemke, for excellent research assistance. We would also like to thank seminar and conference participants at University of Illinois Urbana-Champaign, UC Davis, NOAA Northwest Fisheries Science Center Monster Jam, The World Bank, Resources for the Future, Midwest Energy Fest, the Ostrom Workshop, the AERE Sessions at the AEA, the International Institute of Fisheries Economics & Trade , the NBER EEE SI, and the AEA Economics and Marine Resource Management Session for their helpful comments. We also thank the staff members at the different Fishery Management Councils and the National Oceanic and Atmospheric Administration, especially Karen Greene, for their assistance in accessing, validating, and interpreting the data. We acknowledge financial support from the Energy Policy Institute, and the Becker Friedman Institute at the University of Chicago.

†Harris School of Public Policy, University of Chicago, CEPR and NBER. Office 2057, 1307 E. 60th Street, Chicago, IL 60637, USA. Email: eyalfrank@uchicago.edu

‡School of Marine Science and Policy and Department of Economics, University of Delaware. Robinson 308, 261 S College Avenue, Newark, DE 19716, USA. Email: oremus@udel.edu

1 Introduction

Biological resources are fundamental to human well-being (Daily et al. 2000; Cardinale et al. 2012; Dasgupta 2021), yet they are rapidly being depleted worldwide (Clark 1973; Arrow et al. 2004; Polasky et al. 2019). Economists have provided rigorous evidence on the impacts of policies regulating pollution, energy use, and extractive industries[1], but causal evidence on the effectiveness of key policies governing renewable biological resources such as forests and fisheries is limited.[2] This gap is notable given the scale of the problem: since 1970, global resource use has tripled (UNEP 2020), leading to wetland degradation, biodiversity loss, and collapsing fisheries (Hansen et al. 2013; Ceballos et al. 2015; Costello et al. 2016; Fluet-Chouinard et al. 2023). Marine fisheries in particular embody a canonical common-pool resource problem, where individual incentives to overfish dissipate rents and threaten long-run industry viability (Gordon 1954).

The central federal law addressing this problem in the United States (US) is the Magnuson–Stevens Act (MSA), which regulates all commercial marine fisheries in federal waters—the world's second-largest exclusive economic zone. The 1996 reauthorization required rebuilding plans for overfished stocks.[3] Unlike pollution policies, which reduce external damages through air and water quality standards, fishery policies directly restrict harvest relative to biological reproduction. Under the MSA, when a stock's population falls below a predetermined scientific threshold, total catch must be reduced until the population is rebuilt to sustainable levels within ten years, often necessitating a *doubling or more* of the stock size.[4] These restrictions impose immediate costs on fishers by lowering catch and revenue, while their benefits depend on future ecological recovery and rent generation. This tradeoff has made the rebuilding provisions of the MSA a persistent source of political debate: industry groups argue the requirements are overly rigid and impose unnecessary short-run burdens, while supporters contend that binding, science-based rules are essential to prevent collapse and secure the long-run viability of fisheries (*Reauthorization of MSA:* 2017). The MSA is

[1] See for example existing work that studied US policies, such as: Clean Water Act (Keiser and Shapiro 2019; Jerch 2021), Clean Air Act (Greenstone 2002; Auffhammer and Kellogg 2011; Walker 2013; Isen et al. 2017; Gibson 2018), Superfund sites (Greenstone and Gallagher 2008; Currie et al. 2011), Corporate Average Fuel Efficiency standards (Austin and Dinan 2005; Jacobsen 2013; Jacobsen and Benthem 2015), bond requirements for oil and gas drilling (Davis 2015; Boomhower 2019), and how lease expiration clauses distort drilling decisions (Herrnstadt et al. 2020).

[2] Recent studies on fisheries have focused on the efficacy of Marine Protected Areas (McDonald et al. 2024; Raynor et al. 2025), and studies on deforestation have focused on variety of policies implemented in Brazil (Assunção et al. 2020; Assunção et al. 2023; Abman and Lundberg 2024)

[3] The same requirement is in the Modernizing Recreational Fisheries Management Act of 2018.

[4] A biological fish stock is a group of fish of the same species that live in the same geographic area.

often cited as a gold standard in international fisheries management (Brazer 2018; Coit 2021), yet its actual impacts—on stocks, profits, and compliance—remain debated.

Early studies on MSA found stock biomass trending in a positive direction after the introduction of the MSA or similar policies (Milazzo 2012; Sewell et al. 2013; Oremus et al. 2014; NRC 2014; Hilborn et al. 2020; Britten et al. 2021). None of these studies included a control group, precluding causal interpretation. Other studies have used simulations to explore specific aspects of the MSA or its implementation, such as rebuilding timelines (Patrick and Cope 2014; Carruthers and Agnew 2016), the role of uncertainty (Memarzadeh et al. 2019), or how to set catch quotas at different biomass levels (Benson et al. 2016); or to evaluate the potential of sustainable fishing policies globally (Costello et al. 2016). None of these simulation-based studies empirically measured the MSA's efficacy.

This paper provides causal evidence on the effectiveness of the MSA's rebuilding provisions using a newly compiled dataset linking stock assessments, management actions, and economic outcomes across US and European Union (EU) fisheries from 1990 to 2016. Departing from previous studies, we exploit a scientific threshold that defines a stock as overfished to compare depleted stocks with and without rebuilding plans. Using two complementary research designs, we show that stocks that entered rebuilding plans substantially increased in biomass in the following 6-10 years relative to counterfactuals. To examine whether long-run gains offset the short-run revenue losses imposed by rebuilding plans, we estimate the net present value (NPV) of revenue during the rebuilding and post-rebuilding periods. Among stocks that successfully complete rebuilding plans, NPV is, on average, at least 20 percent higher than it would have been without the policy, and at least 69 percent of these stocks experience NPV gains. Consistent with this, we find that catch and revenue increase after stocks are rebuilt.

To estimate the contemporaneous effects of rebuilding requirements, we compare US and EU fisheries from 1990 to 2016, exploiting the fact that the US implemented rebuilding plans in 1996 while the EU did not adopt comparable provisions until 2013, with full implementation in 2020 (*Common Fisheries Policy* 2013). We apply a cohort-weighted difference-in-differences design that accounts for staggered entry of stocks into treatment. This approach shows that biomass in US stocks placed under rebuilding increased by 52.2 percent, on average, relative to comparable EU stocks without rebuilding requirements.

We complement this analysis with a historical within-US comparison before and after the 1996 reauthorization. We compare the trajectories of stocks that fell below their scientific overfished thresholds under two regimes: prior to 1996, when rebuilding was not required,

and after 1996, when rebuilding plans became mandatory. We implement separate event studies for each regime. This comparison shows that depleted stocks continued to decline before 1996, whereas after 1996 stocks increased in biomass once entering treatment. To hold species composition and fishery characteristics constant, we restrict the sample to stocks observed in both periods and use a paired-differences estimator, finding that biomass more than doubled relative to the historical counterfactual.

In additional analyses, we address potential confounders, such as the possibility that some of the observed effects could be due to changes in environmental conditions, market demand, or potential spillovers (Hilborn et al. 2021; Kroetz et al. 2022). Using fisheries' growth rate as a proxy for environmental conditions (Szuwalski et al. 2015), we do not detect differences between the comparison and treatment groups. Using catch data, we examine changes in supply before stocks receive treatment and do not find evidence consistent with a decline in demand driving the recovery of the stocks. Testing for potential spillovers, we find no evidence that EU stocks decline when the corresponding US species enters rebuilding, validating our use of the EU as a comparison group. We also assess substitutions, finding evidence that fishing effort shifted from stocks in rebuilding toward healthy stocks within the same region and taxonomic groups, validating our reasoning to not use US stocks from the same region as a comparison group. US seafood imports increased, while aggregate consumption of fish remained stable, indicating possible substitution to imports.

Rebuilding plans contribute to the long-term recovery of fisheries, but they can also generate short-term losses while catch limits are reduced. To assess how long-term gains compare to short-term revenue losses, we conduct a NPV analysis on the subset of stocks that were successfully rebuilt. Unlike our primary analysis of biomass, catch, and fishing mortality, the NPV analysis cannot use the cohort-weighted difference-in-differences design because comparable EU revenue data are unavailable before 2006. Instead, we construct three data-driven counterfactuals of revenue without treatment: one based on exponential extrapolation, one based on fishery-specific historical revenue volatility, and one based on estimated changes in catch for US stocks relative to EU stocks. All three approaches recover the same central result: for at least 69 percent of the stocks in the analysis, realized revenue NPV exceeds estimated counterfactual NPV without rebuilding. This comparison shows that, once rebuilding plans have had time to run their course, they often generate long-run economics gains that outweigh short-run revenue losses.

Building on this, we then explore the mechanisms through which rebuilding requirements affected outcomes. Stocks subject to higher compliance with catch limits and more precau-

tionary management buffers exhibited stronger recoveries. Regional heterogeneity, particularly in New England where catch limits were often exceeded, underscores the importance of compliance in determining policy effectiveness.

The economic stakes are meaningful. As of 2018, wild-capture marine fisheries provided 84.4 million tonnes of fish for food security and supported 39 million livelihoods worldwide (FAO 2020). In 2022, US commercial fisheries employed 42,000 harvesters and generated over 5.9 billion USD in catch revenue (NMFS 2022). Fish also play a vital role in the carbon cycle, trapping carbon in the ocean for thousands of years (Wilson et al. 2009; Siegel et al. 2023). Modern harvest levels have reduced the rate of this cycle by half (Bianchi et al. 2021). Rebuilding fish stocks is therefore a UN Sustainable Development Goal, with 193 countries committed to national implementation. Since the MSA's reauthorization, comparable provisions have been adopted in other countries, though such policies remain politically contentious. In the US, the MSA's latest reauthorization has been stalled in Congress since 2013, with competing bills divided over whether the rebuilding requirements should be weakened. Our results show that the MSA's rebuilding provisions substantially increased biomass for depleted stocks, with long-run economic gains that outweighed short-run costs. These findings have direct implications for both domestic and global fisheries management.

2 Background

Theoretical Foundations. Justification for management actions, specifically rebuilding plans, is grounded in theory on natural resource economics and population dynamics.

To illustrate these dynamics, we begin with a simplified logistic growth model of a fictitious fish stock (more complex models can exhibit similar behavior), shown in Figure 1a. Growth depends on population size (biomass), the intrinsic growth rate r, and the carrying capacity K. In steady state—where growth equals harvest—the stock's growth rate (y-axis) varies with biomass (B), which increases along the x-axis and is represented by the black curve.[5] Maximum growth occurs at $K/2$, corresponding to the biomass that produces the maximum sustainable yield (MSY). Theoretically, a stock can be harvested at this rate (F_{MSY}) while maintaining a constant population. This biomass is referred to as B_{MSY}.

Classic natural resource economics (Gordon 1954; Schaefer 1957) shows that in the absence of policy and property rights—i.e., under open access (OA)—fishing effort expands

[5] Formally, in the logistic growth model, the change in the size of the stock N is determined by: $\frac{\partial N}{\partial t} = rN(1 - \frac{N}{K})$.

until average revenue equals average cost, dissipating all economic rent. In this equilibrium, the population declines below B_{MSY} ($B_{OA} < B_{MSY}$ in Figure 1a), where profits are zero. When well-defined property rights are assigned, net present value (NPV) is maximized where marginal revenue equals marginal cost—known as the maximum economic yield (MEY), assuming perfect information and convex costs.[6] MEY is considered a win-win because it yields higher profits while conserving more fish; as biomass decreases, falling catch rates increase the marginal cost, making it optimal to fish less and maintain a higher stock level ($B_{MEY} > B_{MSY}$). In practice, most fishery policy lies somewhere between the OA and MEY.

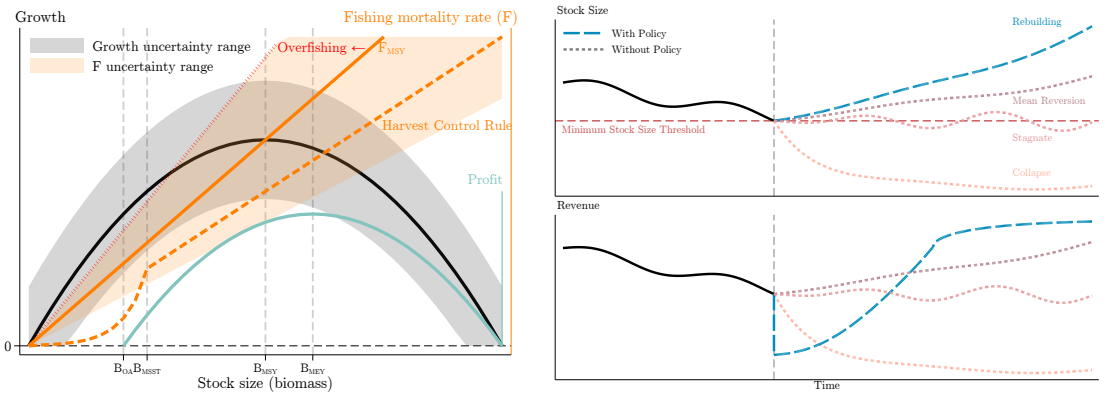
Enactment of the MSA & Development of Rebuilding Provisions. The US first regulated domestic fisheries through the Fishery Conservation and Management Act of 1976. This law tried to close open access by establishing Exclusive Economic Zones (EEZs), restricting fishing to US vessels, and creating regional fishery management councils to regulate fishing effort. Renamed the Magnuson-Stevens Act (MSA), it remains the primary federal law governing marine fisheries. In response to a large post-1976 increase in domestic fishing effort and subsequent stock depletion, the 1996 reauthorization—the Sustainable Fisheries Act—introduced a requirement to rebuild overfished stocks. Rebuilding plans must return stocks to sustainable levels within 10 years, unless biologically infeasible, and must have at least a 50 percent probability of success (*Sustainable Fisheries Act* 1996). The 2006 reauthorization further required rebuilding plans be implemented within two years of a stock being declared overfished and the use of annual catch limits (ACLs).

In practice, data limitations, political constraints, and historical precedent have led to management based on MSY rather than MEY. Vessel-level data, including decisions on what, when and how to fish, the cost of fishing, and market prices, are either strictly protected by law (*Sustainable Fisheries Act* 1996), unavailable, or unpredictable (Dichmont et al. 2010), making MEY difficult to calculate. While the MSA does not preclude the use of MEY, the law defines the optimum yield from the fishery as "the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor" with more explicit use of MSY to define the status of stocks (*Sustainable Fisheries Act* 1996). This limits the true policy outcome to anywhere between MSY and MEY, depending on stock growth, compliance, precautionary management, price elasticities, and uncertainty. This is a significant change from prior to the rebuilding requirements, when the policy outcome could lie anywhere between OA and MEY.

[6] Profit is given by: $\pi = pH(e) - ce^2$, where revenue is price (p) times harvest (H), and cost (c) is convex with fishing effort (e). Harvest depends on catchability (q), fishing effort, and stock size (N): $H = qeN$.

Figure 1: Conceptual Framework for Resource Policy Design & Evaluation

(a) Logistic Growth Rate Curve (b) Potential Stock & Revenue Trajectories



Notes: Fishery management under uncertain growth and harvest rates. Panel (a) is adapted from Anderson and Seijo (2010) and shows the steady state of stock growth versus biomass. Profit (second y-axis) is in turquoise. Uncertainty in the growth rate is represented by the gray region and uncertainty in fishing mortality rate (third y-axis) is represented by the peach region. The harvest control rule, which kinks at the Minimum Stock Size Threshold (MSST), is the dashed orange line. Panel (b) shows year-to-year variability in stock (top figure) and revenue (bottom figure) over time (black line). When the stock declines to the MSST, fishing is restricted, revenue declines, and the stock rebuilds (long-dashed-blue line). The counterfactual (all short-dashed red-shaded lines) in absence of the requirement to rebuild the overfished stock could naturally revert to its previous levels (mean reversion), stagnate, or collapse.

The MSA defines three biological reference points: (1) a stock is in "overfishing" when $F > F_{MSY}$[7]; (2) "overfished" when biomass falls below the minimum stock size threshold (MSST), often set at 50% of B_{MSY}; and (3) "rebuilt" when the stock reaches B_{MSY}. As of 2020, 47 stocks have been rebuilt (NOAA Fisheries, 1997-2020).[8]

Implications of Uncertainty & Stochasticity. Fishers would like managers to set catch or effort controls to $F = F_{MSY}$, where the orange line intercepts the growth rate curve (black line) at B_{MSY}. However, seminal work highlights how uncertainty and stochasticity impede effective management (Reed 1979; Clark 1976). Uncertainty in catchability (due to season, gear, or technology) and prices can lead to uncertainty in F. If the true F exceeds F_{MSY}, overfishing occurs (anywhere between the solid orange line and dotted red line). Environmental and ecological changes create uncertainty in r, shifting the growth curve (gray region). These uncertainties affect estimates of F_{MSY}, B_{MSY}, MSY, MSST, and B_{MEY}. If the true growth curve lies below the overfishing line (dotted red line), the stock

[7] Fishing mortality is typically defined as $F = \frac{Catch}{Biomass}$, and at target levels, $F_{MSY} = \frac{MSY}{B_{MSY}}$.

[8] As an example, we plot the trajectory of one stock, spiny dogfish that experienced the full policy cycle from becoming overfished to rebuilt in Figure A1.

may collapse (Roughgarden and Smith 1996).

These uncertainties also apply outside of a steady-state framework. Figure 1b shows stock size over time. If a negative shock pushes biomass below MSST, the harvest control rule (HCR) lowers F to rebuild the stock biomass (blue dashed line). This would lower catch and subsequent revenue immediately, but then they could increase as the stock rebuilds (bottom panel, blue dashed line). The counterfactual trajectory without rebuilding provisions is unknown—the stock might rebound (mean reversion scenario), stagnate, or collapse.

HCRs are designed to buffer against these uncertainties and are set *a priori*. The dashed orange line in Figure 1a illustrates the Mid-Atlantic HCR. It is set at 75% F_{MSY} when $B > MSST$, but F is reduced once $B < MSST$, after which rebuilding plans apply.[9] Implementation involves a hierarchy of uncertainty buffers. First, an overfishing limit (OFL) is set, corresponding to the annual catch associated with maximum sustainable yield. The OFL can be reduced to the acceptable biological catch (ABC) to reflect scientific uncertainty ($ABC \leq OFL$). The regional fishery management council (FMC) sets the maximum amount a fish stock can be harvested in a given year with an ACL, where $ACL \leq ABC$. Further management uncertainty can be considered using an annual catch target (ACT) ($ACT \leq ACL$). ACLs may be subdivided by areas, seasons, and/or sector and enforced via permits, gear/area restrictions, trap limits, days-at-sea, or, less commonly, individual quotas. ACLs became mandatory starting in 2010. Despite these precautionary measures, stocks can fall below their MSST. This can happen if the uncertainties exceed the buffers set by managers; the HCRs are not properly implemented; or fishers do not comply.

Compliance, Monitoring & Enforcement. ACLs are monitored through dealer reports, in which licensed buyers of commercial landings record their purchases. As the ACL nears its limit, managers may adjust quotas, impose closures, or account for overages the following season.

Species identification, discards, and bycatch are done by third-party observers, who are trained biologists on board fishing vessels or in processing facilities. Some observation is done by electronic monitoring. Observers are not enforcers who can issue citations, but potential violations are forwarded to law enforcement, often to NOAA's Office of Law Enforcement (OLE). The OLE will decide which violations to investigate and either issue a warning, a fine based on a schedule, or send them to General Council for a ruling (Dobson et al. 2023). The Coast Guard can also monitor and enforce provisions of the MSA as well as collaborate with

[9] Free et al. (2022) offer a detailed review of different functional forms for HCRs.

NOAA Fisheries. See Online Appendix Section B.1.5 for challenges in obtaining monitoring and enforcement data.

MSA Reauthorization Failures & Policy Debates. After the MSA's 2006 reauthorization, the act was up for reauthorization in 2013, which failed, followed by another failed attempt in 2018. In July 2021, Congressman Huffman introduced H.R. 4690 to the House after engaging in a year-long, cross-country listening tour. Congressman Young, one of the authors of the original 1976 MSA, introduced an alternative bill, H.R. 59, that has its roots in the failed 2018 bill. The 2018 bill loosened rebuilding provisions in favor of short-term needs of fishing communities. Opponents of the Act have derided it as the "Empty Oceans Act."[10] Huffman reintroduced his bill in 2025, while President Trump created Executive Order 14276, Restoring American Seafood Competitiveness, which stated that there is over-regulation in US fisheries. These debates over reauthorization reflect deeper disagreements about how well the policy works in practice, particularly in regions where compliance and management have been difficult.

The New England Fishery Management Council (NEFMC) has historically struggled with management action and fisher compliance (Layzer 2006) (we report suggestive evidence for compliance in Section A.13), as well as rapidly warming waters (Pershing et al. 2015) and stock assessments that were deemed inaccurate (Schrope 2010). Many fishers in New England do not trust fisheries management (Scyphers et al. 2019).

Without full information, it is unclear whether rebuilding plans are necessary. The debate over reauthorizing the MSA's rebuilding provisions centers on this tradeoff: on one hand, a rebuilding policy may impose costly and unnecessary restrictions on a stock that would recover naturally, albeit more slowly (Hilborn 2019; McQuaw and Hilborn 2020); on the other hand, without such a policy, the stock could economically collapse (Clark 1976). In other words, whether the NPV under the policy is higher than without the policy (NPV of blue-dashed line versus NPV of red-dashed line in Figure 1b).

3 Data

We gather fish stock panel data on catch and biomass, as well as management thresholds that are used to determine a stock's status. A biological fish stock is a group of the same

[10] The bill included extended timelines for rebuilding, exemptions from accountability measures, and provisions allowing managers to override the scientifically-recommended catch quotas. For more details, see: https://usa.oceana.org/wp-content/uploads/sites/4/4046/msa_scientist_support_letter_final.pdf. Accessed: March 24, 2026.

species that live in the same geographic area. For US fish stocks, we also build a complete timeline of policy implementation.

3.1 Data From the United States

We obtain yearly US catch, fishing mortality (F), biomass (B), and productivity for each stock from the National Oceanic and Atmospheric Administration's (NOAA's) Stock SMART System, a database of stock assessments (NOAA 2022). In the Online Appendix, Section A.2, we employ different approaches to validate that the assessment data meaningfully captures a signal about the fishery population level. Management thresholds (in bold, overfished: $B < \mathbf{MSST}$, overfishing: $F > \boldsymbol{F_{MSY}}$ and rebuilt: $B > \boldsymbol{B_{MSY}}$) for each stock are always obtained from the same source and the same assessment year. These are also known as reference points. From 1990 to 2015, stocks slowly move from experiencing overfishing and being overfished to not experiencing overfishing and being rebuilt (Figure A3).

When available, we collect the ACL[11] for each stock(i)-year(t), which reflects the implementation of the harvest control rule and any rebuilding plan. This allows us to examine (1) compliance, measured as $(catch_{it} - ACL_{it})/ACL_{it}$, where positive values indicate overages and negative values indicate underages—and (2) the management buffer, measured as $(MSY_{it} - ACL_{it})/ACL_{it}$, that reflects the precautionary buffer for biological and management uncertainty. Management buffers with positive values reflect precautionary management, zero values represent no precaution, and negative values allow for overfishing. ACLs became binding for most stocks in 2010; before that, they either did not exist or were non-binding targets.

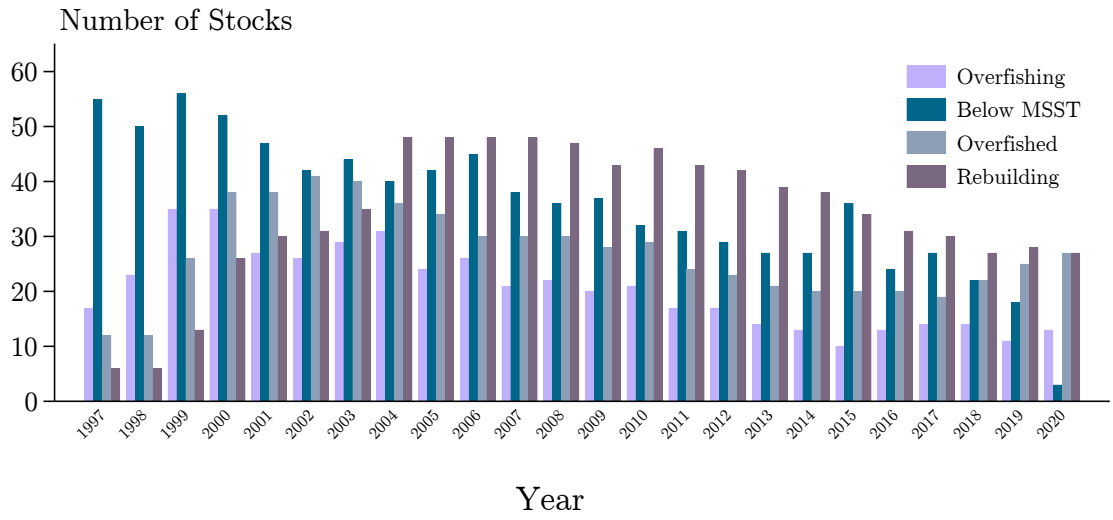
To ensure we are studying stocks primarily affected by US fishing pressure and regulations, we limit our main sample to stocks found in federal waters. We exclude highly migratory species that inhabit international waters, as well as anadromous species like salmon, which spend part of their life cycle in freshwater, subject to different regulatory regimes. We also omit crab species due to their distinct assessment and management processes.

For US stocks, we complement their time series data with a timeline of status determinations and regulatory actions. We went through each of NOAA's yearly Status of Stocks reports (NOAA Fisheries, 1997-2020) to record the years that fishery management councils designated a stock as "in overfishing," near overfished, overfished, in rebuilding, and rebuilt. We validated these years with the information stored at NOAA's Office of Sustainable Fish-

[11] Data for OFL, ABC, ACT, and sub-ACLs, fishery observers, OFL citations, and fines does not exist for most of our study period.

eries.[12] We summarize the number of stocks by MSA designation for each year in Figure 2. In the years before the 1996 MSA, half of the stocks were in overfishing, and more than 20% were overfished (Figure A3). After 1996, a large number of stocks were deemed to be below their MSST. That led to more stocks being designated as in overfishing and overfished. Then the number of stocks that were in rebuilding started to increase, while the number of stocks in overfishing started to decline. More recently, the number of stocks experiencing any MSA event has been declining steadily. By 2015, both overfishing and overfished shares of stocks fell to 16.5 and 15.7 percent, respectively.

Figure 2: Number of Stocks in Each MSA Category by Year



Notes: Summarizing data from the Status of Stocks Reports.

Sixty of the 189 non-migratory and non-anadromous US stocks in our dataset entered rebuilding after the 1996 MSA. However, only 52 stocks have balanced biomass data from 1990-2016, 50 stocks have balanced catch data from 1990-2016, and 49 stocks have both. For the historical analysis, we also have data on 18 stocks whose biomass fell below their MSST before 1989. To date, this is the largest harmonized panel dataset of US fish stock populations and management.

We also gather data on the quantity and revenue of fish sold from the NOAA Fisheries One Stop Shop (NOAA FOSS 2021). In this database, fish landings and revenue are tallied by region and species, often a broader categorization than fish stock. When possible, we match species-region landings to their equivalent Stock SMART stock. In some cases, landings

[12] This validation is especially important during the earlier years of the post-1996 reauthorization of the MSA, because several stocks were incorrectly classified due to confusion about the new designations. These errors were not corrected in the public records, and the true regulatory history is only available in non-public records managed by NOAA. See the Data Appendix for additional details.

data combine landings from multiple stocks of the same species in a given region. (E.g., New England Atlantic cod landings come from two stocks, one in the Gulf of Maine and one in Georges Bank.) For these situations, annual revenue and landings data are distributed to each stock according to its proportion of the total annual catch for the stocks of that species in that region. We have US revenue and landings data for 143 stocks (40 of our 60 treated stocks from 1990-2016).

