PNAS RESEARCH ARTICLE | SUSTAINABILITY SCIENCE OPEN ACCESS

Fisheries subsidies reform in China

Kaiwen Wang[a,1], Matthew N. Reimer[a,b], and James E. Wilen[a]

Edited by Catherine Kling, Cornell University, Ithaca, NY; received January 16, 2023; accepted May 24, 2023

Subsidies are widely criticized in fisheries management for promoting global fishing capacity growth and overharvesting. Scientists worldwide have thus called for a ban on "harmful" subsidies that artificially increase fishing profits, resulting in the recent agreement among members of the World Trade Organization to eliminate such subsidies. The argument for banning harmful subsidies relies on the assumption that fishing will be unprofitable after eliminating subsidies, incentivizing some fishermen to exit and others to refrain from entering. These arguments follow from open-access governance regimes where entry has driven profits to zero. Yet many modern-day fisheries are conducted under limited-access regimes that limit capacity and maintain economic profits, even without subsidies. In these settings, subsidy removal will reduce profits but perhaps without any discernable effect on capacity. Importantly, until now, there have been no empirical studies of subsidy reductions to inform us about their likely quantitative impacts. In this paper, we evaluate a policy reform that reduced fisheries subsidies in China. We find that China's subsidy reductions accelerated the rate at which fishermen retired their vessels, resulting in reduced fleet capacity, particularly among older and smaller vessels. Notably, the reduction of harmful subsidies was only partly responsible for reducing fleet capacity; an increase in vessel retirement subsidies was also a necessary driver of capacity reduction. Our study demonstrates that the efficacy of removing harmful subsidies depends on the policy environment in which removals occur.

fisheries subsidies | China | buyback program | sustainable fisheries

Fisheries worldwide have experienced a vast transformation in governance in the decades since the conclusion of the UN Convention on the Law of the Sea (LOS) negotiations in 1982. Many coastal nations have implemented management institutions and practices that have been instrumental in reversing overfishing and creating economic wealth (1–3). Indeed, most fisheries with strong management institutions and science-based stock assessments are currently rebuilding or harvested at sustainable levels (4, 5).

Despite these successes, several perceived threats to fisheries sustainability remain. Foremost among these threats is the widespread use of capacity-enhancing, or so-called "harmful," subsidies that artificially increase the profitability of fishing, putting undue pressure on fish stocks (6). By one estimate, approximately US$22 billion in harmful subsidies were distributed to fishers worldwide in 2018 (7), representing nearly 15% of global fisheries revenue (8). Empirical and theoretical evidence demonstrates that such subsidies lead to overcapacity, are inefficient, and, in the absence of sound biological controls, can result in overfishing (9–12). To make matters worse, harmful subsidies are also overly represented in fisheries with weaker management institutions that lack complete control over fishing pressure, thereby heightening the threat of overfished stocks (13). In response, scientists worldwide have called for a complete ban on all harmful fisheries subsidies (14), a plea that culminated in a partial ban being adopted recently among members of the World Trade Organization (15).

At the heart of this policy recommendation is the expectation that reducing harmful subsidies can be an effective instrument for promoting fisheries sustainability. But through which mechanisms would subsidy reductions improve fisheries sustainability? Any answer to this question must begin with the fact that fishing mortality ultimately depends upon fishing capacity and how intensively that capital is utilized. But capacity and utilization depend importantly upon the institutions governing fisheries. In open-access fisheries, capacity and utilization are unregulated and determined by profitability. Fishing capital enters and utilization intensifies until fishing mortality drives stocks to low levels with zero economic profits. In open-access settings, subsidies sustain otherwise unprofitable marginal vessels, arguably leading to higher capitalization, more intensive utilization, and lower stock levels. We thus expect that if subsidies could be enforceably eliminated in open-access settings, marginal vessels would experience economic losses, eventually exit, reduce fishing mortality, and result in higher equilibrium biomass levels (16).

Significance

To curb global fishing pressure and overharvesting, scientists worldwide have called for a ban on "harmful" fisheries subsidies that artificially increase the profitability of fishing. However, empirical evidence regarding the effectiveness of removing such subsidies for controlling fleet capacity is lacking. We evaluate a broad reform of fisheries subsidies in China, the world's largest seafood producer and provider of subsidies. We find that reducing harmful fuel subsidies and increasing beneficial vessel retirement subsidies had a significant impact on fleet capacity. But our study also underscores the importance of understanding how subsidies interact with other existing fisheries policy instruments if we wish to predict the potential effects of a global subsidy ban.

Author affiliations: [a]Department of Agricultural and Resource Economics, University of California, Davis, CA 95616; and [b]Department of Environmental Science and Policy, University of California, Davis, CA 95616

Author contributions: K.W., M.N.R., and J.E.W. designed research; K.W., M.N.R., and J.E.W. performed research; K.W. collected data; K.W. analyzed data; and K.W., M.N.R., and J.E.W. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission.

[1]To whom correspondence may be addressed. Email: kvnwang@ucdavis.edu.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2300688120/-/DCSupplemental.

Published June 20, 2023.

However, while this may be an apt description of the institutional conditions that led to fisheries becoming overcapitalized in the decades leading up to the 1982 LOS agreement (17), many, if not most, modern-day fisheries no longer operate under open-access institutions. Instead, coastal nation–states have instituted limits on capacity and its utilization to curb overfishing within their jurisdictions (18). For example, many fisheries utilize limited entry licensing to cap vessel capacity and/or additional controls like closed seasons, closed areas, and gear restrictions to regulate fishing intensity to achieve fishing mortality targets (19). Different governance systems thus aim to achieve sustainability in different ways across intensive margins (fishing intensity) and extensive margins (fishing capacity). If fisheries managers are adept at regulating the intensity of capacity utilization, it is possible to maintain biomass stocks at sustainable levels regardless of fleet size. In these cases, subsidy reductions might reduce fleet capacity, but regulators could then relax fishing intensity restrictions to leave fishing mortality unchanged (20). It is also well understood that limited entry fisheries can sustain positive economic profits, even if not fully efficient (21–23). In these cases, a subsidy reduction might simply eliminate some of these profits without generating incentives to exit and reduce capacity, regardless of actions by regulators.

It is, therefore, not obvious how harmful subsidy reductions might influence fisheries sustainability in modern-day governance systems that are highly heterogeneous and are no longer dominated by open-access institutions. Case studies are thus needed to examine mechanisms at work in many of these new governance settings. Unfortunately, there have been few instances of actual subsidy reductions since the LOS agreement took place to frame our understanding of how subsidy reductions might improve sustainability under modern governance institutions.

