Fisheries Subsidies Reform in China

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To Professor James Wilen,
who first guided me onto the path of economic research in Chinese fisheries.

Contents

Abstract

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, which artificially increase fishing profits. The argument for banning harmful subsidies relies on the assumption that fishing for some fishermen will become unprofitable after eliminating subsidies, incentivizing some to exit and others to refrain from entering. These arguments follow from theories of 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 or the structure of the fleet. Importantly, there have been no empirical investigations of fisheries subsidy reductions to inform us about their likely quantitative impacts in real-world settings.

This dissertation investigates the impact of fisheries subsidy reform on fleet capacity dynamics and structure in the offshore fisheries of Zhejiang Province, China. This study is important for its novelty, 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 and user of harmful fishing subsidies. In 2006, China implemented a fuel subsidy program to insulate fishermen from the sudden shock to diesel prices as the country deregulated its domestic gasoline and diesel markets. But in 2016, China implemented a wide-ranging fuel subsidy reform to reduce fleet size and curb harmful gear use in order to align with new ecological policy objectives. The reform created a unique opportunity to provide the first quantitative investigation of fishery subsidy reductions.

The policy setting investigated in this thesis 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 me 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 occur. 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. I demonstrate that 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.

My research design is based on a conceptual framework that considers individual-level vessel investment decisions, short-run fleet dynamics, and the long-run bioeconomic equilibrium in a limited-entry fishery. Using structural modeling techniques, I generate refutable hypotheses regarding the impact of subsidy reform on fleet capacity and test these hypotheses using state-of-the-art reduced-form empirical methods. Using a unique vessel-level panel that I assembled from administrative data collected by Chinese authorities, I demonstrate that the subsidy reform led to an increase in individual vessel exit rates. However, the extent to which vessel exits led to power quota retirement, and hence capacity reduction, depended on the simultaneous reforms of a buyback program. Using a model of a cap-and-trade market with a price floor, I am able to separately identify the effects of each component of the reform and show that while subsidy reductions induced exit, the buyback program was the primary contributor to fleet capacity reduction. I also explore the impact of the reform on the structure of the fleet and find an acceleration of capacity reduction of harmful gear and adoption of less intensive fishing gear.

Overall, this dissertation highlights the nuanced nature of mechanisms linking subsidy reductions to fleet reduction and restructuring in modern fisheries. In brief, simply removing harmful subsidies may not, as suggested, be a panacea leading to increased conservation of global fish stocks. Indeed, in modern limited entry fisheries like China's trawl fishery, subsidy reductions might have had no effect on capacity reduction without complementary policies like retirement subsidies that induced exiting fishermen to retire rather than replace their vessels. This suggests the need for a strategic design of worldwide fisheries subsidy reforms that carefully accounts for the economic incentives of participants, the complexity of policy environments, and the multiple objectives of fisheries policy.

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CHAPTER 1

Introduction

Fisheries worldwide have experienced a vast transformation in governance in the decades since the conclusion of the U.N. 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 (Grafton et al., 2006; Worm et al., 2009; Costello and Ovando, 2019). Indeed, most fisheries with strong management institutions and science-based stock assessments are currently rebuilding or harvested at sustainable levels (Melnychuk et al., 2017; Hilborn et al., 2020).

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 (Sumaila et al., 2008). By one estimate, approximately US$22 billion in harmful subsidies were distributed to fishers worldwide in 2018 (Sumaila et al., 2019), representing nearly 15% of global fisheries revenue (FAO, 2020). 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 (Clark et al., 2005; Sakai, 2017; Smith, 2019; Sakai et al., 2019). 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 (Costello et al., 2021). In response, scientists worldwide have called for a complete ban on all harmful fisheries subsidies (Sumaila et al., 2021), a plea that culminated in a partial ban being adopted recently amongst members of the World Trade Organization (Cisneros-Montemayor et al., 2022).

At the heart of this policy recommendation is the expectation that reducing harmful subsidies can be an effective tool for controlling fleet capacity. This belief relies on the assumption that removing subsidies will make marginal units of fishing capital unprofitable, thereby reducing fleet capacity as marginal units of capital are incentivized to leave the fishery. This argument is theoretically consistent with mechanisms we would expect to operate in open-access fisheries (Munro and Sumaila, 2002), an apt description of the institutional conditions that led to fisheries becoming overcapitalized in the decades leading up to the 1982 LOS agreement (Finley, 2017). However, many modern-day fisheries are no longer open access, as nation-states have since instituted additional controls, such as limits on entry or fishing effort, to curb overfishing concerns (Reimer and Wilen, 2013). It is well known that such limits have the potential to generate positive marginal economic profits, even if they are not set at their optimal levels (Anderson, 1985; Campbell and Lindner, 1990; Deacon et al., 2011). In these arguably common cases, marginal units of fishing capital may still earn positive economic profits after removing subsidies, leaving fleet capacity unchanged. In practice, there have been few instances of actual subsidy reductions since the LOS agreement that can provide guidance on the potential effectiveness of a subsidy ban.

In this thesis, I examine a recent fisheries policy reform in China that reduced harmful subsidies. This case study is important for its novelty, 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. By 1992, China had become the world's largest fishing nation (Cao et al., 2017). 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 (Cao et al., 2017; Su et al., 2020). 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 (FAO, 2020) and prosecuted by the world's largest domestic marine capture fleet (Rousseau et al., 2019).

China is also the largest user of harmful fishing subsidies (Hopewell and Margulis, 2022). The subsidies I 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 (Zhong et al., 2012). 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 Five-Year 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 Five-year Plan (Cao et al., 2017). The reform reduced subsidies broadly, committed to a gradual reduction over the upcoming five-year period, and targeted specific harmful gear by enhancing incentives to exit. I take advantage of this policy reform and utilize the break from pre-reform subsidy levels as a quasi-experiment to examine the quantitative impact of subsidy reductions.

This dissertation examines the impact of fisheries subsidy reform on fleet capacity dynamics, focusing on offshore fisheries in China's Zhejiang Province, the largest fleet in the East China Sea. Chapter 2 analyzes the evolution of fishery subsidies in China, focusing on the conflict between the fuel subsidy policy and the vessel buyback program. Before 2015, high fuel subsidies counteracted the buyback program, causing vessels to retain their fishing power. The 2016 reform aimed to realign the subsidy policy with capacity retirement targets, increasing buyback prices and reducing fuel subsidies. The reform made the buyback program appealing to fishers again and led to significant capacity reduction. Chapter 3 then presents a conceptual framework to explore the conditions under which subsidy reduction leads to fleet capacity reduction based on the policy setting of Chapter 2. It includes individual-level optimal vessel investment models, a partial equilibrium analysis of short-run fleet dynamics on the engine power quota market, and an extended Gordon-Schaefer model for limited-entry fisheries to consider a shift of the fishery's long-run bioeconomic equilibrium.

Chapter 4 aims to empirically examine the theoretical arguments by utilizing a unique dataset compiled from the Vessel Administrative Database. The study investigates the real-world impact of subsidy reductions on fleet capacity in the large-scale limited-entry domestic trawl fishery of China. The dataset enables the exploitation of the natural experiment associated with the nationwide 2016 fishery subsidy reform, which simultaneously cut fuel subsidies and raised buyback prices for capacity control. Through the application of difference-in-difference and difference-in-discontinuity strategies, the study compares the vessel disposal responses of fishers assigned with different levels of post-reform fuel subsidy payments, quantifying the impacts of subsidy reduction on fleet restructuring. The findings indicate that the subsidy reductions resulted in a significant increase in the probability of vessels scrapping, with older and smaller vessels being more responsive to the subsidy reduction. Additionally, a counterfactual policy analysis reveals that the reduction of harmful subsidies only partly accounts for the observed fleet capacity reduction, and the potential effectiveness of subsidy changes on fleet capacity depends on the complexity of supporting management regimes.

Finally, motivated by the restructuring effect suggested by the treatment effect heterogeneity of fuel subsidy reduction within the trawling fleet, Chapter 5 expands the scope of impact evaluation of the subsidy reform to encompass the entire offshore fishing fleet with a variety of gears. This study investigates the impact of the 2016 fishery subsidy reform on the gear structure of the medium-sized and large fishing vessel fleet in Zhejiang province. By employing an entry-exit model of fishing power and conducting a counterfactual analysis, I quantify the restructuring effect of fuel subsidy reform on the fishing fleet in the post-reform short term. My findings indicate that the reform accelerated capacity reduction and incentivized the adoption of less intensive and more selective fishing gear.

Overall, the policy analysis based upon Zhejiang province's offshore fisheries provides compelling evidence on the effectiveness of fishery subsidy reform for fleet restructuring and capacity control and underscores the importance of carefully designed economic incentives for the effective design of subsidy reforms, offering valuable lessons not only for China but also for global fisheries policy. My examination of the subsidy reform's impact has revealed a nuanced interplay of policy elements influencing the response to fuel subsidy reduction. This underscores the need for a comprehensive approach that carefully weighs the economic incentives driving fishers' behavior within the constraints of the regulatory environment. The policy analysis further highlights that simplistic subsidy removal can not guarantee successful fleet reduction without an effectively designed exit channel for fishers. A careful and holistic approach, accounting for the broader management context, is thus essential to ensure the desired outcomes of capacity control and fisheries sustainability.

