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REGULATING BIOLOGICAL RESOURCES: LESSONS FROM MARINE FISHERIES IN THE UNITED STATES

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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 fact that the European Union has comparable fisheries but only recently developed similar laws. Compiling comprehensive data on US and EU fishery status and management, we examine fish populations that decline to unhealthy levels and measure the effect of a policy that aims to rebuild them to health. We find treated populations increase by 52 percent relative to these counterfactuals, with both catch and revenue rebounding to baseline levels or greater. Analyzing fisheries' revenue, we find net present values are higher for at least 69 percent of rebuilt stocks compared to simulated counterfactuals.

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A data appendix is available at
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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 we still lack causal evidence on the effectiveness of policies governing renewable biological resources such as forests and fisheries. 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.[2] 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.[3] 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 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.

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

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

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 the rebuilding requirement substantially increased stock biomass relative to counterfactuals. Finally, we estimate that the net present value (NPV) of successfully rebuilt stocks is, on average, at least 20 percent larger than it would have been without the policy. At least 69 percent of rebuilt stocks experience NPV gains from undergoing a rebuilding plan, indicating that the long-run economic gains often outweigh the short-run costs. 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.

Building on this, we then explore the mechanisms through which rebuilding requirements affected outcomes. Stocks subject to higher compliance with catch limits and more precautionary 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). 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. In 2022, US commercial fisheries employed 42,000 harvesters and generated over 5.9 billion USD in catch revenue (NMFS 2022). 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.[4] 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 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.[5] 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 (SFA)—introduced a requirement to rebuild overfished stocks. Rebuilding plans must return stocks to sustainable levels within 10 years, unless biologically infeasible, and must

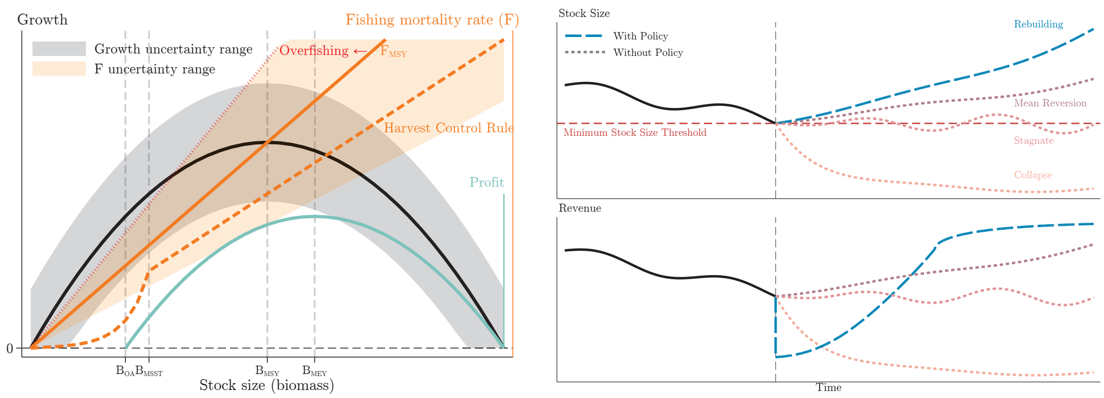
[4] Formally, in the logistic growth model, the change in the size of the stock N is determined by: $\frac{\partial N}{\partial t} = rN(1 - \frac{N}{K})$.

[5] 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): $H = qeN$.

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).

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.

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.

The MSA defines three biological reference points: (1) a stock is in “overfishing” when

$F > F_{MSY}$[6]; (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).[7]

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 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.[8] 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

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

[7] 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.

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

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 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 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." Huffman reintroduced his bill in 2025, while President Trump created Executive Order 14276, Restoring American Seafood Competitiveness, which stated that there is overregulation 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 7), 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 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: $B <$ **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[9] 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

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

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.

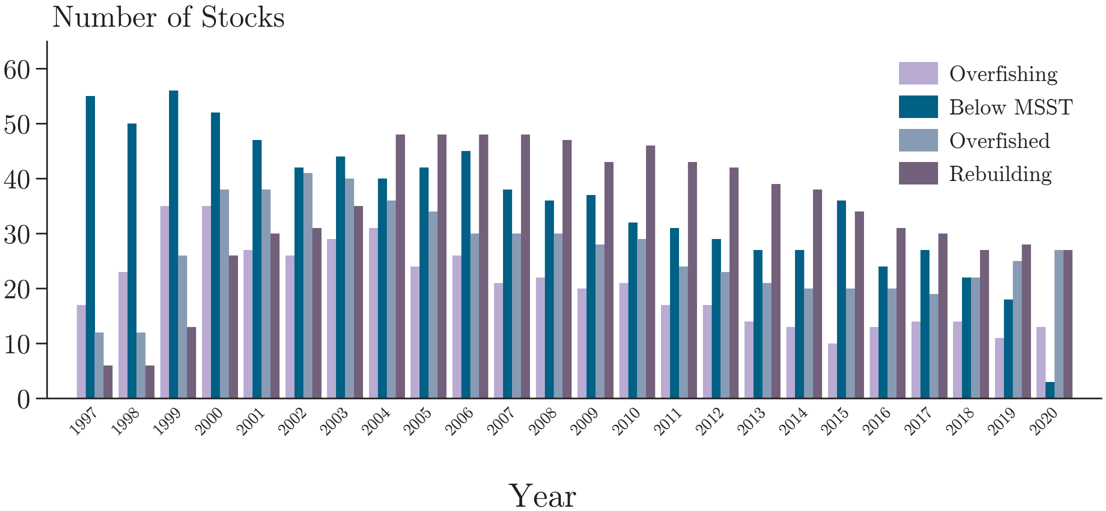
For US stocks, we complement their time series data with a timeline of status determinations and regulatory actions. We went through each of NOAA's yearly Status of Stocks reports (NOAA Fisheries, 1997-2020) to record the years that fishery management councils designated a stock as "in overfishing," near overfished, overfished, in rebuilding, and rebuilt. We validated these years with the information stored at NOAA's Office of Sustainable Fisheries.[10] 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.