In this paper, we examine a recent fisheries policy reform in China that reduced harmful subsidies. This case study is important for the complexity of the policy context, the quality of the data, and the importance of China as a fishing nation–state. China is the world's largest seafood producer. Its rise to dominance began soon after the LOS negotiations concluded, as price controls on aquatic products were lifted and the Communist Party of China (CPC) promoted the full development of domestic and distant water fleets. Under new incentives to invest, the Chinese coastal marine fleet grew precipitously to 250,000 vessels, and domestic marine catch grew at almost 12% per year. By 1992, China had become the world's largest fishing nation (24). But as the decade of the 1990s came to a close, broad signs of overexploitation began to emerge, prompting an abrupt about-face in fisheries management objectives (24, 25). In 2000, the CPC announced a "negative growth" strategy, essentially signaling an end to the decade of rapid growth and development. Today, China remains the world's largest fish-producing nation, producing 15% of global catch (8) and prosecuted by the world's largest domestic marine capture fleet (26).

China is also the largest user of harmful fishing subsidies (27). The subsidies we investigate were conceived in 2006 to cushion the impact of rising diesel prices as China deregulated domestic fuel prices to conform to higher global prices. The complex system of fuel rebates began paying out subsidies that depended on a vessel's engine power, the type of gear used, and the global price of fuel each year. As diesel prices rose throughout the decade that followed, these fuel subsidies became important to fishing profits (28). During 2006–2014, the central government paid 148 billion RMB (23 billion USD) for fuel subsidies (29), amounting to one-fifth of the total value added by the marine capture industry (30, 31).

By 2014, Chinese fisheries managers found themselves juggling multiple objectives in the face of a large domestic fleet, declines in abundance of major target species, and fluctuating fuel and fish prices. As the CPC promoted the "Ecological Civilization" objective for the 2016–2020 5-y Plan, Chinese fisheries policymakers were compelled to confront the fact that subsidizing fuel conflicted with other new ecological goals, particularly those focused on reducing the fleet size and harmful gear use in the East China Sea fleet. As a result, in 2016, China implemented a wide-ranging fuel subsidy reform as part of its 13th 5-y Plan (24). The reform reduced subsidies broadly, committed to a gradual reduction over the upcoming 5-y period, and targeted specific harmful gear by enhancing incentives to exit. We take advantage of this policy reform and utilize the break from prereform subsidy levels as a quasi-experiment to examine the quantitative impact of subsidy reductions.

We investigate the impact of China's fisheries fuel subsidy reform on fleet capacity using a unique administrative dataset of trawl vessels in China's Zhejiang Province, the largest fishing fleet in the East China Sea. Our policy setting offers several advantages for understanding the potential impacts of harmful subsidy reductions. First, fuel subsidy reductions were allocated across vessels in a manner conducive to a quasi-experimental research design, allowing us to identify the reform's treatment effect on fleet capacity. Second, China's fuel subsidy reform took place within an institutional setting that embodies the complexity of the policy environments in which many future subsidy reforms are likely to take place. In particular, fuel subsidies were just one policy instrument among many others, including a cap-and-trade program for engine power, a buyback (or retirement subsidy) program to encourage exit and fleet capacity reduction, gear regulations, and open-season restrictions. As we show, these other elements conditioned the effect of fuel subsidy reductions in complex but understandable ways that provide insights into how banning harmful subsidies might work globally.

Fisheries Management and Subsidy Reform in China

In the early 1980s, the Ministry of Agriculture (MOA) instituted a vessel licensing system requiring vessels to be registered, inspected, and licensed to fish each year. The licensing system tracks vessel power, measured by kilowatts (kW) of engine power, as well as gear fished and vessel attributes. This facilitated management by a "dual control" system whereby the MOA could set local county/provincial targets for vessel numbers and aggregate fleet engine power in order to bring fleet capacity and biological productivity into balance. The licensing system essentially created a cap-and-trade program in engine power whereby new vessels could only be constructed by acquiring power quota from fishers exiting the fleet and scrapping their vessels (32).

In the early 2000s, local leaders were directed to reduce vessel numbers and fleet power, reduce catch targets, and implement input controls such as a summer moratorium on fishing (25). Fleet reduction was facilitated with a vessel buyback system introduced in 2002, which served as a vessel retirement subsidy program by providing compensation to fishers willing to exit and surrender their engine power quota, in addition to retraining funds designed to help transition to other nonfishing occupations.

The Fuel Subsidy Program: 2006–2015. As oil prices surged in the early 2000s, the CPC concluded that China could no longer afford to insulate its economy from international markets to stimulate development with low-priced fossil fuel energy. In 2006, the CPC lifted domestic fuel price controls in order to expose the Chinese economy to global fuel prices. Officials were aware that shocks in fuel prices could cause political instability and hence initiated a fuel subsidy plan to ease the transition in the agriculture, public transportation, and fishing sectors (29).

In the fishing sector, managers conducted surveys to determine vessel fuel consumption by gear type, engine power, and annual average operation time. These were used to compute average fuel consumption "subsidy coefficients," measured in metric tons (MT) of fuel per kW of engine power, for each type of fishing gear. The MOA then formalized a national standard for fuel subsidies in 2009 (33), where annual lump-sum payments for each legally licensed vessel were computed as

$$\begin{aligned}\text{Subsidy} = &\ \text{fuel price standard (RMB/MT)} \\ &\times \text{engine power (kW)} \\ &\times \text{subsidy coefficient (MT/kW)},\end{aligned}$$

where the fuel price standard was adjusted annually to reflect global diesel prices. All vessels of the same gear type thus received the same subsidy amount for each kW of engine power in any given year (Fig. 2). In the face of declining biomass and abundance, the declining market value of catch, and tighter restrictions on the fishing season, these fuel subsidies soon became an important component of fishing revenues, particularly for less efficient vessels (34).

The fuel subsidy program achieved its primary intended goal, which was to ease the transition to global fuel prices and minimize political fallout from price shocks (28). Nevertheless, subsidizing fuel costs conflicted with other management goals, particularly those associated with reducing fleet capacity to bring catch into balance with biological productivity (28, 35). The mechanisms by which fleet reduction goals were compromised were subtle and intricate. For instance, the licensing system capped aggregate fleet engine power and required power-for-power quota transfers for new vessel construction. Prior to the introduction of fuel subsidies, the market price of engine power quota transfers was below the buyback price of engine power, and hence, some exiting fishermen chose to surrender their quota through the buyback program rather than sell to a new entrant (Fig. 1*A*). But as fuel subsidies were introduced, engine power quota prices rose to reflect the capitalized value of anticipated future payments (36). For example, in 2006, reported quota prices for trawlers were around 600 RMB/kW. But by 2014, they had increased to 8,000 to 10,000 RMB/kW, reflecting the present value of the flow of future subsidy payments for the average trawler (*SI Appendix*, Table 2). The value of subsidies thus became embedded in quota transfer prices, causing transfer prices to exceed the buyback price (Fig. 1*B*). This, in turn, choked off incentives for exiting fishermen to surrender their quota to the buyback program. Indeed, during the 4 y leading up to the fuel subsidy reform, no vessels in our sample surrendered their engine power quota to the buyback program (Table 1).