Moreover, the heterogeneous responses of fishers to the subsidy reduction, impacting both fleet capacity and gear structure, unveil the complexity underlying the consequences of fisheries subsidy reforms. The selective retirement of less efficient vessels and the shift toward more selective fishing gears, while in the desire of the policy designer in China, raise pertinent questions about the overall effects of fisheries subsidies on sustainability. This emphasizes the necessity for further investigation to comprehensively understand the consequences of subsidy reforms, alerting fisheries managers that subsidy removal should be seen as a foundational step for broader fishery reforms rather than a panacea for long-term fisheries sustainability.

Beyond the immediate focus on subsidy reform design, this thesis resonates with the broader objective of enhancing Chinese fisheries management. The successful implementation of subsidy reform within China, driven by top-down initiatives and informed by a contextual understanding of the regulatory landscape, serves as a beacon of potential for positive change in fisheries management. As China pursues an ecological transition in ocean and coast management, a more comprehensive and forward-looking approach to fisheries management is essential to balance the socioeconomic needs of coastal communities and the imperative of ecological sustainability. This integrated perspective should chart the course for future endeavors in China's fisheries management, guided by the lessons learned from the subsidy reform experience.

CHAPTER 2

Fishing Capacity Management and Subsidy Reform in China: Historical Evolution

Overcapacity has been the main driver of fishery resource degradation in China since the 1980s. Excessive fishing capacity leads to overcompetition in fishery resource exploitation, exacerbates the insufficiency of monitoring and enforcement, and ultimately results in low returns to fishers as rents are dissipated. Fishing capacity input controls have thus been a primary focus of Chinese fishery management under the framework of the "negative growth" target. A series of policies, including licensing systems, "Dual-Control" on vessel numbers and horsepower, and vessel buyback programs have been implemented starting in 2003 to reduce the fishing power on the sea (Yu and Yu, 2008).

The fishery subsidy policy studied in this dissertation, however, came into conflict with the capacity reduction target by providing subsidies to existing and new-built vessels. Initiated in 2006, the policy was originally intended to compensate fishers for the rise in fuel prices and issued subsidies based mainly on the engine power of vessels. A handful of studies point out that with the overexploitation and degradation of fish abundance, the subsidy has became the primary source of profit for vessel owners, impeding the retirement of excessive fishing power (Shen and Chen, 2022; Zhang, 2016).

Starting in 2015, the Ministry of Agriculture (MOA) decided to reform the fishery subsidy system to help realign the fuel subsidy program with fleet capacity reduction goals. The stringent reform promised to reduce the fuel subsidy for medium and large vessels by 60% in 5 years and to eliminate the subsidy for old vessels and fishing methods classified as harmful and in need of restrictive use, such as pair trawler and stow nets, from 2020 onward. Meanwhile, the reform shifted the basis of the new subsidy standard from engine power to intervals of vessel length to further disentangle the amount of subsidy for vessels with their fuel usage.

This chapter retrospectively examines the policy evolution of domestic marine fishery in China, in particular the evolution of the fuel subsidy policies and their conflict with the vessel buyback policy, which was designed by Chinese fishery managers as the major policy leverage to achieve negative growth in fishing fleet capacity. I will show that engine power quota management, or the so-call "double-control" system, is the key to understanding the interplay of fishing capacity management policies in China. At the same time, this cap-and-trade system for fleet power implemented in past decades in order to address the overcapacity problem can never eradicate fishers' incentives to expand their fishing power by itself.

2.1. Fisheries Management in China

Following the ratification of the Law of the Sea (LOS) treaty in 1982, China, like many other coastal nations, began to develop new institutions to manage its marine resources under the new global framework. In the East China Sea, fisheries that were previously open access and fished by neighboring nations suddenly came under exclusive control by China. Similarly, other distant fisheries that had been fished by Chinese fishermen were closed and allotted to domestic fleets of Japan, Korea, Vietnam, and the Philippines. The realignment of coastal boundaries and the fisheries within them required new regulations, policies, and enforcement structures moving forward over the next decades.

The development of China's fishing sector can best be understood within the context of the broad modernization of China's economy as a whole. China's success in rapid development over the past half-century has been directed by a strong Communist Party of China (CPC) that sets objectives and targets for local officials to implement in a mixed economy of state-owned enterprises, private enterprises, and market incentives. During the 1980s, the goals of the CPC for the economy focused primarily on economic growth, and China's fishing sector also reflected that push. Soon after the LOS treaty came into force, China implemented a sweeping new fisheries directive that lifted price controls on aquatic products, encouraged private vessel ownership, and called for the full development and utilization of its marine and terrestrial fisheries resources.

The encouragement of private ownership and market incentives in China's domestic fishing sector proved wildly successful at first glance. 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, reaching over 13 MMT (18% of global catch) by 1998. But as the decade of the 1990s came to a close, broad signs of overexploitation began to emerge. Traditional commercial species (e.g., largehead hairtail and yellow croaker) disappeared, replaced by pelagic species and small and under-sized juveniles. Peak fishing times when species reached maximum abundance shortened. High catch volumes were maintained, but with more effort and lower quality. These emergent signs of overexploitation prompted an abrupt about-face in fisheries management objectives. In 2000, the CPC announced a "negative growth" strategy, essentially signaling an end to the decade of rapid growth and development. The CPC directed local leaders to reduce vessel numbers and fleet power, reduce catch targets, and implement input controls such as summer moratoria.

The rapid reversal of policy could not have been implemented without the institutions that had been developed to monitor and manage the fleet during the decade of growth. 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 the "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 created a cap-and-trade program in engine power whereby new vessels could only be constructed by acquiring power quota from fishermen exiting the fleet and scrapping their vessels. Since 2003, MOA has been stringently controlling the total amount of engine power quota, officially named as "fishing vessel and net devices control quota," to achieve the "negative growth" target. In 2011, the MOA further developed the national fishing vessel database, named "Marine Fishing Vessel Dynamic Management System (MFVMDS)," to put all the marine fishing vessels in the "dual control" system under direct monitoring.

Fleet reduction was facilitated with a vessel buyback system introduced in 2002. The program provided compensation to fishers willing to exit and surrender their power quota, and retraining funds designed to help transition to other non-fishing occupations. The CPC funded the buyback and retraining programs implemented by local officials at the provincial and county levels to achieve local targets. In 2008, the MOA further raised the buyback compensation for fishing power to 2500 RMB/kW to encourage the voluntary retirement of fishers and vessels.

2.2. The Fuel Subsidy Program: 2006-2015

By the early 2000 decade, fishery managers faced multiple objectives and newly changing directives from the CPC. During the preceding period, China had insulated its economy from rising global fuel prices in order to stimulate development with cheap fossil fuel energy. But buying oil at high prices and selling it domestically at low prices proved a substantial drain on budgets, and hence the Party decided in 2006 to expose the Chinese economy to global fuel prices.

Aware that shocks in fuel prices could cause political instability and that fishers' profits and livelihoods are critically impacted by fuel costs, CPC decided to provide fuel subsidies from 2006 to vulnerable industries, including fisheries. In 2009, the MOA formalized a national subsidy standard to continue the provision of fuel subsidy payments to domestic fishing vessels. Managers implemented surveys to determine average fuel consumption by gear type, engine power, and vessel size. These were used to compute "subsidy coefficients," measured in metric tons of fuel per kW of engine power. Annual subsidy payments for each legally licensed vessel were then computed to be:

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

where the fuel price standard was computed as the difference between the global fuel prices each year relative to a baseline in the fuel price-controlled period. Notably, the fuel subsidy was a lump-sum payment based on vessel engine power owned by the fisher rather than the actual amount of fuel consumed.

At the beginning of each year, the fishery department determines the fuel price standard based on the diesel prices of the previous year and then arranges for the application and issuance of subsidy payments for fishers. All fishing vessels with valid certificates, compliance records, and licensed in the previous year are eligible for the annual subsidy. Subsidy payments are directly deposited to fishers' bank accounts and announced to the public by the local government.

2.3. The Fuel Subsidy Program: 2016-2020

In 2015, the CPC announced that the next Five-Year Plan would be designated the period of "Ecological Civilization". The prominence of "ecological" in the title signified a major shift in the significance of goals involving harmony with nature, reduction in environmental degradation, and sustainable resource use rather than economic growth alone. The regime change was transmitted from top-level decision-makers to local leaders in all sectors of the economy, including the fishing sector.

A major policy focus of the Ecological Civilization plan as it impacted marine fisheries was to reform the fuel subsidy program. Managers recognized several problems with the old system, including 1) fuel subsidies incentivized marginal fishermen to remain in the fleet; 2) fuel subsidies became capitalized into quota prices, inhibiting the effectiveness of the buyback program; and 3) fuel subsidies kept ecologically harmful gear types (e.g., trawlers) in the fishery, inhibiting rebuilding plans. These problems were addressed with a major multi-step reform in the fishery subsidy program, implemented in 2016.