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 data combine landings from multiple stocks of the same species in a given region. (E.g., New

[10] 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.

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



Notes: Summarizing data from the Status of Stocks Reports.

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.[11] 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. If the year the stock was declared overfished happened before the stock declined below its MSST, we use this as our first event year.[12] Our treated group of stocks are 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 7), 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

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

[12] This can happen in cases where the MSST value has changed due to an update in the science. See Online Appendix for more details.

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 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.17.

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.[13] 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.[14] 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.[15]

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

[14] 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.

[15] Because we focus on the sets of leads and lags where the composition of stocks is the same (five years

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.

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 following regression specification separately for the treated and control groups:

before and 10 years after the event) the weighted average simplifies to a simple average where each cohort receives the same weight.

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

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. [16]

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.

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

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 (Table 1, Panel a, column 1).[17] 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 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 7), 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. 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 addi-

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

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

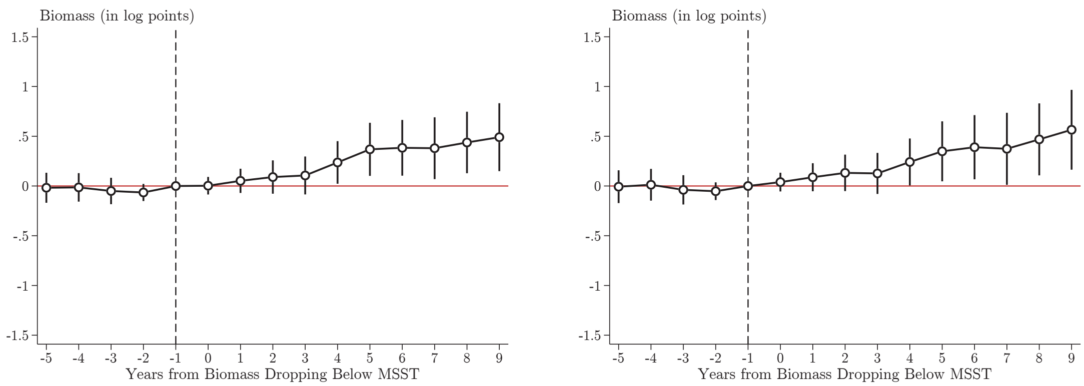
Notes: Estimation results from the DD specification in Equation (1). We report the linear combinations for the event time dummies after the stock drops below the MSST for the average of the first to fifth lags, and the sixth to tenth lags, excluding the top-coded lag coefficient. Column 1 includes all 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

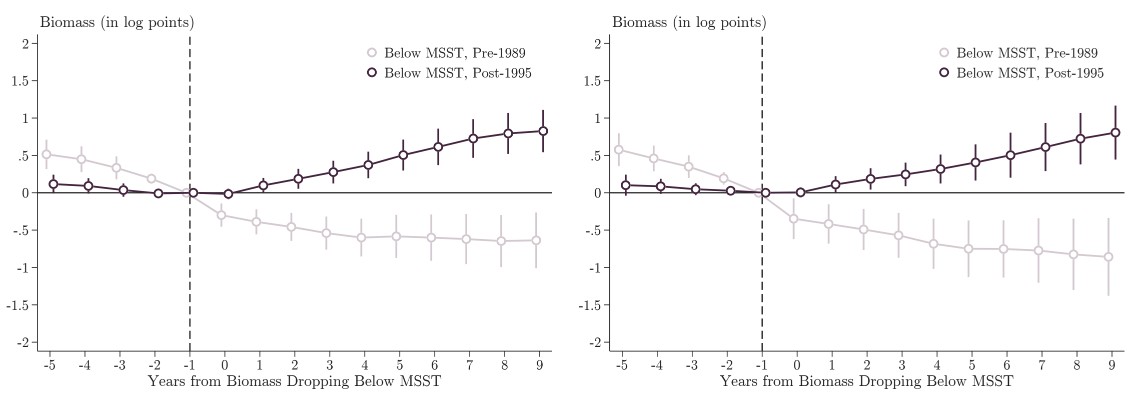
Contemporaneous Comparison, US to EU

(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.

tional 44.9% five to ten years after falling below the MSST. 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 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 dropping 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 A17, we plot the results of estimating the event-study specification on the paired differences.

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.[18] Consequently, this is a lower bound for the total gain in biomass. To better anchor this number, we sum

[18] 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.

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.