The Fuel Subsidy Program: 2016–2020. In 2016, the MOA implemented a nationwide reform to its fuel subsidy program, in part due to the CPC's embrace of marine ecosystem protection in its new agenda for "Ecological Civilization" (25) as well as intense international pressure to reform its fisheries subsidies out of overfishing concerns (27, 37). Reforms to the fuel subsidy program were designed to address several issues that compromised capacity reduction and resource conservation objectives, including the following: i) Fuel subsidies propped up revenues of marginal fishermen, incentivizing them to remain in the fleet; ii) fuel subsidies became capitalized into power quota prices, inhibiting the effectiveness of the buyback program; and iii) fuel subsidies kept ecologically harmful gear types (e.g., trawlers) in the fishery, impeding rebuilding plans (38).

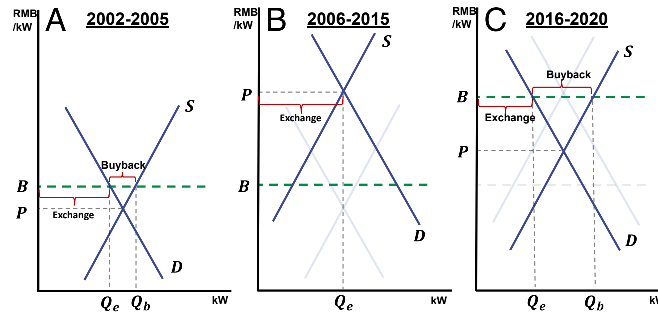

Fig. 1. The cap-and-trade market for engine power quota under different fuel subsidy policy regimes. With no buyback subsidy, the equilibrium price (*P*) and exchange of quota (Q_e) are determined by the intersection of the demand (*D*) and supply (*S*) curves (*SI Appendix*). Before the fuel subsidy program (Panel *A*), capacity reduction was achieved through a buyback subsidy. By setting the buyback price (*B*) above *P*, some vessel owners retired their quota, resulting in capacity reduction of $Q_b - Q_e$. With fuel subsidies (Panel *B*), engine power quota became more lucrative, shifting the quota demand and supply curves up and pushing the equilibrium price above the buyback price. Capacity reduction was thereby choked off. Reform of the fuel subsidy program (Panel C) regained capacity reduction by reducing fuel subsidy payments and raising the buyback price above the new equilibrium quota price.

In contrast to its original design, the reformed fuel subsidy program decoupled subsidy payments from fuel costs. Rather than basing subsidy coefficients on estimated annual fuel consumption, the coefficients were revised to reflect fishery managers' judgments about the ecological harm done by each gear type, so that fishing operations regarded as ecologically harmful were assigned lower subsidy coefficients. In addition, subsidies were no longer determined by a vessel's registered engine power; instead, vessels were assigned to vessel classifications based on their fishing gear and length, and the average engine power of a vessel class was used as the basis for fuel subsidy payments. Finally, rather than adjusting the fuel subsidy standard to reflect prevailing diesel prices, it was set to the 2014 fuel price standard and then further reduced by 18% annually so that subsidy payments would be decreased by 60% by the end of the 5-y Plan (39).

In addition to revising fuel subsidy payments, the MOA made two other complementary reforms to promote its capacity reduction and resource conservation objectives. First, the MOA announced that new construction of vessels using ecologically harmful gears, such as double-otter trawlers, would be prohibited in 2017 (the ban was expanded to general trawl vessels in 2019) (32, 40). Second, the MOA enhanced the buyback program by raising buyback prices from 2,500 to 5,000 RMB/kW, made possible by diverting the savings from reforming fuel subsidies into the buyback program. Further, the province of Zhejiang added 2,500 RMB/KW to the buyback price to meet its own target of reducing its fleet size by 2,580 fishing vessels by 2020 (41).

Table 1. Fleet and fishery dynamics for trawling vessels in China's Zhejiang Province

Year	Fleet size (No.)*	Avg. power (kW)	Vessel exits (No.)	Vessel buybacks (No.)	Vessels constructed (No.)	Fuel subsidy (RMB/kW)†	Fuel price (RMB/MT)	Buyback price (RMB/kW)	CPUE (MT/kW)‡
2012	7646	262	247	0	208	1681	7765	2500	0.90
2013	7613	267	439	0	406	1831	7651	2500	0.89
2014	7533	271	386	0	306	1774	7315	2500	0.94
2015	7515	272	113	0	95	1608	5706	2500	0.99
2016	7252	275	357	182	94	1148	5380	7500	1.01
2017	6506	280	808	585	62	950	6195	7500	1.02
2018	6151	284	467	148	112	786	7455	7000	0.93
2019	5860	287	338	165	47	645	6924	7000	0.92

*Fleet capacity dynamics are summarized from the sample of large trawlers compiled from the Zhejiang fishing vessel management system, where fleet size is measured at the end of the year. Statistics of the postreform period are shaded.

†Fuel subsidy is calculated as the annual average payments per power.

‡Catch per unit effort (CPUE) is calculated from the aggregated statistics for trawling fisheries in Zhejiang, reported by the ChinanFisheries Yearbook.

The reformed fuel subsidy program had immediate implications for fishermen, particularly those experiencing sharp reductions in subsidy coefficients associated with vessel operations classified as being harmful (e.g., trawlers). Indeed, fuel subsidy payments decreased dramatically in the first year of the reform and continued to decrease thereafter as the fuel subsidy standard was adjusted downward annually (Fig. 2). In turn, the reduction of expected future fuel subsidy payments brought about decreases in quota prices for engine power (Fig. 1*C* and *SI Appendix*, Table S2). Together with the revised buyback prices, surrendering engine power quota through the buyback program began to look more attractive to fishers (42).

The reformed fuel subsidy program also has important implications for our research design. As discussed, reformed fuel subsidy payments were based on vessel classes determined by vessel-length thresholds. For example, vessels just below the 30-m threshold received fuel subsidy payments that were approximately 25% lower than vessels just above the 30-m threshold in the postreform years, despite receiving nearly the same fuel subsidy payments in the prereform years (Fig. 3). Such sharp local discontinuities yield quasi-experimental variation in the assignment of fuel subsidy reductions across vessels, which we use to identify changes in vessel-exiting decisions that are solely attributable to the reform itself.

Results

To evaluate the impact of China's fuel subsidy reform, we assemble a vessel-level longitudinal database of nearly all large trawlers (≥24 m) registered in 2011 (7,685 vessels) in China's Zhejiang Province, the largest fishing fleet in the East China Sea (44). The database includes information on a vessel's age, length, tonnage, and engine power. Most importantly, we are able to determine whether a vessel exits the fishery in any year, either retired through the buyback program or acquired through the engine power quota market. We supplement these vessel registry databases with county-level data on fuel subsidy payment records.