The first step of the subsidy reform was to classify vessels above 12 meters into 12 length classes. The basis of fuel subsidy calculation then switched from the engine power of each vessel to the average engine power in each of the 12 vessel classes, so as to weaken the linkage between subsidy eligibility and engine power quota. In the second step, vessels in each bin were assigned revised subsidy coefficients that accounted for the harmfulness of their gear types. So, for example, pre-reform trawlers were assigned subsidy coefficients of 0.48 MT/kW while squid jig vessels were 0.328, reflecting actual survey-based fuel consumption estimates. Post-reform coefficients were set at 0.30 for double-otter trawls, 0.35 for single-otter trawls, and 0.40 for squid jig vessels. These new coefficients reflect revised judgments about the ecological harm done by each gear type, rather than the actual fuel consumption used by each gear type. The third step was to decouple the annually varying fuel price standard from actual annual fuel prices. Instead, future fuel price standards would be calculated from a baseline associated with 2014 fuel prices and remain unchanged as actual fuel prices changed. The third step further committed to an annual reduction of 18% from the baseline standard so that total subsidy payments would be reduced by 60% over the five-year planning period. The post-reform subsidy payment thus became:

$$\begin{aligned}\text{Subsidy} &= \text{baseline fuel price standard (RMB/MT)}\\ &\times \text{average engine power per length class bin (kW)}\\ &\times \text{revised subsidy coefficient (MT/kW).}\end{aligned}$$

In addition to the subsidy reform, the MOA announced that new construction of double-otter bottom trawlers would be prohibited after 2017 and that all new construction of trawl gear vessels would stop after 2019.

The implementation plan of fuel subsidy reform for the next five years was issued to fishery managers at the provincial level by MOA at the end of 2015. In the middle of 2016, Zhejiang along with other provincial governments published its own execution standards based on the design of MOA. The issuance of the subsidy payments based on the new subsidy standard then began in the coastal counties of Zhejiang province in the middle of 2016 and was not finished until early 2017. 2016 is thus regarded as the first year of the execution of the new subsidy standard.

2.4. Vessel Buybacks in the Era of Fuel Subsidies

The vessel buyback program is the core policy instrument for fishing fleet capacity reduction for the "negative growth" strategy of China's fishery management program. Under the quota management program for fishing power, excess engine power retrieved from the double-control system by the government buyback program becomes a permanent reduction of the fleet capacity. The buyback process had been ineffective and languished for years because of the counteracting effects of high fuel subsidies against low buyback prices before 2015. A primary intent of the subsidy reform was thus to bring back into coherence the fuel subsidy policy with the capacity retirement targets based on the new focus on ecological harmony.

As admitted by fishery managers in Zhejiang province and the Ministry of Agriculture, the introduction of the fuel subsidy program collided with and stalled the progress of vessel buyback, which worked as intended before 2006. According to Zhejiang province officials, fishery managers successfully bought back over 4400 vessels and 438MW of engine power from 2002 to 2006, whereas after 2006, progress stalled. For example, in an interview in 2015, the fishery manager of Xiangshan county reported that this largest fishing county in Zhejiang formerly retired 200 vessels annually through voluntary buybacks before the fuel subsidy policy, but had seen zero vessel buybacks since 2006. The same dilemma for fishery managers was also reported in other fishing counties of Zhejiang. As summarized by the minister of agriculture at the 2016 National Fisheries Work Conference, fishers were willing to retire their vessel at the beginning of the 2002 buyback program, but the willingness was dampened by the fuel subsidy payments after 2006.

The mechanisms by which fleet reduction goals were compromised were subtle and intricate. As noticed by local fishery managers, the primary driver for fishers' unwillingness to surrender their quota for buyback was the higher market value of their engine power quotas resulting from anticipated fuel subsidy payments, in comparison with the fixed government buyback price. For example, as discussed above, the licensing system capped aggregate fleet engine power and required power-for-power quota transfers for new vessel construction. The buyback program paid exiting fishermen up to 2500 RMB/kW to surrender their quota, making aggregate quota more scarce. But as quota became more scarce, it began to take on a market price.

During the early phase of the buyback program, due to severely declining fishery resources and rising costs, the market price of quota was below the buyback price, and hence exiting fishermen chose quota surrender rather than selling to a new entrant. But as fuel subsidies were introduced, quota prices rose to reflect the capitalized value of anticipated future payments. For example, in 2006, reported trawler quota transfer prices were around 600 RMB/kW. But by 2014, they were 8,000-10,000 RMB/kW. This increase reflected the (market-determined) present value of the flow of future subsidy payments for the average trawler. The value of subsidies thus became embedded in quota transfer prices, causing transfer prices to exceed the buyback price. This, in turn, choked off incentives for exiting fishermen to surrender their quota to the buyback program. The subsidy program thus had two avenues by which it counteracted the intended goals of reducing the fleet, namely: 1) by propping up revenues of marginal vessels and hence delaying their decisions to exit, and 2) by raising power quota prices above buyback prices, reducing incentives of exiting vessels to surrender their quota into the buyback program.

Hence, in addition to the multi-pronged reform of the incentives built into the structure of the fuel subsidy program, local authorities also enhanced the buyback program in order to resume the process of fleet reduction that had been halted as quota prices rose above buyback prices. This was made possible by diverting the savings from reforming fuel subsidies into the buyback program. The CPC raised buyback prices from 2500 to 5000 RMB/kW, and provinces like Zhejiang added 2500 RMB/kW to meet its targeted regional reductions. The higher buyback prices thus began to exceed quota prices, which themselves were reduced as expected future fuel subsidy payments were reduced. The result was that vessels and their associated power quota began to be eliminated, particularly older, smaller, and wooden-hulled vessels that were safety concerns and obsolete technology.

The effects of the reformed fuel subsidy program were dramatic. For example, in the Zhejiang province alone, during the post-reform period of 2016-2020, a total engine power of 446MW was retired through the buyback program, exceeding the capacity reduction target of the 13th Five-Year Plan by 16MW.

2.5. The Multi-objective Design of Fisheries Subsidies

The reform of the fisheries subsidies program offers a compelling illustration of the predicament confronting the Communist Party of China (CPC) in the domain of natural resource management. The evolution of fisheries policies in China can be understood as a sequence of "top-down" initiatives aimed at recalibrating and harmonizing diverse administrative objectives concerning the fishery sector. These objectives encompass the economic pursuit of ensuring an adequate supply of aquatic products, the ecological imperative of safeguarding the marine environment, and the social objective of maintaining political stability within fisheries communities (Zhang, 2016).

As one might expect, the transition of marine resource management in China to encompass ecological goals is significant, given the rapid growth in China's income. When the GDP per capita of China grew from $2100 to $8100 from 2006 to 2016, the willingness to pay by the Chinese society for environmental quality also surged, in line with the predictions of the theory of the environmental Kuznets Curve. The earnest commitment towards fishing capacity reduction since the implementation of the 13th Five-year Plan exemplifies the central government's inclination to prioritize marine environment conservation over fisheries' food production.

On the other hand, the design of fuel subsidy policies prominently reveals the overriding influence of historical sociopolitical objectives in the decision-making process of policy design, even in the pursuit of other policy objectives. The introduction of the fuel subsidy in the marine fishery sector was initially aimed at alleviating the adverse effects of fuel price deregulation on the livelihoods of fishers. However, this came at the cost of impeding the progress of capacity reduction efforts. A decade later, when deciding to discontinue the fuel subsidy in favor of resource conservation, the policy designers opted for a more strategic approach. Instead of abruptly eliminating the subsidy and causing a drastic reduction in fishing power, the funds were redirected to establish a competitive buyback program, encouraging fishers' voluntary withdrawal from fishing activities. Simultaneously, a stepwise reduction in the fuel subsidy was implemented, ensuring active fishers continued to receive support during the transitional period.

The complete abolition of fuel subsidies, however, has never been part of the plan, except for a limited number of vessel types that fishery managers have identified as unsuitable for continued operation within the fisheries. Indeed, the provision of fuel subsidies for fishing vessels persisted beyond 2020 but was rebranded as a payment for ecosystem service. In the latest phase of fisheries subsidies reform commencing in 2021, the MOA has undertaken a complicated redesign of the previous fuel subsidy, now referred to as the "fishery stewardship subsidy." Although the amount of new subsidies assigned to fishing vessels remains comparable to that of the reduced fuel subsidy in 2019, its disbursement is now contingent upon the performance of individual fishers. A fisher's annual stewardship subsidy is evaluated based on two distinct components: the first assesses compliance with closed seasons, and the second evaluates responsible fishing practices according to specified criteria. These criteria include adherence to port entry and exit reporting, monitoring data on fishing locations, maintenance of comprehensive fishing logs, utilization of designated landing ports, efforts towards ocean wildlife protection, and the proportion of juvenile fish in the catch. Notwithstanding its intricacy, the efficacy of the well-intended restructuring of the fishery subsidy demands ongoing monitoring, given the constraints posed by the deficiencies in technical expertise and enforcement capabilities within China's fishery management.