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 dropping below the MSST (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 is surprising given how reducing fishing mortality, seen as the key policy instrument, requires lowering catch. (We present fishing mortality results in the next section.) 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 dropping below the MSST, and then appears to recover to above baseline levels. However, the confidence intervals 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

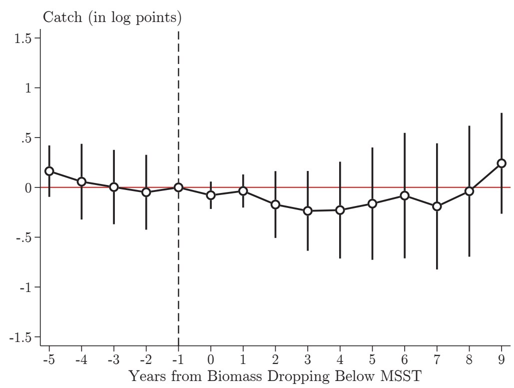
The results on biomass in Section 5.1 and catch in Section 5.2 mask important heterogeneity. Stock-specific estimates are shown in Online Appendix Figure A11 for the same treated and control stocks used in the paired-difference historical comparison. Holding stock composition constant allows for direct 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 falling below their MSST. Kernel density plots of these estimates confirm that both biomass

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

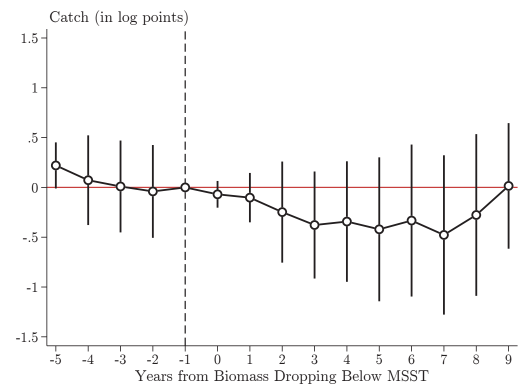
Including All US Stocks	Excluding New England Stocks

Contemporaneous Comparison, US to EU

(a)

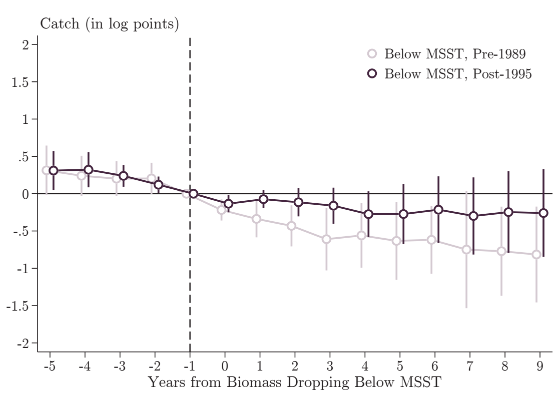


(b)

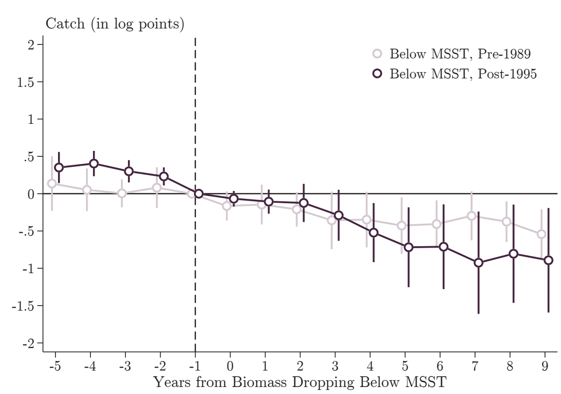


Historical Comparison, Present-US to Past-US

(c)



(d)



Notes: See Figure 3.

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 falling below their MSST, 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 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.[19] We classify rebuilding plans as short if their duration is 10 years or less and long if greater than 10 years.[20] 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 falling below the MSST, catch for long-plan stocks is estimated to be 62.8% lower.

5.4 Results for the Main Policy Instrument: Fishing Mortality

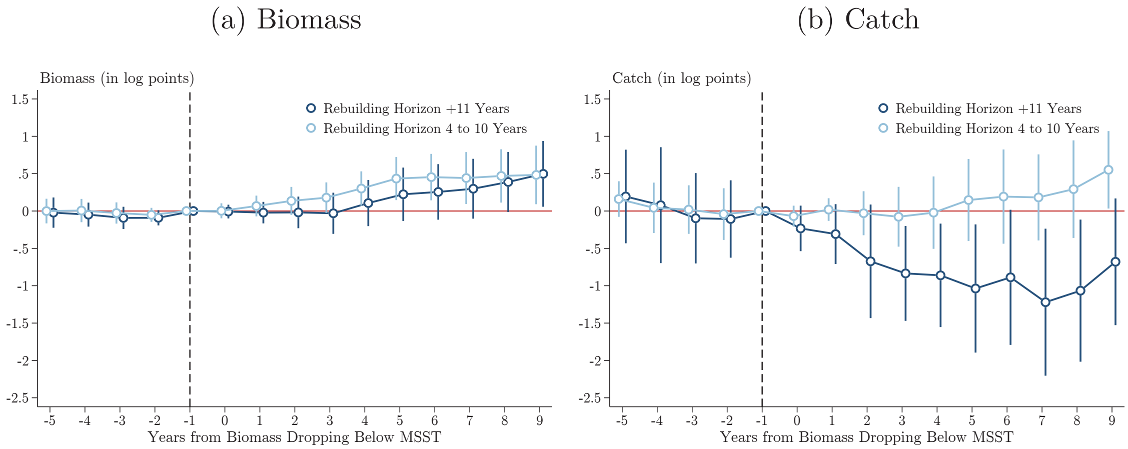
Fishing mortality, defined as the ratio of catch to biomass, measures stock utilization. A rebuilding plan reduces fishing mortality by lowering catch in the short term.

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 7). 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).

[19] 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.