3.2 Data From the European Union

EU catch, biomass, and productivity time series data, as well as management reference points, were obtained from a European Commission et al. (2020) report monitoring the *Common Fisheries Policy* (2013), the primary EU fisheries law. The EU defines for each stock the Safe Biological Limit (SBL), equivalent to the MSST under the MSA. Catch data came from three sources: the ICES Stock Assessment Database (ICES 2022) for Northeast Atlantic stocks, and two databases—the EU's Scientific, Technical and Economic Committee for Fisheries database (STECF 2022) and FAO's validated stock assessment forms (FAO GFCM 2022)—for Mediterranean stocks. There are a total of 293 EU stocks in our dataset, of which 46 dropped below their SBL at any point between 1990 and 2016, inclusive. Unfortunately, consistent reporting of landing and revenue data only start in 2006, which is too short a time series for our analysis. We explored alternative sources of data on landings, revenue, and ex-vessel prices from the Food and Agriculture Organization (FAO) and Sea Around Us (SAU). However, when we tried to validate the data with existing US and EU data, we found the FAO and SAU data were biased for the US and the EU and in opposite directions. The differences were also extremely large in some cases. This led us to not consider these data sources as reliable regarding fishery revenue in the EU.

Figure A4 shows trends in biomass and catch before and after stocks fall below their MSST, experience overfishing, are declared overfished, and enter rebuilding for stocks with and without rebuilding plans. Our analysis is limited to stocks with enough management, data, and scientific knowledge to develop a MSST or SBL value. Tables A1 and A2 list all stocks with and without rebuilding plans included in the main contemporaneous and historical analyses.

4 Estimating the Treatment Effect of the Magnuson-Stevens Act

In an ideal experiment, we would randomly assign rebuilding plans to stocks depleted below their MSST. In practice, rebuilding plans are required by law for all stocks that fall below their MSST. Once that happens, the stock is publicly declared overfished, and a rebuilding plan is developed.[13] To avoid anticipatory effects, in our main analysis, we define the event of interest and first event year as the year the stock's biomass dropped below its MSST (we report results for the other MSA events, a stock being declared overfished and a stock entering a rebuilding plan, in the Online Appendix). Only treated stocks (US stocks that enter rebuilding between 1996 and 2016) are assigned an event of interest. Our treated group of stocks is those that experience an event of interest and have ever entered a rebuilding plan. Because stocks managed by the NEFMC might exhibit different responses than stocks managed by the other fishery management councils (see Section 2 and A.13), we report a set of results excluding NEFMC stocks.

Rebuilding plans can also affect stocks that are not in a rebuilding plan, violating the stable unit treatment value assumption (SUTVA). Restrictions on species in rebuilding could benefit other species if they are typically caught together, or if the stock in rebuilding serves as a food source for the stock that is not in rebuilding (Estes et al. 2011). There could also be economic spillovers. Stocks in rebuilding that undergo changes in fishing effort, such as changes to catch limits, allowed days at sea, or the timing and length of the fishing season, might result in fishers substituting their efforts toward other species in the region (Kroetz et al. 2019). Finally, declines in catch could affect relative prices, increasing the demand for fish from other regions.

The key identifying assumption is that the stocks that entered rebuilding would have developed along parallel trends to the control stocks in the absence of the policy treatment. US stocks that receive rebuilding plans (unhealthy stocks) are systematically different than US stocks that do not (healthy stocks). A valid comparison group needs to approximate the population dynamics of an unhealthy stock that is depleted below the MSST, but does not enter a rebuilding plan. We overcome this inference problem using two comparison groups: (i) a contemporaneous comparison group in the EU (see Online Appendix A.6 for historical comparison of US and EU policies), and (ii) a historical comparison group of stocks in the US that have data going back to 1984 or longer, when rebuilding was not required by law.

Another assumption needed for causal interpretation is that untreated stocks do not

[13] There can be delays between each of these events. See Figure A5 for a summary of those delays.

experience spatial spillovers or leakage from treated stocks. Finally, we need to ensure stock assessments are not being manipulated to make a stock appear rebuilt when it is not. We evaluate to what degree is it likely that these assumptions are violated in Sections 6.1 and A.19.

In what follows, we provide more details about the estimation of each research design.

4.1 Contemporaneous Comparison Cohort-Weighted Difference-In-Differences Specification

The EU's 2013 amendment of the Common Fisheries Policy (CFP) called for rebuilding all commercial fish stocks above levels capable of producing MSY. It set a goal of reducing fishing mortality, F, below F_{MSY} by 2015, or 2020 at the latest. The EU defines for each stock the Safe Biological Limit (SBL), equivalent to the MSST under the MSA. We will refer to the SBL as a MSST-equivalent reference point for the remainder of the paper.

We consider the 46 EU stocks whose biomass dropped below the SBL between 1996 and 2016 to be a valid comparison group. These EU stocks are less likely to be affected by rebuilding plans taking place in the US, but share similar stock assessment practices (Dichmont et al. 2016), fishing market structure (Swartz et al. 2010), and fishing gear and technologies (Rousseau et al. 2019).

We estimate the dynamic treatment effects around the MSA event of interest relative to the contemporaneous comparison group by estimating the cohort-weighted regression specification developed in Sun and Abraham (2021). This DD estimator allows us to estimate the staggered DD research design while avoiding the estimation issues with two-way fixed effects (TWFE) estimators. The key intuition about the undesired properties of using TWFE estimators for a staggered DD design is that the TWFE estimator would use stocks that receive early treatment as controls for stocks that receive treatment later, potentially violating the parallel trends assumption. This could give rise to negative weights in the weighted estimate for the average treatment effect on the treated (ATT), distorting and potentially even flipping the sign of the effect. These problems are more pronounced when there are dynamic treatment effects and/or heterogeneous treatment effects—both of which are likely present in our empirical setting (see Chaisemartin and D'Haultfoeuille (2020) and Goodman-Bacon (2021) for additional details and discussion of these issues).

We follow the formulation of the cohort-weighted DD estimator and define the set of treatment US cohorts that entered rebuilding as E. The set of EU stocks that dropped below their MSST is C and event timing is not assigned to EU stocks. The estimator developed

by Sun and Abraham (2021) estimates a separate set of leads and lags around the event of interest by interacting those leads and lags with a cohort dummy. Those specific cohort ATT (CATT) estimates are then weighted for each event time to obtain an estimate for the coefficient of interest on each lead and lag. This process results in a minor modification to the canonical TWFE specification by simply adding an interaction term for each cohort that undergoes treatment:

$$y_{st} = \sum_{e \neq C} \sum_{\tau \neq -1} \beta_{e,\tau} \mu_{e,\tau} \mathbb{1}\{E_s = e\} + \lambda_s + \delta_t + \varepsilon_{st} \tag{1}$$

Where y_{st} is the outcome of interest (biomass, catch, fishing mortality and revenue), in log points, for fishery stock s, in year t.[14] We include leads and lags, $\mu_{e,\tau}$, that are equal to one when the stock in cohort e is τ years away to the event of interest: dropping below its MSST, receiving an overfished determination, or entering a rebuilding plan. Our focus is on the time window of five years leading up to the MSA event and 10 years after the MSA event. As a result, we bottom and top code the leads and lags, and exclude the bottom- and top-coded coefficients when reporting the estimation results.[15] The set of coefficients, $\beta_{e,\tau}$, recovers the dynamic path around the time of the event for each cohort, relative to one year prior to the event. The final estimation step is calculating a simple mean of the coefficients for each event time coefficient.[16]

We include stock fixed effects, λ_s, to account for time-invariant characteristics of each stock, such as the fishing gear used to catch it, long-term demand and market size, and the biological factors that determine its growth dynamics. The stock fixed effects also nest cross-sectional, fishery management variation across jurisdictions. To flexibly account for pooled time shocks, we include year fixed effects, δ_t, that absorb large macroeconomic cycles as well as large-scale changes to environmental conditions. Any unobserved heterogeneity is captured by the error term, ε_{st}, which we cluster at the stock level.

[14] Explicitly, we use the inverse-hyperbolic-sine: $\log(y + \sqrt{1 + y^2})$ that approximates the log transformation while also being defined for zero.

[15] Bottom coding is when more than 6 years of leads ($\tau < -6$) are coded as -6. Top coding is when more than 10 years of lags ($\tau > 10$) are coded as 10.

[16] Because we focus on the sets of leads and lags where the composition of stocks is the same (five years before and 10 years after the event) the weighted average simplifies to a simple average where each cohort receives the same weight.

4.2 Historical Comparison Event-Study Regression Specification

In the historical comparison, we compare stocks before and after the 1996 reauthorization of the MSA. Before 1996, if a stock's biomass fell below its MSST, it was not required to be rebuilt. Here, we define the event of interest and first event year as the year the stock's biomass fell below its MSST in both the treated and control stocks. Our treated stocks are those that have ever entered a rebuilding plan after 1995. Stocks included in this analysis were below the MSST either before 1989 (control stocks), after 1995 (treated stocks), or both. If stocks are in both, then they are in the control group prior to 1989 and the treatment group after 1995. Their biomass either fell below MSST before 1989 and stayed below MSST after 1995; or it fell below MSST before 1989, recovered, and fell below MSST again after 1995. We reserve the 1989 to 1995 period as the post-treatment period for control stocks. For stocks that were already below the MSST in the latter period, we assign 1995 as their first year of falling below the MSST.

Finally, we subset our data to the same stocks in both time periods. Focusing on the same stocks has the advantage of holding their biology and potentially their stock assessment methodologies constant. However, comparing stocks in the 1970s and 1980s to stocks in the 2000s and 2010s raises concerns that other factors might be driving their recovery. Over these decades, there could have been changes to the market demand for these stocks; or changing environmental conditions could have affected the growth rate of fish stocks. We address these concerns in Section 5.7.

We use a simpler event study specification where we run the following regression specification separately for the treated and control groups:

$$y_{st} = \sum_{\tau \neq -1} \beta_\tau \mu_\tau + \lambda_s + \boldsymbol{X_{st}}\boldsymbol{\theta} + \varepsilon_{st} \tag{2}$$

The specification in Equation (2) is identical to the one in Equation (1) except for the year fixed effects, which we replace with less flexible time trends. We avoid including year fixed effects when we subset the sample to either treated or control stocks because we cannot separately estimate the event time coefficients and the year fixed effects (Borusyak et al. 2024). In the main results, we include quadratic time-trends as part of the set of controls, $\boldsymbol{X_{st}}$. Quadratic time-trends allow us to control for changes in fishing technology, changes in input prices, and oscillations in environmental conditions. In the Appendix, we report a set of results that excludes the quadratic time-trends, as well as results that include diesel

prices on the east and west coasts, along with annual climatic indices that are relevant for the habitat range of each stock. [17]

This simple event-study design relies on the unexpected timing of the stock's biomass falling below MSST. While this estimation lacks a comparison group, we find this parsimonious specification provides an important summary of stock dynamics around key MSA events. For the sample we use in the main analysis, we balance stocks such that we observe both biomass and catch for the entire 15-year time window.

5 The Effects of Rebuilding Plans on Fishery Stocks

We present results from the two research designs: contemporaneous and historical comparisons. Section 5.1 reports effects on stock biomass, the primary outcome of interest for the policy, and Section 5.2 reports effects on catch levels. Section 5.3 examines heterogeneity in biomass and catch responses. Section 5.4 reports effects on fishing mortality, the primary policy instrument. Section 5.5 provides evidence on the economic benefits of the policy, focusing on revenue and net present value. Section 5.6 presents results for rebuilt stocks. Section 5.7 addresses potential measurement issues and additional checks. Throughout, the event of interest is a stock's biomass falling below its MSST (or MSST-equivalent). Unless noted otherwise, treated stocks are those that experience this event and have been placed in a rebuilding plan. Results for other events of interest (overfished determination, or entering a rebuilding plan) are in Table A3 and Figure A6.

5.1 Results for the Main Fishery Health Outcome: Stock Biomass

Using Equation (1) in the contemporaneous research design, US stocks with biomass that fall below their MSST (whether they enter rebuilding or not) have biomass levels that are 50.7% higher relative to the EU control stocks, on average, six to ten years after the event year (Table 1, Panel a, column 1).[18] Limiting our sample to US stocks that experience an event and enter a rebuilding plan (our preferred specification), this estimate increases to 52.2% (column 2). These baseline estimates (columns 1 and 2) exclude all Mediterranean stocks, which diverge from other EU stocks in that they are heavily overfished and do not have defined MSST-equivalent values (Froese et al. 2018). If we also include stocks for which we need to use a pseudo MSST value (see Online Appendix and Table A2, which

[17] See Rousseau et al. (2024) for data showing similar shares of fishing vessel types over time in the US and EU.

[18] After transforming the coefficient from log-points to percent increase, $0.507 = e^{0.41} - 1$

includes 3 Mediterranean and 2 Black Sea stocks), we recover an estimate of 63.2% (column 3). Excluding US stocks from the New England Fishery Management Council (NEFMC), which struggled with policy implementation and compliance (see Section A.13), results in a biomass gain of 53.7% (column 4), or a gain of 69.9% when including stocks with pseudo MSST values (column 5). Finally, the results are robust to the inclusion of stock-level linear time trends (columns 6 and 7).

Since stock recovery depends on reproduction and growth, biomass may take years to increase after a stock falls below its MSST. There may be an additional lag between the event and biomass recovery due to the time it takes to declare a stock overfished and implement a rebuilding plan (see Figure A5 for a summary of these delays). Dynamic contemporaneous results show US stock biomass increasing significantly relative to EU stocks beginning five years after the event year. By year ten, US stock biomass is, on average, 58.4% higher than EU stocks, and 70.2% higher when New England stocks are excluded. Prior to the event, US stocks were not systematically different, on average, than stocks that declined below their threshold in the EU (Figures 3a-3b), supporting the validity of the parallel trends assumption. Estimates are similar when we subset our sample to stocks in the same taxonomic order that are more likely to have similar habitat, require similar fishing gear, and be in similar product categories (Figure A7). These estimates include stock fixed effects and order-by-year fixed effects instead of year fixed effects (see Section 6.3 for discussion on potential leakage). We also observe similar patterns when normalizing the biomass by the MSST, instead of using logged biomass (Figure A8).

Using the historical comparison research design, we find that stocks increased in biomass by 97.9%, on average, five to ten years after falling below their MSST in the post-1995 period (Figure 3c). In the pre-1989 period, by contrast, biomass continued to decline by an additional 44.9% five to ten years after the event year. Note that the coefficients from each historical comparison regression are not directly comparable to one another because they are measured relative to different omitted categories. In a similar manner, we avoid drawing comparisons between the contemporaneous and historical analyses because they each have a different comparison group. These effects remain similar in magnitude when excluding New England stocks (Figure 3d), when controlling for fuel prices and climate indices (see Figure A9), and when not including quadratic time trends (see Figure A10).

To better compare the historical to the contemporaneous research design, we restrict the sample to the *same stocks* during two different time periods. Using stocks that met the conditions for a rebuilding plan in both time periods allows us to construct paired differences

Table 1.
Contemporaneous Comparison of US to EU Stocks DD Estimation Results

Panel A. Log(Biomass) (*recovery lags due to time needed for reproduction*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Event Time 1-5	0.10	0.10	0.15	0.13	0.18	0.16	0.25
	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.09)	(0.09)
Event Time 6-10	0.41	0.42	0.49	0.43	0.53	0.60	0.74
	(0.14)	(0.14)	(0.13)	(0.16)	(0.15)	(0.21)	(0.21)
Within R^2	0.136	0.134	0.141	0.159	0.166	0.089	0.126
Observations	2,295	2,214	2,511	1,620	1,863	2,214	1,863
Clusters	85	82	93	60	69	82	69

Panel B. Log(Catch) (*decline reverses as biomass recovers*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Event Time 1-5	-0.18	-0.18	-0.19	-0.24	-0.21	-0.11	-0.18
	(0.14)	(0.14)	(0.13)	(0.17)	(0.15)	(0.19)	(0.20)
Event Time 6-10	-0.03	-0.06	-0.06	-0.29	-0.25	0.16	-0.14
	(0.27)	(0.27)	(0.24)	(0.32)	(0.28)	(0.43)	(0.41)
Within R^2	0.057	0.058	0.055	0.064	0.061	0.051	0.056
Observations	2,295	2,214	2,511	1,620	1,863	2,214	1,863
Clusters	85	82	93	60	69	82	69
Ever Entered Rebuilding		X	X	X	X	X	X
Including Pseudo MSST			X		X		X
Excluding NEFMC Stocks				X	X		X
Linear Stock Trends						X	X

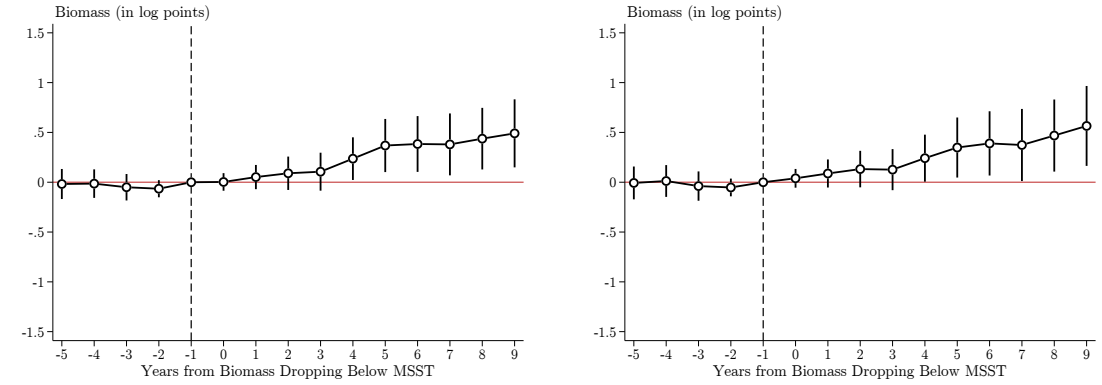
Notes: Estimation results from the DD specification in Equation (1). We report the linear combinations for the event time dummies after the stock drops below the MSST for the average of the first to fifth lags, and the sixth to tenth lags, excluding the top-coded lag coefficient. Column 1 includes all US stocks whose biomass dropped below the MSST. Column 2 narrows the treated sample to stocks that also entered a rebuilding plan. Column 3 expands the control group by including stocks with pseudo MSST values (see Section 4 for details). Column 4 repeats column 2, but excludes New England stocks (see Section 2 for details). Column 5 repeats column 4 but includes stocks with pseudo MSST values. Column 6 repeats column 2, but includes linear stock time trends. Column 7 repeats column 6 but includes pseudo MSST values, and excludes New England stocks. All regressions include stock and year fixed effects. Standard errors are clustered at the stock level.

Figure 3: Evidence for the Policy's Outcome: Fish Biomass Recovery

Including All US Stocks	Excluding New England Stocks

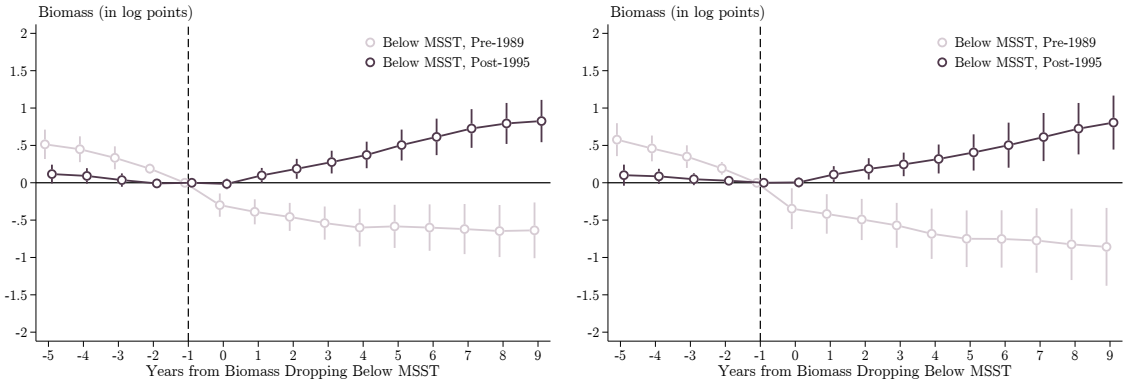
Contemporaneous Comparison, US to EU

(a) (b)



Historical Comparison, Present-US to Past-US

(c) (d)



Notes: Panels (a) and (b) report estimation results showing coefficients and 95% CIs for the DD specification in Equation (1). Panels (c) and (d) report estimation results from two separate regressions showing coefficients and 95% CIs for the specification in Equation (2). The results on the left column of the panels include all US stocks that ever entered rebuilding (#treated=49), while those on the right exclude stocks in the New England Region (#treated=27, see main text for details). Standard errors are clustered at the stock level.

for each stock in each event time period relative to the year prior to the event year. For each stock, we take the difference in logged biomass in each event time period. We use this stock-specific difference in logged biomass as our outcome variable in Equation (2). We summarize the estimation results from this approach in Table 2. On average, biomass increased 163.8% in the five to 10 years after falling below the MSST in the post-1995 regime(column 2), slightly higher than when includeing stocks that did not enter a rebuilding plan (column 1). This specification compares the difference in how biomass evolves in the years after meeting the condition for a rebuilding plan, relative to the difference in biomass in the year prior to meeting the condition. These results are robust to controlling for fuel prices and for climatic indices (column 3, see Online Appendix A.11 for details). In Figure A20, we plot the results of estimating the event-study specification on the paired differences.

Table 2.
Historical Comparison of US Stocks Post-1995 to Pre-1989 Estimation Results

	Log(Biomass)			Log(Catch)		
	(1)	(2)	(3)	(4)	(5)	(6)
Event Time 1-5	0.47	0.46	0.47	0.30	0.26	0.26
	(0.13)	(0.15)	(0.16)	(0.15)	(0.16)	(0.17)
Event Time 6-10	0.93	1.00	1.04	0.60	0.64	0.67
	(0.20)	(0.23)	(0.25)	(0.28)	(0.30)	(0.35)
Within R^2	0.332	0.383	0.393	0.086	0.095	0.096
Observations	448	393	387	398	353	347
Clusters	32	28	28	29	25	25
Ever Entered Rebuilding		X	X		X	X
Fuel & Climate Controls			X			X

Notes: Estimation results from the specification in Equation (2). All regressions include stock fixed effects. Regressions in columns 3 and 6 also include fuel price and climate indices controls. Standard errors are clustered at the stock level.

Both the contemporaneous and the historical comparisons highlight that in the absence of a rebuilding plan, stock biomass does not recover, at least within the 10 years after stocks decline below their MSST. This finding aligns with the middle-ground scenario of the stock stagnating—neither collapsing nor reverting to the mean—in the absence of rebuilding plans (Figure 1).

To contextualize our results, we estimate the policy's contribution to total biomass in US waters. Using our main result from the contemporaneous comparison, we estimate a total biomass increase of 947,412 metric tons by the tenth year after dropping below the MSST.

However, we can perform this calculation for only the 31 treated stocks (out of 49 total) that have their biomass data reported in metric tons, and not in a biomass proxy.[19] Consequently, this is a lower bound for the total gain in biomass. To better anchor this number, we sum the biomass and commercial catch in 2016 for 119 US stocks for which we can convert these variables to metric tons. The total amount of commercial catch in the US is 2.74 million metric tons, and the total biomass value is 14.9 million metric tons.

5.2 Results for the Main Fishing Industry Outcome: Catch

Catch is a function of fishing effort, catchability, and stock size (Section 2). Without vessel-level data, we cannot calculate the fishing effort or catchability. However, managers reduce ACLs in order to lower catch when biomass is low, especially in the early years of a rebuilding plan, and raise ACLs when the stock recovers. In Table 1, Panel b, we report the results of the contemporaneous research design for catch. We estimate that one to five years after stocks drop below their MSST, catch imprecisely declines (columns 1 to 7). This decline becomes smaller and remains noisily estimated, reflecting a near return to baseline levels in the six to 10 years after the event year (column 1 to 3, and 6). However, when we exclude New England stocks, the reduction in catch persists even in the latter time period, albeit imprecisely estimated (columns 4, 5, and 7).

The results in Table 1 suggest that biomass can experience a meaningful recovery even without a large catch reduction in the short term. This might seem counterintuitive given that reducing fishing mortality, seen as the key policy instrument, requires lowering catch. (We present fishing mortality results in the next section.) However, biomass recovery without steep reductions in catch can still occur due to the non-linear dynamics of biological resources. When a population is depleted, even modest reductions in catch can allow for the growth rate to exceed the mortality rate. From those low stock levels, growth can compound, allowing biomass recovery despite relatively small initial changes in catch (Figure 1a). In Figure 4, we plot the catch results for the contemporaneous and historical research designs. In the contemporaneous research design, catch is similar between the US and EU stocks before the US stocks decline below their MSST. In the years after US stocks decline below their MSST, the estimates are negative, but confidence intervals are wide—masking potential heterogeneity (Figure 4a). Catch returns to baseline levels about six years after the event year, and then appears to recover to above baseline levels. However, the confidence intervals

[19] We convert each stock's biomass into metric tons. We take its biomass from one year before the event, and apply the average increase from the tenth year after the event. We sum these gains across the 31 stocks to arrive at the total biomass gain.

only allow us to reject either large falls or gains in catch. When we exclude New England stocks (Figure 4b), we see a larger drop in catch in the first few years after the event and a recovery towards baseline levels. Again, the effects are imprecisely estimated. In Figure 5, we find that the intended rebuilding plan time frame (above or below 10 years) is an important dimension of heterogeneity. Stocks with rebuilding plans that are intended to take more than 10 years see a larger and more precisely estimated drop in catch.

In the historical research design, we see that both treated and untreated US stocks experience a decline in catch as their biomass approaches the MSST. This is what we would expect to see, as lower biomass results in higher search costs and lower yields, conditional on effort levels remaining similar. Whether we include all US stocks or exclude New England stocks, we find that catch levels continue to decline even further after the stocks decline below the MSST (Figures 4c-4d). In this comparison, we do not find evidence that catch levels recover back to baseline. The linear combinations for the coefficients on catch in the five to 10 years after the event highlight that stocks appear to stabilize at levels that are 22.3% and 55.6% lower, with or without New England stocks, respectively. The continued decline in catch might reflect the delay between the event and the implementation of a rebuilding plan. To better assess whether catch recovers to baseline levels, we examine stocks that were declared rebuilt in Section 5.6.

5.3 Heterogeneity by Stock and Length of First Rebuilding Plan

The results on biomass in Section 5.1 and catch in Section 5.2 mask important heterogeneity. Stock-specific estimates are shown in Online Appendix Figure A14 for the same treated and control stocks used in the paired-difference historical comparison. Holding stock composition constant allows for direct comparison of treatment and control estimates. Most stocks post-1995 gained biomass and reduced catch six to ten years after falling below their MSST. Whereas before 1989 almost all stocks declined in biomass and catch six to ten years after the event year. Kernel density plots of these estimates confirm that both biomass and catch were higher post-1995 than pre-1989. Catch estimates post-1995 may be higher because some stocks were declared "rebuilt" within six to ten years of the event year, allowing catch to rise once biomass exceeded B_{MSY}.

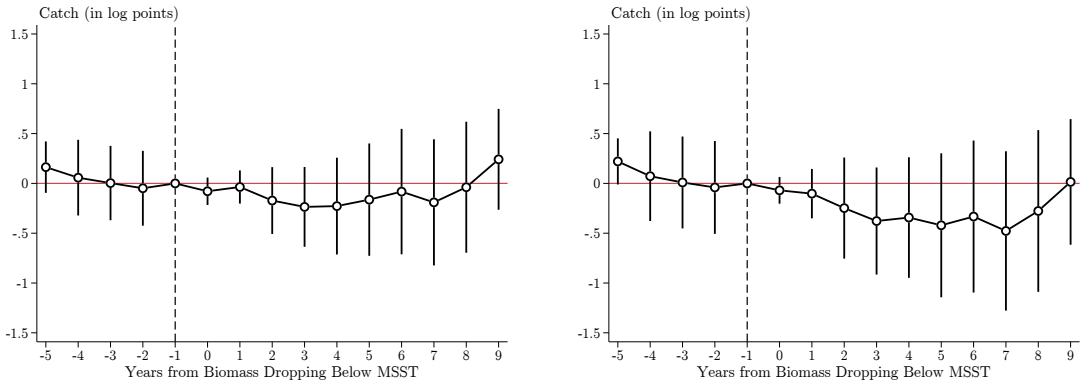
We further explore heterogeneity based on the length of the planned rebuilding period. Stocks predicted to take longer to rebuild will likely require larger reductions in catch. Under the MSA, rebuilding plans must return biomass to B_{MSY} within ten years with at least a 50% probability of success. Extensions beyond ten years are permitted only for biological

Figure 4: Evidence for the Policy's Benefits: Sustaining Catch

Including All US Stocks	Excluding New England Stocks

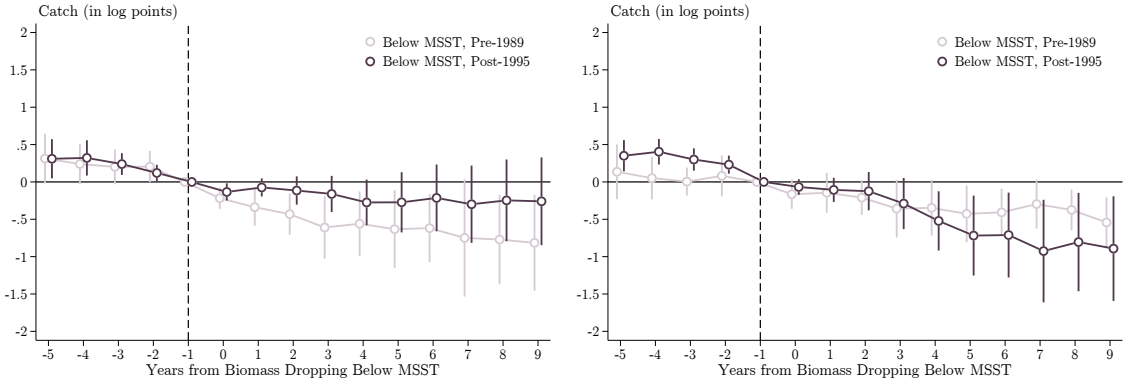
Contemporaneous Comparison, US to EU

(a) (b)



Historical Comparison, Present-US to Past-US

(c) (d)



Notes: See Figure 3.

reasons (e.g., long generation times, low fecundity), not for economic considerations.