A before-and-after comparison of vessel activity suggests that vessel exit and construction decisions were substantively affected by the reformed fuel subsidy program (Table 1). In the 4 y following the reform, the number of large trawling vessels in the Zhejiang Province decreased by 22%, compared to 2% in the 4 y before the reform. The decrease in the number of vessels was due to both an increase in the number of vessels exiting the fishery—the annual exit rate increased from 3.9% in the prereform years to 7.1% in the postreform years—and a decrease in the number of new vessels being constructed. Most notably, 54% of the vessels that exited the fishery in the postreform years surrendered their

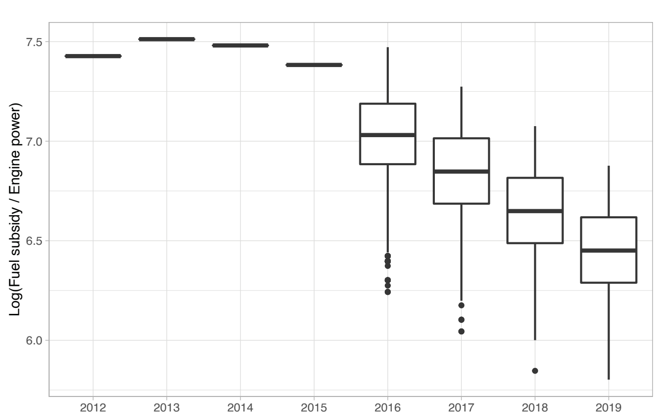

Fig. 2. Fuel subsidy payments per kW of engine power for all large trawling vessels (≥24 m) in the Province of Zhejiang. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers extend to 1.5 times the interquartile range (IQR).

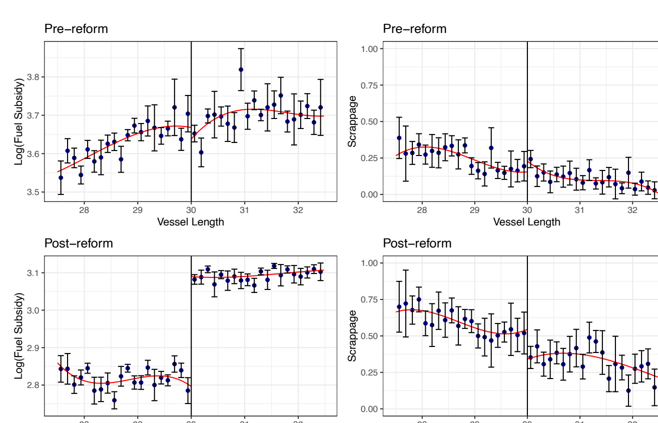

Fig. 3. Average fuel subsidies (*Left*) and vessel exit rates (*Right*) as a function of vessel length (meters), before (*Top*) and after (*Bottom*) the fuel subsidy reform. The vertical line denotes the vessel-length threshold for determining vessel classes. Blue dots denote sample means in evenly spaced bins of vessel length with 95% CI (43). Red lines are fitted by cubic regressions on either side of the threshold.

engine power quota through the buyback program, a considerable increase over 0% in the 4 y preceding the fuel subsidy reform.

While such statistics are revealing, they do not distinguish changes in vessel-exiting patterns stemming from other factors that may coincide with the reform (e.g., fish and input prices, fishing conditions, etc.). To control for such factors, we estimate the relationship between fuel subsidy reductions and the hazard rate of exiting the fishery using two quasi-experimental approaches. First, we use a continuous-treatment difference-in-differences (DD) design based on the reform's differential treatment of fuel subsidy reductions across all vessels. Second, we use a regression discontinuity difference-in-differences (RD-DD) design that focuses on a discontinuity in fuel subsidy reductions created by assigning vessels to discrete classes in the postreform years. Both approaches estimate the marginal effect of a persistent reduction in fuel subsidies brought about by the reform on a vessel's probability of exiting the fishery in any given year; however, the DD design utilizes variation in fuel subsidy reductions across all vessel classes while the RD-DD design only utilizes local variation around a particular vessel-length threshold (30 m).

Using the DD approach, we find that a one-percent reform-induced reduction in a vessel's annual fuel subsidy is associated with a 0.153-percentage-point increase in the probability of exiting the fishery on an annual basis, or a 0.350-percentage-point increase in the probability of exiting the fishery anytime during the postreform period (Table 2). Given that the reform was responsible for decreasing average annual fuel subsidies by 20.6% (*SI Appendix*, Table S6), this equates to increasing the probability of exiting the fishery during the postreform years by 7.2 percentage points, which is approximately one-and-a-half times the observed exiting rate during the prereform period. The marginal effect of fuel subsidy reductions on the annual rate of exit is relatively constant and persistent during the postreform years after the initial transition period in 2016: The percentage-point increase in the annual exit rate associated with a one-percent lower annual subsidy payment is around 0.20 in the years proceeding the reform (Fig. 4).

Our RD-DD approach confirms the effect of fuel subsidy reductions on vessel exit decisions. Before the reform, fuel subsidy payments were smoothly allocated to vessels across vessel length, with no discontinuities at the postreform 30-m vessel-length threshold; accordingly, there was no difference in the probability of exiting on either side of the threshold (Fig. 3). In contrast, the difference in fuel subsidy payments at the vessel-length threshold in the postreform years corresponds to a significant difference in the probability of exiting on either side of the threshold. Combining the discontinuity in fuel subsidy payments

Table 2. Average treatment effect of a one-percent fuel subsidy reduction on vessel exit and buyback probabilities

	Exit		Buyback	
	Annual (1)	Quadrennial (2)	Annual (3)	Quadrennial (4)
Fuel Subsidy Reduction	0.153*** (0.0185)	0.350*** (0.0408)	0.0651*** (0.0140)	0.156*** (0.0350)
Mean of Y (%)	6.10	22.2	2.07	7.51
R^2	0.168	0.509	0.136	0.303
Observations	50,984	14,016	50,984	14,016

SEs in parentheses. *P<0.05, **P<0.01, ***P<0.001.

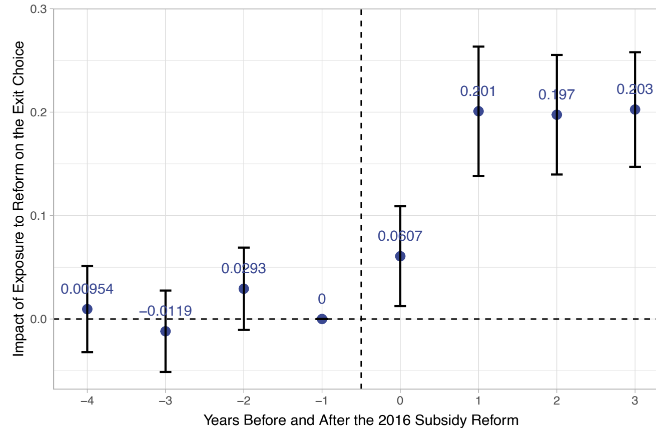

Fig. 4. Annual marginal treatment effects of a one-percent reduction in fuel subsidy payments on the probability of exiting, relative to the baseline year 2015. Estimates from the difference-in-differences model with 95% CI.

with the discontinuity in vessel exit rates at the vessel-length threshold, we find that a one-percent reduction in fuel subsidy payments is associated with a 0.158 percentage-point increase in the probability of exiting on an annual basis (*SI Appendix*, Table S4), which is virtually identical to our estimate using the DD approach.