In conclusion, the four-decade evolution of fisheries management in China, which commenced in 1985 with the central government's call for the comprehensive development of marine fishery resources and the expansion of seafood markets, has taken place in the face of a gradual reduction in the dominant role of marine capture fisheries as a source of accessible aquatic protein. Nevertheless, the delicate balance between ecological management and ensuring the livelihood stability of millions of fishers in coastal areas is expected to persist as an ongoing challenge. The reform of fisheries subsidies, exemplified by the redesign of fuel subsidies and the strategic buyback program, reflects the complexity of balancing multiple administrative objectives in the pursuit of sustainable fisheries. The way forward for fisheries management in China still involves the adoption of a holistic approach that balances ecological conservation, sustainable resource utilization, and the socio-economic needs of coastal communities. Fortunately, China has been accumulating valuable experiences in navigating these complex challenges through the fishery reforms over the period.

CHAPTER 3

Vessel Investment under Fisheries Subsidies and the "Double-Control" Policy: A Conceptual Framework

This chapter presents a conceptual framework designed to illuminate the impacts of subsidy reform policies on fleet capacity. It builds on the contrasts between the incentives to retire power quota and vessels before and after the 2016 subsidy reform, as discussed in Chapter 2.

First, I develop individual-level optimal vessel investment models for both current vessel owners and potential future vessel owners in a fishery. This fishery operates with an active engine power quota market, which is generated by the "double-control" management of engine power for fishing vessels. Under reasonable assumptions, I demonstrate that an escalation in the engine power quota price will reduce the demand for engine power quota in the vessel construction plans of potential enterers. Simultaneously, it will increase the supply of power quota resulting from existing vessel owners exiting the fishery. Comparative statics of the model indicate that subsidy reductions will increase the likelihood of choosing vessel exit via the buyback program if fuel subsidies are not fully capitalized into permit values (i.e., engine power quota prices).

Additionally, I provide further insights by conducting a partial equilibrium analysis of the engine power quota market and its influence on short-run fleet dynamics. This analysis examines how individual fishers' entry and exit decisions collectively contribute to the market's demand and supply of engine power quota, ultimately determining the equilibrium price of engine power quota. This price reflects the combined impact of fishing profit and subsidy income, capturing the overall rent generated in the fishery. The market-level analysis yields refutable hypotheses: If the reform reduces power quota prices below the buyback price, the fleet capacity will decrease as vessel owners are incentivized to retire their engine power quotas through the buyback program. The increase in the vessel exit rate resulting from the reform will be sustained over the short term, primarily involving smaller, older, and less efficient vessels in the fleet.

Finally, I extend the classic Gordon-Schaefer model to incorporate limited-entry features. The model's stationary analysis sheds light on how fisheries subsidies can influence the long-run bioeconomic equilibrium of the fishery, with aforementioned short-run fleet dynamics serving as an intermediate process during this transitional period. The analysis also implies that, without capital stuffing, a properly set buyback price can serve as a second-best policy tool to align the fishery's capacity with the level corresponding to the maximum economic yield.

The theoretical analysis emphasizes the importance of comprehending fishers' economic incentives to design effective subsidy reforms, especially in complex policy environments with multiple objectives. In China's marine fishery context, economic incentives are reflected in fishers' investment decisions and their interactions within the engine power quota market, governed by the "double-control" management. Understanding the dynamics of the engine power quota market serves as the basis for examining different fisheries subsidies.

3.1. Vessel Investment Problems of Individual Fishery Participants

3.1.1. Existing vessel owners' investment problem. To comprehend the implications of fisheries subsidies policy on fleet dynamics from a micro perspective, I examine a representative fishing vessel within the fishery, characterized by attributes $\{E, a\}$, where E denotes vessel capacity measured by fishing power, and a represents its vessel age. The market-assigned asset value of this fishing vessel is determined through the optimization of its discounted net cash flow, considering the period from its current age to the time of scrappage. Consequently, the life span of the vessel $\mathcal{T}$ is endogenously determined in the context of the ensuing optimal stopping problem, aimed at maximizing its operational value:

$$\max_{\mathcal{T} \geq a} \mathbb{E}V(\mathcal{T}|E, a, s, w).$$

The vessel owner derives income from two sources: fishing profits and fuel subsidies. The anticipated fishing profit $\pi(\cdot)$ is contingent on the fishing capacity E and a vector of input and output factors w that are integral to the bioeconomic fishery production function. Within the context of trawling production surveys in China, significant factors influencing fishing profits encompass weather conditions, biomass levels, and prices for harvest, fuel, and labor.

Moreover, the vessel owner expects to receive a fuel subsidy, which is merely the product of the subsidy standard and the vessel's fishing power sE. However, possessing and maintaining the fishing vessel will entail a maintenance cost $m(E, a)$, which is a non-decreasing function concerning both the vessel's capacity E and its age a. This implies that repair and maintenance expenses tend to be higher for larger and older vessels.

Assuming a stable market price for engine power quota as P and disregarding any recycling value of vessel materials and ship-breaking costs, the projected scrap value for an individual vessel would be equivalent to the product of the engine power quota value and the vessel's capacity PE.

Denoting the rest of vessel life as $T = \mathcal{T} - a$, the optimal stopping problem can be expressed as:

$$\max_{T \geq 0} \int_0^T e^{-\rho t}[\pi(E, w) + sE - m(E, a + t)] \, \mathrm{d}t + e^{-\rho T} PE.$$

3.1.2. Would-be vessel owner's investment problem. Assuming the construction cost for a vessel with capacity E follows a non-decreasing function $C(E)$, a prospective owner's primary challenge when entering the fishery lies in devising an optimal vessel size E and life span $\mathcal{T}$. The objective is to maximize the value of the vessel construction project, considering the following optimization problem:

$$\max_{\mathcal{T} \geq 0, E \geq 0} \mathbb{E}V(\mathcal{T}, E|s, w) - C(E).$$

As assumed in the existing vessel holder's problem, the planned vessel will incur the maintenance cost of the vessel and the capital cost of the power quota while profiting from fishery production. The problem can thus be expressed as:

$$\max_{\mathcal{T} \geq 0, E \geq 0} \int_0^{\mathcal{T}} e^{-\rho t}[\pi(E, w) + sE - m(E, a + t) - \rho PE] \, \mathrm{d}t - C(E).$$

I first list the assumptions under which this vessel construction problem admits a unique interior solution. I then explore the relationship between the vessel construction plan and the engine power quota price for such a would-be vessel owner.

Assumption 1: [First-order conditions.] The value function $f(\mathcal{T}, E) = \mathbb{E}V(\mathcal{T}, E|s, w) - C(E)$ satisfies first-order conditions of local optimum at $\{E^* > 0, \mathcal{T}^* > 0\}$.

More specifically, I assume $\exists E^* > 0, \mathcal{T}^* > 0 \; s.t.$

$$\frac{\partial f}{\partial \mathcal{T}} = \pi(E^*) + sE^* - m(E^*, \mathcal{T}^*) - \rho PE = 0,$$

and

$$\frac{\partial f}{\partial E} = \int_0^{\mathcal{T}^*} e^{-\rho t} [\frac{\partial \pi}{\partial E} + s - \frac{\partial m}{\partial E} - \rho P] \; \mathrm{d}t - \frac{\partial C}{\partial E} = 0.$$

Assumption 2: [Second-order conditions.] The value function $\mathbb{E}V(\mathcal{T}, E|s, w) - C(E)$ is strictly concave for $\mathcal{T} > 0, E > 0$.

More specifically, I assume that $\forall E > 0, \mathcal{T} > 0$,

$$\frac{\partial^2 f}{\partial \mathcal{T}^2} = -\frac{\partial m}{\partial \mathcal{T}} < 0,$$

and

$$\frac{\partial^2 f}{\partial E^2} = \int_0^{\mathcal{T}} e^{-\rho t} [\frac{\partial^2 \pi}{\partial E^2} - \frac{\partial^2 m}{\partial E^2}] \; \mathrm{d}t - \frac{\partial C^2}{\partial E^2} < 0.$$

Proposition 1: [Existence of the optimal contraction plan.] Under Assumption 1 and 2, the would-be vessel owner's problem will admit a unique global interior maximum $\{E^*, \mathcal{T}^*\}$.

Assumption 3: [Non-positive cross derivative of maintenance costs.] The growth rate of maintenance costs with respect to time is slower for larger vessels:

$$\forall E > 0, \mathcal{T} > 0: \; \frac{\partial^2 m}{\partial \mathcal{T} \partial E} \leq 0$$

This assumption aligns with the empirical observation that larger vessels are engineered to exhibit greater resilience in adverse sea conditions and possess a longer service life than smaller vessels. Consequently, the average maintenance cost per unit of power increases at a slower rate for larger vessels. In China, the official service life for vessels over 24m is extended by one-third compared to smaller vessels. Designed to reduce the risks associated with operating over-aged and less robust fishing vessels, this policy is driven by the recognition that small vessels are more prone to damage and becoming unmanageable during sea operations.