We use data on the initial rebuilding plan timeframe, as designated when the stock first entered rebuilding.[20] We classify rebuilding plans as short if their duration is 10 years or less and long if greater than 10 years.[21] We modify Equation (1) to include two sets of leads and lags, each interacted with indicators for short and long plans.

Figure 5a shows that stocks with short plans appear to recover sooner, though we cannot reject equal effects across plan lengths. By year ten after falling below the MSST, both groups converge to the same recovery level relative to baseline. Catch remains relatively flat before recovering for stocks with short plans, but declines sharply for those with long plans. When combining coefficients from years six to ten after the event year, catch for long-plan stocks is estimated to be 62.8% lower.

Stocks may experience different recovery trajectories because of variation in management practices. In Online Appendix Section A.13, we describe heterogeneity across two dimensions of management: precautionary buffers in catch limits and compliance with those limits. We observe that larger precautionary buffers and smaller deviations from the catch limits are, on average, correlated with larger biomass gain during rebuilding. We also document substantial heterogeneity across FMCs in the number overages, defined as years where a stock's catch exceeds the catch limit, with the largest number occurring in New England.

5.4 Results for the Main Policy Instrument: Fishing Mortality

Fishing mortality, defined as the ratio of catch to biomass, measures stock utilization. A rebuilding plan reduces fishing mortality by lowering catch in the short term.

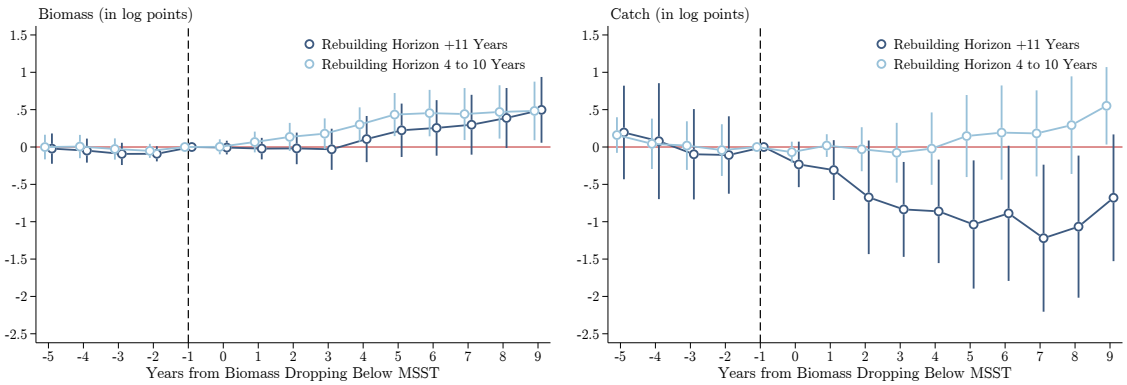
In the contemporaneous comparison including all US stocks, fishing mortality is higher on average in the pre-event period relative to EU stocks (Figure 6a). Post-event, US fishing mortality declines relative to its pre-event level but is not statistically different from the EU, possibly reflecting New England's difficulties with policy implementation and compliance (see Section A.13). Excluding New England stocks, we find no systematic pre-event differences in fishing mortality between US and EU stocks, and a precisely estimated post-event decline averaging 11.7% for US stocks compared to EU stocks (Figure 6b).

[20] Rebuilding plans can be updated over time, changing their length. We use the initial timeframe because it shows what managers knew when the stock first entered rebuilding, before later issues like compliance arose.

[21] There are 36 stocks with short rebuilding plans and 13 with long plans. Plan lengths range from 4 to 95 years (mean 17.5; standard deviation: 16.9). Five stocks lack a plan length because they were rebuilt before receiving a full plan; we classify these as short.

Figure 5: Contemporaneous Comparison Estimation Results for Rebuilding Plan Length

(a) Biomass (b) Catch



Notes: Estimation results showing coefficients and 95% CIs using Equation (1) modified with dummies for short (4-10 years) and long (>10 years) rebuilding plans interacted with event time. n = 36 short, 13 long. Standard errors are clustered at the stock level.

With all stocks included, fishing mortality is imprecisely lower for the treated group (post-1995 period) relative to the control group (pre-1989 period) after stocks fall below their MSST (Figure 6c). Excluding New England stocks, the estimates become precise: fishing mortality of treated stocks declined by 27.9% by the tenth year after the event (Figure 6d). By contrast, untreated stocks in the pre-1989 period show no change in fishing mortality after the event year.

5.5 Evidence on Fishers' Welfare: Revenue & Net Present Value

In this section, we present revenue results and calculate net present values (NPVs) of revenue flows under different scenarios to assess whether the policy's long-run gains from ecological recovery outweigh the short-run costs to fishers from reduced catch. Unfortunately, revenue data for EU stocks is only widely available starting in 2006. Despite examining other datasets, we were unable to obtain credible data for the EU before 2006 (see Section 4.2 and Online Appendix Section A.16 for more details). This limits our ability to use the contemporaneous research design for revenue. In Figure 7, we repeat the historical analysis for revenue and prices, as those only require US data.

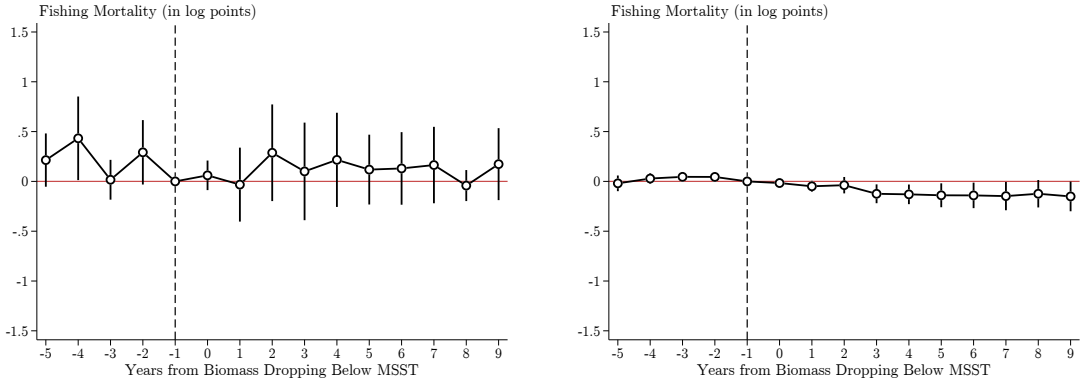
We find that in the post-1995 period, revenue was already declining before biomass fell below the MSST and continued to decline afterward (Figure 7a). During the same time period, prices also fell, failing to offset any declines in catch (Figure 7b). In the pre-1989 period, the pattern differs: prices trended upward and continued to rise even after the event

Figure 6: Evidence for the Policy's Instrument: Lowering Fishing Mortality

Including All US Stocks	Excluding New England Stocks

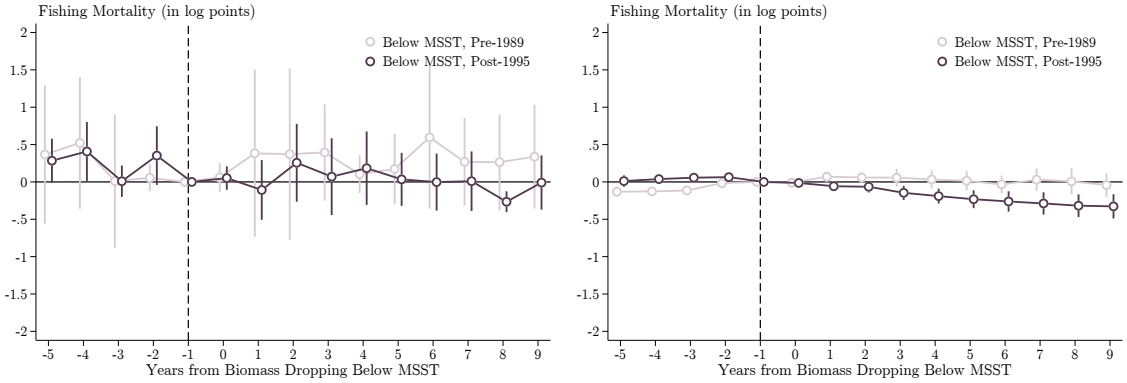
Contemporaneous Comparison, US to EU

(a) (b)



Historical Comparison, Present-US to Past-US

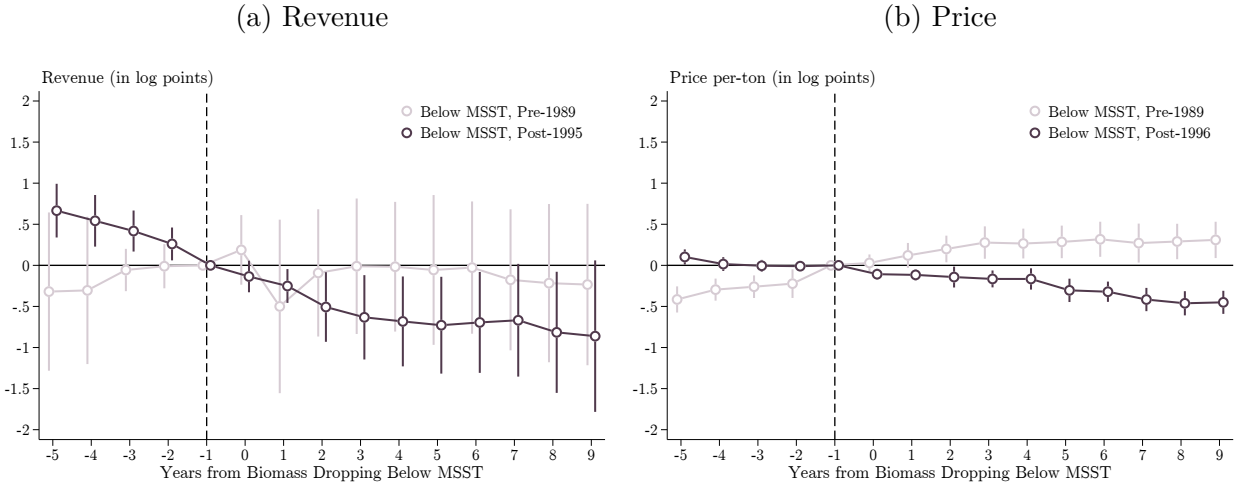
(c) (d)



Notes: See Figure 3.

year. This allowed for revenue to remain relatively stable while catch was declining. In both periods, catch was declining in the years before the event (Figure 4c). A potential explanation for why prices increased in the pre-1989 but not in the post-1995 period is the role of imports—large increases in imports post-1995 place downward pressure on prices, limiting their ability to adjust to the declining catch levels in the US. We examine this more descriptively in Section 6.

Figure 7: Historical Comparison of Revenue & Prices, Present-US to Past-US



Notes: See Figure 3.

In place of a contemporaneous DD comparison, we estimate how revenue would have evolved without the policy under alternative assumptions. The NPV analysis is restricted to stocks declared rebuilt, as only these complete the rebuilding process.[22] For each rebuilt stock, we calculate the NPV from the event year to 2016, capturing both short-term revenue losses during rebuilding and potential longer-term gains after recovery (being rebuilt). After a stock is rebuilt, catch levels increase as we document in the following subsection. These gains can offset the catch and revenue losses that occur after a stock falls below its MSST, as shown in Table 1).

To compare the observed NPV to the NPV without a policy, we develop three potential data-driven counterfactual revenue trajectories for each stock: (i) using exponential extrapolation, (ii) using fishery-specific historical revenue volatility, or (iii) using the estimated changes in catch for US stocks relative to EU stocks. Each approach imposes different assumptions and structure on how revenue would have developed in the absence of the policy

[22] Our sample has 26 US stocks that have balanced data on biomass and catch, as in the main analysis, also have balanced revenue data, and were declared rebuilt at least once.

measures—namely, a rebuilding plan—taken after the biomass of a US stock fell below its MSST. We use three approaches to construct counterfactual NPVs, ensuring that the comparison of the realized NPV is not driven by any single counterfactual assumption. In what follows, we outline each approach and summarize the comparison between observed and counterfactual NPVs.

For the exponential extrapolation approach, we regress log revenue on a time trend for each stock, from 1986 until the event. The study period starts in 1986, rather than 1990 as in the contemporaneous DD, so that the time-trend coefficient is estimated using at least 10 years of data. We then use the stock-specific time-trend coefficient to fit either an exponential decay or a saturating exponential growth function to revenue after the stock falls below its MSST. If the coefficient is negative, we calculate an exponential decay function by using the following equation: $R_t = e^{\lambda\tau} R_{\tau=0}$. Where $R_{\tau=0}$ is the revenue at the time the biomass falls below the MSST, τ is the number of years after the event year, and λ is the estimated growth rate from the stock-specific regression. Alternatively, if the growth rate is positive, then we calculate a saturating exponential growth.[23] We use the following equation for the saturated exponential growth function: $R_t = R_{\tau=0} + (1 - e^{-\lambda\tau})R_{\tau=0}$.[24]

For the simulated volatility approach, we calculate changes in revenue from 1986 to the event year. We first calculate year-on-year relative changes in revenue: $\Delta_t = \frac{R_t - R_{t-1}}{R_{t-1}}$. We then use the mean and the standard deviation of these changes to calibrate a normal distribution. For each year after the event year, we simulate the revenue using: $R_{t+1} = \frac{R_t + R_{t-1}}{2} + \zeta_{t+1} \min\left\{\frac{R_{t-1}}{\overline{R}}, 1\right\}$. The first term is the moving average of revenue, to which we add a random shock, ζ_{t+1}, drawn from the normal distribution. We multiply the random shock by a dampening factor to prevent the revenue from becoming negative. This factor equals the previous period's revenue divided by the historical mean revenue when that fraction is less than one, and equals one otherwise. This simply attenuates the random shock as revenue falls substantially below its historical level.

For the approach that uses changes in catch to approximate changes in revenue, we estimate a modified cohort-weighted DD specification. Using catch as the outcome, we estimate a full set of lags and use the resulting coefficients as a proxy for how revenue would have changed. This approach effectively holds prices constant, potentially exaggerating the revenue decline following the event year. Specifically, we estimate a modified version of

[23] We do so to avoid revenue values increasing by orders of magnitude in just a few years.

[24] This specific functional form caps revenue growth at twice the revenue when $\tau = 0$.This assumption is consistent with many rebuilding plans that consider a stock rebuilt once biomass has approximately doubled. See Section 2 for more details.

Equation (1) that includes all lags and combines all the leads prior to the omitted year (one year before the event year) into a single dummy variable. Figure A17 shows the results. Although the coefficients are imprecisely estimated, they suggest that catch declines during the first eight years after the event year. By year nine, catch begins to increase for US stocks relative to EU stocks. We then use each coefficient as the inverse effect on counterfactual revenue. For example, if catch is estimated to be 20 percent lower for treated stocks relative to untreated stocks five years after the event year, we assign counterfactual revenue five years after the event year that is 20 percent higher than treated stock revenue.

To illustrate the three counterfactual trajectories, we plot two examples in Figure 8a. American plaice in New England (Panel a, left side) shows biomass recovery but slow revenue recovery: revenue hovered around its 2002 level before biomass fell below the MSST, then declined by up to 60 percent and recovered to about 85 percent of its 2002 level by 2016. Depending on the method used—exponential extrapolation, simulated volatility, or catch-based predictions—revenue in 2016 would have been 21 percent higher, about the same, or 64 percent lower than in 2002. The catch-based prediction differs the most because it applies the average change in catch between US and EU stocks, whereas the other two rely on stock-specific data. However, the second example—pollock in New England (Panel a, right side)—reflects a case where revenue more than doubled relative to historical levels, while all three counterfactuals predict declines in revenue.

Figure 8b shows histograms of observed to counterfactual NPV ratios. Most stocks have a ratio higher than one, indicating their observed revenue NPV under a rebuilding plan is larger than the counterfactual revenue NPVs. We calculate NPVs using a five percent discount rate.[25] The three histograms, one for each method, are truncated at the 90th percentile. In all three cases, at least 69 percent of the ratios are above one. The unweighted means of the ratios for each method are 4.1 (exponential extrapolation), 3.4 (simulated volatility), and 2.6 (catch-based predictions). When weighted by revenue in the year a stock fell below its MSST, these values are 2.4, 1.97, and 2.62.[26] Overall, this analysis suggests that for most stocks, the benefits of completing a rebuilding plan outweigh the costs, although for some stocks, the costs are not fully offset.

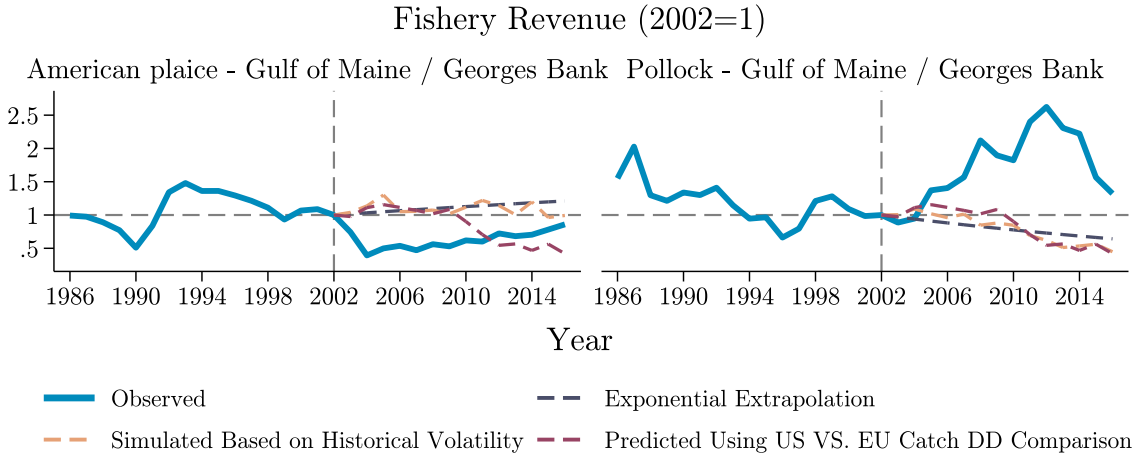
These results provide evidence at the fishery level and allow us to examine heterogeneity of regional council jurisdiction and species' characteristics, specifically recruitment and func-

[25] This choice of a discount rate offers a middle ground between commonly used discount rates of two percent when considering social benefits, and market interest rates.

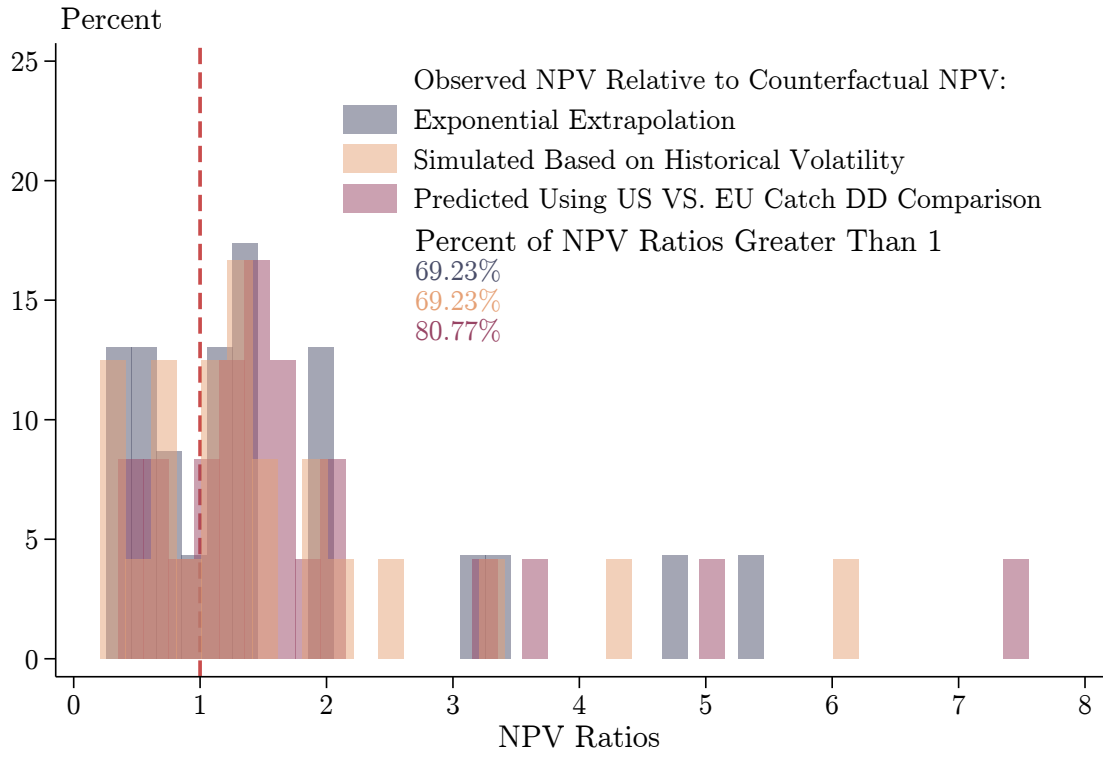
[26] Truncating at the 90th percentile yields unweighted means of 1.6, 1.6, and 1.9, and weighted means of 2.1, 1.8, and 2.4.

Figure 8: Revenue & Net Present Values for Rebuilt Fisheries

(a) Comparing Observed & Potential Counterfactual Revenue Trajectories



(b) NPV Ratios



Notes: Panel (a) shows revenue trajectories for two stocks. Observed revenue (blue) is plotted for the full period, 1986 to 2016. Three counterfactual trajectories—extrapolated exponential growth, simulated using previous volatility, and catch-based predictions—approximate revenue without the policy after 2002, when each stock falls below their MSST. Panel (b) shows three histograms of observed to counterfactual NPV ratios, one for each counterfactual, truncated at their 90th percentile (using a five percent discount rate).

tional group. Recruitment is measured by the biomass of juvenile stocks and is a proxy for population replenishment. High-recruitment stocks may require shorter rebuilding plans and experience smaller revenue losses than low-recruitment stocks. Functional group describes a species' ecological niche. We classify stocks as demersal (bottom-dwelling) or pelagic (open-water). As abundance falls, demersal species become harder and more costly to catch, reducing revenue, while schooling can make pelagic species comparatively easier to catch. In Online Appendix Table A4, we summarize how the NPV ratios vary by these dimensions, along with differences in baseline revenue. NPV ratios are nearly always greater than one for stocks managed by the Gulf of Mexico, South Atlantic, or Mid-Atlantic FMCs, but less often for stocks managed by the New England and Pacific FMCs or jointly by the New England and Mid-Atlantic FMCs. Given small regional sample sizes, these comparisons are descriptive and should be interpreted cautiously. A high share of stocks have NPV ratios across functional and recruitment groups, with higher shares among pelagic and high-recruitment stocks. However, these fishery-level estimates may mask important within-fishery distributional effects, for which we lack vessel-level data to quantify.

For a full welfare analysis of the policy, we would need to account for both fisher surplus and consumer surplus. Our NPV estimates are based on fishery revenue rather than profits because we lack fishing cost data. We also lack sufficient data to quantify consumer surplus. Product data is rarely species-specific and cannot be linked cleanly to stock-level management and catch data. Relevant demand elasticities are also limited in the literature, and potential substitution between stock-specific wild-caught fish, aquaculture, imported seafood, and land-based protein sources is largely unknown.

We can, however, use imports to illustrate how the sign of the change in consumer surplus depends on different assumptions. Total US catch from 2011 to 2016 was similar to 1993 and 1994 levels, before rebuilding provisions were enacted (National Marine Fisheries Service 2026). In Section 6.4, we show that US fish imports increased after 1996, leading to an increase in total fish consumption. If consumers are largely indifferent across fish species and sources, consumer surplus could have increased after 1996 as fish consumption rose, provided prices did not increase enough to offset those gains. Under these assumptions, our revenue-based NPV estimates would understate the policy's welfare effects. However, if consumers strongly prefer stocks under rebuilding and demand is inelastic, imperfect substitution could reduce consumer surplus, making the policy's net effect ambiguous. Determining the policy's effect on consumer surplus would require linking changes in imported fish causally to rebuilding plans. However, prior work does not identify fishery policy as a key driver in

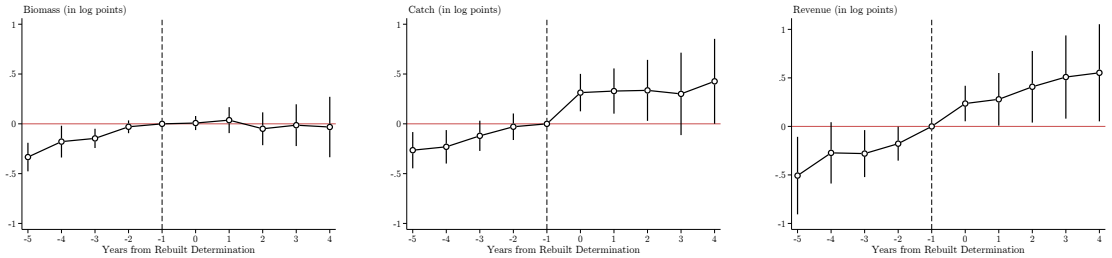
rising imports; broader changes in technology and global trade likely played a larger role in increasing US fish imports (Shamshak et al. 2019).

5.6 Results for Fisheries After Rebuilt Determination

Rebuilding plans take 10 years, on average. A successful rebuilding will lead to the recovery of the stock, allowing managers to increase catch without jeopardizing the biomass gains. In Figure 9, we focus on 31 stocks that were determined rebuilt. We estimate how biomass, catch, and revenue evolved following the rebuilt determination using the event study specification in Equation (2).

Figure 9: Biomass, Catch, & Revenue Following Rebuilt Determination

(a) Biomass (b) Catch (c) Revenue



Notes: Estimation results showing coefficients and 95% CIs for the specification in Equation (2) that estimates the change in biomass, catch, or revenue around the time of the stock receiving a rebuilt determination (when biomass is determined to be at or above B_{MSY}). Standard errors are clustered at the stock level.

Stocks that receive a rebuilt determination experience steady biomass levels, but a sharp increase in catch, in the five years afterward. Biomass increases in the years leading to the rebuilt determination, but remains flat after (Figure 9a). Catch also increases in the years leading up to the rebuilt determination, but increases by about 36.8% in the first year after being classified as rebuilt (Figure 9b). The magnitude of the increase in catch remains stable, yet the estimates become less precise over time. Revenue follows a similar path as catch, but with a larger increasing trend before and after the rebuilt determination.