The subsidy reform significantly increased the rate at which vessels exited the fishery. But an exiting vessel can either be retired through the buyback program or purchased for its engine power quota, which is then transferred to a new vessel. Fleet capacity is thus only reduced by exit through the buyback program as the engine power quota associated with retired vessels is removed from the aggregate supply of quota. Determining the effect of the subsidy reform on fleet capacity, therefore, requires us to distinguish between these two forms of exit. We find that nearly half of the reform's effect on vessel exit rates is driven by vessels retiring through the buyback program: A one-percent reform-induced reduction in a vessel's annual fuel subsidy is associated with a 0.065-percentage-point increase in the annual probability of participating in the buyback program or a 0.156-percentage-point increase in the probability of a buyback anytime during the postreform period (Table 2). The reform induced some vessels to retire their vessels through the buyback program since the postreform buyback price of 7,500 RMB/kW was above the prevailing postreform market price of engine power quota, which various estimates place at 6,000 to 9,000 RMB/kW (*SI Appendix*, Table S2). The subsidy reform, therefore, induced a decrease in the aggregate supply of engine power available to the fishery.

To explore the exit decisions of heterogeneous fishermen in response to the subsidy reform, we allow the marginal effects on exit and buyback rates from our DD design to vary over observed vessel characteristics, such as vessel size, vintage, engine power, and gear type. We find that the subsidy reform had a meaningful impact on the structure of the fleet. For a constant percentage reduction in fuel subsidy payments, double-otter trawlers were more likely to exit the fishery in the postreform years relative to single-otter and beam trawlers (Fig. 5). Given that they also received the largest reduction in payments under the reformed fuel subsidy program, exiting double-otter trawl vessels were disproportionately responsible for the overall increase in vessel-exiting rates. We also find that smaller and older vessels were more responsive to the reduced fuel subsidy payments than larger and newer vessels, which experienced negligible impacts from the reform. This heterogeneity is echoed in the marginal effects of

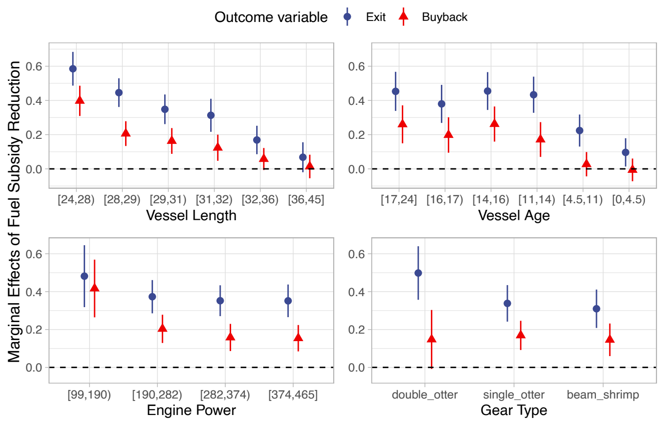

Fig. 5. Estimates of heterogeneous treatment effects of a one-percent fuel subsidy reduction on quadrennial postreform exit and buyback probabilities across quantiles or categories of vessel characteristics with 95% CI, where vessel length (m) and vessel age (in 2012) are grouped into six quantiles, and engine power (kW) is grouped into 90-kW intervals.

subsidy reductions for buyback decisions. Notably, smaller and older exiting vessels were more likely to surrender their engine power quota through the buyback program than larger and newer vessels. Altogether, the fuel subsidy reform led to an acceleration of exit and buyback rates in smaller and older vessels, thereby shifting the structure of the remaining fleet to newer and bigger trawling vessels.

The subsidy reform simultaneously decreased fuel subsidy payments to fishermen and increased the buyback price offered for retiring vessels. Using a model of the cap-and-trade market for engine power quota and estimates from our DD model, we decompose the separate contributions of each reform to the total impact on fleet capacity by considering several counterfactual scenarios in which each reform is implemented in isolation (*SI Appendix*, Fig. S3). We find that raising the buyback price was instrumental in reducing fleet capacity. Indeed, raising the buyback price alone would have resulted in 4-y exit and buyback rates of 19.4% and 9.7% in the postreform years, respectively, compared to 15.4% and 0% in the prereform years (*SI Appendix*, Table S6). Increasing the buyback price alone would have induced additional vessels to exit and converted would-be exiters to retire their quota through the buyback program since the postreform buyback price of 7,500 RMB/kW would have been above the counterfactual market price of engine power quota, which we estimate to be between 4,000 and 7,000 RMB/kW (*SI Appendix*). We find that of the 1,080 vessels (249 MW of engine power quota) retired in the postreform period, 640 vessels (127 MW quota) would have been retired if buyback prices alone had increased, suggesting that the remaining 440 vessels (122 MW quota) were induced to retire because of fuel subsidy reductions.

Discussion

A synthesis of the marine science literature would suggest that eliminating harmful fishing subsidies is the foremost solution to addressing threats to fisheries sustainability. While there is logic behind this suggestion, a difficulty is that there have been very few cases where subsidies have actually been reduced and virtually no empirical studies that unravel how removing subsidies impacts fisheries. In this paper, we utilize a unique dataset and natural experiment where subsidies were actually reduced to estimate how subsidy reductions affected the trawl fleet in China's Zhejiang province. Our study suggests that the relationship between subsidies and sustainable fisheries is nuanced rather than simple and that the elimination of subsidies should be viewed within the institutional and regulatory context at hand rather than viewed as a panacea for fisheries sustainability challenges worldwide (45).

Our main empirical results show that reducing subsidies increases the probability that a given vessel owner will decide to exit the fishery, particularly for owners of smaller and older vessels. This result is consistent with economic theory and suggests that the economic profits of marginal fishermen were largely composed of fuel subsidy payments, as indicated by a survey of trawling vessel owners (34). The decision to exit fishing, however, is only the first part of the mechanism leading to fleet capacity reductions. In a limited entry fishery, like our example in China, whether an exit decision ultimately leads to reduced fleet size depends on the existence of institutional design features that deny exiting fishing capital from reentering the fishery. For example, one design feature of a limited entry program that would translate exit decisions immediately into fleet reduction would be a design that mandated retiring fishermen to fully surrender their quota upon exit. This was not done when Chinese management authorities set up the limited-entry licensing scheme in the early 1980s. Instead, China followed the precedent of most other limited entry programs by licensing vessels and engine power on each vessel and then allowing that licensed power quota to be bought and sold by entrants and exiters, respectively. In such a regulatory setting, it is important to realize that there will be no change in fleet capacity when subsidies are reduced without some other institutional design features that purposefully and permanently retire quota from exiters.