Proposition 2: [Optimal vessel size and life in construction decrease with quota price.] Under Assumptions 1 to 3, the demand for fishing power of would-be vessel owner's problem will decrease with power quota price, as does the planned vessel life:

$$\frac{\partial E^*}{\partial P} < 0, \frac{\mathcal{T}^*}{\partial P} < 0$$

Proof: Applying Mean Value Theorem to the second FOC, we get $\exists \hat{t} \in (0, T^*)$ s.t.:

$$\frac{\partial f}{\partial E} = T^* e^{-\rho \hat{t}} [\frac{\partial \pi}{\partial E} + s - \frac{\partial m}{\partial E}(E^*, \hat{t}) - \rho P] - \frac{\partial C}{\partial E} = 0.$$

Then

$$\frac{\partial C}{\partial E} > 0, \frac{\partial^2 m}{\partial \mathcal{T} \partial E} \leq 0,$$

together imply that

$$\begin{aligned}
\frac{\partial^2 f}{\partial \mathcal{T} \partial E} &= e^{-\rho \mathcal{T}^*} [\frac{\partial \pi}{\partial E} + s - \frac{\partial m}{\partial E}(E^*, \mathcal{T}^*) - \rho P] \\
&\geq e^{-\rho \mathcal{T}^*} [\frac{\partial \pi}{\partial E} + s - \frac{\partial m}{\partial E}(E^*, \hat{t}) - \rho P] \\
&= T^* e^{-\rho(\mathcal{T}^* - \hat{t})} \frac{\partial C}{\partial E} \\
&> 0
\end{aligned}$$

Then applying Implicit Function Theorem to the FOCs, we get

$$\begin{aligned}
\frac{\partial \mathcal{T}^*}{\partial P} &= \frac{\Delta_1}{\det(\mathbf{H})} < 0, \\
\frac{\partial E^*}{\partial P} &= \frac{\Delta_2}{\det(\mathbf{H})} < 0,
\end{aligned}$$

since

$$\Delta_1 := \begin{vmatrix} \rho E & \dfrac{\partial^2 f}{\partial \mathcal{T} \partial E} \\ 1 - e^{-\rho \mathcal{T}^*} & \dfrac{\partial^2 f}{\partial E^2} \end{vmatrix} < 0,$$

$$\Delta_2 := \begin{vmatrix} \dfrac{\partial^2 f}{\partial \mathcal{T}^2} & \rho E \\ \dfrac{\partial^2 f}{\partial \mathcal{T} \partial E} & 1 - e^{-\rho \mathcal{T}^*} \end{vmatrix} < 0,$$

and $\det(\mathbf{H}) > 0$ by Assumption 2 and 3.

3.1.3. Comparative statics of fuel subsidy on vessel life. I now return to the question of the vessel exit decisions of existing holders, who need to decide the exiting time T for an existing vessel of age a.

Proposition 3: [Existence of the optimal exit timing.] With Assumption 1 and 2, The vessel holder's problem admits a unique solution $T^* \geq 0$ for vessel life. The vessel exits at age a if and only if the shadow value of life T diminishes to zero:

$$T^* = 0 \Leftrightarrow y^* := \pi(E) + sE - m(E, a) - \rho PE \leq 0$$

Proof: The FOC is given as

$$\pi(E) + sE - \rho PE = m(E, a + T^*).$$

Proposition 4: [Vessel exit increases on quota price.] The vessel faced with higher market price of quota will exit sooner:

$$\frac{\partial T^*}{\partial P} = -\rho e^{-\rho T^*} E < 0.$$

This Corollary implies vessels in the fleet will exit sooner so that the supply of engine power quota will increase, given higher engine power quota price.

Proposition 5: [Smaller and older vessels exit earlier.] With Assumption 3, given the same subsidy level, newer and larger vessels will always have longer expected life:

$$\frac{\partial T^*}{\partial E} = [\frac{\partial \pi}{\partial E} + s - \frac{\partial m}{\partial E} - \rho P]\frac{1}{\dot{m}} < 0,$$
$$\frac{\partial T^*}{\partial a} = -1 < 0,$$

where $\dot{m} := \dfrac{\partial m}{\partial t} > 0$.

Finally, I am particularly interested in the comparative statics of $\frac{\partial T^*}{\partial s}$, which represents the marginal effect of the fuel subsidy standard on a vessel's useful life. In a rational capital market, the subsidy eligibility s of engine power quota can influence its market value through the capitalization effect. The functional form of $P(s)$ thus adds complexity to the implications of subsidy reform.

Proposition 6: [Impact of fuel subsidy reduction on vessel life.] The reduction in fuel subsidy standard will increase the likelihood of vessel scrappage if and only if the capitalization elasticity of scrap value to subsidy is sufficiently low.

$$\frac{\partial T^*}{\partial s} > 0 \Leftrightarrow \frac{\partial P}{\partial s} < \frac{1}{\rho}.$$

Proof: The relationship is evident from the equation

$$\frac{\partial T^*}{\partial s} = (1 - \rho\frac{\partial P}{\partial s})\frac{E}{\dot{m}}.$$

This proposition reveals that the reduction in fuel subsidy standard will impact the vessel scrappage decision based on the capitalization elasticity of scrap value to subsidy. If the capitalization effect is full, the reduction in fuel subsidy will proportionately impact the power quota price but will not affect the exit incentives. Conversely, if the quota price in transactions is restricted by some price floors, leading to rigid price changes, we can expect $\frac{\partial T^*}{\partial s} > 0$.

3.2. A Simple Model of the Engine Power Quota Market

As stated in **Proposition 6**, the impact of fuel subsidy reduction is conditional on the expectations of the scrap value faced by the vessel owner, and further prediction will require us to analyze the interplay of fuel subsidies, engine power quota prices, and buyback prices to decide the scrap value would react to the fuel subsidy reductions. Based on the insights derived from the individual-level model on optimal vessel investment decisions, I construct a simplified model of the cap-and-trade market for engine power quota to illustrate the mechanisms underlying the impact of China's fuel subsidy reform on fleet capacity.

3.2.1. The engine power quota market. Consider a vessel owner who holds engine power quota, which gives them the perpetual right to fish with a vessel with a given engine capacity. At any given time, the vessel owner receives net benefits through fishery profits from operating the vessel and a lump-sum fuel subsidy. Fishery profits are assumed to be increasing in ex-vessel prices and fishing productivity while decreasing in operating and maintenance costs, which in turn are increasing functions of age. At any given time, a vessel owner weighs the benefit of holding onto their engine power quota against the price they would receive by selling the engine power quota on the market. A vessel owner's reservation price, or the minimum willingness to accept for their engine power quota, is equal to the net present value of the flow of fishery profits over the vessel's expected life and fuel subsidy payments in perpetuity (**Proposition 3**). As power quota prices rise above a vessel owner's reservation price, a vessel owner will be increasingly willing to supply their engine power quota to the market (**Proposition 4**).

The industry supply curve is the horizontal sum of individual vessel owner supply curves and represents the total amount of engine power supplied to the quota market at various prices. Higher quota prices will exceed more vessel owners' reservation prices, giving rise to the upward-sloping supply curve for engine power quota depicted as S^0 in Panel A of Figure 3.1. The industry supply curve can be thought of as representing the periodic flow of engine power quota offerings at any given time. Older, less efficient vessels are located toward the bottom of the supply curve, and new, more efficient vessels are located toward the top (**Proposition 5**).

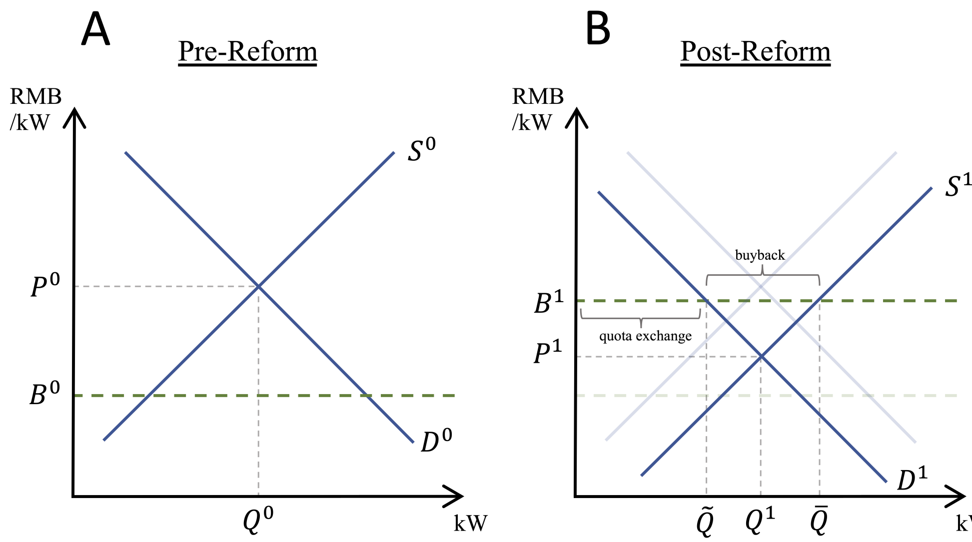

FIGURE 3.1. Model depiction of the market for engine power quota.