5.7 Additional Threats to Identification & Interpretation

In the Online Appendix, we report additional analyses supporting the internal validity of the analysis. First, we show that the recovery of stocks in rebuilding is observed even in the raw survey data, making it unlikely that our findings are an artifact of stock assessment modeling (Figure A18). Second, we provide descriptive evidence that environmental conditions in the

US have been deteriorating rather than improving for fish over time, reducing the likelihood that improved environmental conditions explain the results (Figure A19). Third, we report results for a paired-differences estimation on catch that shows no systematic difference prior to the main event of interest—which we interpret as suggestive evidence that demand for these stocks has not changed substantially (Figure A20). Fourth, we verify that the main contemporaneous results are not sensitive to the exclusion of one stock at a time—verifying that the results are not driven by outliers (Figure A21).

6 Examining Substitution & Spillover Patterns

Regulations can have knock-on effects as the regulated actors, their unregulated competitors, and consumers shift their behaviors in response. In this section, we present analyses and descriptions of substitution and spillovers from MSA-treated stocks to untreated stocks. First, we address potential leakage to EU stocks due to higher demand for similar fish species to those regulated in the US, which would violate SUTVA. Second, we examine substitution from stocks in rebuilding to US stocks not in rebuilding (presumably healthy stocks). Third, we examine beneficial spillovers to stocks that are simultaneously caught with stocks in rebuilding. Finally, we discuss substitution from stocks in rebuilding to imports, using descriptive evidence on growing fish imports, which may rise–particularly if they become relatively cheaper–helping to meet a greater share of US seafood demand, along with no evidence of reduced seafood consumption in the literature.

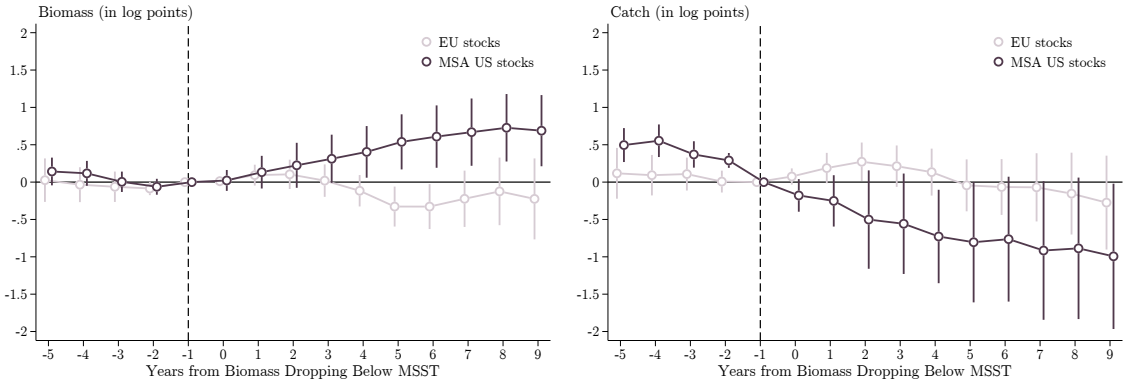
6.1 Ruling Out Leakage from the US to the EU

If demand for rebuilding stocks remains constant, but catch for rebuilding stocks declines, then their prices could increase. If this causes global prices for the same species to increase, then EU fishers might respond by increasing catch for the same species. This could lower the biomass for these stocks in the EU, leading us to double count the gain in US biomass and the decline in EU biomass, which is a violation of SUTVA. To examine this threat to identification, we perform the following test: We subset our contemporaneous sample to the same species of fish—where spillovers are most likely to occur—and estimate how EU species respond after the same US species drop below their MSST. Then we run the double event study using Equation (2), setting the event year for the EU stock to the year that its US counterpart dropped below its MSST (not when the EU stock drops below its MSST-equivalent).

Our results do not provide evidence for double counting. Figure 10a shows no change in EU biomass for the first four years after the corresponding US stock enters treatment; biomass then declines in years five and six but returns to baseline by year seven. Corresponding US biomass is continuously increasing during this time and its catch has leveled off in years 5-7. Figure 10b shows an imprecise increase in EU catch one year after its US counterpart enters treatment, but returns to baseline by year three, even as US catch continues to decline until leveling off in year five.

Figure 10: Ruling Out Leakage from US to EU Fisheries

(a) Biomass (b) Catch



Notes: We examine potential leakage to EU fisheries when the same species in the US enters treatment. We use the specification in Equation (2), but assign treatment to EU fishery species based on the year their US counterpart drops below its MSST.

6.2 Substituting Fishing Effort Toward Healthy US Stocks

A single vessel may target multiple stocks, raising the possibility that US fishing effort substitutes from rebuilding stocks to healthy stocks within the same region serving the same market. We classify stocks within the same FMC region as substitutes based on taxonomic order.[27] For each FMC, we calculate annually how many stocks within each order are receiving treatment. A stock is considered treated in any given year it is in rebuilding or the stock's biomass is below its MSST. We employ a second metric for treated stocks, their share of baseline revenue. To calculate revenue shares, we use a 1990-1995 baseline, dividing each stock's total revenue in that period by the total revenue of all stocks in the same order-FMC pair. Once a stock enters treatment (post-1995), its 1990-1995 order-FMC revenue

[27] This captures the characteristics that are used to describe fish in cooking (e.g. lean, firm, oil-rich, flaky, etc.). Some fish species are closer substitutes than others. For example, haddock might be a good substitute for cod, and both are members of the Gadiformes order.

share is counted as part of the treatment variable—shifting from a "one stock one vote" representation to one where stocks with higher baseline revenue are more consequential.

In a given order-FMC pair, we expect effort to shift from treated stocks to untreated stocks as more stocks enter rebuilding plans (or fall below their MSST) and a larger share of the baseline revenue is affected by rebuilding policies. On average, 2.7 stocks–11 percent of the revenue share–in an order-FMC pair are under rebuilding plans or below their MSST. Table 3 reports estimation results for how biomass, catch, and prices of untreated stocks respond to current and lagged numbers of stocks under rebuilding or below MSST (Panel a) or the sum of baseline revenue shares of such stocks (Panel b). Results show precisely estimated declines in biomass (columns 1-3), imprecisely estimated increases in catch (columns 4-6), and a precisely estimated increase in price consistent with effort shifting from treated to untreated stocks. This reflects declines, on average, in biomass of up to 4.6 (Panel b, column 3) up to 8.1 percent (Panel a, column 3), increases in catch of up to 8 percent (Panels a and b, column 6), and price increases of at least 2.4 percent (Panel b, column 9). The causal interpretation of these estimates relies on the assumption that fishers are only responding to changes in rebuilding/MSST status within the order-FMC pair and are not strategically depleting one stock to increase the value of another.

6.3 Beneficial Spillovers on Concurrently Caught Stocks

Beneficial spillovers can occur because fishing vessels end up catching non-target stocks (known as bycatch) because many species share the same habitat and get caught by the same fishing gear. Consequently, when a stock enters rebuilding, restrictions are placed on both the fishery targeting that stock and its incidental catch in other fisheries. Some concurrently caught species will have their season closed early because the bycatch quotas of a stock in rebuilding have been met. Shortening the fishing season could lead to biomass gains for the stocks that are not in a rebuilding plan.

Stock assessments explicitly mention this type of restriction on stocks that are not in a rebuilding plan. For example, the 2016 stock assessment of the chilipepper rockfish—which never entered a rebuilding plan—describes how "catches have been greatly reduced as a consequence of trip limit reductions and area closures implemented to reduce catches and rebuild populations of overfished species" (Field et al. 2016). Similarly, the 2011 stock assessment of the greenspotted rockfish highlights that it is not a highly sought fish, but is affected by regulations that are "intended to alter fishing mortality of primary targets and/or overfished species" (Dick et al. 2011).

Table 3.
Examining Substitution Within Species Order & Fishery Management Countil

	Log(Biomass)			Log(Catch)			Log(Price)		
Panel A. Number of Affected Stocks									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Stocks_t	-0.01	-0.03	-0.03	-0.01	0.04	0.03	0.06	0.02	0.02
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Stocks_{t-1}		0.02	-0.00		-0.05	-0.01		0.04	-0.00
		(0.01)	(0.00)		(0.03)	(0.01)		(0.01)	(0.01)
Stocks_{t-2}			0.02			-0.04			0.04
			(0.01)			(0.02)			(0.02)
Within R^2	0.0028	0.0091	0.0153	0.0003	0.0057	0.0089	0.1019	0.1159	0.1285
N	1,575	1,575	1,575	1,575	1,575	1,575	1,115	1,115	1,115
Clusters	63	63	63	63	63	63	47	47	47
Panel B. Affected Baseline Revenue Share									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Revenue Share_t	-0.41	-0.40	-0.42	0.15	0.05	0.03	0.25	0.24	0.22
	(0.15)	(0.11)	(0.13)	(0.30)	(0.24)	(0.23)	(0.18)	(0.11)	(0.09)
$\text{Revenue Share}_{t-1}$		-0.01	-0.09		0.15	0.07		0.01	-0.07
		(0.07)	(0.04)		(0.16)	(0.09)		(0.15)	(0.12)
$\text{Revenue Share}_{t-2}$			0.15			0.13			0.12
			(0.07)			(0.15)			(0.12)
Within R^2	0.0076	0.0076	0.0082	0.0002	0.0003	0.0004	0.0021	0.0021	0.0024
N	1,575	1,575	1,575	1,575	1,575	1,575	1,115	1,115	1,115
Clusters	63	63	63	63	63	63	47	47	47

Notes: Estimation results from a specification of logged biomass, catch, or price on measures of MSA treatment intensity within a Fishery Management Council's (FMC) jurisdiction. In these regressions, the focus is on US stocks that do not have an MSA event (dropping below the MSST or entering rebuilding during the sample period). For each non-MSA-event stock, we estimate how it responds to more stocks in the taxonomic group of order experiencing an MSA event. Within the same FMC and order, fishers might substitute more with non-MSA-event stocks as more stocks become affected by an MSA event. In Panel (a), we count the number of stocks that are below their MSST or are in rebuilding in each order-FMC pair. In Panel (b), we calculate the total revenue of each stock in the order-FMC pair, during the baseline period of 1990 to 1995. We then calculate the revenue share for each stock within the order-FMC pair. In each year, we sum the revenue shares of stocks that are experiencing an MSA event. Sample is balanced for both biomass and catch. Each regression includes stock and year fixed effects. Standard errors are clustered at the stock level.

Our main analysis in Section 5 focuses on stocks that had their MSST defined well before 2007. However, for some US stocks, the biological reference points needed for management were only developed more recently. This may reflect their lower commercial value, which reduced priority for developing reference points, or difficulties in modeling their population dynamics. We use recently developed MSST values to identify stocks that, in hindsight, fell below their MSST but did not receive a rebuilding plan because the information needed to designate them as overfished was unavailable at the time. These "would've, should've" stocks represent another group whose biomass declined to MSST levels, similar to those in our main analysis, but without receiving treatment.

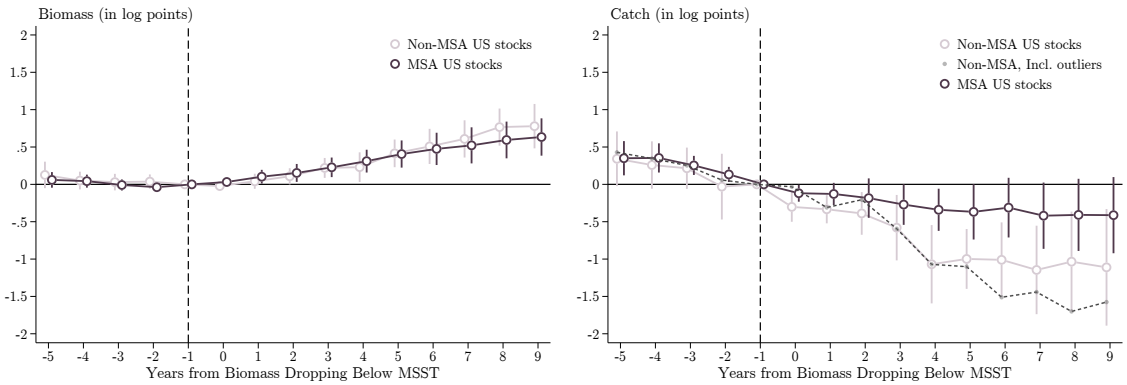
Using data from Oremus et al. (2023), we verify that out of 20 "would've, should've" stocks, 14 (70%) are either of low commercial value or are caught with other stocks that entered rebuilding. We estimate an event study using the specification in Equation (2), and compare their dynamics after dropping below the MSST to those of the US stocks that entered rebuilding in Figure 11a. Stocks that we know in hindsight should have entered a rebuilding plan exhibit biomass gains as large as the stocks that eventually entered rebuilding. Benefits across the marine ecosystem are often not accounted for in the evaluation of the MSA, yet this result shows that these beneficial spillovers are real and meaningful in magnitude. In fact, we see that the catch levels for these stocks drop sharply, despite not entering rebuilding or being determined overfished (Figure 11b). The observed decline in catch is due to the restrictions placed on fish that are co-caught with other fish that do enter rebuilding plans, as discussed above. This result also confirms that contemporaneous US stocks present challenges to use as a comparison group, as they are affected by the treatment status of stocks with overlapping habitats. In the online appendix, we report results that use untreated US stocks as the comparison group in Figure A15.

6.4 Trends in Fish Imports to the US & Domestic Consumption

Foreign fish imports are another channel through which domestic demand for fish can be met. Because data on fish imports are less granular, often lumping many species into product categories as vague as "fish and crustaceans," we cannot match the data to stock-specific management and instead present a descriptive analysis of US fish import data in Figure A22. Panels a and b show changes to domestic fish supply from 1990 to 2016. If we exclude one outlier stock (Pacific hake), we observe that landings of stocks ever in rebuilding fell by half, from 0.2 to 0.1 million metric tons (Panel a). Landings of stocks never in rebuilding experienced some volatility, but kept an average close to two million metric tons (Panel b).

Figure 11: Evidence for the Scope of Beneficial Spillovers

(a) Biomass (b) Catch



Notes: We examine potential beneficial spillovers within the US. We estimate the specification in Equation (2) for US stocks that had their MSST value determined recently, after 2016. In the case of US catch, for the non-MSA stocks, in Panel (b), we report the coefficients and 95% CIs when excluding four outlier stocks (chilipepper - Southern Pacific coast, greenspotted rockfish - Pacific coast, walleye pollock - Bogoslof, and walleye pollock - Southeast Gulf of Alaska). We also report the coefficients (gray dashed line) from including those four outliers in the sample. In Panel (a), we only report results that include the four outliers.

Panel c shows fish imports to the US by region of origin from UN COMTRADE. The largest sources of imports are the Americas and Asia, with Asia seeing the largest growth over the time period. In total, we find that total imports doubled from one to two metric tons a year (Panel d). In Panel e, we use FAO FishStat data, which allows us to exclude species groups outside our treated set of stocks–such as sharks and salmon–and find a similar, though smaller-magnitude, pattern of increasing imports.

Finally, if consumers purchase less domestic fish because of sustainability concerns or higher prices, and do not completely substitute it with imported fish, then they potentially could be making substitutions with non-fish protein sources. However, studies from recent years fail to find any declines in the share of fish in the dietary composition of US adults (Rehm et al. 2016; Shan et al. 2019). In fact, per capita consumption of fish has remained nearly flat since 1990, but has been composed of fewer species, with a larger share of those sourced via imports and aquaculture (Shamshak et al. 2019).

7 Conclusions

Regulating renewable resources is a challenging problem. Our analysis shows that fish stocks under MSA rebuilding provisions experience biomass improvements; catch and revenue recover once stocks are rebuilt; and NPVs are higher under the policy than without it. We

caution against interpreting the estimated improvements in biomass from rebuilding plans as representative of global fish stocks. While many nations are adopting similar laws to fulfill their commitment to the UN's Sustainable Development Goals, implementing these policies requires scientific infrastructure and enforcement. To put this in perspective, a recent study estimates half of global catch come from stocks whose populations and health are not even assessed (Hilborn et al. 2020).

Even within our study region, outcomes are heterogeneous, with some stocks performing better than others. Our analysis studies how the policy affects outcomes at the fishery level, yet is limited in terms of its ability to study individual response to the regulation. Future research should explore whether the policy is welfare-enhancing for individual US fishers, which groups benefit, and what drives compliance. Our data suggests that precautionary quotas (ACLs) and stronger compliance are linked to policy effectiveness. Our data also suggest mandating science-based ACLs could be linked to fewer overages. Whether mandated, *a priori*, science-based thresholds reduce political debate and regulatory capture when conservation measures are needed remains an open question for future research (Anderson and Seijo 2010). More broadly, future research could explore whether rebuilding policies with *a priori* thresholds can be extended to other natural resources, including wildlife populations, reservoir levels, or forest cover.

References

Abman, Ryan, and Clark Lundberg. 2024. "Contracting, market access and deforestation." *Journal of Development Economics* 168:103269.

Anderson, Lee G, and Juan Carlos Seijo. 2010. *Bioeconomics of Fisheries Management.* Nashville, TN: John Wiley & Sons. ISBN: 9781119949244.

Arrow, Kenneth, Partha Dasgupta, Lawrence Goulder, Gretchen Daily, Paul Ehrlich, Geoffrey Heal, Simon Levin, et al. 2004. "Are We Consuming Too Much?" *The Journal of Economic Perspectives* 18 (3): 147–172.

Assunção, Juliano, Clarissa Gandour, and Romero Rocha. 2023. "DETER-ing Deforestation in the Amazon: Environmental Monitoring and Law Enforcement." *American Economic Journal: Applied Economics* 15 (2): 125–156.

Assunção, Juliano, Clarissa Gandour, Romero Rocha, and Rudi Rocha. 2020. "The effect of rural credit on deforestation: Evidence from the Brazilian Amazon." *Economic Journal* 130 (626): 290–330.

Auffhammer, Maximilian, and Ryan Kellogg. 2011. "Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality." *The American Economic Review* 101 (6): 2687–2722.

Austin, David, and Terry Dinan. 2005. "Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes." *Journal of Environmental Economics and Management* 50 (3): 562–582.

Benson, Ashleen Julia, Andrew B Cooper, and Thomas R Carruthers. 2016. "An Evaluation of Rebuilding Policies for U.S. Fisheries." *PLoS One* 11 (1): e0146278.

Bianchi, Daniele, David A Carozza, Eric D Galbraith, Jérôme Guiet, and Timothy DeVries. 2021. "Estimating global biomass and biogeochemical cycling of marine fish with and without fishing." *Science advances* 7 (41): eabd7554.

Boomhower, Judson. 2019. "Drilling Like There's No Tomorrow: Bankruptcy, Insurance, and Environmental Risk." *American Economic Review* 109 (2): 391–426.

Borusyak, Kirill, Xavier Jaravel, and Jann Spiess. 2024. "Revisiting Event Study Designs: Robust and Efficient Estimation." *Review of Economic Studies.*

Brazer, Eric. 2018. *Testimony in H.R.200: Strengthening Fishing Communities and Increasing Flexibility in Fisheries Management Act: Hearings before the House of Representatives, 115th Congress.*

Britten, Gregory L, Carlos M Duarte, and Boris Worm. 2021. "Recovery of assessed global fish stocks remains uncertain." *Proc. Natl. Acad. Sci. U. S. A.* 118 (31).

Cardinale, Bradley J, J Emmett Duffy, Andrew Gonzalez, David U Hooper, Charles Perrings, Patrick Venail, Anita Narwani, et al. 2012. "Biodiversity loss and its impact on humanity." *Nature* 486 (7401): 59–67.

Carruthers, Thomas R., and David J. Agnew. 2016. "Using simulation to determine standard requirements for recovery rates of fish stocks." *Marine Policy* 73:146–153. ISSN: 0308-597X.

Ceballos, Gerardo, Paul R Ehrlich, Anthony D Barnosky, Andrés Garcı a, Robert M Pringle, and Todd M Palmer. 2015. "Accelerated modern human-induced species losses: Entering the sixth mass extinction." *Science Advances* 1 (5): e140025.

Chaisemartin, Clément de, and Xavier D'Haultfoeuille. 2020. "Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects." *American Economic Review* 110 (9): 2964–2996.

Clark, Colin W. 1973. "The economics of overexploitation." *Science* 181 (4100): 630–634.

———. 1976. *Mathematical bioeconomics: The optimal management of renewable resources.* Pure & Applied Mathematics S. Nashville, TN: John Wiley & Sons.

Coit, Janet. 2021. *Testimony in H.R. 59, H.R. 4690, and H.R. 5770: Legislative Hearing before the House Subcommittee on Waters, Oceans, and Wildlife, 116th Congress.*

Common Fisheries Policy: Council Regulation (EU) No 1380/2013 of the European Parliament and of the Council on the Common Fisheries Policy. 2013. OJ L 354/22.

Costello, Christopher, Daniel Ovando, Tyler Clavelle, C Kent Strauss, Ray Hilborn, Michael C Melnychuk, Trevor A Branch, et al. 2016. "Global fishery prospects under contrasting management regimes." *Proc. Natl. Acad. Sci. U. S. A.* 113 (18): 5125–5129.

Currie, Janet, Michael Greenstone, and Enrico Moretti. 2011. "Superfund Cleanups and Infant Health." *The American Economic Review* 101 (3): 435–441.

Daily, Gretchen C, Tore Söderqvist, Sara Aniyar, Kenneth Arrow, Partha Dasgupta, Paul R Ehrlich, Carl Folke, et al. 2000. "The Value of Nature and the Nature of Value." *Science* 289 (5478): 395–396.

Dasgupta, Partha. 2021. *The Economics of Biodiversity: The Dasgupta Review.* Technical report.

Davis, Lucas W. 2015. "Policy Monitor—Bonding Requirements for U.S. Natural Gas Producers." *Review of Environmental Economics and Policy* 9 (1): 128–144.

Dichmont, C M, S Pascoe, T Kompas, A E Punt, and R Deng. 2010. "On implementing maximum economic yield in commercial fisheries." *Proc. Natl. Acad. Sci. U. S. A.* 107 (1): 16–21. ISSN: 0027-8424,1091-6490. doi:10.1073/pnas.0912091107.

Dichmont, Catherine M, Roy A Deng, Andre E Punt, Jon Brodziak, Yi-Jay Chang, Jason M Cope, James N Ianelli, et al. 2016. "A review of stock assessment packages in the United States." *Fish. Res.* 183:447–460.

Dick, E J, Don Pearson, and Steve Ralston. 2011. *Status of Greenspotted Rockfish, Sebastes chlorostictus, in U.S. waters off California.* Technical report. {Southwest Fisheries Science Center}.

Dobson, Jessica L, Matthew R Kahley, Anna M Birkenbach, and Kimberly L Oremus. 2023. "Harassment and obstruction of observers in U.S. fisheries." *Frontiers in Marine Science* 10. ISSN: 2296-7745. doi:10.3389/fmars.2023.1232642.

Estes, James A, John Terborgh, Justin S Brashares, Mary E Power, Joel Berger, William J Bond, Stephen R Carpenter, et al. 2011. "Trophic downgrading of planet Earth." *Science* 333 (6040): 301–306.

European Commission, Joint Research Centre, and Scientific, Technical and Economic Committee for Fisheries. 2020. *Monitoring the performance of the Common Fisheries Policy (STECF-Adhoc-20-01).* Edited by E Jardim, P Vasilakopoulos, A Mannini, C Pinto, and C Konrad. Publications Office. doi:doi/10.2760/230469.

FAO. 2020. *The State of World Fisheries and Aquaculture.*

FAO GFCM. 2022. *Validated stock assessment forms.* https://www.fao.org/gfcm/data/safs/en.

Field, John C, Sabrina G Beyer, and Xi He. 2016. *Status of the Chilipepper Rockfish, Sebastes goodei, in the California Current for 2015.* Technical report. {Pacific Fishery Management Council}.

Fluet-Chouinard, Etienne, Benjamin D Stocker, Zhen Zhang, Avni Malhotra, Joe R Melton, Benjamin Poulter, Jed O Kaplan, et al. 2023. "Extensive global wetland loss over the past three centuries." *Nature* 614 (7947): 281–286.

Free, Christopher M, Tracey Mangin, John Wiedenmann, Conner Smith, Halley McVeigh, and Steven D Gaines. 2022. "Harvest control rules used in US federal fisheries management and implications for climate resilience." *Fish and Fisheries.*

Froese, Rainer, Henning Winker, Gianpaolo Coro, Nazli Demirel, Athanassios C Tsikliras, Donna Dimarchopoulou, Giuseppe Scarcella, Martin Quaas, and Nele Matz-Lück. 2018. "Status and rebuilding of European fisheries." *Mar. Policy* 93:159–170. ISSN: 0308-597X,1872-9460. doi:10.1016/j.marpol.2018.04.018.

Gibson, Matthew. 2018. "Regulation-induced pollution substitution." *The Review of Economics and Statistics.*

Goodman-Bacon, Andrew. 2021. "Difference-in-differences with variation in treatment timing." *Journal of Econometrics.*

Gordon, H Scott. 1954. "The Economic Theory of a Common-Property Resource: The Fishery." *The journal of political economy* 62 (2): 124–142.

Greenstone, Michael. 2002. "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures." *The Journal of Political Economy* 110 (6): 1175–1219.

Greenstone, Michael, and Justin Gallagher. 2008. "Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program." *The Quarterly Journal of Economics* 123 (3): 951–1003.

Hansen, M C, P V Potapov, R Moore, M Hancher, S A Turubanova, A Tyukavina, D Thau, et al. 2013. "High-resolution global maps of 21st-century forest cover change." *Science* 342 (6160): 850–853.

Herrnstadt, Evan M, Ryan Kellogg, and Eric Lewis. 2020. "The Economics of Time-Limited Development Options: The Case of Oil and Gas Leases." *NBER Working Paper No. 27165,* no. w27165.

Hilborn, Ray. 2019. "Measuring fisheries performance using the "Goldilocks plot"." *ICES journal of marine science: journal du conseil* 76 (1): 45–49.

Hilborn, Ray, Ricardo Oscar Amoroso, Christopher M Anderson, Julia K Baum, Trevor A Branch, Christopher Costello, Carryn L de Moor, et al. 2020. "Effective fisheries management instrumental in improving fish stock status." *Proc. Natl. Acad. Sci. U. S. A.* 117 (4): 2218–2224.

Hilborn, Ray, Daniel J Hively, Nicole Baker Loke, Carryn L Moor, Hiroyuki Kurota, Johannes N Kathena, Pamela M Mace, et al. 2021. "Global status of groundfish stocks." *Fish Fish,* no. faf.12560.

ICES. 2022. *ICES Stock Assessment Database.* Copenhagen, Denmark. https://standardgraphs.ices.dk.

Isen, Adam, Maya Rossin-Slater, and W Reed Walker. 2017. "Every Breath You Take—Every Dollar You'll Make: The Long-Term Consequences of the Clean Air Act of 1970." *The journal of political economy.*

Jacobsen, Mark R. 2013. "Fuel Economy and Safety: The Influences of Vehicle Class and Driver Behavior." *American Economic Journal. Applied Economics* 5 (3): 1–26.

Jacobsen, Mark R, and Arthur A van Benthem. 2015. "Vehicle Scrappage and Gasoline Policy." *The American Economic Review* 105 (3): 1312–1338.

Jerch, Rhiannon. 2021. "The local benefits of federal mandates: Evidence from the Clean Water Act." *Working Paper.*

Keiser, David A, and Joseph S Shapiro. 2019. "Consequences of the Clean Water Act and the Demand for Water Quality." *Quarterly Journal of Economics:* 349–396.

Kroetz, Kailin, Linda Nøstbakken, and Martin Quaas. 2022. "The Future of Wild-Caught Fisheries: Expanding the Scope of Management." *Review of Environmental Economics and Policy* 16 (2): 241–261.

Kroetz, Kailin, Matthew N Reimer, James N Sanchirico, Daniel K Lew, and Justine Huetteman. 2019. "Defining the economic scope for ecosystem-based fishery management." *Proceedings of the National Academy of Sciences of the United States of America:* 201816545.

Layzer, Judith. 2006. "Fish stories: Science, advocacy, and policy change in New England fishery management." *Policy Stud. J.* 34 (1): 59–80.

McDonald, Gavin, Jennifer Bone, Christopher Costello, Gabriel Englander, and Jennifer Raynor. 2024. "Global expansion of marine protected areas and the redistribution of fishing effort." *Proceedings of the National Academy of Sciences* 121 (29): e2400592121.

McQuaw, Kristin, and Ray Hilborn. 2020. "Why are catches in mixed fisheries well below TAC?" *Marine Policy* 117:103931.