[20] 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



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 falling below their MSST.

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.15 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.

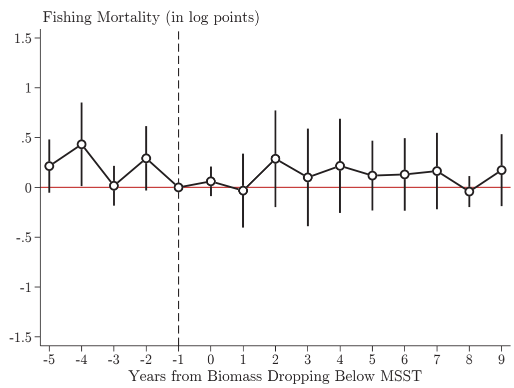
We find that in the post-1995 period, revenue was already declining before biomass fell below the MSST and continued to decline afterward (Figure 7a). During the same time period, prices also fell, failing to offset any declines in catch (Figure 7b). In the pre-1989 period, the pattern differs: prices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

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

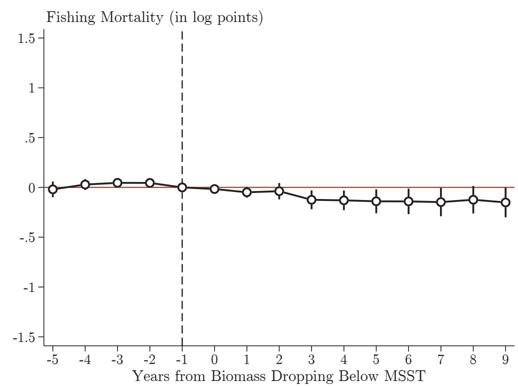
Including All US Stocks	Excluding New England Stocks

Contemporaneous Comparison, US to EU

(a)

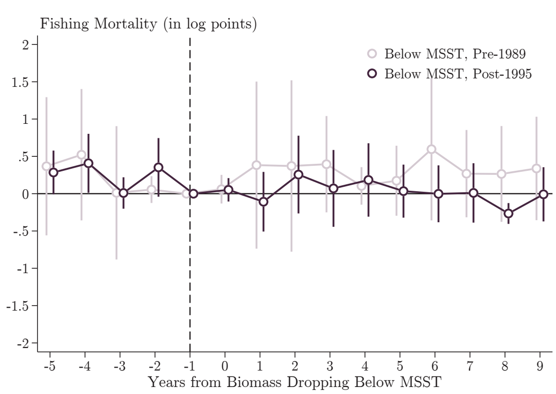


(b)

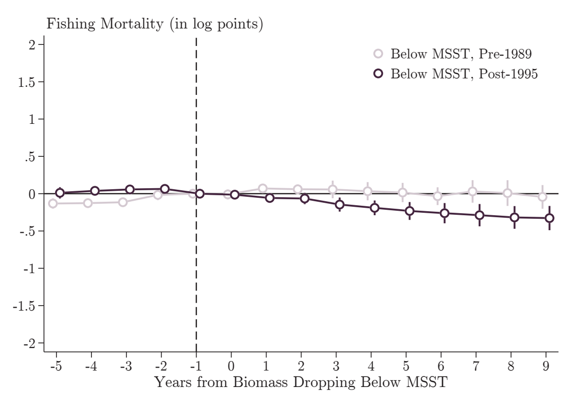


Historical Comparison, Present-US to Past-US

(c)



(d)

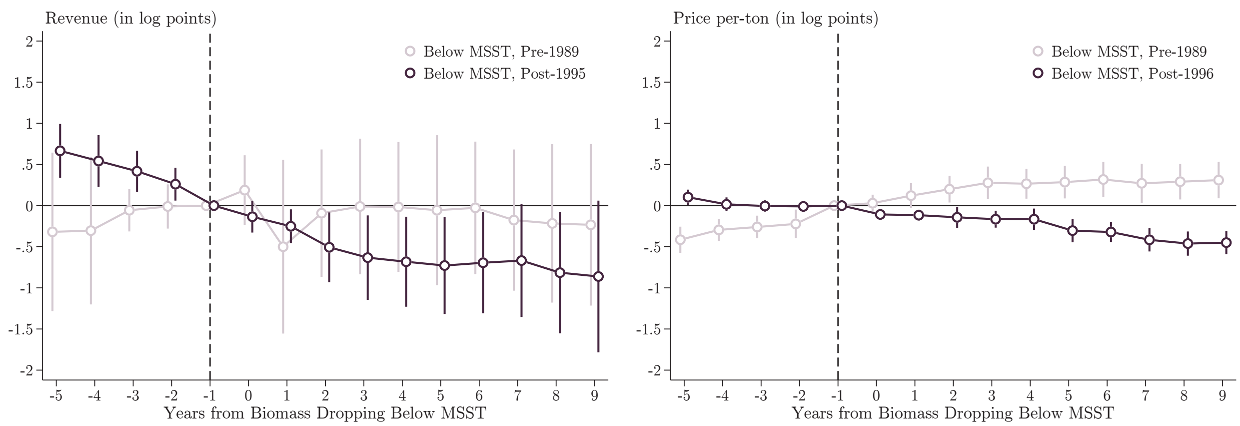


Notes: See Figure 3.

fell below the MSST. This allowed for revenue to remain relatively stable while catch was declining. In both periods, catch was declining in the years before biomass dropping below the MSST (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

(a) Revenue (b) Price



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.[21] For each rebuilt stock, we calculate the NPV from the time it dropped below its MSST up to 2016, capturing both short-term revenue losses and potential longer-term gains that may offset those declines.