Note: Panel A represents the quota market in the pre-reform period, where the equilibrium per-unit quota price (P^0) and quota exchanges (Q^0) are determined by the intersection of the quota demand (D^0) and supply (S^0) curves. Since P^0 exceeds the prevailing buyback price (B^0), no engine power quotas are retired, and fleet capacity remains constant over time. Panel B represents the quota market in the post-reform period, where both the demand and supply curves for quota shift down to D^1 and S^1, respectively, in response to the reduction in fuel subsidy payments. Since the equilibrium quota price (P^1) lies below the new (and higher) buyback price (B_1), a total of $\overline{Q}$ units of quota are transacted, of which $\tilde{Q}$ are market exchanges. The remaining quotas ($\overline{Q} - \tilde{Q}$) are retired through the government buyback program, thereby reducing fleet capacity.

Now consider a would-be new vessel owner who must purchase engine power quota before constructing (or operating) a vessel. A would-be vessel owner's maximum willingness to pay for q units of engine power quota will be equal to the net present value of the flow of fishery profits from operating a vessel with an engine power of size q over its economic life and the lump-sum fuel subsidy payments, in perpetuity (**Proposition 1**). Assuming that the production function of a vessel exhibits decreasing marginal returns to scale in engine power, a would-be vessel owner's maximum willingness to pay per unit of engine power quota is decreasing in engine power. This gives rise to a downward-sloping industry demand curve for engine power quota (**Proposition 2**), depicted as D^0 in Panel A of Figure 3.1, which is the horizontal sum of individual would-be vessel owner demand curves and represents the total amount of engine power demanded in the new-vessel quota market for a given price.

The equilibrium per-unit quota price and flow of quota exchange at any given time are determined by the intersection of the industry supply and demand curves, at which point no more gains from trade remain between current and would-be vessel owners. In Figure 3.1, these are represented by P^0 and Q^0, respectively. In this market, aggregate fleet size does not change over time; rather, exiting vessels sell engine power quotas to entrants, and older, less efficient vessels are replaced by newer and more efficient vessels.

3.2.2. Pre-reform market for engine power quota. Now consider a buyback program in which the government pays vessel owners to retire their power quota at a price of B per unit of power and remove their engine power quotas from the aggregate amount of quota available for the fleet. Vessel owners now have the option of either selling their power quota to a would-be vessel owner at price P^0 or retiring their power quota to the government at price B. Intuitively, vessel owners would be expected to sell their power quota to would-be vessel owners if $P^0 > B$ and if P^0 is greater than their reservation price. Conversely, if $B > P^0$ and B is greater than their reservation price, vessel owners would be expected to retire their power quota to the government. Thus, the buyback price B acts as a price floor in the engine power quota market.

Consider the buyback price B^0 in Panel A of Figure 3.1, which is set below the equilibrium price P^0. In this case, the buyback price does not affect the market for engine power quota. Vessel owners whose reservation price is below P^0 sell their engine quota to would-be vessel owners, and no power quota is removed from the aggregate amount of quota available to the fleet. This situation depicts the situation in China's Zhejiang Province prior to the fuel subsidy reform (2012-2015), where the buyback price was set to 2,500 RMB/kW compared to power quota prices that ranged from 7,000 to 10,000 RMB/kW (Table 4.2). As a result, there were no observed vessel buybacks in the four years prior to the fuel subsidy reform.

3.2.3. Post-reform market for engine power quota. Now consider the situation in China's Zhejiang Province after the fuel subsidy reform in 2016. The reform consisted of two distinct changes: a reduction in the annual lump-sum fuel subsidies and an increase in the per-unit buyback price.

Consider first the reduction in fuel subsidy payments, whose effects are felt by both current and would-be vessel owners. For current vessel owners, the reduction in fuel subsidy payments reduces the net present value of the flow of benefits stemming from receiving lump-sum fuel subsidy payments in perpetuity. Thus, a reduction in fuel subsidy payments results in a decrease in vessel owners' reservation price and a corresponding downward shift in the power quota supply curve equal to the reduced net present value of the flow of subsidy payments in perpetuity. This shift is depicted by a shift in the supply curve from S^0 to S^1 in Panel B of Figure 3.1.

For would-be vessel owners, the reduction in fuel subsidy payments also reduces the net present value of the flow of benefits they would receive from the fuel subsidy payments with the purchase of power quota. Thus, a reduction in fuel subsidy payments results in a decrease in would-be vessel owners' maximum willingness to pay and a corresponding downward shift in the power quota demand curve equal to the reduced net present value of the flow of subsidy payments in perpetuity. This shift is depicted by a shift in the demand curve from D^0 to D^1 in Panel B of Figure 3.1.

The result of reducing fuel subsidy payments is a reduction in the equilibrium power quota price, from P^0 to P^1 in Panel B of Figure 3.1, equal to the reduction in the net present value of the flow of all future subsidy payments. The degree to which fuel subsidy reductions change the quota allocation between market exchanges or quota retirements depends on whether the new equilibrium quota price lies above or below the buyback price. Suppose the buyback price remained unchanged at the pre-reform price B^0, as Panel B of Figure 3.1 depicts. Then there is no change in the flow of power quota exchanges or vessel retirements since the demand and supply curves shift down by the same amount, and the new equilibrium quota price lies above the buyback price. In this case, reducing fuel subsidy payments does not lead to any capacity reduction.

Now consider the situation observed in China's Zhejiang Province after the fuel subsidy reform, where the buyback price was raised to the pre-reform equilibrium power quota price (approximately), depicted by B^1 in Panel B of Figure 3.1, which lies above the new equilibrium quota price P^1. At a buyback price of B^1, current vessel owners are willing to supply $\overline{Q}$ units of engine power quota, while would-be new vessel owners are only willing to purchase $\tilde{Q}$ units. Thus, the flow of vessel exits would be expected to increase from Q^0 to $\overline{Q}$, of which $\overline{Q} - \tilde{Q}$ units of power quota are retired to the government. In this case, a reduction in fuel subsidy payments and an increase in the buyback price do lead to capacity reduction. Moreover, owners with older and less efficient vessels, whose reservation prices are lower, would be expected to comprise the bulk of fleet capacity reduction.

In the short run, this new pattern of vessel exits and retirements would be expected to persist as the current stock of vessels ages. Over the long run, however, with fewer new vessels entering the fleet as vessel owners retire their power quotas, the power quota supply curve would be expected to shift up over time until the power quota equilibrium price is equal to the buyback price. At that point, a new long-run equilibrium fleet capacity is reached, and vessel exits take place through the power quota market.

Testable Hypotheses. The analysis above leads to the following testable hypotheses:

- *Hypothesis 1*: The reform of China's fuel subsidy program will increase the vessel exit rate.
- *Hypothesis 2*: The reform-induced increase in the vessel exit rate will persist over time in the short run.
- *Hypothesis 3*: If the reform reduces power quota prices below the buyback price, fleet capacity will decrease as vessel owners are incentivized to retire their engine power quotas to the government through the buyback program.
- *Hypothesis 4*: Fleet capacity reduction will disproportionately be comprised of older and less efficient vessels.

3.3. Capacity Dynamics in the Long-run Bioeconomic Equilibrium

The preceding sections have formulated testable hypotheses concerning the short-term effects of subsidy reform regarding vessel investment behaviors and fleet dynamics. However, before delving into the examination of these hypotheses using micro-level data in the next chapter, I aim to conclude the analysis of capacity management and fisheries subsidy with an industry-level long-run stationary analysis from the perspective of a fishery manager. Utilizing a bioeconomic model will provide valuable insights into the long-term consequences of subsidy reform and aid in determining the optimal design of the buyback program for capacity reduction.

3.3.1. Competitive equilibrium of an open-access fishery. To illustrate the working mechanisms of the buyback program on the capacity management of marine fisheries in China, I construct a stylized model for a limited entry fishery managed with engine power quotas.

I begin with the classical Gordon-Schaefer model, where E represents the total fishing power in the fishery, X denotes the biomass stock, and the Schaefer harvest function is given as $Q = \theta EX$. The biomass growth can be represented as:

$$\dot{X} = \gamma X \left(1 - \frac{X}{K}\right) - Q,$$

and from $\dot{X} = 0$, the stationary yield function of the fishery can be derived as:

$$Q(E) = \theta KE \left(1 - \frac{\theta E}{\gamma}\right).$$

Assuming a perfectly competitive fish market and rising marginal cost of production due to congestion, the profit function of the industry can be represented as:

$$\Pi(E) = pQ(E) - cE^2.$$

In an open-access fishery, the fishing power in the competitive equilibrium E^c will be determined by the condition $\Pi(E^c) = 0$.

3.3.2. Engine power quota price in a limited-entry fishery. Now, let's introduce the cap-and-trade management of engine power to restrict entry into the fishery. The fishery manager aims to cap the total fishing power by issuing the engine power quota at $\overline{E} \leq E^c$, resulting in a perfectly inelastic supply curve of engine power quota, where $E = \overline{E}$.