Memarzadeh, Milad, Gregory L Britten, Boris Worm, and Carl Boettiger. 2019. "Rebuilding global fisheries under uncertainty." *Proc. Natl. Acad. Sci. U. S. A.* 116 (32): 15985–15990.

Milazzo, Matteo J. 2012. "Progress and problems in U.S. marine fisheries rebuilding plans." *Rev. Fish Biol. Fish.* 22 (1): 273–296.

National Marine Fisheries Service. 2026. *Fisheries economics of the united states 2023.* Technical report NMFS-F/SPO-254.

NMFS. 2022. *Fisheries Economics of the United States, 2022.* U.S. Department of Commerce, NOAA Tech. Memo., National Marine Fisheries Service.

NOAA. 2022. *Stock SMART data records.*

NOAA Fisheries. 1997-2020. *Report to Congress on the Status of U.S. Fisheries.* https://www.fisheries.noaa.gov/national/status-stocks-reports.

NOAA FOSS. 2021. *NOAA Fisheries One Stop Shop.* https://www.fisheries.noaa.gov/foss/f?p=215:200:13359200179404:Mail:NO:::.

NRC. 2014. *Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States.* Washington, DC.

Oremus, Kimberly L, Eyal G Frank, Jesse Jian Adelman, Seleni Cruz, Janna Herndon, Brad Sewell, and Lisa Suatoni. 2023. "Underfished or unwanted?" *Science* 380 (6645): 585–588. ISSN: 0036-8075,1095-9203. doi:10.1126/science.adf5595.

Oremus, Kimberly Lai, Lisa Suatoni, and Brad Sewell. 2014. "The requirement to rebuild US fish stocks: Is it working?" *Marine Policy* 47 (0): 71–75. ISSN: 0308-597X.

Patrick, Wesley S, and Jason Cope. 2014. "Examining the 10-year rebuilding dilemma for U.S. fish stocks." *PLoS One* 9 (11): e112232.

Pershing, Andrew J., Michael A. Alexander, Christina M. Hernandez, Lisa A. Kerr, Arnault Le Bris, Katherine E. Mills, Janet A. Nye, et al. 2015. "Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery." *Science* 350 (6262): 809–812.

Polasky, Stephen, Catherine L Kling, Simon A Levin, Stephen R Carpenter, Gretchen C Daily, Paul R Ehrlich, Geoffrey M Heal, and Jane Lubchenco. 2019. "Role of economics in analyzing the environment and sustainable development." *Proceedings of the National Academy of Sciences of the United States of America* 116 (12): 5233–5238.

Raynor, Jennifer, Sara Orofino, Christopher Costello, Gavin McDonald, Juan Mayorga, and Enric Sala. 2025. "Little-to-no industrial fishing occurs in fully and highly protected marine areas." *Science* 389 (6758): 392–395.

Reauthorization of MSA: Oversight of Fisheries Management Successes and Challenges. 2017. https://www.commerce.senate.gov/2017/9/reauthorization-of-the-magnuson-stevens-fishery-conservation-and-management-act-oversight-of-fisheries-management-successes-and-challenges. Accessed: 2025-7-30.

Reed, William J. 1979. "Optimal escapement levels in stochastic and deterministic harvesting models." *J. Environ. Econ. Manage.* 6 (4): 350–363. ISSN: 0095-0696,1096-0449. doi:10.1016/0095-0696(79)90014-7.

Rehm, Colin D, José L Peñalvo, Ashkan Afshin, and Dariush Mozaffarian. 2016. "Dietary intake among US adults, 1999-2012." *JAMA: the journal of the American Medical Association* 315 (23): 2542–2553.

Roughgarden, J, and F Smith. 1996. "Why fisheries collapse and what to do about it." *Proc. Natl. Acad. Sci. U. S. A.* 93 (10): 5078–5083.

Rousseau, Yannick, Julia L Blanchard, Camilla Novaglio, Kirsty A Pinnell, Derek P Tittensor, Reg A Watson, and Yimin Ye. 2024. "A database of mapped global fishing activity 1950-2017." *Scientific Data* 11 (1): 48.

Rousseau, Yannick, Reg A Watson, Julia L Blanchard, and Elizabeth A Fulton. 2019. "Evolution of global marine fishing fleets and the response of fished resources." *Proc. Natl. Acad. Sci. U. S. A.* 116 (25): 12238–12243. ISSN: 0027-8424,1091-6490. doi:10.1073/pnas.1820344116.

Schaefer, Milner B. 1957. "Some considerations of population dynamics and economics in relation to the management of the commercial marine fisheries." *J. Fish. Res. Board Can.* 14 (5): 669–681. ISSN: 0015-296X. doi:10.1139/f57-025.

Schrope, Mark. 2010. "Fisheries: What's the catch?" *Nature* 465:540–542.

Scyphers, Steven B, J Steven Picou, and Jonathan H Grabowski. 2019. "Chronic social disruption following a systemic fishery failure." *Proc. Natl. Acad. Sci. U. S. A.* 116 (46): 22912–22914. ISSN: 0027-8424,1091-6490. doi:10.1073/pnas.1913914116.

Sewell, Brad, Seth Atkinson, David Newman, and Lisa Suatoni. 2013. *Bringing back the fish: an evaluation of U.S. fisheries rebuilding under the Magnuson-Stevens Fishery Conservation and Management Act.*

Shamshak, Gina L, James L Anderson, Frank Asche, Taryn Garlock, and David C Love. 2019. "U.S. seafood consumption." *Journal of the World Aquaculture Society* 50 (4): 715–727.

Shan, Zhilei, Colin D Rehm, Gail Rogers, Mengyuan Ruan, Dong D Wang, Frank B Hu, Dariush Mozaffarian, Fang Fang Zhang, and Shilpa N Bhupathiraju. 2019. "Trends in dietary carbohydrate, protein, and fat intake and diet quality among US adults, 1999-2016." *JAMA: the journal of the American Medical Association* 322 (12): 1178–1187.

Siegel, David A, Timothy DeVries, Ivona Cetinić, and Kelsey M Bisson. 2023. "Quantifying the Ocean's Biological Pump and Its Carbon Cycle Impacts on Global Scales." *Annual review of marine science* 15:329–356.

STECF. 2022. *Mediterranean & Black Sea Stock Assessments.* https://stecf.jrc.ec.europa.eu/reports/medbs.

Sun, Liyang, and Sarah Abraham. 2021. "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects." *Journal of Econometrics.*

Sustainable Fisheries Act: Amendments to the Magnuson Fishery Conservation and Management Act. 1996. Pub. L. No. 104–297. 110 Stat. 3559.

Swartz, Wilf, U Rashid Sumaila, Reg Watson, and D Pauly. 2010. "Sourcing seafood for the three major markets: The EU, Japan and the USA." *Marine Policy* 34 (6): 1366–1373.

Szuwalski, Cody S, Katyana A Vert-Pre, André E Punt, Trevor A Branch, and Ray Hilborn. 2015. "Examining common assumptions about recruitment: a meta-analysis of recruitment dynamics for worldwide marine fisheries." *Fish Fish* 16 (4): 633–648.

UNEP. 2020. *Global resources outlook 2019: Natural resources for the future we want.* UN.

Walker, W Reed. 2013. "The Transitional Costs of Sectoral Reallocation: Evidence From the Clean Air Act and the Workforce." *The Quarterly Journal of Economics* 128 (4): 1787–1835.

Wilson, R W, F J Millero, J R Taylor, P J Walsh, V Christensen, S Jennings, and M Grosell. 2009. "Contribution of fish to the marine inorganic carbon cycle." *Science* 323 (5912): 359–362.

Online Appendix

A.1 The Rebuilding of the Atlantic Spiny Dogfish

To better clarify the variables, definitions and thresholds, as well as how they interact, we plot the regulatory and stock health history of the Atlantic spiny dogfish in Figure A1. The stock was doing well in the early 90s, then increased fishing mortality led to reductions in biomass. The stock was designated as overfished in 1999. The rebuilding plan was implemented in 2002. The plan reduced fishing mortality, which reversed the trend in declining biomass and led to the stock being declared rebuilt in 2010. It is important to note that there is a lag between the stock being declared overfished and entering rebuilding. There is another lag before we observe declining fishing mortality, and another lag before observing biomass recovery.

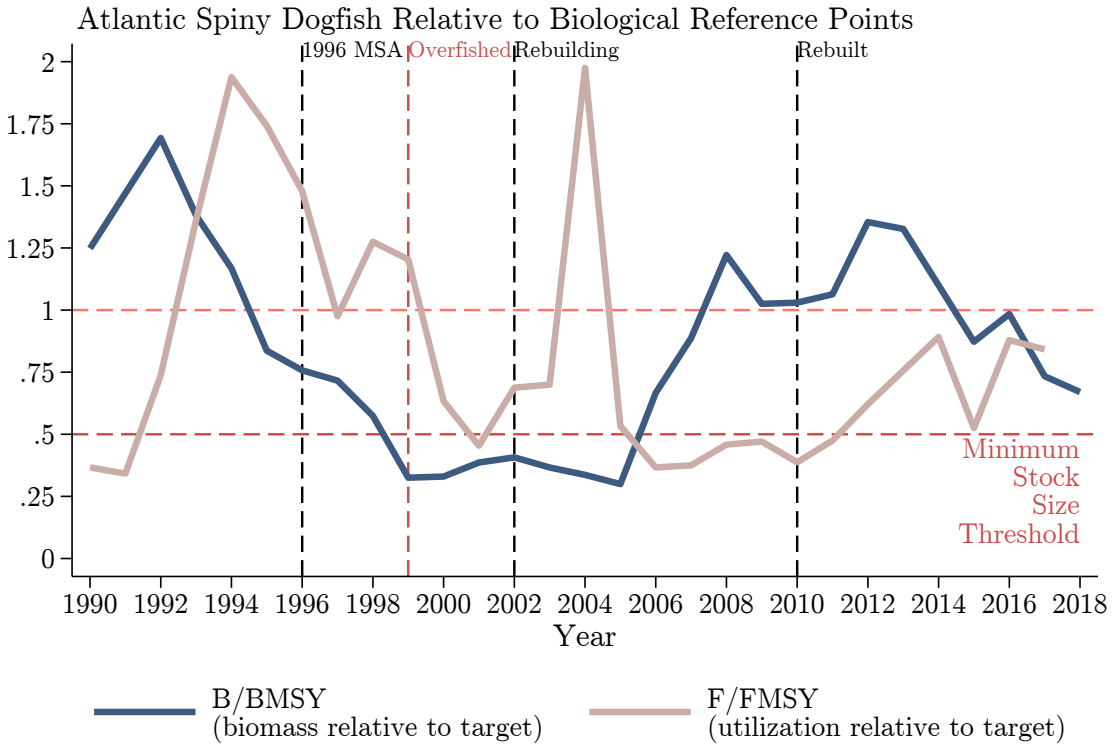
At face value, this appears to be a successful case study for the policy. A stock's biomass declined below healthy levels (B_{MSY}), and then declined below the regulatory threshold that considers it overfished (MSST). The stock received treatment by entering a rebuilding plan where management lowered catch. Finally the stock successfully rebuilt to sustainable levels (B_{MSY}). However, interpreting the changes to the stock as a causal treatment effect of the rebuilding plan assumes that in the absence of rebuilding plans, the stock would have either continued to decline or stagnate around its MSST.

This example also clarifies the causal inference challenge of attributing the recovery of the fishery to the rebuilding plan. We cannot rule out other explanations such as natural variability in a stock's population dynamics. Causal inference can be especially challenging when variability is combined with measurement error in the estimated size of the stock. As the stock approaches a low value in its cycle, even small measurement error could end up determining that the stock is below its MSST. It will be hard to disentangle how much of the observed increase is due to the rebuilding plan and how much is simply driven by natural variability.

A.2 Validating Stock Assessment Data

Fish stock assessment reports are developed by NOAA fish scientists. They use peer-reviewed models to estimate fish populations and reference points. NOAA's website describes stock assessments as conceptually similar to their National Weather Service dynamic atmospheric models: "Even though fish stock assessments operate on much longer time scales than

Figure A1: MSA Management Example: Atlantic Spiny Dogfish



Notes: Plotting the the biomass relative to the target biomass (B/B_{MSY}), and the fishing mortality relative to the target fishing mortality (F/F_{MSY}). When the stock is meeting both its targets, for biomass and fishing mortality, the values of B/B_{MSY} and F/F_{MSY} should be centered around one. When biomass drops below the Minimum Stock Size Threshold (50% of its B_{MSY} target), the Atlantic spiny dogfish is considered to be overfished (below the red dashed line). When the fishing mortality is above F_{MSY}, the stock is considered to be experiencing overfishing (above the coral dashed line).

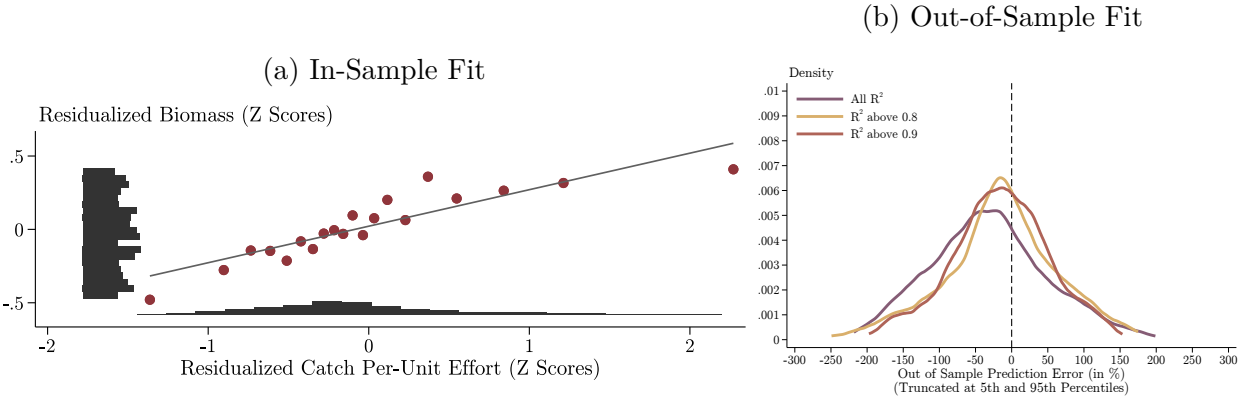
weather models—months and years rather than hours and days—they similarly combine and incorporate many different complex observations into a holistic picture of the situation." The data that we use for this analysis come from the retrospective components of stock assessments. Their higher fidelity to historic observations makes them more reliable than the predictions that managers use to make decisions. They benefit from the availability of full catch records and survey data, and are not affected to the same degree by the uncertainties that managers face in real time regarding the management of the stock (see Section 2).

Stock assessment models are calibrated using observed data from NOAA abundance surveys and catch data from fishers. Survey data are reported in units of catch-per-unit-effort (CPUE). Catch data include landings that are sold at the dock, discards at sea, and bycatch, which is accidental catch of a species that fishers were not targeting. A network of monitoring

programs is used to enforce quality control of this data, including third-party dockside and boat observers, log books, and recreational sampling. Abundance surveys employ fishing methods, but they are statistically designed, run by NOAA, and use standardized sampling methods (same boat, gear, ocean sampling grid, and time of year).

To verify that the stock assessments are consistent with the observed data, we perform two empirical validation exercises. First, we examine the in-sample fit by estimating a simple regression model linking the stock assessment output (biomass) to the key inputs (NOAA abundance sampling survey data and catch). We obtain the survey data records from NOAA's Distribution Mapping and Analysis Portal, and we standardize the biomass, catch, and survey data by stock. Then we residualize the standardized biomass as a function of lagged standardized survey data and contemporaneous and lagged standardized catch, along with stock and year fixed effects. We repeat this residualization for the standardized survey data. We plot the relationship between the residuals of biomass and survey data (in z scores) in Figure A2a. There is a strong linear fit between the survey data and the assessed biomass. In other words, the survey data, which provides a proxy for stock abundance, is a strong predictor of assessed biomass.

Figure A2: Validating the Stock Assessments Using Survey and Catch Data



Notes: Results from running two sets of tests to verify that the stock assessments are capturing features that appear in their raw data inputs instead of generating patterns that do not agree with the catch and survey data.

In the second validation exercise, we run a regression on each stock, excluding one year at a time, using the same model as above. For each omitted year of data, we generate a predicted value for the assessed biomass. Because we are running the regression for each stock separately, we keep the data in levels and do not transform it into z-scores. In Figure A2b, we report the distribution of prediction errors. While some prediction errors are large, they are centered and concentrated around zero, especially for the models with high R-squared

values. Overall, we find a strong in-sample and out-of-sample fit of biomass to survey and catch data, even though we are using a very simple regression specification that does not incorporate any biological theory, which the stock assessments do include. We interpret these results as evidence that the stock assessments are not generating artifacts that are not observed in the raw data inputs.

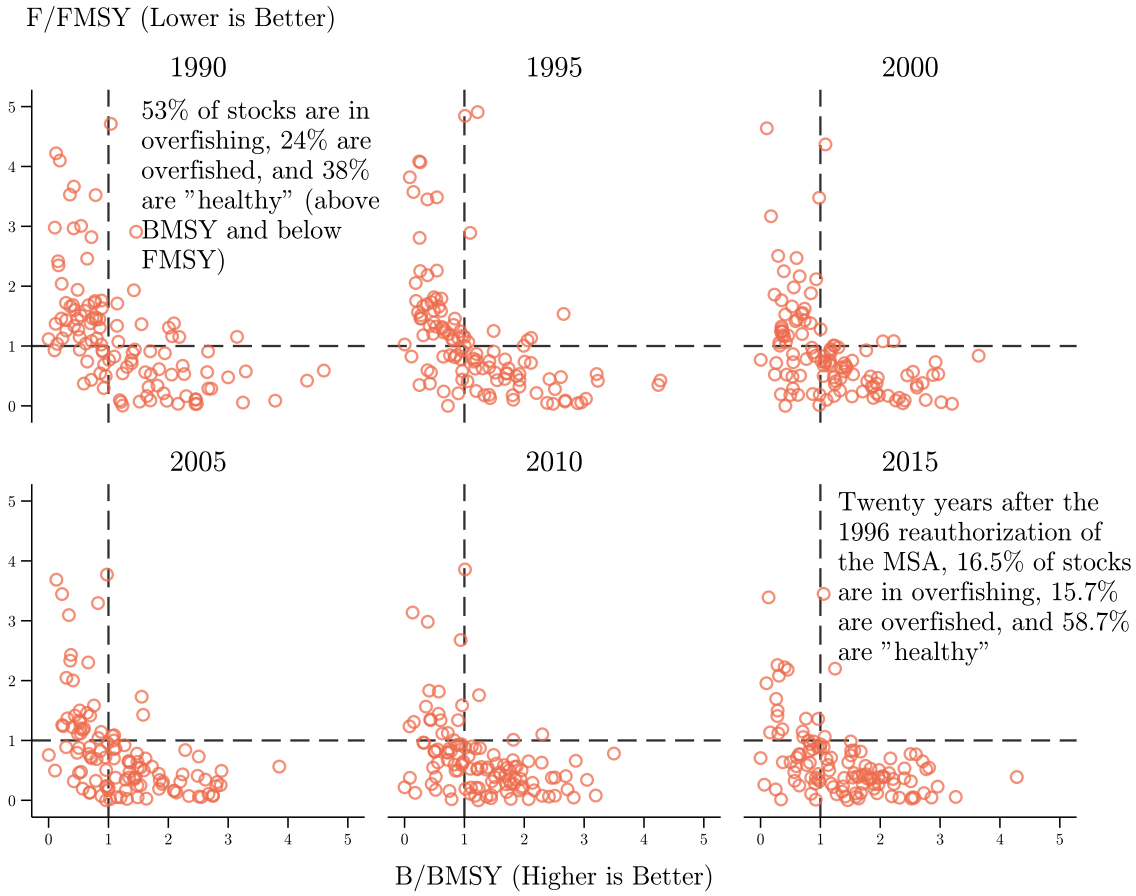
A.3 Summarizing Fishing Mortality & Biomass Relative to Targets Over Time

To summarize the raw data on the status of fisheries in the years before and after the 1996 reauthorization of the MSA, we plot the two key metrics relative to their reference points: fishing mortality and biomass. In Figure A3, we present scatter plots for six time periods, two before 1996, and four after. Across all six panels, we restrict the sample to 121 stocks that have balanced data (i.e. no missing data on F/FMSY and B/BMSY in all six periods). From 1990 to 2015, we observe a reduction in the number of stocks that are in the top left area of the plot where fishing mortality is above its target (F/FMSY above 1) and where the biomass is below its target level (B/BMSY is below 1). The percent of stocks that are meeting their targets (F/FMSY is below 1 and B/BMSY is above 1) increases from 40.3 to 58.7 between 1990 and 2015.

A.4 Descriptive Data on Changes to Catch & Biomass Around MSA Events

Figure A4 plots the mean levels of biomass (Panels a-b) and catch (Panels c–d) in event time, standardized by their levels in the event year. For treated stocks, the events are the first year the stock experiences overfishing, falls below its MSST, is declared overfished, or enters a rebuilding plan (Panels a and c). For control stocks, we use EU stock biomass declining below its SBL, and US stock biomass declining below its MSST in the pre-MSA period (Panels b and d). Because official stock status (overfishing, overfished) and regulatory responses (entering rebuilding) often lag behind a stock falling below its MSST, biomass may begin to recover earlier as the harvest control rule reduces catch and promotes recovery. This is more likely when the lag between biomass falling below its MSST and an overfished determination or rebuilding plan is longer (see Figure A5 for a summary of such delays). By contrast, declines in catch around event timings are more similar because they reflect both reduced stock availability and policy-imposed harvest reductions.

Figure A3: Stocks' Statuses Relative to Biological Reference Points



Notes: Summarizing the status of stocks relative to their target reference points in five-year intervals, for stocks that have data reported in each time period (n=121). The y-axis shows the fishing mortality (catch over biomass) relative to the target level (F_{MSY}), while the x-axis shows the biomass relative to the biomass target level (B_{MSY}). Stocks with F/F_{MSY} above one are experiencing overfishing. Stocks with low B/B_{MSY} values, generally below half of their B_{MSY} value (below 0.5 on the x-axis), are considered overfished. We truncate the axes at 5 to allow for easier visual inspection of the data.

A.5 Delay Between Overfished Determination & Rebuilding Plan

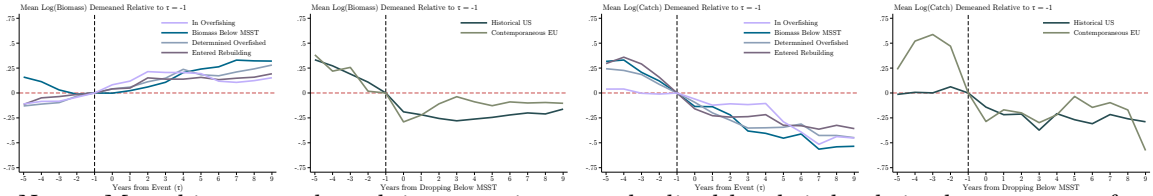
Under the MSA, regional management must develop and implement a rebuilding plan for stocks designated as overfished. Historically, many stocks experienced long delays between being declared overfished and entering a rebuilding plan. There can also be delays between when a stock's biomass declines below its MSST and when it is declared overfished.

We summarize these delays in Figure A5. Before the 2006 reauthorization of the MSA—which introduced the requirement to implement a rebuilding plan within two years of an overfished designation—delays were substantial. After 2006, fewer stocks were declared overfished, or entered rebuilding, and those that did saw mostly short delays. After 2006,

Figure A4: Changes in Key Outcomes Around MSA Events

Biomass | Catch

(a) With Reb. (b) Without Reb. (c) With Reb. (d) Without Reb.



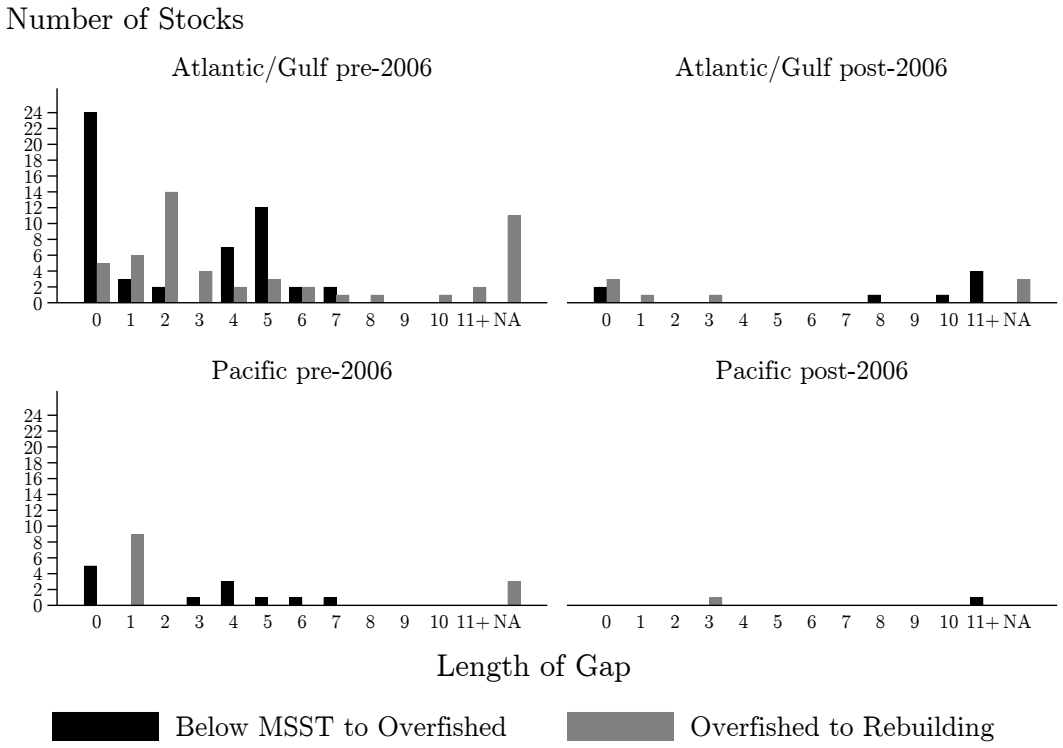
Notes: Mean biomass and catch in event time, standardized by their levels in the event year for stocks with (a-b) or without (c-d) rebuilding plans.

the longer delays happened between the year a stock declined below its MSST and the year it was declared overfished. These delays could be due to changes in the science. At the time, the stock may not have even been considered overfished, but based on improved, scientific estimates of the MSST, we now consider the stock to have been overfished (see the Online Data Appendix for more details on scientific changes to reference points over time). Stocks that have not yet received a rebuilding plan have either rebuilt prior to the implementation of a rebuilding plan, do not have sufficient data to design a rebuilding plan, or are listed under the Endangered Species Act where their recovery plans would be governed by this Act.

A.6 Historical Comparison of US and EU Policy

US and EU fisheries policies share many features, although EU policy has lagged behind the US. Both jurisdictions adopted fishery laws in the 1970s, but the EU required international agreement among member states, making coordination more difficult than passing national legislation in the US. In 1970, the European Economic Community (EEC) assumed responsibility for conserving member states' fish stocks, granting reciprocal access to territorial waters. However, member states could not agree on a common fisheries policy (Hegland and Raakjaer 2020; Battista et al. 2018). At the same time, US Congress debated two competing 1975 bills, both extending the EEZ to 200 nm. One proposed creating a new federal Fisheries Management Council, while the other—backed by New England fishermen—favored state management. The compromise became the 1976 Magnuson–Stevens Act (MSA), which established regional councils guided by national standards, including sustaining optimum yield (Walsh 2014). The following year, the EEC extended its Exclusive Fisheries Zone (EFZ) to 200 nm, but the first Common Fisheries Policy (CFP) was not adopted until 1983. The CFP introduced total allowable catches (TACs), allocated under the "relative

Figure A5: Years From Below MSST to Overfished to Rebuilding Plan



Notes: Summarizing the time, in years, between either the first year we observe the stock below its MSST and the first year it was declared overfished, as well as the number of years between a stock being declared overfished and and the first year it entered a rebuilding plan, if any.

stability" principle, which promoted stability in national shares rather than sustainability. Regional advisory councils were only introduced with the 2003 CFP reform (Hegland and Raakjaer 2020; Battista et al. 2018). Both US and EU regional councils are composed of stakeholders, but EU councils serve in an advisory capacity to the EU commission on fisheries management, whereas US councils create and implement fisheries management under national guidelines (Hegland and Raakjaer 2020; Battista et al. 2018; Walsh 2014).