To compare the observed NPV to the NPV without a policy, we develop three potential data-driven counterfactual revenue trajectories for each stock. First, we estimate the mean revenue growth rate from 1986 to the year the stock drops below its MSST. We choose 1986 instead of 1990 to allow for the revenue growth rate to be estimated using at least 10 years of data. Using the revenue growth rate, we fit either an exponential decay or logarithmic growth function to revenue from the time the stock dropped below its MSST. Second, we calculate the year-on-year changes in revenue from 1986 up to the year the stock dropped below its MSST. We use the mean and standard deviation of the historical volatility to

[21] Our sample is 27 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.

calibrate a normal distribution, and simulate how revenue would evolve. Third, we estimate a modified cohort-weighted DD specification on catch where we recover a full set of lags. We use the coefficients on how catch changes as a substitute for how revenue would have changed. This approach effectively holds prices constant, potentially exaggerating how much revenue would decline following the drop in the MSST. See Online Appendix **??** for more details on each approach.

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.[22] 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 1.2 (catch-based predictions). When weighted by revenue in the year a stock fell below its MSST, these values are 2.4, 1.97, and 1.3.[23] 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.

5.6 Results for Fisheries After Rebuilt Determination

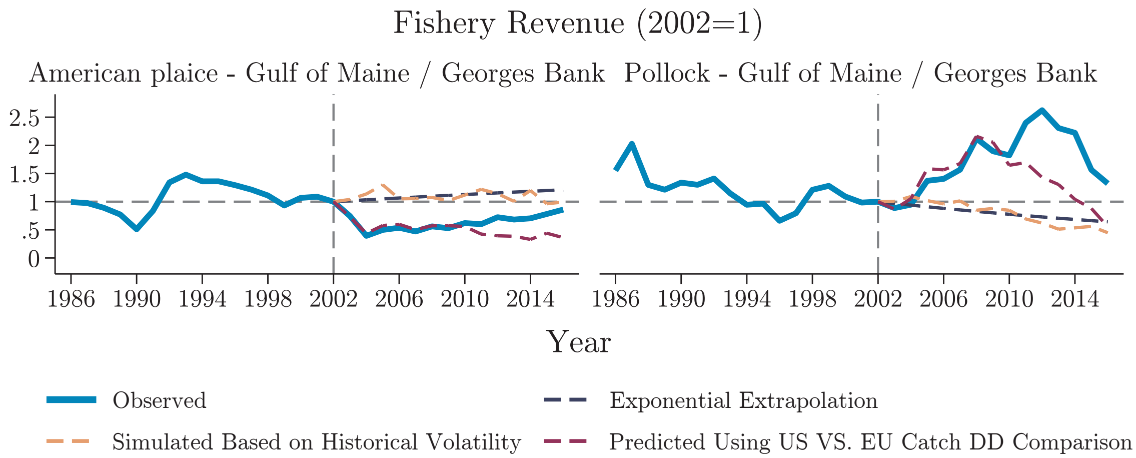
Rebuilding plans take 10 years, on average. A successful rebuilding will lead to the recovery of the stock, allowing managers to increase catch without jeopardizing the biomass gains.

[22] 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.

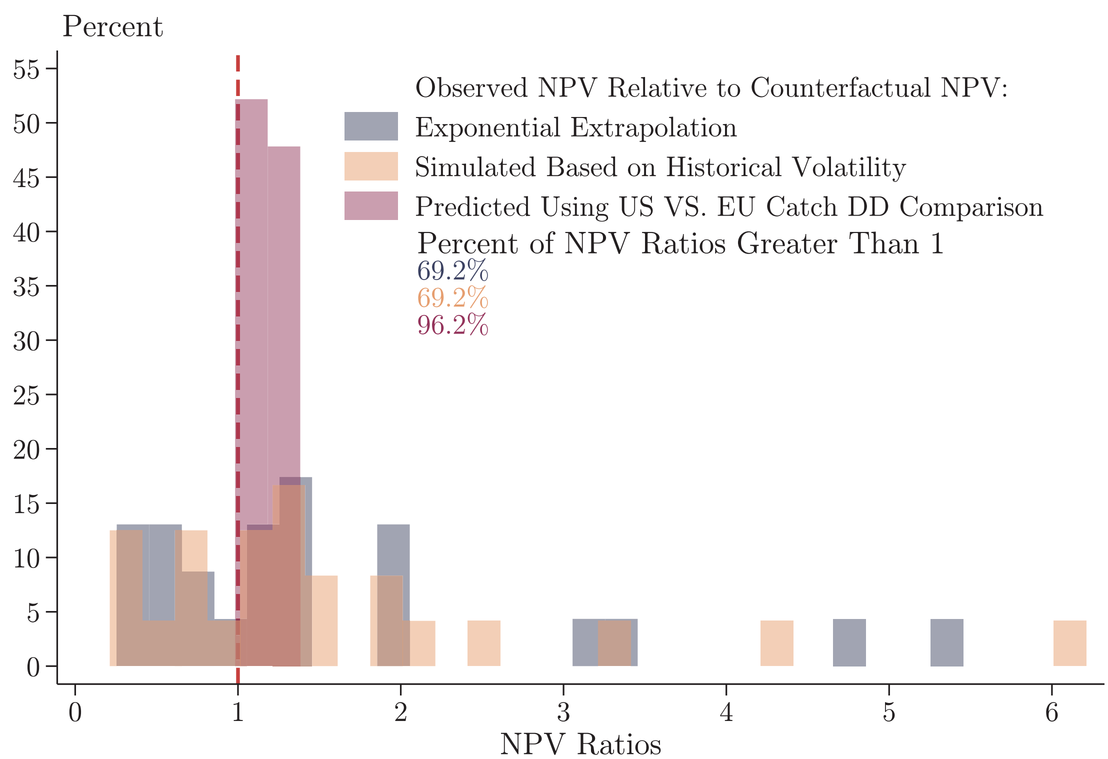
[23] Truncating at the 90th percentile yields unweighted means of 1.6, 1.6, and 1.2, and weighted means of 2.1, 1.8, and 1.2.