In the long run and under perfect competition, the market price of quota will rise to a level where the NPV of entry is 0, as shown in the following equation:

$$NPV = \int_0^\infty e^{-\rho t}\Pi(\overline{E})\mathrm{d}t - P^M\overline{E} = 0.$$

From the zero-profit condition, the price-quantity relationship for the power quota can be derived as:

$$P^M(\overline{E}) = \frac{\Pi(\overline{E})}{\rho\overline{E}} = \frac{p\theta K}{\rho} - \frac{p\theta^2 K + c\gamma}{\gamma\rho}\overline{E}.$$

The derived inverse demand curve for power quota is linear and slopes downward until all rent dissipates if the total engine power quota exceeds the maximum capacity of the competitive equilibrium. This can be simplified as:

$$P^M(\overline{E}) = \begin{cases} \alpha - \beta\overline{E} & \text{if } \overline{E} \leq E^c \\ 0 & \text{if } \overline{E} > E^c, \end{cases}$$

where α and β are positive constants.

3.3.3. Engine power quota price with fuel subsidy. Consider a fishery subsidy issued based on power quota, with a long-run discounting rate to fishers denoted as r. The market equilibrium condition can be expressed as follows:

$$NPV = \int_0^\infty e^{-\rho t}\Pi(\overline{E})\mathrm{d}t + \int_0^\infty e^{-rt} s\overline{E}\mathrm{d}t - P^M\overline{E} = 0.$$

Letting $\delta = \frac{1}{r}$, we obtain:

$$P^M(\overline{E}) = \alpha - \beta\overline{E} + \delta s.$$

Thus, an increase in fuel subsidy will shift the demand curve for power quota rightward, ultimately raising the quota price in the limited entry fishery.

It is important to note that, with fishery subsidies, fishing power can be maintained at $\overline{E} > E^c$, whereby the subsidy compensates the loss from fishery operation. Only under such conditions can reductions in the subsidy standard effectively reduce the total fishing power in the system, leading marginal fishermen experiencing operational losses to exit the fishery.

3.3.4. The optimal buyback price for capacity control. Suppose the fishery manager initiates a buyback program, proposing a buyback price B for fishers willing to divest their vessels. However, when when the buyback price $B < P^M(\overline{E})$, rational vessel owners seeking to maximize their profits will refrain from selling their quota to the government, rendering the program ineffective. This scenario is particularly relevant post the introduction of the fuel subsidy and prior to the 2016 subsidies reform.

Alternatively, when $B > P^M(\overline{E})$, the power quota held by the exiting vessels will be reclaimed from the system, causing a reduction in the overall quota supply. Consequently, the market price of the quota will increase until it reaches or falls below the buyback price $B \leq P^M(E^B)$. In the context of the model, in the post-buyback equilibrium, the total amount of fishing power remaining in the fishery will be determined by the solution to the equation:

$$B = \alpha - \beta E^B + \delta s,$$

where $E^B - \overline{E}$ represents the capacity reduction resulting from the buyback program.

In conclusion, the buyback price serves as the stipulated minimum price for capacity exit within this cap-and-trade system, as administered by the fishery manager to regulate the supply of power quota. To optimize the sustainable economic profit of the fishery, the fishery manager should determine the buyback price as $B = P^M(E^{\text{MEY}})$, where E^{MEY} represents the fishing power associated with the maximum economic yield on the yield curve, denoted as $E^{\text{MEY}} := \text{argmax}_E \Pi(E)$.

CHAPTER 4

Fisheries Subsidy Reform and Fishing Capacity Control: Evidence from the Largest Trawl Fleet on the East China Sea

4.1. Introduction

In recent years, the world has witnessed a growing awareness of the need to address the challenges posed by overcapacity and dwindling marine resources in fisheries. As governments seek to align their policies with global sustainability targets, fishery subsidy reform has emerged as a pivotal solution to rectify misaligned incentives and enhance resource conservation among members of the World Trade Organization. However, the effectiveness and necessity of such reforms remain topics of significant debate, particularly in regions with unique fishery management structures, like China.

Against this backdrop, this chapter focuses on two essential dimensions of fishery subsidy reform. First, I delve into the effectiveness of subsidy reduction as a means of controlling fleet capacity. By exploiting the quasi-experimental design created by the reform, I disentangle the impact of subsidy reductions on vessel exit from contemporaneous shocks and confounding features correlated with subsidy assignments.

Second, I explore the interplay between subsidy reform and other input control mechanisms, such as cap-and-trade systems for fishing permits and buyback subsidies. These additional policy instruments present a complex regulatory landscape, and understanding how subsidy reform interacts with them is crucial for devising integrated and effective management strategies.

The centerpiece of the research design is a unique natural experiment provided by the large-scale fuel subsidy reform undertaken in China's trawling fleet in 2016. The institutional background and theoretical modeling regarding this profound subsidy reform have been introduced in detail in

Chapters 2 and 3. Building upon the insights derived in previous chapters, this chapter assesses the real-world impact of subsidy reform on fleet dynamics and vessel scrappage.

By utilizing extensive and detailed administrative data, I can assess the real-world impact of subsidy reform on fleet dynamics and vessel scrappage. This rich dataset allows me to investigate the short-term effects of fuel subsidy reduction on fleet capacity and buyback dynamics. Focusing on China's trawling fleet, the analysis seeks to draw reliable and robust conclusions regarding the effectiveness of subsidy reform in controlling fleet capacity.

Leveraging this empirical setting, I employ a difference-in-differences (DD) design with a continuous treatment to assess the exit (or buyback) elasticity concerning fuel subsidy reductions for all vessels. To enhance the analysis, I incorporate a regression-discontinuity difference-in-differences (RD-DD) approach, which directly exploits the variation in fuel subsidy payments resulting from the vessel-length thresholds in the post-reform years. Within the fleet under investigation, I observe that a 1% decrease in fuel subsidy leads to a 0.15 percentage point increase in the likelihood of a vessel exiting, with older and smaller vessels displaying higher responsiveness to the subsidy reduction.

Decomposing the treatment effect through counterfactual analysis, I find that the reduction of harmful subsidies was accountable for 40% of fleet capacity reduction through vessel buyback. At the same time, an increase in vessel retirement subsidies also played a vital role in driving capacity reduction. This finding illustrates that the effectiveness of eliminating harmful subsidies hinges on the specific policy context in which these removals take place.

The findings in this chapter carry significant implications for the discussions about global fishing subsidy reform. As the first large-scale empirical micro-level study in this domain, by shedding light on the intricate relationship between subsidy reform and other policy instruments, this investigation serves to advance the understanding of the role of fishery subsidy reform in fostering sustainable fisheries, not only in China but also across diverse fisheries worldwide. The lessons gleaned from this research offer valuable practical experiences for policymakers seeking to strike a balance between ecological conservation, socio-economic development, and the long-term sustainability of marine resources.

The chapter is structured as follows. Section 4.2 details the data sources used in the empirical analysis. Section 4.3 describes my empirical strategy and the natural experiment induced by the fuel subsidy reform. Sections 4.4 and 4.5 present the main results, robustness checks, and heterogeneity analyses. Section 4.6 simulates the counterfactual fleet capacity of the reform based on the empirical results. Section 4.7 discusses and concludes.

4.2. Data Description

This study focuses on the dynamics of a fleet of trawling vessels in China's Zhejiang Province, which is the largest fishing fleet in the East China Sea and is managed by the most important coastal province for the marine fisheries of China. Trawling is the dominant form of fishing method in the offshore fisheries of China and Zhejiang, contributing to one-half of the marine harvest by weight for China and two-thirds for Zhejiang. By 2011, Zhejiang residents owned 8,459 trawl gear vessels, accounting for one-third of the total fishing power in all of China's trawl fisheries. Under the Communist Party of China's (CPC) "negative growth" strategy, fishery managers have devoted special administrative efforts to restrict the use of trawlers due to their high fishing intensity, low selectivity, and extensive damage to sea-floor habitats. Since 2007, the fishery department of Zhejiang has limited entry to the trawling fishery by restricting the conversion of other gears into trawling vessels.

4.2.1. Data Sources.

4.2.1.1. *Administrative records of trawling vessels in Zhejiang.* Vessel-level information primarily comes from the records of the Marine Fishing Vessel Dynamic Management System (MFVDMS) provided by the Zhejiang government. Established by the Ministry of Agriculture (MOA) and accessible to fishery departments in 2011, this administrative platform of fleet capacity is comprised of five modules: power quota, vessel name, vessel inspection, vessel registration, and fishing license, corresponding to each section of the vessel management activities. Each module is responsible for documenting the acquisition and cancellation of respective certificates for all fishing vessels in the so-called "double control" system. The five modules together are integrated into a relational database to monitor vessels' lifetime dynamics from construction to scrappage. This national administrative database contains the most comprehensive and authoritative vessel-level information with respect to the fishing fleet dynamics of China.

The raw datasets from MFVDMS are archived information of certificates issued by the fishery departments to fishing vessels in Zhejiang province. The archives cover management activities within each module over the fleet until early 2021. All datasets provide "vessel ID", a 16-digit code uniquely assigned to each vessel by the fishery departments, to link vessels across datasets.