The goals of maintaining optimum yield in the 1976 MSA and relative stability of catch in the 1983 CPA were not stringent. The US and EU experienced rising overfishing throughout the end of century. The 1996 MSA reauthorization (the Sustainable Fisheries Act) required the rebuilding of overfished stocks (*Sustainable Fisheries Act* 1996). Some US fisheries had already adopted MSY-based management with TACs, landing obligations, limited entry, gear restrictions, days-at-sea limits, and fishery management plans—for example, New England sea scallops had TACs by 1994. Similarly, some EU fisheries adopted MSY-based measures and effort restrictions (e.g. North Sea herring) using the same tools (Table 1, Hegland and

Raakjaer (2020)) before the 2013 CFP reform, which aimed to restore fish stocks to levels capable of producing maximum sustainable yield (*Common Fisheries Policy* 2013). Our study is limited to stocks with an established MSST or SBL, indicating sufficient data, scientific knowledge, and management to define biological reference points (see Data Appendix).

The 1996 MSA and 2013 CFP share similarities: both aimed to rebuild stocks through MSY-based fishery management plans developed or advised by regional councils[28], using catch quotas (ACLs in the US; TACs in the EU). Both also struggled with loopholes and compliance, particularly TACs set above scientific advice (*Natural Resources Defense Council, Inc. v. Daley, 62 F. Supp. 2d 102 (D.D.C. 1999);* Battista et al. 2018). The US addressed these gaps through the 2006 MSA reauthorization and the subsequently revised National Standard 1 Guidelines that were implemented in 2010 (*Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006* 2007). The 2013 CFP required full implementation by 2020 and arguably still has loopholes to address (Battista et al. 2018). The period 1996 to 2016 offers a valuable counterfactual: how US fisheries might have evolved without legally binding rebuilding requirements.

A.7 Summarizing Information on Stocks Included in the Analysis

Tables A1 and A2 provide details on the stocks that are included in the contemporaneous and historical analyses in the main text.

A.8 DD Results Centered Around Overfished Determination & Rebuilding Plan Implementation

In the main text, we define the year a stock declines below its MSST as the event of interest. In Figure A6, we report results for the same specification in Equation (1), centering around the year a stock is declared overfished or entered a rebuilding plan. Overall, we recover qualitatively similar results to those we report in the main text. However, under the MSA, treatment starts before the implementation of a rebuilding plan. In other words, increases in biomass can be observed before these alternative events of interest. We summarize these re-centered estimations in Table A3. The results for biomass (columns 1 to 3) demonstrate how the full effect we estimate is attenuated as some of the early gains in biomass are excluded from the treatment period, and instead become part of the pre-treatment trends. We also see that in the one to five years after the event, the biomass increases more than it does in

[28] Mediterranean and Black Sea stocks are excluded from our main analysis.

Table A1.
Summarizing Information About US Stocks Included in the Analysis

Stock Name	FMC	Order	Included in Comparison			Long Rebuilding Plan	Determined Rebuilt
			C. DD	H. (Pre)	H. (Post)		
Acadian redfish	NE	Scorpaeniformes	Y	Y	Y	Y	Y
American plaice	NE	Pleuronectiformes	Y	N	Y	N	Y
Atlantic cod	NE	Gadiformes	Y	Y	Y	N	N
Atlantic mackerel	MA	Scombroidei	Y	N	Y	N	N
Atlantic wolffish	NE	Zoarcoidei	Y	N	Y	N	N
Barndoor skate	NE	Rajiformes	Y	Y	Y	Y	Y
Black grouper	SA	Percoidei	N	Y	Y	N	N
Black sea bass	MA	Percoidei	Y	Y	Y	N	Y
Black sea bass	SA	Percoidei	Y	N	N	N	Y
Bluefish	MA	Percoidei	Y	Y	Y	N	Y
Bocaccio	P	Scorpaeniformes	Y	N	Y	Y	Y
Butterfish	MA	Stromateoidei, Anabantoidei	Y	N	N	N	Y
Canary rockfish	P	Scorpaeniformes	Y	N	Y	Y	Y
Cowcod	P	Scorpaeniformes	Y	Y	N	Y	Y
Darkblotched rockfish	P	Scorpaeniformes	Y	N	Y	Y	Y
Gag	SA	Percoidei	Y	Y	Y	N	N
Gag	GM	Percoidei	Y	Y	Y	N	Y
Gray triggerfish	GM	Tetraodontiformes	N	N	Y	N	N
Greater amberjack	GM	Percoidei	N	Y	Y	N	N
Haddock	NE	Gadiformes	Y	Y	Y	N	Y
Haddock	NE	Gadiformes	Y	Y	Y	N	Y
King mackerel	SA	Scombroidei	Y	Y	Y	N	Y
Lingcod	P	Scorpaeniformes	Y	Y	Y	N	Y
Lingcod	P	Scorpaeniformes	Y	N	Y	N	Y
Ocean pout	NE	Zoarcoidei	Y	Y	Y	N	N
Pacific hake	P	Gadiformes	Y	N	N	N	Y
Pacific ocean perch	P	Scorpaeniformes	Y	N	N	Y	Y
Petrale sole	P	Pleuronectiformes	Y	Y	Y	N	Y
Pollock	NE	Gadiformes	Y	N	N	N	Y
Red grouper	GM	Percoidei	Y	N	N	N	Y
Red grouper	SA	Percoidei	N	Y	Y	N	N
Red hake	NE	Gadiformes	Y	N	Y	N	N
Red porgy	SA	Percoidei	Y	Y	Y	Y	N
Red snapper	SA	Percoidei	N	Y	Y	N	N
Scup	MA	Percoidei	Y	Y	Y	N	Y
Sea scallop	NE	Bivalvia	Y	Y	Y	N	Y
Silver hake	NE	Gadiformes	Y	N	Y	N	Y
Silver hake	NE	Gadiformes	Y	N	Y	N	Y
Smooth skate	NE	Rajiformes	Y	Y	Y	N	Y
Snowy grouper	SA	Perciformes	Y	Y	Y	Y	N
Spiny dogfish	NE / MA	Squaliformes	N	N	Y	N	N
Summer flounder	MA	Pleuronectiformes	Y	Y	Y	N	Y
Thorny skate	NE	Rajiformes	Y	Y	Y	Y	N
Tilefish	SA	Perciformes	Y	N	Y	N	N
Tilefish	MA	Perciformes	Y	Y	Y	N	Y
Vermilion snapper	SA	Percoidei	Y	N	N	N	N
White hake	NE	Gadiformes	Y	Y	Y	N	N
Widow rockfish	P	Scorpaeniformes	Y	N	N	Y	Y
Windowpane	NE	Pleuronectiformes	Y	N	N	N	Y
Winter flounder	NE	Pleuronectiformes	Y	N	Y	N	N
Winter flounder	NE	Pleuronectiformes	Y	N	Y	N	Y
Winter skate	NE	Rajiformes	Y	Y	Y	N	Y
Yelloweye rockfish	P	Scorpaeniformes	Y	N	Y	Y	N
Yellowtail flounder	NE	Pleuronectiformes	Y	Y	Y	Y	N
Yellowtail flounder	NE	Pleuronectiformes	Y	N	Y	N	Y

Notes: A list of the US stocks included in the biomass and catch analyses including treated stocks in the contemporaneous DD comparison (C. DD), treated (H. Post) and control stocks (H. Pre) in the historical double event study comparison. For each stock, we report the common name, the fishery management council (FMC), the taxonomic order the species belongs to, which comparison the stock is included in, whether the stock has a long rebuilding plan, and whether they were determined rebuilt.

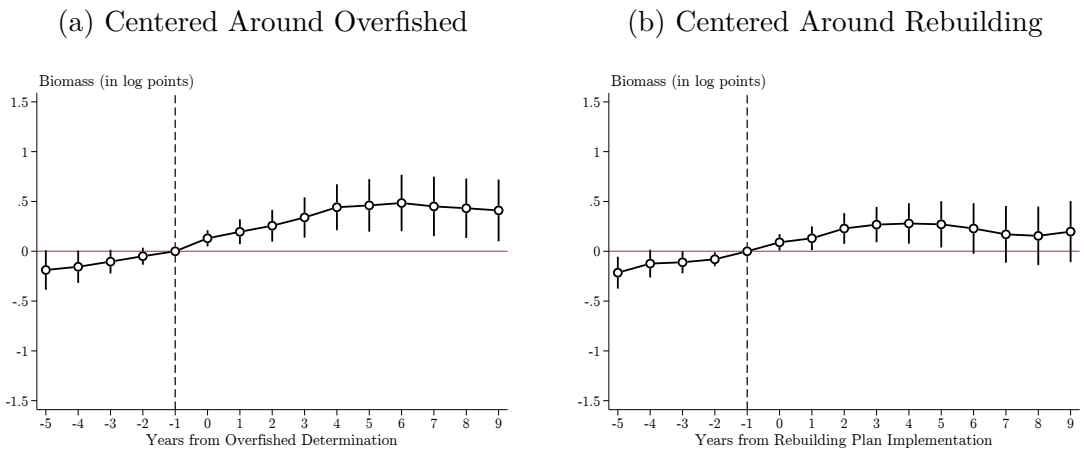
Table A2.
Summarizing Information About EU Stocks Included in the Analysis

Stock Name	Region	Ecological Region	Order	Has MSST
Angler	Northeast Atlantic	BBIC	Lophiiformes	Y
Atlantic cod	Northeast Atlantic	CS , GNS , ONA	Gadiformes	Y
Atlantic cod	Northeast Atlantic	F	Gadiformes	Y
Atlantic cod	Northeast Atlantic	CS	Gadiformes	Y
Atlantic cod	Northeast Atlantic	GNS	Gadiformes	Y
Atlantic cod	Northeast Atlantic	CS	Gadiformes	Y
Atlantic herring	Northeast Atlantic	CS	Clupeiformes	Y
Atlantic herring	Northeast Atlantic	CS , F , ONA	Clupeiformes	Y
Atlantic herring	Northeast Atlantic	BS	Clupeiformes	Y
Atlantic mackerel	Northeast Atlantic	AC , A , BBIC , BaS , CS , F , GS , IS , GNS , NS , ONA	Scombroidei	Y
Capelin	Northeast Atlantic	AC , BaS , F , GS , IS , NS	Salmoniformes	Y
Common sole	Northeast Atlantic	CS	Pleuronectiformes	Y
Common sole	Northeast Atlantic	BS , GNS	Pleuronectiformes	Y
Common sole	Northeast Atlantic	GNS	Pleuronectiformes	Y
European anchovy	Northeast Atlantic	BBIC , ONA	Clupeiformes	Y
European anchovy	Mediterranean and Black Sea	CM	Clupeiformes	N
European anchovy	Mediterranean and Black Sea	WM	Clupeiformes	N
European flounder	Northeast Atlantic	GNS	Pleuronectiformes	N
European hake	Northeast Atlantic	BBIC , CS , F , GNS , ONA	Gadiformes	Y
European hake	Northeast Atlantic	BBIC	Gadiformes	Y
European pilchard	Mediterranean and Black Sea	CM	Clupeiformes	N
European pilchard	Northeast Atlantic	BBIC	Clupeiformes	Y
European plaice	Northeast Atlantic	CS	Pleuronectiformes	Y
European plaice	Northeast Atlantic	GNS	Pleuronectiformes	Y
European seabass	Northeast Atlantic	CS , GNS	Percoidei	Y
European sprat (27.4)	Northeast Atlantic	GNS	Clupeiformes	Y
European sprat (27.3A)	Northeast Atlantic	GNS	Clupeiformes	N
Four-spot megrim	Northeast Atlantic	BBIC	Pleuronectiformes	Y
Golden redfish	Northeast Atlantic	AC , CS , F , GS , IS , NS , ONA	Scorpaeniformes	Y
Haddock	Northeast Atlantic	F	Gadiformes	Y
Haddock	Northeast Atlantic	CS , GNS	Gadiformes	Y
Megrim	Northeast Atlantic	BBIC	Pleuronectiformes	Y
Norway pout	Northeast Atlantic	GNS	Gadiformes	Y
Picked dogfish	Mediterranean and Black Sea	Black Sea	Squaliformes	N
Red mullet	Mediterranean and Black Sea	Black Sea	Percoidei	N
Sandeel (1R)	Northeast Atlantic	GNS	Perciformes	Y
Sandeel (3R)	Northeast Atlantic	GNS	Perciformes	Y
Sandeel (2R)	Northeast Atlantic	GNS	Perciformes	Y
Whiting	Northeast Atlantic	GNS	Gadiformes	Y
Whiting	Northeast Atlantic	CS	Gadiformes	Y

Notes: A list of the EU fishery stocks included in the analysis. We report stocks that are included in the contemporaneous DD comparison. For each stock, we report the common name, the FAO fishery region, the taxonomic order the species belongs to, the ecological region the stock resides in, and whether the stock has an MSST value, or we calculate a pseudo MSST for it. We abbreviate the ecological regions using the following: Azores, A; Arctic Ocean , AO; Baltic Sea, BS; Barents Sea, BaS; Bay of Biscay and the Iberian Coast, BBIC; Celtic Seas, CS; Central Mediterranean, CM; Faroes, F; Greater North Sea, GNS; Greenland Sea , GS; Iceland Sea, IS; Norwegian Sea, NS; Oceanic Northeast Atlantic, ONA; Western Mediterranean, WM.

the one to five years after the stock falls below the MSST. The results for catch demonstrate a similar pattern, where once the stock has started to recover, we see catch levels increasing relative to one year before the event. Finally, the number of stocks in the sample slightly declines in columns 2, 3, 5, and 6 because we have fewer stocks with a 10-year balanced time window after these events.

Figure A6: The Effect of Rebuilding Plans on Stock Biomass Using Different Treatment Onsets



Notes: Panels (a) and (b) report estimation results showing coefficients and 95% CIs for the DD specification in Equation (1). Standard errors are clustered at the stock level.

A.9 Including Order-by-Year Fixed Effects in the Contemporaneous Comparison

In the main text, when reporting results for the contemporaneous comparison of US to EU stocks, we include year fixed effects that pool together common shocks to all stocks (e.g. technological changes, shifts in demand, development of aquaculture, etc.). Here, we use the taxonomic data on the order that each fish species belongs to in order to narrow down the residual variation to stocks within the same order. First, we include order-by-year fixed effects (instead of the year fixed effects, but in addition to the fishery stock fixed effects). Second, we narrow the sample to the taxonomic order group that has stocks in both the US and the EU. We report the results in Figure A7. On average, we recover a nearly identical evolution of biomass for the treated US stocks relative to the untreated EU stocks. We do not observe a pre-trend in the years leading to stocks dropping below their MSST, and we estimate larger coefficients for the biomass recovery, yet those fall well within the 95% CIs we report in Figure 3. For catch, we estimate a similar imprecisely estimated trajectory of

Table A3.
Contemporaneous Comparison Results When Centering Around Different Events

	Logged Biomass			Logged Catch		
	(1)	(2)	(3)	(4)	(5)	(6)
Event Time 1-5	0.10	0.27	0.20	-0.18	0.05	0.18
	(0.07)	(0.07)	(0.07)	(0.14)	(0.13)	(0.16)
Event Time 6-10	0.42	0.45	0.20	-0.06	0.50	0.35
	(0.14)	(0.13)	(0.13)	(0.27)	(0.26)	(0.22)
Within R^2	0.134	0.143	0.095	0.058	0.034	0.042
Observations	2,214	2,106	2,025	2,214	2,106	2,025
Clusters	82	78	75	82	78	75
Centered On:						
Biomass Below MSST	X			X		
Determined Overfished		X			X	
Entered Rebuilding			X			X

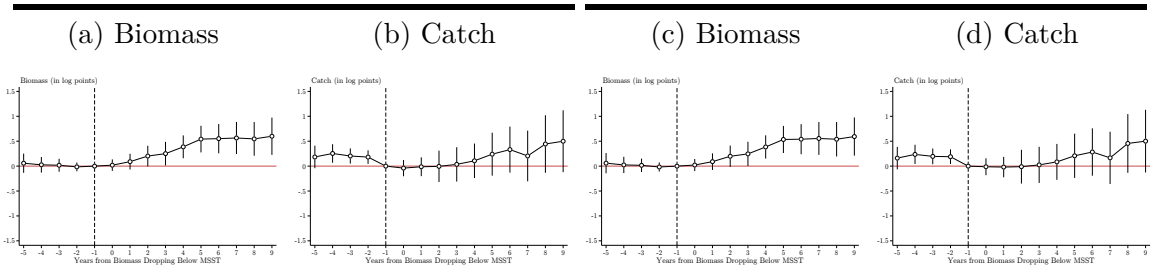
Notes: Estimation results from the DD specification in Equation (1). We report the linear combinations for the event time dummies after the stock drops below the MSST (columns 1 and 4), is determined to be overfished (columns 2 and 5), and enters rebuilding (columns 3 and 6), for the average of the first to fifth lags, and the sixth to tenth lags, excluding the top-coded lag coefficient. Columns 1-3 report results for biomass, in log points, while columns 4-6 report results for catch, in log points. All regressions include stock and year fixed effects. Standard errors are clustered at the stock level.

an initial estimated decline with a later recovery. The key difference here is that while there is no pre-trend in catch (leads -5 to -2 are all similar to each other), when controlling for order-by-year fixed effects, US stocks experience a drop in catch relative to EU stocks one year before dropping below their MSST.

A.10 Using Normalized Biomass Instead of Logged Biomass

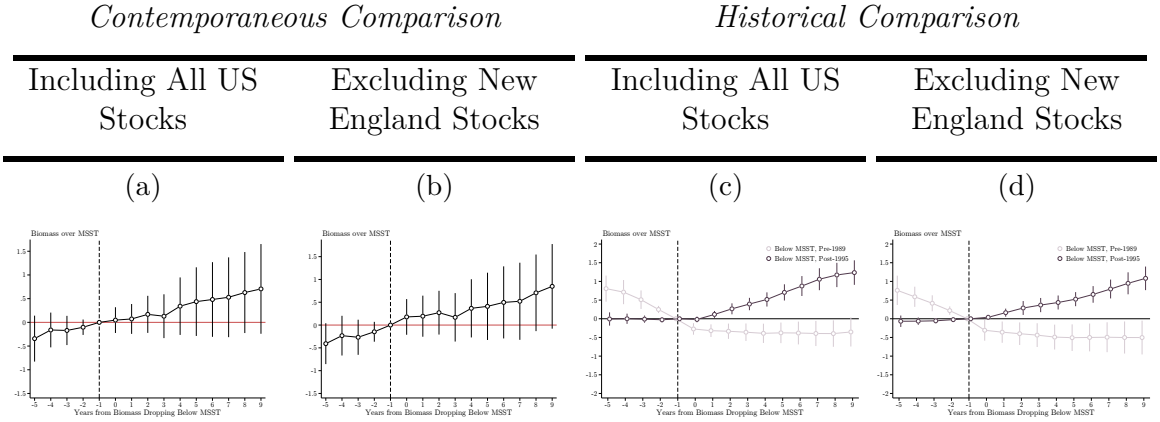
In the main text, we use logged values for all the outcomes. In Figure A8, we report the same estimation as in Figure 3, only using normalized instead of logged biomass. We recover the same patterns, and similar magnitudes. However, the results are less precisely estimated in the contemporaneous comparison.

Figure A7: Contemporaneous Comparison, US to EU, With Order-by-Year FEs



Notes: Same as in Figures 3 and 4, for the contemporaneous comparison, only here we include order-by-year fixed effects (a-d), and narrow the sample to orders with stocks in both the US and the EU (c-d).

Figure A8: Evidence for the Policy's Outcome: Fish Biomass Recovery



Notes: Panels (a) and (b) report estimation results showing coefficients and 95% CIs for the DD specification in Equation (1). Panels (c) and (d) report estimation results from two separate regressions showing coefficients and 95% CIs for the specification in Equation (2). Standard errors are clustered at the stock level.

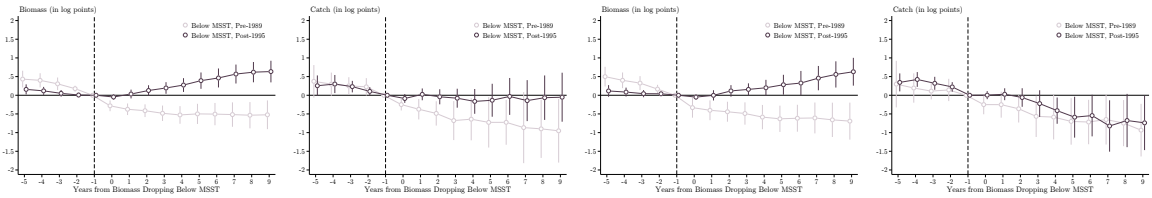
A.11 Historical Comparison Results With Fuel Prices and Climate Indices

In the main text, in the historical comparison event study analysis, we include quadratic trends. Here, we also add fuel prices and climate indices (see Online Data Appendix for more details) as additional time-varying controls. The results in Figure A9 show similar patterns and magnitudes as the results in the main text. This means that costs, proxied by diesel fuel costs, and environmental conditions, proxied by climate indices, fail to explain the results we report in the main text.

Figure A9: Historical Comparison Biomass Results with Fuel & Climate Controls

Historical Comparison, Present-US to Past-US

Including All US Stocks		Excluding New England Stocks	
(a) Biomass	(b) Catch	(c) Biomass	(d) Catch



Notes: Versions of Figures 3 and 4 (Panels c and d) with controls for fuel prices and climate indices.

A.12 Historical Comparison Results Without Quadratic Time Trends

In the main text, results for the historical comparison include quadratic time trends. In Figure A10, we repeat the estimation reported in the main text, but only include unit fixed effects without time trends. Overall, we recover similar trajectories for the outcomes after stocks enter rebuilding.

A.13 Suggestive Evidence for Precautionary Management and Compliance

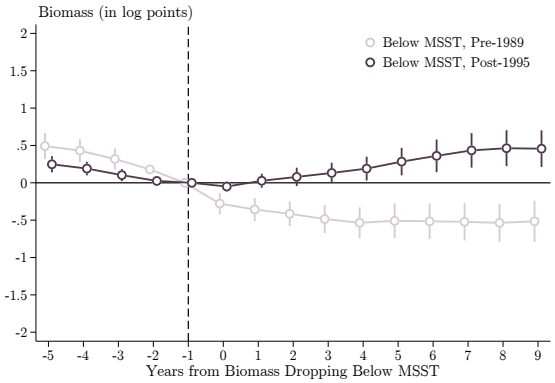
In Section 2, we discuss some of the challenges that the New England Fishery Management Council faced with implementing rebuilding plans and fishers compliance. Although we lack vessel-level data and quasi-experimental variation in the degree of compliance, we can explore this channel descriptively by stock and region. Figure A11 shows the mean change in stock biomass from five years before entering rebuilding to 6-10 years after, plotted against two measures of interest, compliance (Panel a) and precautionary management (Panel b).

For each stock, compliance is measured as the mean normalized overage—the extent to which total catch exceeds the allowable catch limit (ACL)—during the five years after entering rebuilding (see Section 3). This serves as a proxy for how fishers adhere to management decisions. Panel a shows that biomass decreases with overages and increases when catch is below the ACL, indicating a positive correlation between biomass change and compliance. New England stocks make up most of the lower, right quadrant of Panel a where overages are correlated with declines in biomass.

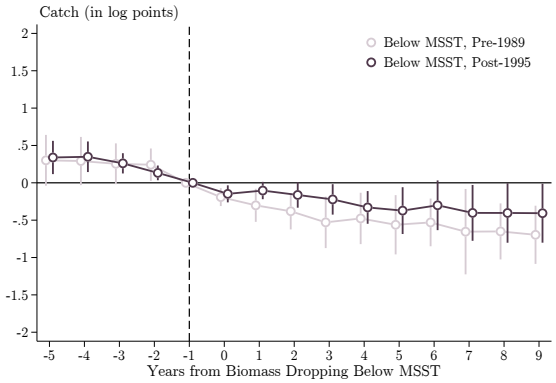
Figure A10: Estimation Results for the Historical Comparison Group With Unit FEs Only

All Stocks That Were Below Their MSST Either Pre- or Post-SFA

(a) Biomass: Double-Event-Study

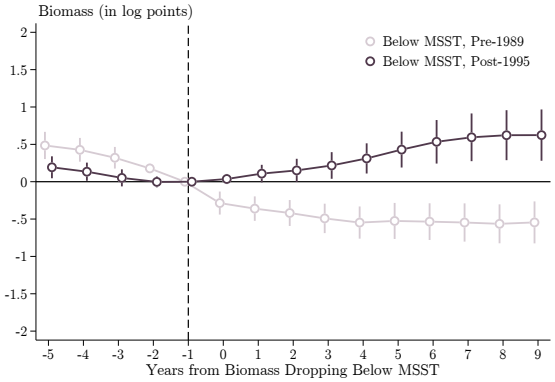


(b) Catch: Double-Event-Study

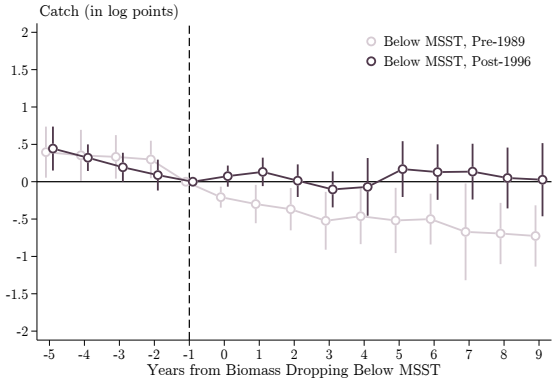


Holding Stock Composition Constant

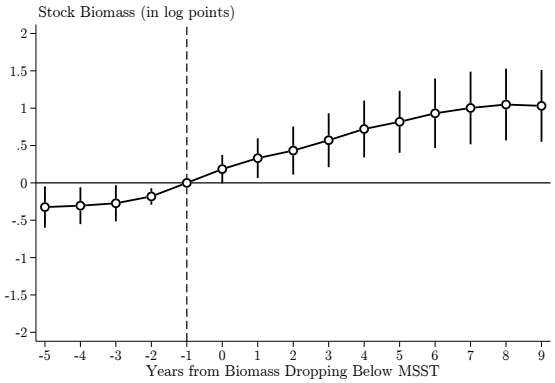
(c) Biomass: Double-Event-Study



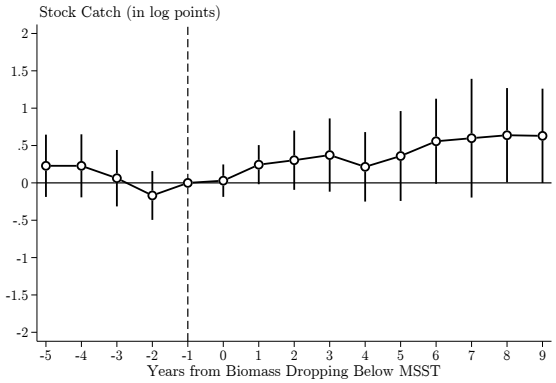
(d) Catch: Double-Event-Study



(e) Biomass: Paired-Differences

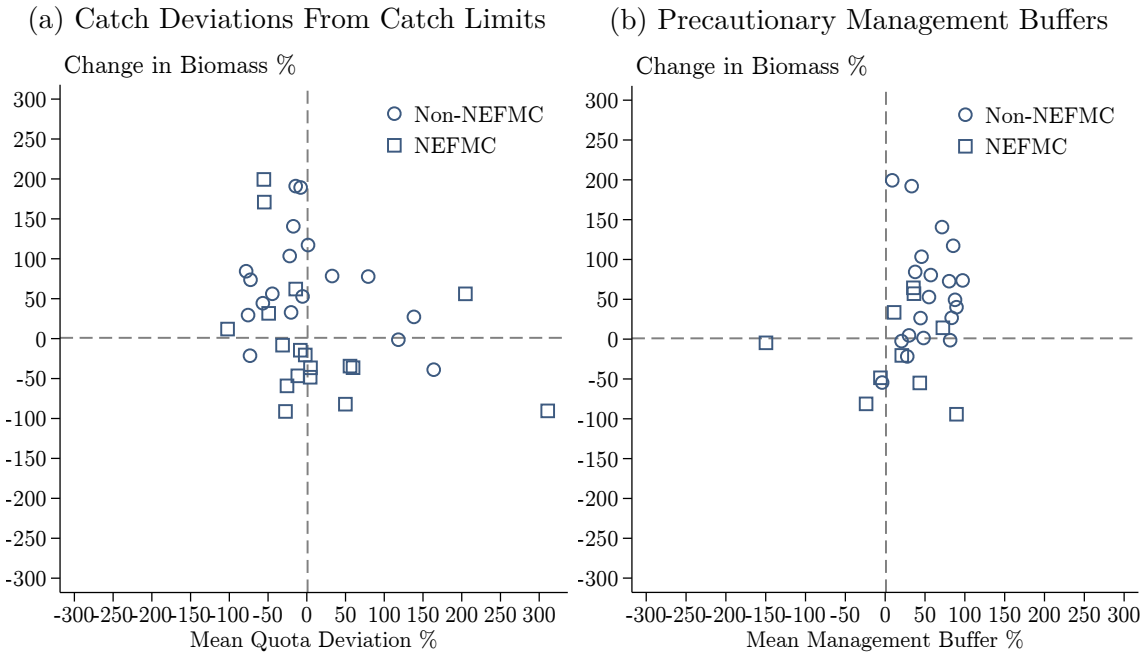


(f) Catch: Paired-Differences



Notes: Estimation results showing coefficients and 95% for the specification in Equation (2), excluding the quadratic time trends. Standard errors are clustered at the stock level.