Figure 8: Revenue & Net Present Values for Rebuilt Fisheries

(a) Comparing Observed & Potential Counterfactual Revenue Trajectories



(b) NPV Ratios

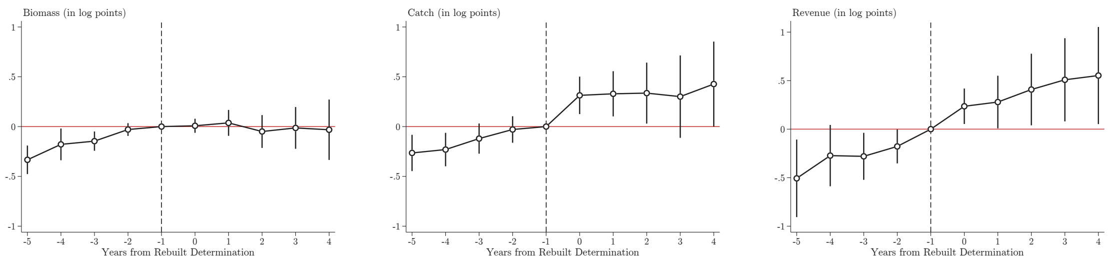


Notes: Panel (a) shows revenue trajectories for two stocks. Observed revenue (blue) is plotted for the full period, 1986 to 2016. Three counterfactual trajectories—extrapolated exponential growth, simulated using previous volatility, and catch-based predictions—approximate revenue without the policy after 2002, when each stock drops below their MSST. See Section 5.5 for more details. 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).

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 A15). 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 A16). 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 A17). 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 A18).

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.

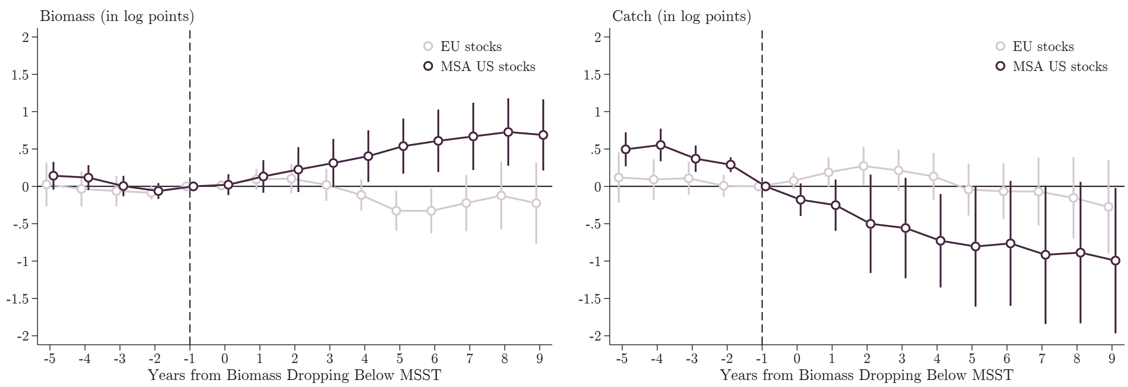
6.1 Ruling Out Leakage from the US to the EU

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.[24] 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 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

[24] 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.

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).

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

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

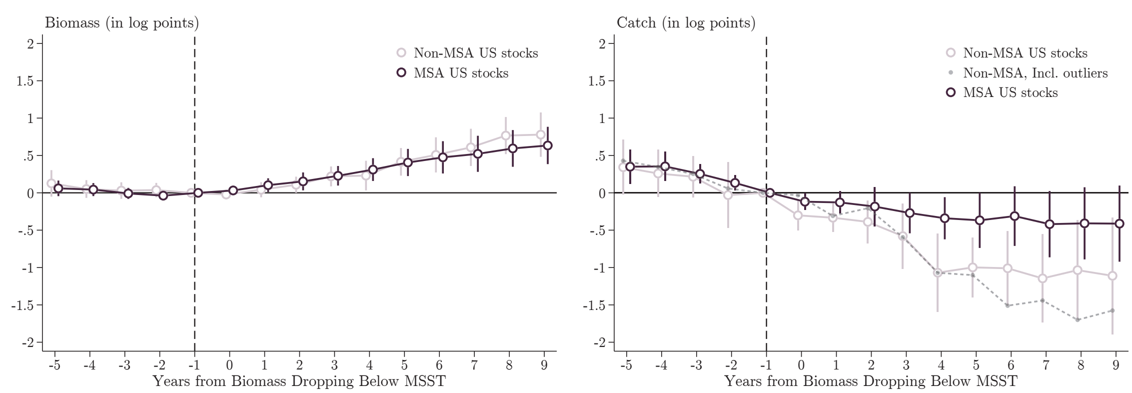
Notes: Estimation results from a specification of logged biommas, catch, or price on measures of MSA treatment intensity within a Fishery Management Council's (FMC) jurisdiction. In these regressions, the focus is on US stocks that do not have an MSA event (dropping below the MSST or entering rebuilding during the sample period. For each non-MSA-event stock, we estimate how it responds to more stocks in the taxonomic group of order experiecning 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 experiecning 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, 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 A12.