In the case we examine here, the specific institutional design feature that ultimately fostered fleet reduction was a buyback program. The buyback program was introduced by Chinese authorities not to reduce fleet capacity per se but to ease the transition of the thousands of fishermen removed from foreign fishing grounds as part of the renegotiation of marine boundaries associated with LOS. But as managers reversed the growth focus of the 1980s and implemented negative growth targets, fleet capacity reduction became possible by reinvoking and enhancing the vessel buyback program. This was made possible by diverting the savings from reduced fuel subsidies into the buyback program, essentially repurposing the subsidies to incentivize vessel exit while aiding fishermen in transitioning to nonfishing occupations. In doing so, Chinese authorities not only enabled a mechanism for reducing fleet capacity but also addressed one of the largest hurdles to subsidy reforms, namely the short-run cost imposed on fishermen from reducing subsidy payments (13).

In our natural experiment, the simultaneous reduction in fuel subsidies and increase in buyback prices led to an increase in the exit rate of vessels. During the four prereform years, approximately 15% of the fishermen in our sample exited by selling their power quota to new entrants. During the four postreform years, the exit rate increased to approximately 30%, and most of the increase in the exit rate went into the buyback program. Changes in both fuel subsidies and the buyback price played roles in motivating the observed reduction in fleet capacity: The former decreased the annual returns to owning a vessel and the market value of engine power quota, while the latter increased the opportunity cost of not retiring a vessel. The contribution of each of these changes to fleet capacity reduction is confirmed by our counterfactual estimates, suggesting that reducing fuel subsidies has the potential to induce vessel owners to leave fishing, as proponents expect.

But perhaps the more important observation is that vessel exit decisions would not have likely translated into fleet capacity reduction without the buyback program. Indeed, even with the buyback program in place, if buyback prices had remained at their prereform level, there would have likely been no postreform capacity reduction. This is because prereform buyback prices (2,500 RMB/kW) were below the postreform power-quota prices that would have likely existed if only the fuel subsidies had been reduced (3,000 to 6,000 RMB/kW, *SI Appendix*). Under these circumstances, if buyback prices had not been raised to 7,500 RMB/kW, exiting vessels would have preferred selling their power quota on the market to potential entrants rather than surrendering it to authorities through the buyback program. This is important because it implies that subsidy reductions alone do not guarantee capacity reduction.

Our analysis demonstrates that China's reform of its fuel subsidy program reduced fleet capacity. But such reforms are only a first step toward sustainable fisheries. The end goal of subsidy removal is surely to reduce fishing mortality in overharvested fisheries. But as argued above, fleet capacity is only one of many factors determining fishing mortality, such as capacity utilization and the technical efficiency of vessels. If the desire is to rebuild fisheries and/or hold them at sustainable levels, managers must either control fishing mortality directly (e.g., through a total allowable catch and enforced individual quotas) or regulate capacity utilization. Indeed, a cross-country empirical investigation found no effect of fisheries subsidies on the status of fish stocks in countries with individual quota-based fisheries management systems, which often have rigorous monitoring and enforcement requirements for controlling fishing mortality (10).

Whether reduced fleet capacity from China's reformed fuel subsidy program translates into improved fisheries sustainability is an open question and an important area of future research. On the one hand, conservation gains from reduced fleet capacity could be eroded by increased capacity utilization and/or the transition to a fleet of newer, bigger, and more technically efficient vessels. On the other hand, prohibiting the construction of vessels with trawling gear, which tend to be more productive and indiscriminate in their harvests (46), could result in a fleet of vessels with lower CPUE harvesting technology and drastically different catch compositions of species. All of this must also be considered within the historical context of China's persistent high fishery catches, despite the perception of overfishing for decades (47, 48).

As the preceding discussion demonstrates, subsidy removals and buyback programs can be effective tools for fleet capacity reduction, provided they are tailored to the policy context at hand. However, they should not be viewed as long-term solutions to sustainability challenges for fisheries. Simply reducing fleet capacity does not address the underlying incentives of remaining vessel owners to overinvest in unregulated dimensions of the harvesting production process (20, 49–51). At best, subsidy removal should be viewed as a short-term aid for transitioning to a more sustainable governance system that addresses the root cause of overfishing rather than the symptoms. It remains to be seen how the management of China's postreform fisheries will evolve and how complementary policies will foster the "ecological economy" goals of a sustainable fishery.

Materials and Methods

Data. Individual-level information on fishing vessels primarily comes from the records of the Marine Fishing Vessel Dynamic Management System provided by the Zhejiang government. This administrative platform comprises five modules corresponding to each section of the vessel management activities: engine power quota, vessel name, vessel inspection, vessel registration, and fishing license. Each module is responsible for documenting the acquisition and cancelation of respective certificates for fishing vessels in the double-control system. We compile a dataset for all exiting vessels in the archives, identify the time at which each vessel exited, and identify each vessel who exited through the buyback program. With construction and exit time identified for each trawler in our compiled dataset, we can recover the dynamic fleet capacity of trawlers in the Zhejiang Province. Fuel subsidy payment records are available through public county-level databases. More details on the assembly of our dataset can be found in *SI Appendix*.

Baseline Empirical Model. We use a difference-in-differences (DD) design with a continuous treatment to measure the exit (or buyback) elasticity with respect to fuel subsidy reductions for all vessels. We model the decision to exit (or buyback) using the following linear transition probability model:

$$y_{it} = \beta \Delta_i I_t + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t \mathbf{X}_i + u_{it}, \quad [1]$$

where y_{it} is a binary variable indicating whether vessel i exited (or participated in the buyback program) in year t, c_i and γ_t are fixed effects for vessels and years, respectively, $\lambda_{a_{it}}$ captures the baseline hazard at age a_{it}, and u_{it} is the idiosyncratic component of the exit (buyback) decision. The variable $I_t = \mathbf{1}\{t \geq 2016\}$ indicates the postreform period. The linear transition probability model in Eq. **1** is motivated as a linear approximation of the discrete-time conditional hazard function for a duration model of vessel life (*SI Appendix*). We supplement the DD model with a regression-discontinuity difference-in-differences (RD-DD) approach, which directly exploits the variation in fuel subsidy payments created by the vessel-length thresholds in the postreform years. The details of this approach are discussed in *SI Appendix*.