Figure A11: Change in Biomass Plotted Against Compliance & Precautionary Catch Limits



Notes: For each stock, we calculate the mean change in biomass from five years before entering rebuilding to 6-10 years after. Panel (a) plots this biomass change against the mean difference between the realized catch and the catch limit (ACL or TAC) during the first five years of rebuilding, capturing how fisher adherence to quotas relates to stock recovery. Larger biomass gains later in the rebuilding (positive y-axis values) are correlated with compliance (negative x-axis values). One outlier, Gray Triggerfish (GMFMC), with coordinates (956.8, -21.2), is excluded. Panel b shows biomass change versus the management buffer—the difference between MSY value and the catch quota—illustrating how more precautionary catch limits (positive x-axis values) correlate with biomass gains (positive y-axis values).

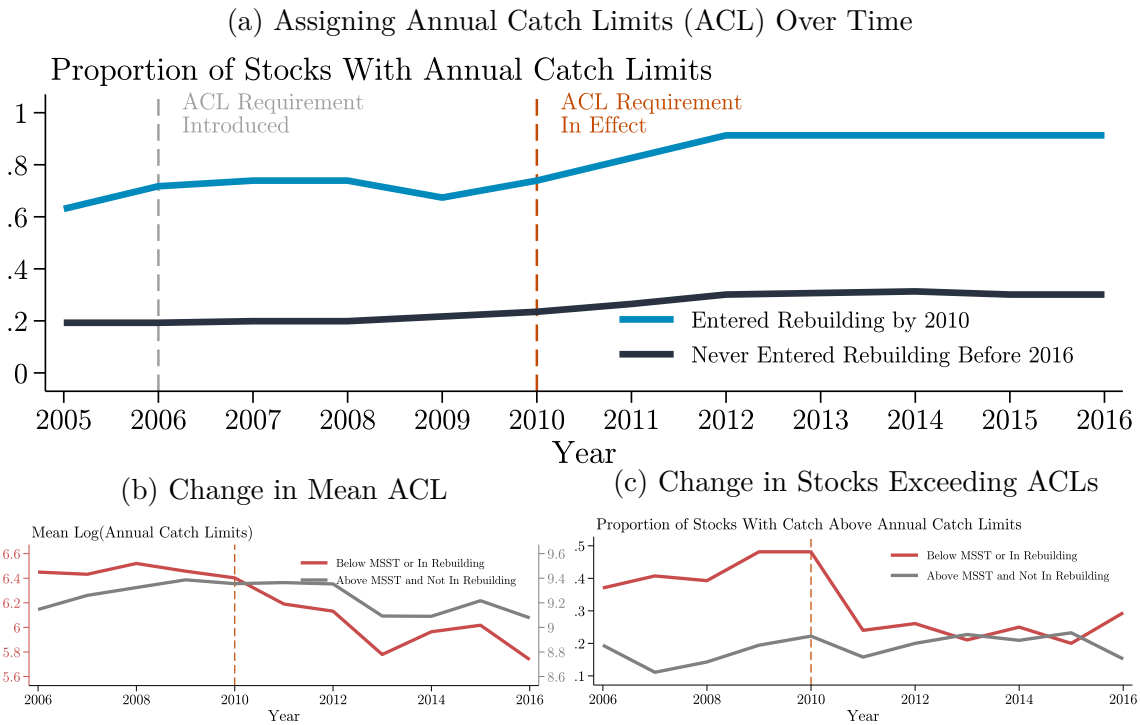
We also see a positive correlation between biomass change and precautionary management, defined as the presence of a management buffer between MSY and the ACL (MSY > ACL) during the first five years of rebuilding (Panel b). Buffers are implemented when there is uncertainty in population dynamics or policy enforceability. Although some managers set no buffer (ACL = MSY), others apply one to every stock.[29] Most stocks exhibit large buffers, suggesting that managers often restrict catch during rebuilding. Panel b suggests that larger buffers allow stocks to recover more effectively. New England stocks make up most of the lower-left quadrant where ACLs exceed MSY.[30]

The 2006 reauthorization of the MSA required FMCs to develop ACLs and accountability

[29] A larger management buffer reflects more precautionary management.

[30] This may be due to the fact that we use the most recent MSY reference point (see Online Appendix B.1) that could be lower than the estimated MSY at the time the ACL was created, reflecting changes to our scientific understanding of the stock (assessors thought the stock was healthier than it was).

Figure A12: Descriptive Evidence on Targeting & Compliance



Notes: Panel (a), plots Annual Catch Limits (ACLs), showing an increase in ACLs from 2009-2012, especially for stocks in rebuilding. Panels (b) and (c) shows the mean ACL and overage decline for stocks below their MSST or in rebuilding. In Panel (d), we summarize the number of overages that are above five percent of their ACL, by Fishery Management Council (FMC)—New England and South Atlantic FMCs have a high number of overages, even for stocks that are below their MSST or in rebuilding.

measures, which became mandatory starting in 2010. In Figure A12a, we show the proportion of stocks assigned an ACL from 2006 to 2016. We focus on stocks that had entered rebuilding by 2010, when ACLs became enforceable, to examine how the mandate was applied to depleted fisheries. In 2006, more than 60 percent of stocks that entered rebuilding by 2010 already had an ACL, rising to over 80 percent by 2010. In contrast, only 20 percent of stocks that never entered rebuilding by 2016 received an ACL, increasing to about 30 percent after 2010. This differential reflects the prioritization of the law on depleted stocks.

In 2010, when ACLs became mandatory, stocks with biomass below their MSST or in rebuilding experienced a sharp decline in their ACLs (Figure A12b) and their proportion of overages fell by half (Figure A12c). Adherence to ACLs, however, varies across FMCs. Figure A12d plots total overages from 2006 to 2016 by region, both for all stocks and for those below their MSST or in rebuilding. New England shows the highest number of overages, with 75 percent of them occurring in stocks where overages are likely delaying rebuilding.

A.13.1 Declines in Catch as a Proxy for Compliance With Rebuilding Plans

Another measure of compliance is how much catch declines after the event year. Catch should drop quickly to align with the HCR (see Section 2). Figure A13a shows the mean relative change in catch by treatment cohort (the year the stock biomass dropped below the MSST). We plot the mean relative change in catch from the year after to the year before biomass fell below the MSST for 1995–2016, by treatment cohort. Catch did not show consistent declines until before 2000, reflecting early challenges in implementing the MSA (Merrill 2011). From 2000 onward, catch dropped by 30 to 60 percent on average.

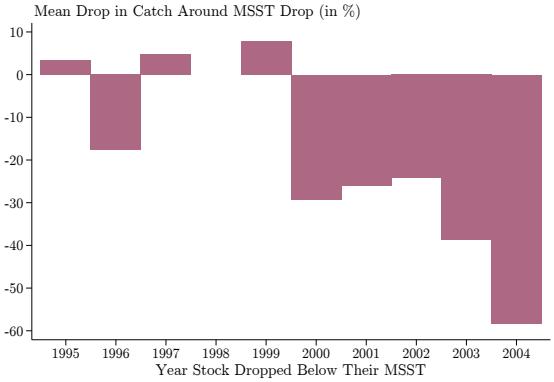
We test how biomass responds to stocks that enter treatment prior to 2000 (1995-1999) and after 2000 (2000-2004). Figure A13b plots a contemporaneous comparison, interacting event time with dummies for stocks whose biomass dropped below their MSST in 1995-1999 (earlier) or 2000-2004 (later). Biomass recovery is primarily driven by the later treatment cohorts, which experienced large catch declines after the event year. Five to 10 years after the event, these later cohorts' biomass gained 75 percent in biomass, on average. However, we cannot reject the null hypothesis of no difference between this estimate and the mean estimate of 52.2 percent in Table 1.

A.14 Stock-Specific Estimation Results

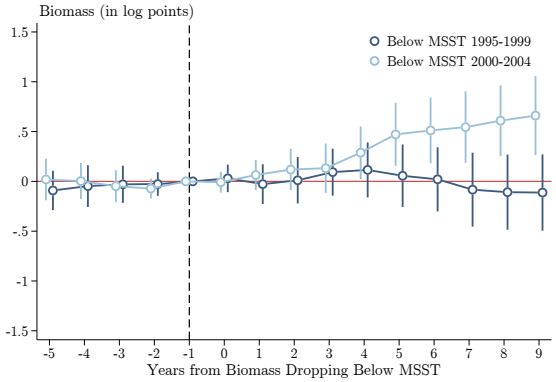
In the main text, we report results for the historical comparison that examines stocks whose biomass declines below their MSST pre-1989 as well as post-1995. Here, we report separately

Figure A13: Contemporaneous Comparison Estimation Results for MSST Drop Period

(a) Change in Catch Around MSST Drop



(b) Biomass



Notes: Panel (a) shows the mean relative change in catch from the year after relative to the year before the biomass dropped below the MSST, by treatment cohort. Panel (b) shows coefficients and 95% CI using Equation 1 modified with dummies for stocks whose biomass dropped below the MSST before or after 2000 interacted with event time.

estimated regressions for the same set of stocks to fully describe the heterogeneity in Figures 3c and 4c. We use the same sample, but estimate a single regression for each stock. Each regression includes a dummy variable for being one to five years after declining below its MSST, and another dummy variable for being six to 10 years after declining below its MSST. These two coefficients are estimated relative to the omitted category of years before declining below its MSST. For each stock, we estimate four regressions: for biomass and catch outcomes, and for biomass declining below its MSST before 1989, and after 1995.

In Figure A14, we report the separately estimated coefficients for each stock on the effect of being six to 10 years after being below the MSST. One immediate observation that arises from the figure is that nearly all stocks that dropped below their MSST, pre-1989, were still below their MSST six to 10 years after dropping below that threshold. However, the results from after rebuilding plans were required show that several stocks increased in biomass in the six to 10 years after having biomass below the MSST. Results for catch are more mixed. Some stocks experience lower catch in both pre-1989 and post-1995 periods, while others switch from continued low catch to higher catch, or vice-versa.

For visual inspection of the stock-specific estimation results, we summarize them using kernel densities for the biomass and catch outcomes in Figures A14b and A14c. The distribution for both the effects on biomass and catch in the post-1995 are shifted to right relative to the results from pre-1989. More importantly, the pre-1989 distributions are centered around negative values, highlighting that with falling biomass levels, catch levels declined as

well. The same stocks, however, experienced growth in biomass, as well as higher levels of catch, once harvest control rules and rebuilding provisions were put in place as part of the 1996-reauthorization of the MSA.

A.15 Contemporaneous Comparison Using US Stocks That Never Entered Rebuilding

In the main text, the contemporaneous analysis uses EU stocks as the control group. We emphasize the importance of using a control group that is less likely to be affected by restrictions on catch on US stocks. Here, we report the results of the contemporaneous analysis that compares how the treated stocks to the untreated US stocks as the control group.

We find slight evidence of pre-trends in Figure A15, unlike the results for the contemporaneous comparison in Figures 3 and 4. For biomass, we observe that treated stocks experienced a larger depletion trend four and five years before dropping below their MSST. We still observe a large and meaningful gain in biomass for the treated stocks in the years after they drop below the MSST. For catch, we estimate a similar decline in catch that starts five to four years before the stock drops below the MSST. After stocks drop below their MSST, we estimate small and noisy declines in catch. The results remain nearly identical whether we include or exclude NEFMC stocks.

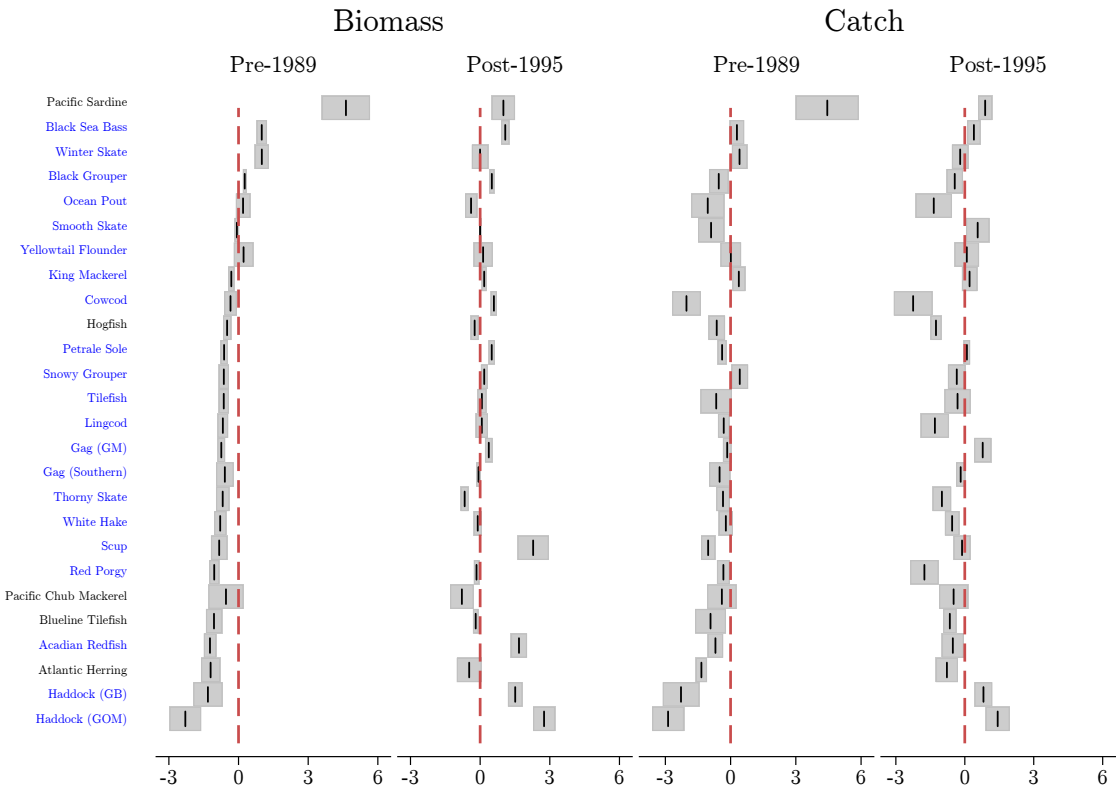
A.16 Documenting Inaccuracies in Alternative Fishery Revenue Data

EU revenue data for the is not widely available prior to 2006 (see main text Section 5.5). We explored using an alternative data set on prices and revenue for fisheries made available by the Sea Around Us (SAU) organization. However, upon inspecting the quality of the data we discovered serious discrepancies that we think invalidate any use of the data for the purpose of our analysis.

The key flaw of the SAU data is that it fails to reproduce the revenue data we have for the US. We compare for each US stock the revenue we obtain from US sources, the FOSS, (see Section 3 for more details) to that in the SAU data. In Figure A16 we plot the distribution of the percentage difference between the FOSS and SAU revenue data for the stocks that enter rebuilding. Even with truncating the data at the 25th percentile, the distribution reveals massive discrepancies between the sources of data we expected to align very closely.

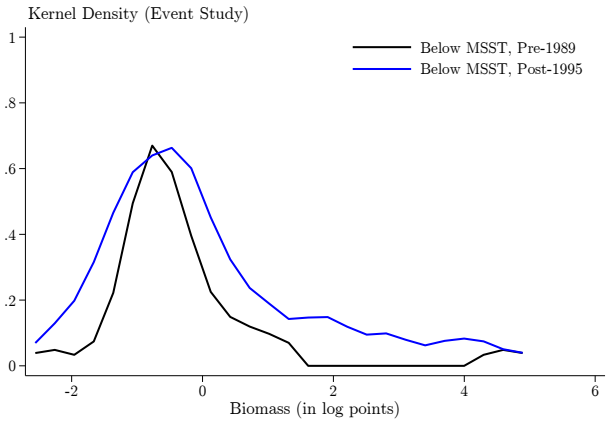
Figure A14: Changes in Biomass & Catch Following Decline Below MSST, by Stock

(a) Biomass & Catch, by Stock, Six to 10 Years Post-Event

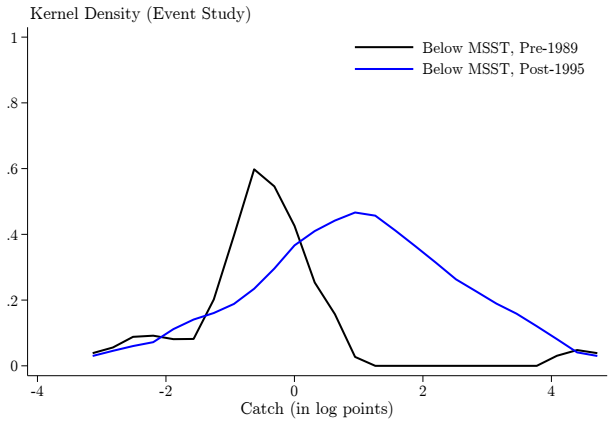


Effects of Biomass Dropping Below MSST (in log points): 95% CI

(b) Biomass



(c) Catch

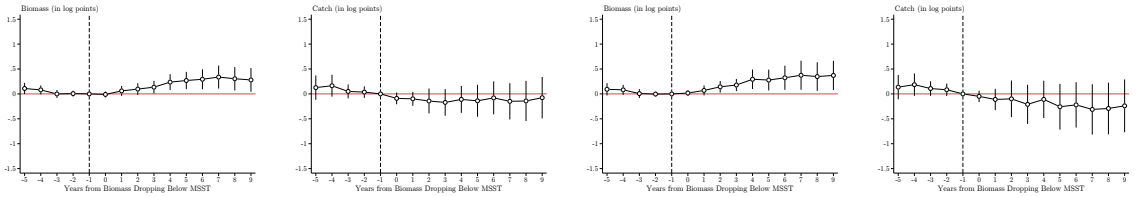


Notes: We report the estimates from a stock-by-stock regression, where we report the coefficient on a dummy variable for being six to 10 years after the event of dropping below the MSST. We repeat the estimation in pre-1989 and post-1995 periods, capturing the historical comparison when holding the composition of stocks constant (see Figure A20). Stock that are highlighted in blue are those that also entered a rebuilding plan post-1995. In Panels (b) and (c), we summarize the distribution of the coefficients by the time period for each outcome.

Figure A15: Contemporaneous Comparison, Treated US to Untreated US

Including All US Stocks | Excluding New England Stocks

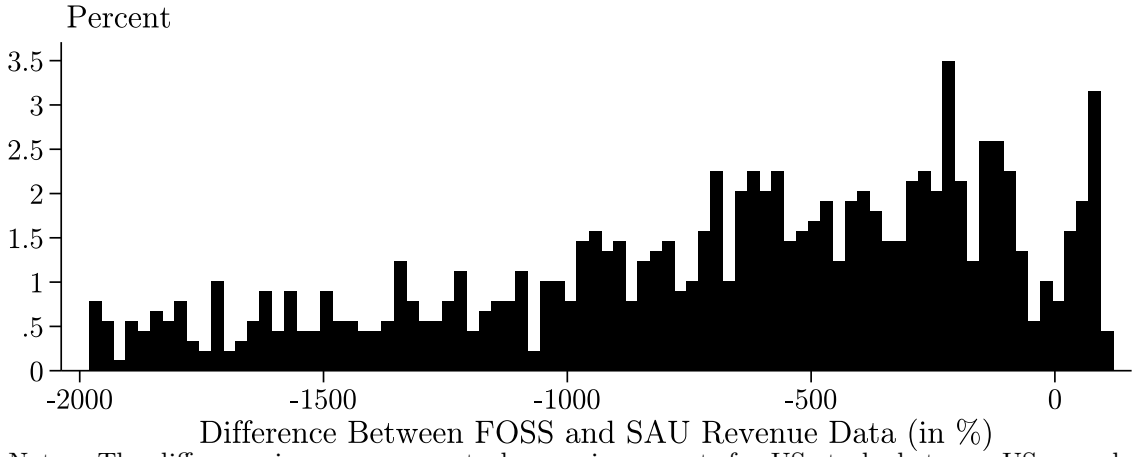
(a) Biomass (b) Catch (c) Biomass (d) Catch



Notes: Same as in Figures 3 and 4, but using US stocks that did not enter rebuilding as the controls instead of EU stocks that did not enter rebuilding.

The distribution extends up to 10th, 5th, and 1st percentile values of -32,105.31, -12,6525.7, -2,154,961 percent, respectively. For this reason alone, we consider the data unusable. This prevents us from running a contemporaneous cohort-weighted DD comparison as we do not have a valid source of EU data across the 1990 to 2016 period.

Figure A16: Differences in FOSS and SAU Revenue Data

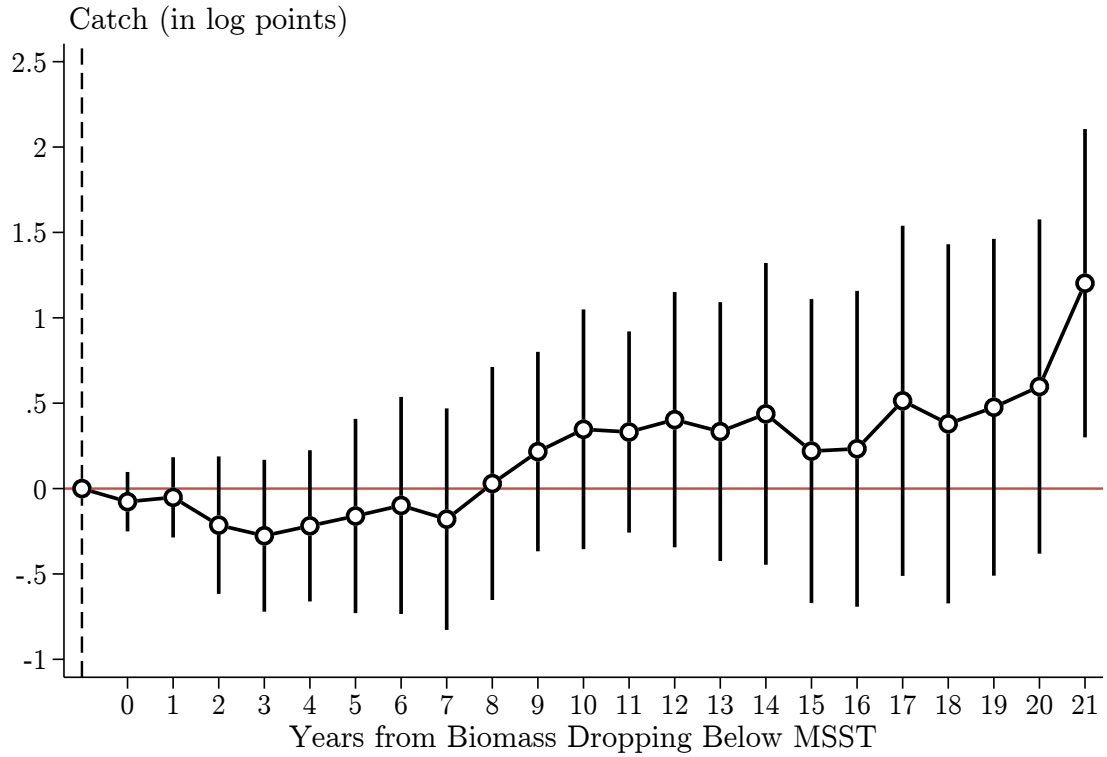


Notes: The difference in revenue per stock-year, in percent, for US stocks between US records (FOSS) and non-US record (SAU).

A.17 Coefficients for Catch-Based Revenue Counterfactual

Figure A17 plots the coefficients used in the catch-based revenue counterfactual. See Section 5.5 for a discussion of these results.

Figure A17: Contemporaneous Comparison, US to EU, All Lags



Notes: A modified specification to that in Equation (1) where we include all lags, and combine all leads up to one year prior to the omitted category as one dummy variable. The regression includes stock and year fixed effects. The sample include all US stocks that got determined as rebuilt. Standard errors are clustered at the stock level.

A.18 NPV Heterogeneity

In the main text (Section 5.5), in lieu of EU revenue data, we use three approaches to produce potential counterfactual revenue flows for each US fishery. For at least 69 percent of successfully rebuilt stocks, the NPV of revenue is higher than counterfactual NPV (i.e., the NPV ratio > 1). This number might mask important heterogeneity across different dimensions. In Table A4, we break down this number by several sub-groups. First, we summarize the percent of stocks whose NPV ratios are greater than one by FMC. New England has the largest number of rebuilt stocks in our sample (11 out of 26). For those stocks, the realized NPV is greater than the counterfactual NPVs in 72.7 percent of the cases for the first two approaches (exponential and simulated-volatility), and 81.8 percent of the cases for the third approach (catch-based). In comparison, the Gulf of Mexico, Mid-Atlantic, and South Atlantic FMCs comprise 7 stocks, which almost all exhibit a realized NPV greater than the counterfactual NPV (with one exception in the case of Gulf of Mexico

in the simulated volatility counterfactual). The three stocks that are jointly managed by the New England and Mid-Atlantic FMCs exhibit the lowest NPV ratios, ranging from zero to 66 percent of stocks with NPV ratios greater than one. Finally, the Pacific FMC comprises five stocks in our sample, of which the same three stocks have realized NPVs above all of the counterfactual NPVs.

We next explore heterogeneity by two functional groups, demersal and pelagic species. Our sample of 26 rebuilt stocks is evenly split between demersal and pelagic species. We find that fewer demersal species exhibit NPV ratios that are greater than one when using the exponential and simulated-volatility counterfactuals, though the numbers are similar when using the catch-based counterfactual. This suggests that when the search costs increase, as is the case with demersal species, revenue levels decline more and are harder to offset after the stock is rebuilt.

Finally, we explore heterogeneity of baseline revenue and recruitment. For each stock, we calculate the mean level of revenue or recruitment during a baseline period of 1986 to 1995.[31] We assign high or low status based on stocks being above or below the median level of baseline revenue or recruitment. Higher-revenue stocks may receive more FMC attention and faster rebuilding action, but industry pressure to maintain catch may make fishing mortality harder to reduce. Our comparison of high versus low baseline revenue stocks does not show notable heterogeneity. Finally, high-recruitment stocks have a larger share of NPV ratios greater than one than low-recruitment stocks.

A.19 Validating Fishery Recovery is Not Driven by Assessed Biomass Modeling

Throughout the main text we use biomass to measure the policy's efficacy. One concern is the possibility that stock assessments may be somehow manipulated to create the appearance that populations are being successfully rebuilt. In part, we address this in Section A.2, where we use catch data and survey data on fish abundance to demonstrate that there is strong agreement between the inputs to a stock assessment and its output of assessed biomass (see Figure A2). A second concern is that the assessed biomass might be higher simply due to a mechanistic relationship in the population biology model between lower catch levels and higher biomass. In other words, we want to reject that the higher biomass levels are simply a product of the theoretical model used to estimate biomass. We want to ensure that they are instead capturing a true signal about the status of the fishery.

[31] We are missing recruitment data for three stocks.