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.

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 A19. 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). 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 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 quasi-experimental variation in the degree of compliance, we can explore this channel descriptively. Figure 12 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.

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). Such buffers are implemented when there is uncertainty in population dynamics or in management's ability to enforce policy. Although some managers set no buffer (ACL = MSY), others apply one to every stock.[25] 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, essentially allowing for overfishing. 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).

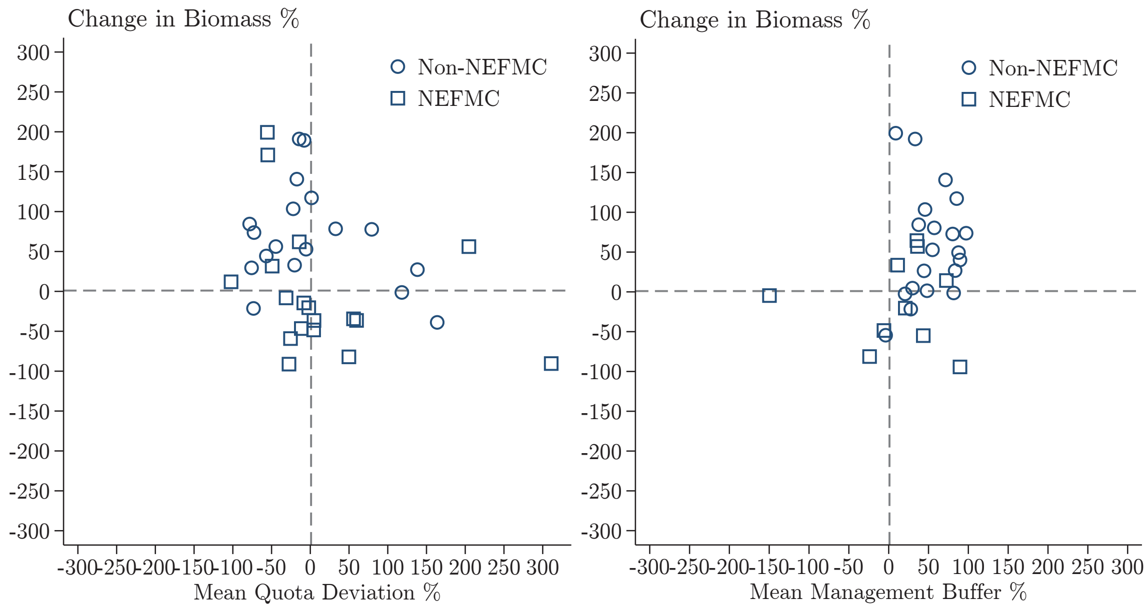
In Figure 13a, we show the proportion of stocks assigned an ACL from 2006 to 2016. The 2006 reauthorization of the MSA required FMCs to develop ACLs and accountability measures, which became mandatory starting in 2010. Because 2010 marks the point when ACLs became enforceable, we focus on stocks that had entered rebuilding by this year to examine how the mandate was applied to depleted fisheries. In 2006, more than 60 percent of stocks that ever 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 13b) and their proportion of overages fell by half (Figure 13c). Adherence to ACLs, however, varies across FMCs. Figure 13d 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. By contrast, in regions such as the North Pacific, Mid-Atlantic, Pacific, and Gulf of Mexico,

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

Figure 12: Change in Biomass Plotted Against Compliance & Precautionary Catch Limits

(a) Catch Deviations From Catch Limits (b) Precautionary Management Buffers



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).

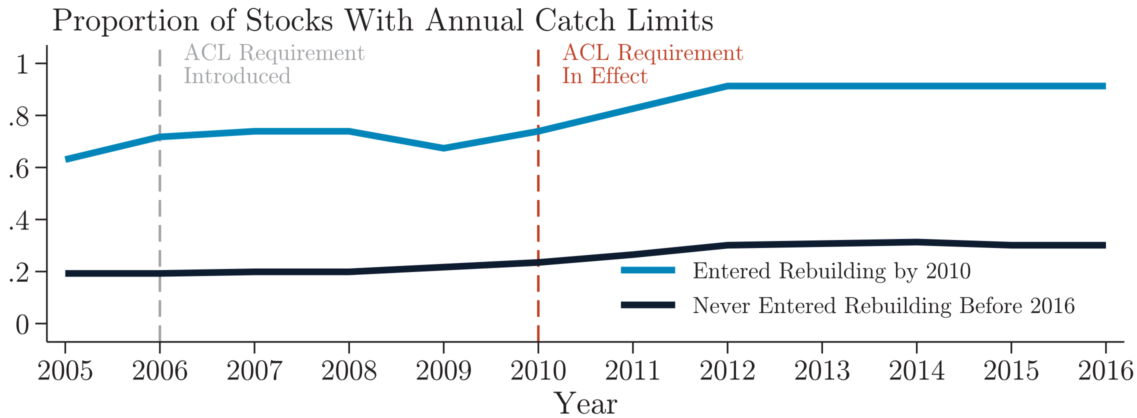
fewer than half of the overages occurred in stocks below their MSST or in rebuilding. This reflects regional challenges in New England with implementing and enforcing the MSA.