Our treatment variable Δ_i is defined as the reduction rate in the average annual postreform fuel subsidy relative to the prereform period for vessel i:

$$\Delta_i = \log\left(\frac{\bar{s}_i^{pre}}{\bar{s}_i^{post}}\right), \quad [2]$$

where $\bar{s}_i^{pre}$ and $\bar{s}_i^{post}$ are the average fuel subsidy payments during the pre- and postreform periods, respectively. Since the year fixed effects γ_t absorb the common annual adjustments in fuel subsidy payments across vessels, the subsidy reduction rate Δ_i indicates vessel i's persistent treatment exposure to the subsidy reform (*SI Appendix*). Our parameter of interest is β, which represents the marginal effect of a persistent reduction rate in fuel subsidies on the probability of exit (or buyback), conditional on not exiting prior to year t.

The vessel characteristics that determine the subsidy assignment Δ_i may intrinsically correlate with exiting and buyback decisions as well as impacts of unobserved time-varying factors such as fuel prices, buyback prices, sea conditions, and fishery stocks. To purge out omitted variable bias associated with vessel characteristics, we further introduce the interactive fixed effects $\nu_t \mathbf{X}_i$ to capture characteristic-specific common trends, where ν_t are factor loadings and $\mathbf{X}_i$ is a vector of vessel characteristics allowed to influence the exit (buyback) decision differently across years. In the baseline specification, $\mathbf{X}_i$ includes engine power, vessel length, total tonnage, and a categorical variable representing fishing operation (gear). After the absorption of $\nu_t \mathbf{X}_i$, the exogenous variation in Δ_i remaining for identification primarily comes from the discontinuities in the postreform subsidy assignments generated by the multiple eligibility thresholds (Fig. 2).

Additional Specifications. We modify our baseline model Eq. **1** in several ways. First, to investigate time-varying treatment effects across years, we replace $\beta \Delta_i I_t$ with $\beta_j \Delta_i I_t^j$ for $j = 2012, \ldots, 2019$, where $I_t^j = \mathbf{1}\{t = j\}$. This produces the event-study plot in Fig. 4. Second, to investigate heterogeneous treatment effects, we replace $\beta \Delta_i I_t$ with $\beta_m V_i^m \Delta_i I_t$ for $m = 1, \ldots, M$, where $V_i^m = \mathbf{1}\{\text{vessel class}_i = m\}$ is a binary variable indicating whether vessel i is in a particular vessel class m, based on quantiles (or categories) associated with vessel characteristics in **X**. This produces the heterogeneous treatment effects in Fig. 5. Finally, to estimate the marginal effect of subsidy reform on exit (or buyback) decisions over the entire 4-y postreform period, we estimate an aggregated two-period pre- and postreform version of Eq. **1**. These produce the quadrennial marginal effects reported in columns (2) and (4) in Table 2.

Validation and Robustness Checks. We perform various validation and robustness checks for our DD and RD-DD estimation models. A subset of these robustness checks, including sensitivity to vessel and interactive fixed effects, vessel-length thresholds, and anticipatory effects, can be seen in *SI Appendix*, Tables S3–S5. A more detailed discussion of these robustness checks and the identification assumptions underlying the DD and RD-DD approaches can be found in *SI Appendix*.

Fleet Capacity Counterfactuals. We estimate the individual contributions of the fuel and buyback subsidy reforms to the total impact on fleet capacity. We consider several counterfactual scenarios in which each reform is implemented in isolation (or not at all). Our estimates are informed by a model of the cap-and-trade market for engine power quota and estimates from our DD model (where appropriate). Details of the model and the counterfactual analysis are described in *SI Appendix*.

Data, Materials, and Software Availability. Anonymized data and code data have been deposited in openICPSR (https://doi.org/10.3886/E192086V1) (52). This includes the desensitized dataset and code to replicate all figures and tables, the code to compile the desensitized dataset from raw archives, and policy documents assisting the study. Raw archives of the Marine Fishing Vessel Dynamic Management System can be obtained (upon approval) from the OpenData Platform of China's Zhejiang government (https://data.zjzwfw.gov.cn/) and contain sensitive information of local fishers.

ACKNOWLEDGMENTS. We thank Joshua Abbott, James Sanchirico, Martin Smith, and the NatuRE Policy Lab at UC Davis, and three anonymous reviewers for insightful comments that improved the quality of the manuscript. We thank the Sustainable Oceans NSF Research Traineeship (Award No. 1734999) for funding and research support. We thank Wenbin Zhu, Lijun Liu, and the Marine Fisheries Institute of Zhejiang for helping arrange field trips. Finally, we thank Yuyuan Xia, Haiyan Zhu, and Xiurou Wu for their support in discussions and data acquisition.