Table A4.
Summary of Heterogeneity in the NPV Analysis

Heterogeneity Dimension	n	Percent of NPVs>1		
		Exp.	Vol.	Catch
Gulf of Mexico	2	100.00	50.00	100.00
Mid-Atlantic	3	100.00	100.00	100.00
New England	11	72.73	72.73	81.82
New England / Mid-Atlantic	3	0.00	33.33	66.67
Pacific	5	60.00	60.00	60.00
South Atlantic	2	100.00	100.00	100.00
Demersal	13	53.85	61.54	76.92
Pelagic	13	84.62	76.92	84.62
High Revenue	13	69.23	69.23	84.62
Low Revenue	13	69.23	69.23	76.92
High Recruitment	11	81.82	81.82	81.82
Low Recruitment	12	66.67	66.67	83.33

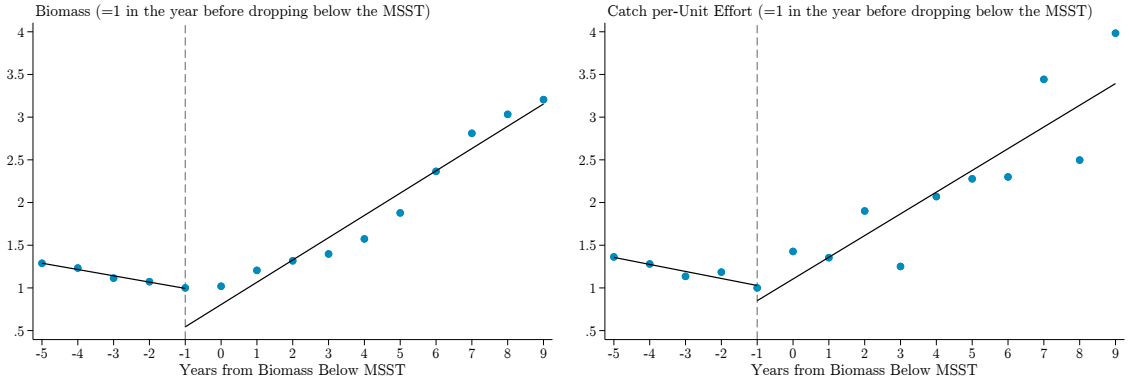
Notes: NPV heterogeneity referenced in Section 5.5. We break down the percent of stocks with a realized NPV that is greater than one of the three counterfactual NPVs by the following subgroups: Fishery Management Council (FMC), whether the species is demersal or pelagic, whether the species has high baseline revenue or high baseline recruitment (defined as above median revenue or recruitment in in the 1986 to 1995 period). See text for more details.

The survey data, measured as catch per unit effort (CPUE), are designed to estimate the abundance of fish in the fishery. We compare these raw data, a proxy for biomass, to biomass after a stock declines below its MSST. Our comparison focuses on the 34 stocks that have received a rebuilding plan, and for which we have balanced data on both biomass and CPUE during the 1990 to 2016 period. To simplify interpretation and comparison between biomass and CPUE, for each stock, we normalize its biomass or CPUE data to be equal to one in the year just before it drops below its MSST. In Figure A18, we plot the binned means of either biomass or CPUE, re-centered around the year of dropping below the MSST.

Figure A18: Fishery Recovery Observed in Biomass & Survey Proxy for Biomass

(a) Biomass

(b) Survey Proxy for Biomass



Notes: Binscatters for scaled biomass and CPUE data for 34 balanced stock during 1990 to 2016, that dropped below their MSST and subsequently entered rebuilding. CPUE acts as a proxy for fish abundance and is used in the assessment process as a key input in order to assess the stock's biomass.

Both biomass and CPUE exhibit a strong recovery, preceded by a slight downward trend prior to the event year (Figure A18). The fact that CPUE also increases suggests the increase in assessed biomass is not simply an artifact of the assessment process. On average, biomass increases threefold, while CPUE almost quadruples, in the 10 years after the event. These increases in magnitudes are meaningful; potentially highlighting the importance of using additional inputs (such as catch) as well as population biology to determine the stock's status (its biomass).

A.20 Addressing Changes in Environmental Conditions

Environmental conditions are in constant flux in both the Pacific and Atlantic oceans due to known climatic oscillations, as well as stochastic perturbations (Chavez et al. 2003; Vert-pre

et al. 2013; Overland et al. 2010).[32] A key concern for our study is that more beneficial environmental conditions could be increasing fish populations. If the main reason stocks declined below their MSST was poor environmental conditions, caused by either long-term climatic oscillations or short-term shocks, then a reversal of the oscillations or return to baseline would lead to higher levels of biomass. If these conditions are more common today, and more common in the US than in the EU, then these variables could be driving our results.

The full interaction of environmental conditions with each stock is a complex function, however, we can observe an important proxy of stocks' recovery: productivity of the stock, also referred to as recruitment.[33] Explicitly, we can calculate the recruitment per-unit of fish biomass (hereafter, recruitment per-biomass). If recruitment per-biomass is increasing over time, especially after 1996, then it could be the main mechanism responsible for the observed improvement in biomass.

We do not observe an increase in recruitment per-biomass over time. Instead, we observe the opposite—recruitment is declining on average. Lower recruitment per-biomass in recent years suggests it should be harder for stocks to recover after being overfished. In Figure A19a, we plot the recruitment per-biomass over time for each of the 133 stocks for which we have both recruitment and biomass data. We include the average across stocks in each year (orange line), as well as linear fits before MSA reauthorization (1976-1996) and after reauthorization (after 1996), with or without residualizing on stock fixed effects (green and dark purple line, respectively).

We repeat the contemporaneous and historical analysis with recruitment-per-biomass as our outcome variable. In both cases, we find that the recruitment-per-biomass ratio remains stable around the event of interest until biomass begins to recover, overtaking any growth in total recruitment (Figures A19b and A19c). In other words, more beneficial environmental conditions are not driving increases in biomass because recruitment-per-biomass it not differentially higher for stocks in the US relative to the non-US stocks or historical US stocks.

Potential explanations for the decline in recruitment among treated stocks are outside the scope of this paper. One possibility is a permanent decline in productivity due to changing environmental conditions (Free et al. 2019; Pershing et al. 2015), especially for US New England stocks. Another possibility is behavioral responses by fishers that reduce stock

[32] Examples for known oceanic oscillations in the northern hemisphere are El Niño–Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO).

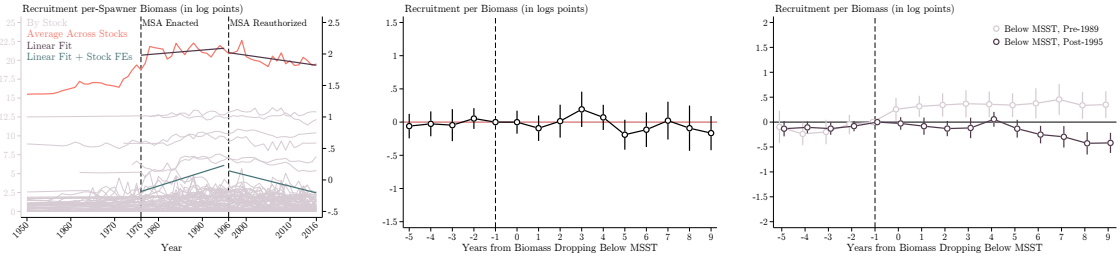
[33] Recruitment is often measured as a quantity of juvenile fish within a particular fish stock during a given year. Changes to habitat, upwelling, primary productivity, food availability, predators and temperature can all impact recruitment.

Figure A19: Assessing Changes in Stock Growth Dynamics

(a) Trends in Recruitment Dynamics

(b) Contemporaneous Comparison

(c) Historical Comparison



Notes: In Panel (a), each gray line (left y-axis) corresponds to recruitment per-biomass of one stock over time. The coral line (right y-axis) is the average across stocks in each year. The linear fit lines (right y-axis), in dark purple and dark teal, are estimating a simple linear trend model either between 1976 and 1996, and post-1996. The dark teal line fits the recruitment per-spawning biomass after residualizing them on stock fixed effects. Panel (b) repeats the contemporaneous DD estimation as in Figure 3a, and Panel (c) repeats the paired differences between the same stocks in the historical comparison group as in Figure 3c.

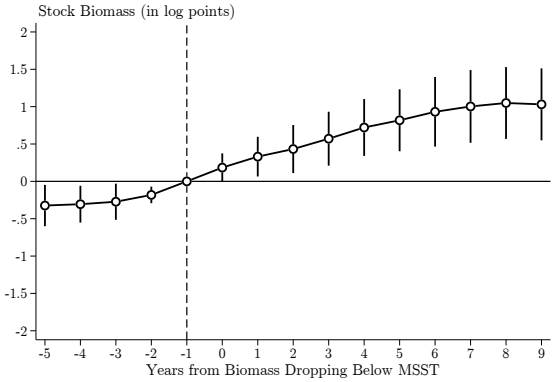
productivity. When a stock enters rebuilding, annual quotas are reduced, potentially creating a "race to fish" before the total allowable catch (TAC) is reached thereby compressing the fishing season. Such compression has been empirically documented in US fisheries, and "the race to fish" has been linked to fishing practices that damage habitat and increase bycatch (Birkenbach et al. 2017; Costello et al. 2008; Essington 2010; Gordon 1954; Huang and Smith 2014).

A.21 Event-Study Results for the Paired Differences Estimation

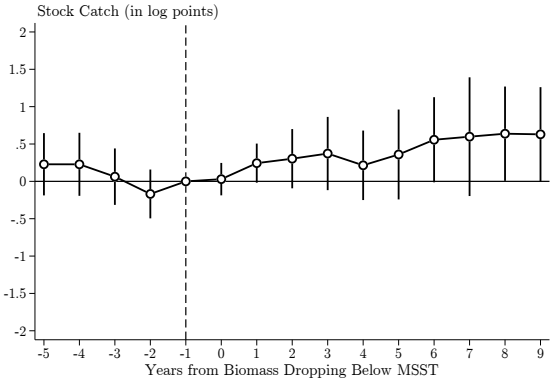
In the main text, we report a summary of the paired difference results in Table 2. Here, we present the full event-study coefficients for biomass and catch. The results for biomass (Figure A20a) show that compared to the years before rebuilding plans were required, stocks have more than doubled in biomass in the years after the event year. For catch, we note that in the pre-event period, catch levels are not systematically different, suggesting that that are no large changes to the demand for those stocks that might explain the recovery following the event.

Figure A20: Paired-Differences Event Study Estimation Results

(a) Biomass



(b) Catch



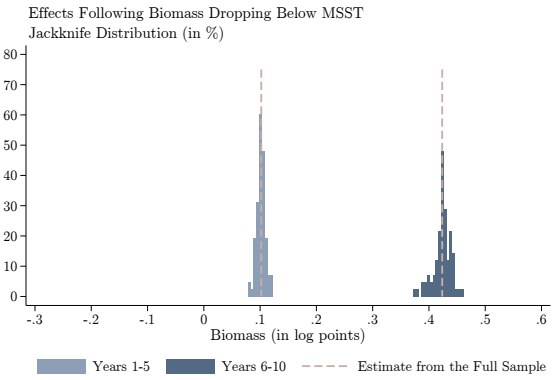
Notes: Estimation results showing coefficients and 95% CIs for the specification in Equation (2). Standard errors are clustered at the stock level.

A.22 Examining Sensitivity to Outliers by Using Leave-One-Out Estimation

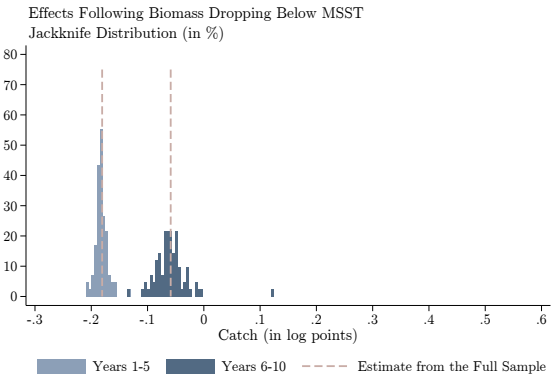
Extreme outliers in either the treated sample or the comparison sample could have a large influence on the results. In Figure A21, we repeat the estimation by leaving one stock out of the sample each time. Overall, the jackknifing distributions are narrowly centered around the estimated coefficient from the full sample (those reported in Table 1).

Figure A21: Contemporaneous Comparison Jackknifing Estimation Results

(a) Biomass

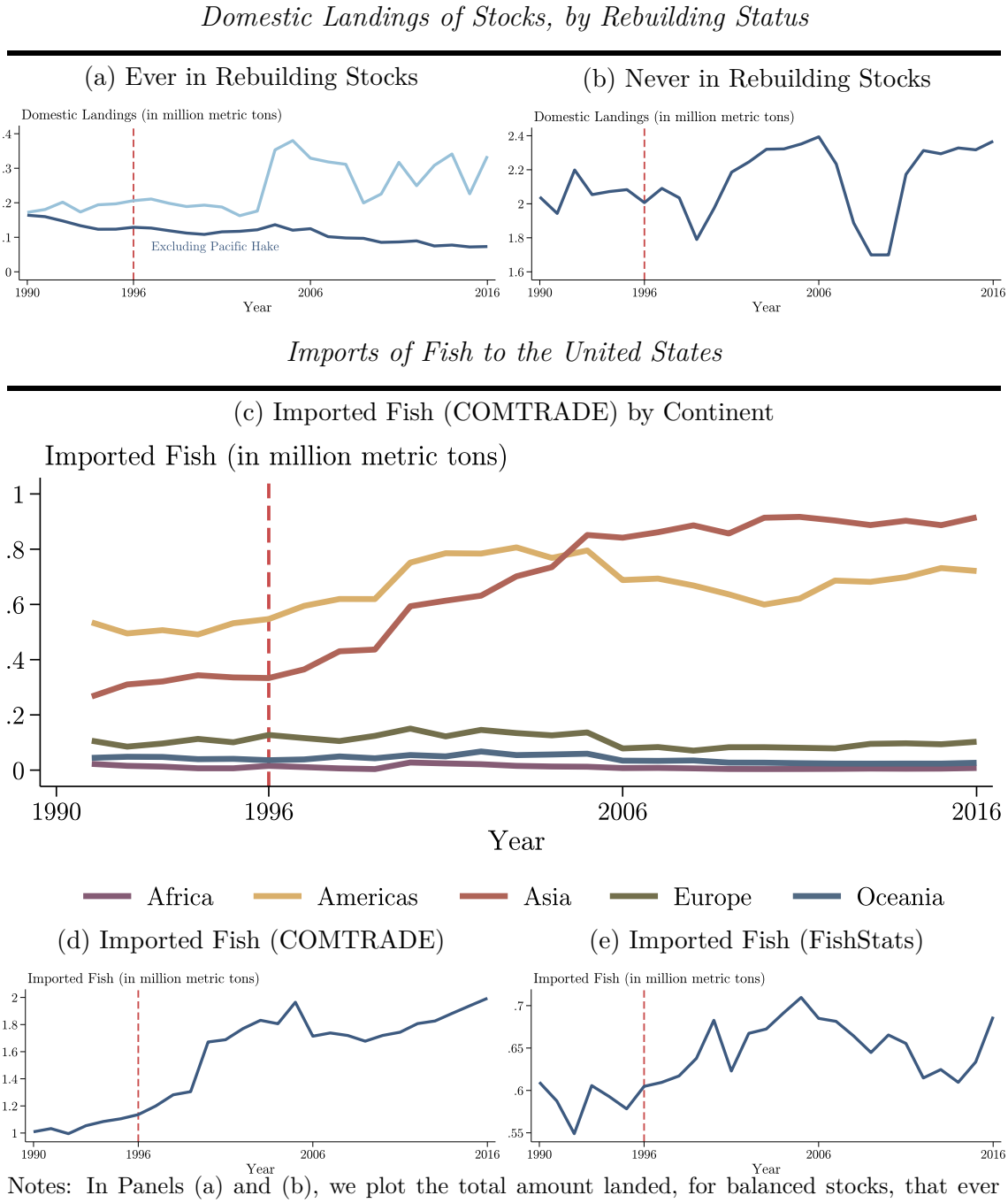


(b) Catch



Notes: Repeating the estimation reported in Table 1, column 2, while excluding one stock from the sample in each iteration.

Figure A22: Substitution Through Increased Imports



Notes: In Panels (a) and (b), we plot the total amount landed, for balanced stocks, that ever or never entered rebuilding during our sample period. In Panel (c), we plot the total amount of imported fish, as recorded in the COMTRADE database ,by different regions. In Panel (d), we aggregate all fish imports in the UN-COMTRADE database, and compare those to imports of specific fish species, which more closely align with the species that we focus on in the analysis, as recorded in the FAO FishStats database.

Online Data Appendix

B.1 US Data

B.1.1 Times Series and Reference Point Data

We sourced US stock biomass, catch, fishing mortality, and recruitment (productivity) data from NOAA's Stock SMART (Status, Management, Assessments, & Resource Trends) database. Stock SMART collects its data from stock assessments. As of October 2021, Stock SMART contained data for 311 stocks.

Stock SMART's database is incomplete, resulting in stocks with missing time series, missing biological reference points, and mismatched units between the time series and reference point data. To fill in these gaps in data, we performed the following steps when encountering a stock with one or more of these issues. First, we would search through the stock assessment report published by the responsible scientific agency for the missing data. If the missing data was not found in the assessment report but the report alluded to its existence, we would then contact the stock assessors and request the missing data. Once the data was found or provided, we would populate the missing values in our dataset (see "Stock documentation and data cleaning.csv" for all manual entries and unit conversions). When a stock's biological reference point did not match the units of its time series data, such as a stock's MSST and its biomass time series, we would convert the reference point to match the units of the time series data.

A single stock can have multiple stock assessments over time, where each new stock assessment may supplement or completely update the time series and reference point data from the previous stock assessment. Stock SMART collects the data from stock assessments as far back as 2005. However, stock assessments do exist prior to 2005. In this study, we used the most recent stock assessment to use for each stock, unless it had limited data availability. In some cases, we chose an older assessment if it had a longer time series of data or possessed a variable (such as catch) that the newer assessment lacked. See "Stock documentation and data cleaning.csv," in the supplementary files for the specific assessment year's data we used for each stock in the study.

Choosing one stock assessment also means we are using the set of reference points (MSY, B_{MSY}, MSST, and F^{MSY}) that were calculated and reported in that assesssment, and applying them to the time series of the stock. This decision leaves reference points constant for the entirety of a given stock's time series. The implication is that the MSST reference point may

not reflect whether the MSST was crossed in an earlier period of a stock's time series, due to changes in fishery selectivity, weight at age, maturity at age, or natural mortality.

Constructing a dataset that reflects annual changes in reference points over a stock's entire time series is currently not viable due to a lack of readily available data, especially prior to 2005. In some cases, reference points are reported in different units that cannot be easily converted from one type to another. For example, one assessment could report a B_{MSY} value in kilograms per tow (reflecting reliance on survey data and potentially no population biology model), whereas a subsequent assessment might report B_{MSY} in metric tons. In more extreme examples, one assessment can report the reference point in eggs, and another assessment in the number of individuals or in metric tons.

In addition to time series data from Stock SMART, we compile a time series dataset of stock survey data from NOAA's Distribution Mapping and Analysis Portal. Biomass time series data reported from Stock SMART are typically the output of a model used in a stock assessment to estimate a stock's biomass. An input of these models is, among other collected data, survey data. Survey data are gathered via bottom trawl surveys, where a research boat (a trawler) will go fishing. Researchers use the same boat and gear and will fish at the same time every year. They also grid off the ocean and trawl the same number of times in each grid. They will catch, identify, measure, and dissect the fish. Bottom trawl surveys provide data for stocks such as length, age, gender, and diet. The total amount of a particular stock captured during these surveys is a preliminary measure of its abundance, typically measured in kilograms per tow. We use survey data to validate that the stock assessment data does not deviate significantly from observed data.

B.1.2 Landings and Revenue Data

US landings and revenue data were collected from NOAA's Fisheries One Stop Shop (FOSS) Landings System database. FOSS reports annual commercial and recreational landings and revenue data at the stock-region and stock-state levels sourced from regional partners that collect these data. Landings are the amount of fish of a particular species that are sold. Landings data is required to be reported by permitted dealers who buy the fish. This is different from catch, which includes landings, bycatch, and discards, and is estimated from the stock assessments. For some fisheries, third-party observers are placed with dealers and on fishing boats to verify landing and catch data, including discards and bycatch.

B.1.3 Management Determination Data

We compiled data on when stocks were declared overfished or entered a rebuilding plan primarily from NOAA's Status of Stocks (SOS) reports. These annually released reports list changes in determination statuses for stocks across each fishery management council, namely, experiencing overfishing, approaching overfished, overfished, entering rebuilding, currently in rebuilding, and determined rebuilt. We convert these SOS reports into a time series for each of these statuses, then merge this dataset with the stock data we collected from Stock SMART. In addition, we verified our stock status data with internal documents obtained from NOAA, specifically for the earliest SOS reports, which used the overfishing and overfished determinations interchangeably. These documents also allowed us to verify the original rebuilding plan lengths for stocks which were determined overfished and required a rebuilding plan. These original rebuilding plan lengths may differ from the length the actual rebuilding plan had. It is worth noting that our data on stock status is more accurate than what is available in public records. Our quality assurance process resolved several inaccuracies that were never corrected in publicly available records.

B.1.4 Catch Limit Data

We use annual catch limit (ACL) data to examine fishers' compliance with these annual quotas of each stock, as well as management's setting of precautionary buffers between MSY and ACL. We recorded ACL data by stock and year from each FMC. North Pacific ACL data was sourced from NOAA's Alaska Catch Accounting System, which provides values for groundfish stocks in the Bering Sea/Aleutian Islands and Gulf of Alaska. Regional fishery management councils and science centers provided ACL data for Pacific groundfish stocks and ACL data for both New England and Mid-Atlantic stocks. ACL data for South Atlantic and Gulf of Mexico stocks were taken directly from the NOAA Fisheries Southeast Region Annual Catch Limit (ACL) Monitoring website, which provided ACL data along with each stock's commercial and recreational landings data.[34] Lastly, we verified and filled gaps in the dataset using ACL data obtained through from a FOIA request to NOAA.[35]

[34] https://www.fisheries.noaa.gov/southeast/sustainable-fisheries/southeast-region-annual-catch-limit-acl-monitoring. Accessed: 10/31/2022

[35] FOIA request number is DOC-NOAA-2022-001089

B.1.5 Observer Coverage & Violations Data

We collected data via the Freedom of Information Act for NOAA's Office of Law Enforcement (OLE) and various observer programs. Unfortunately, individual citation data was not available before 2014, and most of the 2014-2016 data was spotty, and could not match it to a particular stock.

We found it was impossible to match observer programs to specific stocks for most stocks. Methods for allocating observers changed from year-to-year and realized observer coverage was even harder to collect. The only complete dataset we were able to collect was the annual total number of vessel observers and total funding (from federal and industry sources) from 2005 to 2016. During this time period, the number of observers doubled, and funding increased by 39 percent (not reported here).

B.1.6 Fuel Prices and Climate Indices Data

Fuel data comes from the US Energy Information Administration (EIA) database, which has retail prices of diesel fuel in dollars per gallon from 1978-2020. Climate data includes climate indices from three sources covering different regions. For the US Atlantic coast, we use monthly North Atlantic Oscillation (NAO) values from 1951-2021. To merge the NAO with our yearly time series, we take the average from December to March for each year. For the Pacific coast, we use the El Niño/Southern Oscillation (ENSO) index by taking the annual average of its monthly index values from 1980-2021. Lastly, for the North Pacific US, we use yearly averages of monthly Arctic Oscillation index (AO) from 1951-2021.

B.2 EU Data

B.2.1 Time Series and Reference Point Data

EU time series and reference point data is primarily sourced from the Common Fisheries Policy monitoring report from 2020. This report compiled the time series and reference point data for Northeast Atlantic stocks reported by The International Council for the Exploration of the Sea (ICES) Stock Assessment Database, and for Mediterranean stocks reported by the EU's Scientific, Technical and Economic Committee for Fisheries database, and FAO's validated stock assessment forms.

B.3 Defining Pseudo MSST Values

Some stocks in our EU dataset did not have MSST-equivalents. (The EU MSST equivalent was the Safe Biological Limit, SBL.) Reasons for this absence are typically due to a lack of sufficient data to calculate values on which MSST is based, namely B_{MSY} and MSY. For stocks missing their MSST or MSST-equivalents, we calculated a pseudo MSST value. First, a B_{MSY} proxy equal to 50% of the stock's maximum historical biomass (in cases where the B_{MSY} is also absent) was created. Then, The pseudo MSST was defined as half of this proxy value. If a stock had a B_{MSY} value already, we simply took half of this value and set it as our pseudo MSST. For the US, we constructed pseudo MSSTs for 66 stocks, of which 28 stocks have their biomass drop below their pseudo MSST. For EU stocks, we created 142 pseudo MSSTs, and 64 of those stocks' biomass dropped below their pseudo MSST.

References

Battista, Willow, Ryan P Kelly, Ashley Erickson, and Rod Fujita. 2018. "Fisheries governance affecting conservation outcomes in the United States and European union." *Coast. Manage.* 46 (5): 388–452. ISSN: 0892-0753,1521-0421. doi:10.1080/08920753.2018.1498711.

Birkenbach, Anna M, David J Kaczan, and Martin D Smith. 2017. "Catch shares slow the race to fish." *Nature* 544 (7649): 223–226.

Chavez, Francisco P., John Ryan, Salvador E. Lluch-Cota, and Miguel Niquen C. 2003. "From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean." *Science* 299 (5604): 217–221. doi:10.1126/science.1075880.

Common Fisheries Policy: Council Regulation (EU) No 1380/2013 of the European Parliament and of the Council on the Common Fisheries Policy. 2013. OJ L 354/22.

Costello, Christopher, Steven D Gaines, and John Lynham. 2008. "Can catch shares prevent fisheries collapse?" *Science* 321 (5896): 1678–1681.

Essington, Timothy E. 2010. "Ecological indicators display reduced variation in North American catch share fisheries." *Proceedings of the National Academy of Sciences of the United States of America* 107 (2): 754–759.

Free, Christopher M, James T Thorson, Malin L Pinsky, Kiva L Oken, John Wiedenmann, and Olaf P Jensen. 2019. "Impacts of historical warming on marine fisheries production." *Science* 363 (6430): 979–983.

Gordon, H Scott. 1954. "The Economic Theory of a Common-Property Resource: The Fishery." *The journal of political economy* 62 (2): 124–142.

Hegland, Troels Jacob, and Jesper Raakjaer. 2020. "The Common Fisheries Policy." In *Oxford Research Encyclopedia of Politics.* Oxford University Press. ISBN: 9780190228637. doi:10.1093/acrefore/9780190228637.013.1099.

Huang, Ling, and Martin D Smith. 2014. "The Dynamic Efficiency Costs of Common-Pool Resource Exploitation." *The American Economic Review* 104 (12): 4071–4103.

Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006. 2007. Pub. L. No. 109-479. 120 Stat. 3575.

Merrill, J. 2011. "Trawling for meaning: A new standard for "best scientific information available" in the Magnuson-Stevens fisheries conservation act." *Catholic University Law Review* 60 (2): 475–504.

Natural Resources Defense Council, Inc. v. Daley, 62 F. Supp. 2d 102 (D.D.C. 1999). https://law.justia.com/cases/federal/district-courts/FSupp2/62/102/2410549/. Accessed: 2025-8-23.

Overland, James E, Juergen Alheit, Andrew Bakun, James W Hurrell, David L Mackas, and Arthur J Miller. 2010. "Climate controls on marine ecosystems and fish populations." *J. Mar. Syst.* 79 (3): 305–315.

Pershing, Andrew J., Michael A. Alexander, Christina M. Hernandez, Lisa A. Kerr, Arnault Le Bris, Katherine E. Mills, Janet A. Nye, et al. 2015. "Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery." *Science* 350 (6262): 809–812.

Sustainable Fisheries Act: Amendments to the Magnuson Fishery Conservation and Management Act. 1996. Pub. L. No. 104–297. 110 Stat. 3559.

Vert-pre, Katyana A., Ricardo O. Amoroso, Olaf P. Jensen, and Ray Hilborn. 2013. "Frequency and intensity of productivity regime shifts in marine fish stocks." *Proceedings of the National Academy of Sciences* 110 (5): 1779–1784. doi:10.1073/pnas.1214879110.

Walsh, James P. 2014. "The origins and early implementation of the Magnuson-Stevens fishery conservation and management act of 1976." *Coast. Manage.* 42 (5): 409–425. ISSN: 0892-0753,1521-0421. doi:10.1080/08920753.2014.947227.