Another measure of compliance is how much catch declines after stock biomass falls below the MSST. Catch should drop quickly to align with the HCR (see Section 2). Figure 14a 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.

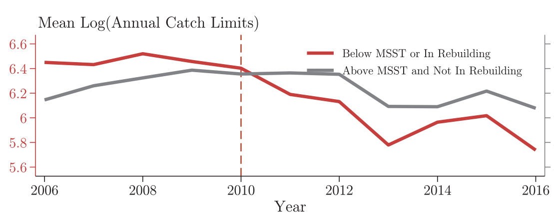
We test how biomass responds to stocks that enter treatment prior to 2000 (1995-1999) and after 2000 (2000-2004). Figure 14b plots a contemporaneous comparison, interacting event time with dummies for stocks whose biomass dropped below their MSST in 1995-1999 (earlier) or 2000-2004 (later). Biomass recovery is primarily driven by the later treatment

Figure 13: Descriptive Evidence on Targeting & Compliance

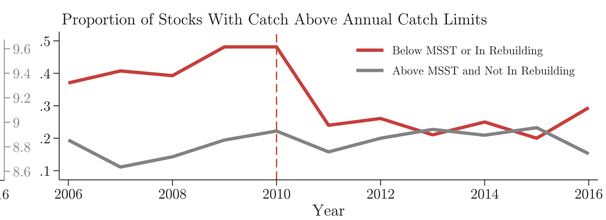
(a) Assigning Annual Catch Limits (ACL) Over Time



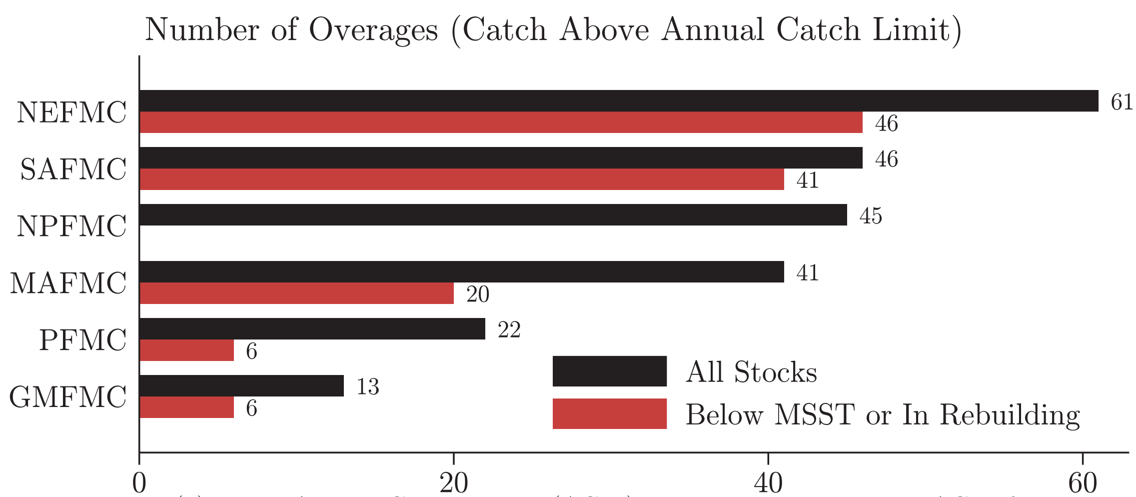
(b) Change in Mean ACL



(c) Change in Stocks Exceeding ACLs



(d) Overages by FMC

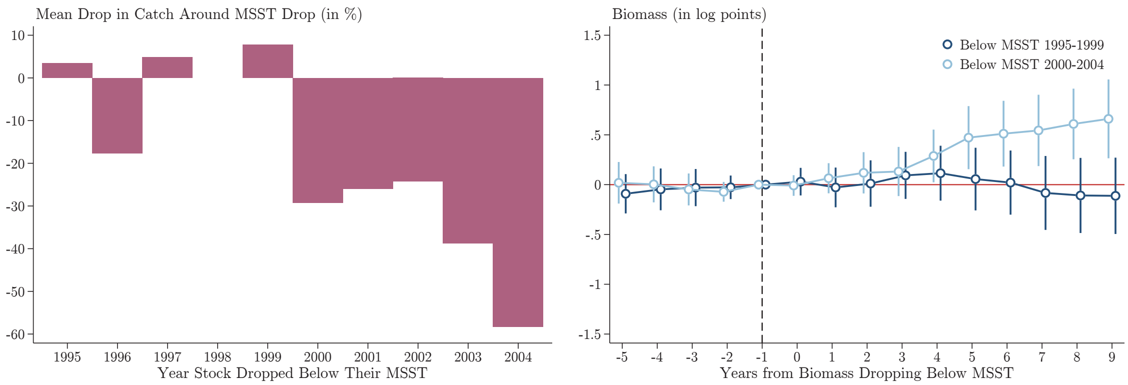


Notes: Panel (a), plots Annual Catch Limits (ACLs), showing an increase in ACLs from 2009-2012, especially for stocks in rebuilding. Panels (b) and (c) shows the mean ACL and overage decline for stocks below their MSST or in rebuilding. In Panel (d), we summarize the number of overages, by Fishery Management 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.

cohorts, which experienced large catch declines after falling below their MSST. 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.

Figure 14: 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.

8 Conclusions

Regulating open-access 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. 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. 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.

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