1. R. Q. Grafton *et al*., Incentive-based approaches to sustainable fisheries. *Can. J. Fish. Aquat. Sci.* **63**, 699–710 (2006).
2. B. Worm, R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, Rebuilding global fisheries. *Science* **325**, 578–584 (2009).
3. C. Costello, D. Ovando, Status, institutions, and prospects for global capture fisheries. *Annu. Rev. Environ. Res.* **44**, 177–200 (2019).
4. M. C. Melnychuk, E. Peterson, M. Elliott, R. Hilborn, Fisheries management impacts on target species status. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 178–183 (2017).
5. R. Hilborn *et al*., Effective fisheries management instrumental in improving fish stock status. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 2218–2224 (2020).
6. U. R. Sumaila, L. Teh, R. Watson, P. Tyedmers, D. Pauly, Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES J. Mar. Sci.* **65**, 832–840 (2008).
7. U. R. Sumaila *et al*., Updated estimates and analysis of global fisheries subsidies. *Mar. Policy* **109**, 103695 (2019).
8. FAO, *The State of World Fisheries and Aquaculture 2020* (FAO, 2020).
9. C. W. Clark, G. R. Munro, U. R. Sumaila, Subsidies, buybacks, and sustainable fisheries. *J. Environ. Econ. Manage.* **50**, 47–58 (2005).
10. Y. Sakai, Subsidies, fisheries management, and stock depletion. *Land Econ.* **93**, 165–178 (2017).
11. M. D. Smith, Subsidies, efficiency, and fairness in fisheries policy. *Science* **364**, 34–35 (2019).
12. Y. Sakai, N. Yagi, U. R. Sumaila, Fishery subsidies: The interaction between science and policy. *Fish. Sci.* **85**, 439–447 (2019).
13. C. Costello *et al*., Ambitious subsidy reform by the WTO presents opportunities for ocean health restoration. *Sustainability Sci.* **16**, 1391–1396 (2021).
14. U. R. Sumaila *et al*., WTO must ban harmful fisheries subsidies. *Science* **374**, 544 (2021).
15. A. M. Cisneros-Montemayor *et al*., A constructive critique of the World Trade Organization draft agreement on harmful fisheries subsidies. *Mar. Policy* **135**, 104872 (2022).
16. G. Munro, U. R. Sumaila, The impact of subsidies upon fisheries management and sustainability: The case of the North Atlantic. *Fish Fish.* **3**, 233–250 (2002).
17. C. Finley, *All the Boats on the Ocean: How Government Subsidies Led to Global Overfishing* (University of Chicago Press, Chicago, IL, 2017).
18. M. Reimer, J. Wilen, Regulated open access and regulated restricted access fisheries. *Encycl. Energy Nat. Res. Environ. Econ.* **2**, 215–33 (2013).
19. C. M. Anderson *et al*., How commercial fishing effort is managed. *Fish Fish.* **20**, 268–285 (2019).
20. F. R. Homans, J. E. Wilen, A model of regulated open access resource use. *J. Environ. Econ. Manage.* **32**, 1–21 (1997).
21. L. G. Anderson, Potential economic benefits from gear restrictions and license limitation in fisheries regulation. *Land Econ.* **61**, 409–418 (1985).
22. H. F. Campbell, R. K. Lindner, The production of fishing effort and the economic performance of licence limitation programs. *Land Econ.* **66**, 56–66 (1990).
23. R. T. Deacon, D. Finnoff, J. Tschirhart, Restricted capacity and rent dissipation in a regulated open access fishery. *Res. Energy Econ.* **33**, 366–380 (2011).
24. L. Cao *et al*., Opportunity for marine fisheries reform in China. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 435–442 (2017).
25. S. Su, Y. Tang, B. Chang, W. Zhu, Y. Chen, Evolution of marine fisheries management in China from 1949 to 2019: How did China get here and where does China go next? *Fish Fish.* **21**, 435–452 (2020).
26. Y. Rousseau, R. A. Watson, J. L. Blanchard, E. A. Fulton, Evolution of global marine fishing fleets and the response of fished resources. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 12238–12243 (2019).
27. K. Hopewell, M. E. Margulis, Emerging economy subsidies undermining sustainability of global fisheries. *Nat. Food* **3**, 2–3 (2022).
28. X. Zhong, G. Yu, W. Zhou, G. Ji, Advices on application of diesel subsidies in fishery. *Fish. Inf. Strat.* **27**, 272–276 (2012), in Chinese.
29. Ministry of Finance, Ministry of finance and ministry of agriculture jointly deploy fisheries fuel subsidies policy adjustment work (2015). http://www.gov.cn/xinwen/2015-07/09/content_2894870.htm, in Chinese. Accessed 14 December 2022.
30. Ministry of Agriculture Fisheries Administration Bureau, *China Fisheries Yearbook 2012* (China Agricultural Press, Beijing, China, 2012), in Chinese.
31. Ministry of Agriculture Fisheries Administration Bureau, *China Fisheries Yearbook 2016* (China Agricultural Press, Beijing, China, 2016), in Chinese.
32. Ministry of Agriculture, Provisions on the administration of fishing licenses (2018). www.gov.cn/gongbao/content/2019/content_5368590.htm, in Chinese. Accessed 14 December 2022.
33. Ministry of Finance and Ministry of Agriculture, Interim measures for the administration of special funds for fisheries fuel subsidies (2009). http://www.gov.cn/gongbao/content/2010/content_1629134.htm, in Chinese. Accessed 14 December 2022.
34. C. Shen, T. Chen, Impact of fuel subsidies on bottom trawl fishery operation in China. *Mar. Policy* **138**, 104977 (2022).
35. M. Su, L. Wang, J. Xiang, Y. Ma, Adjustment trend of China's marine fishery policy since 2011. *Mar. Policy* **124**, 104322 (2021).
36. Y. Wang, Y. Pan, Financial effect of fishing boats with fuel subsidies: Based on Ganyu county village. *Chin. Fish. Econ.* **34**, 18–22, Chinese (2016).
37. H. Yang, M. Ma, J. R. Thompson, R. J. Flower, Reform China's fisheries subsidies. *Science* **356**, 1343 (2017).
38. Ministry of Finance and Ministry of Agriculture, Notice of adjusting fuel subsidies for capture fisheries and aquaculture to enhance the sustainable development of fisheries (2015). http://www.gov.cn/xinwen/2015-07/13/content_2895987.htm, in Chinese. Accessed 14 December 2022.
39. Zhejiang Province Ocean and Fisheries Bureau, Notice of the issuance of the implementation plan for Zhejiang province domestic fisheries production cost subsidies (2016). https://www.zj.gov.cn/art/2021/8/16/art_1229278041_2320538.html, in Chinese. Accessed 14 December 2022.
40. Ministry of Agriculture, Notice of further strengthening the management and control of domestic fishing vessels and implementing the total amount management of marine fishery resources (2017). http://www.moa.gov.cn/nybgb/2017/derq/201712/t20171227_6130861.htm, in Chinese. Accessed 14 December 2022.
41. Zhejiang Province Ocean and Fisheries Bureau, Notice of the issuance of the implementation plan for Zhejiang province fishing vessel reduction and industry transition for marine capture fishers (2016). https://www.zj.gov.cn/art/2021/8/16/art_1229278041_2320548.html, in Chinese. Accessed 14 December 2022.
42. China National Radio, Fishermen in Ningbo are surrendering their vessels to quit from fisheries: What's the reason behind? (2016). http://country.cnr.cn/focus/20161214/t20161214_523337772.shtml, in Chinese. Accessed 14 December 2022.
43. S. Calonico, M. D. Cattaneo, R. Titiunik, rdrobust: An R package for robust nonparametric inference in regression-discontinuity designs. *R J.* **7**, 38 (2015).
44. S. Zhang *et al*., Distribution of bottom trawling effort in the Yellow Sea and East China Sea. *PLoS ONE* **11**, e0166640 (2016).
45. O. R. Young *et al*., Moving beyond panaceas in fisheries governance. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 9065–9073 (2018).
46. M. Sun, Y. Li, Y. Chen, Unveiling unselective fishing in China: A nationwide meta-analysis of multispecies fisheries. *Fish Fish.* **24**, 142–158 (2023).
47. C. Costello, Fish harder; catch more? *Proc. Natl. Acad. Sci. U.S.A.* **114**, 1442–1444 (2017).
48. C. S. Szuwalski, M. G. Burgess, C. Costello, S. D. Gaines, High fishery catches through trophic cascades in China. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 717–721 (2017).
49. D. S. Holland, E. Gudmundsson, J. Gates, Do fishing vessel buyback programs work: A survey of the evidence. *Mar. Policy* **23**, 47–69 (1999).
50. Q. Weninger, K. E. McConnell, Buyback programs in commercial fisheries: Efficiency versus transfers. *Can. J. Econ./Rev. Can. d'Écon.* **33**, 394–412 (2000).
51. D. Squires, Fisheries buybacks: A review and guidelines. *Fish Fish.* **11**, 366–387 (2010).
52. K. Wang, Fisheries subsidies reform in China - Zhejiang, China, 2012–2019. *ICPSR*. https://doi.org/10.3886/E192086V1. Deposited 7 June 2023.