4.2.1.2. *Subsidy payments.* I collected policy documents for the fuel subsidy and buyback program published by the fishery departments in Zhejiang Province from 2006 to 2019 to calculate the eligible annual subsidy payments for each trawler in the dataset. Moreover, as required by the MOA, each subsidy payment should be directly deposited to fishers' bank accounts and announced to the public by the local government for transparency. Therefore, I also collected the vessel-level subsidy payment records of major coastal counties from announcements on government websites and digitized newspapers to validate the implementation details of the fishery subsidy standards for the corresponding periods.

4.2.1.3. *Catch-per-unit-effort, diesel prices, and engine power quota prices.* I collected aggregated statistics on fishing capacity and harvests from the Fishery Yearbook of China for the years 2003 to 2020 to compute the CPUE of the trawling fishery in Zhejiang. I also collected the ex-factory diesel prices from the announcements of China's Ministry of Commerce. Lastly, I collected and cross-checked the observed market prices of engine power quota in Zhejiang province from published papers, surveys, and news reports.

4.2.2. Main Dataset. I begin the compilation of the main dataset by finding all vessels whose main gears are registered as "trawl" in the latest records of fishing license and vessel scrappage certificates from the power quota and fishing license modules. I then match those vessels with the records of vessel registration and inspection certificates for characteristics including construction time, principle dimensions, vessel material, and fishing operation. At the end of this step, I am left with a dataset of 10,519 trawlers identified with unique vessel IDs.

To extract the information on vessel exiting, I combine the records of the scrappage and deregistration certificates to screen out all fishing vessels that applied for scrappage. I then match the dataset for trawlers with the dataset for scrapped vessels to identify the scrappage status and buy-back choice for each trawler in the fleet. The scrappage time in the resultant dataset ranges from 2009 to 2020.

Under the monitoring of the fishery administration, each fishing vessel must have their license and registration certificates renewed within at most 5 years. Each vessel to be removed from the fleet must apply for proof of vessel scrappage and for the cancellation of its current vessel registration and fishing license. Therefore, the dataset should capture all the vessels in the trawling fleet of Zhejiang from 2011, except for those who had switched to different gear types before 2015. I compare the fleet dynamics recovered from the dataset with the aggregated statistics from Fishery Yearbooks to verify the sample representativeness.

The empirical analysis focuses on steel-hulled motor-powered trawlers with lengths greater or equal to 24 meters, which are officially large vessels under China's taxonomy of fishing vessels and the main force of the off-shore fisheries. This sample selection procedure screens out trawlers at the left tail of the capacity distribution and leaves us with a dataset of 9,183 trawlers for further analysis.

To study the impact of the subsidy reform on exiting activities in the fleet, I select all trawlers recorded to exist in 2011 but not subject to compulsory scrappage in the main dataset. I reshape it into an unbalanced panel to track the exiting activities of the 7,685 vessels in the 2011 cohort between 2012 and 2019. The outcome variables in the panel are binary failure indicators of exiting decisions and the treatment variable is the eligible annual fuel subsidy payments defined for surviving vessels in each year.

4.2.3. Descriptive Evidence. Table 4.1 summarizes the fleet dynamics of large trawlers in Zhejiang province from the compiled dataset. A before-and-after comparison of vessel activity suggests that vessel exit and construction decisions were substantively affected by the reformed fuel subsidy program. In the four years following the reform, the number of large trawling vessels in the Zhejiang Province decreased by 22%, compared to 2% in the four years 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 pre-reform years to 7.1% in the post-reform years—and a decrease in the number of new vessels being constructed.

Most notably, consistent with the raised buyback price and the reduced fuel subsidies, fishers' willingness for vessel buyback program was rekindled after the 2016 subsidy reform: 54% of the vessels that exited the fishery in the post-reform years surrendered their engine power quota through the buyback program, a considerable increase over 0% in the four years preceding the fuel subsidy reform.

TABLE 4.1. 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)[a]	Fuel Price (RMB/MT)	Buyback Price (RMB/kW)	CPUE (MT/kW)[b]
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

Source: 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 post-reform period are shaded.

[a] Fuel subsidy is calculated as the annual average payments per power.

[b] Catch per unit effort (CPUE) is calculated from the aggregated statistics for trawling fisheries in Zhejiang, reported by the China

Table 4.2 compares the dynamics of annual fuel subsidy, buyback price, and engine quota prices observed in Zhejiang fisheries since the introduction of fuel subsidy program. 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 exiting fishermen chose to surrender their quota through the buyback program rather than sell to a new entrant. But as fuel subsidies were introduced, engine power quota prices rose beyond the buyback price to reflect the capitalized value of anticipated future payments (Wang and Pan, 2016). This in turn choked off incentives for exiting fishermen to surrender their quota to the buyback program.

Table 4.2. The 2006-2019 dynamics of fuel subsidy standards and engine power quota prices in Zhejiang trawling fisheries

Year	Fuel subsidy (RMB/kW)	CPUE (MT/kW)	Diesel Price (RMB/MT)	Buyback Price (RMB/kW)	Quota Price (RMB/kW)
2006	205	0.90	4328	800	500~800
2007	330	0.65	4654	1000	1000~1200
2008	850	0.65	5564	2500	1500~2000
2009	-	0.75	5519	2500	1800~2200
2010	747	0.83	6509	2500	3500~4000
2011	1232	0.90	7508	2500	5000~6000
2012	1681	0.90	7765	2500	7000~9000
2013	1831	0.89	7651	2500	10000
2014	1774	0.94	7315	2500	8000~10000
2015	1608	0.99	5706	2500	7000
2016	1148	1.01	5380	7500	6000~9000
2017	950	1.02	6195	7500	6000~9000
2018	786	0.93	7455	7000	6000~9000
2019	645	0.92	6924	7000	6000~9000

Note: Fuel subsidy is calculated as the average annual payment per kW for trawlers. 2009 is the transition year and starting in 2010, the annual fuel subsidy was paid to fishers based on the diesel prices of the previous year. Engine power quota prices were taken from field observations on the market of Zhejiang.

The reformed fuel subsidy program thus 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 (Figure 4.1). In turn, the reduction of expected future fuel subsidy payments brought about decreases in quota prices for engine power (Table 4.2). Together with the revised buyback prices, surrendering engine power quota through the buyback program began to look more attractive to fishers.

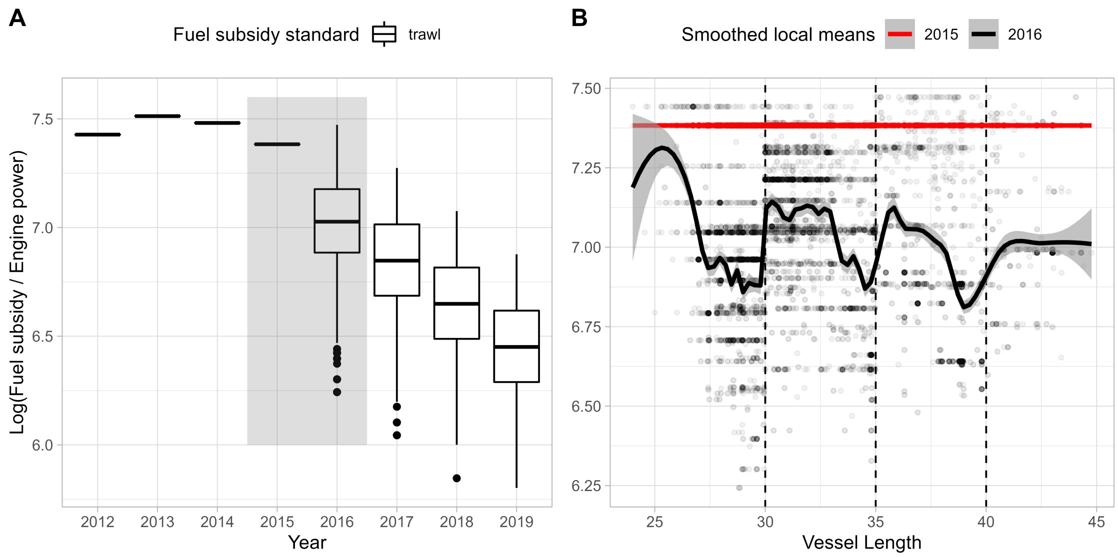

FIGURE 4.1. Exogenous variations in fuel subsidy payment per engine power aross years and vessel length.

The reformed fuel subsidy program also has important implications for the evaluation of its impact. As discussed, reformed fuel subsidy payments were based on vessel classes determined by vessel-length thresholds. For example, vessels just below the 30-meter threshold received fuel subsidy payments that were approximately 25% lower than vessels just above the 30-meter threshold in the post-reform years, despite receiving nearly the same fuel subsidy payments in the pre-reform years (Figure 4.1). Such sharp local discontinuities yield quasi-experimental variation in the assignment of fuel subsidy reductions across vessels, which I use to identify changes in vessel exiting decisions that are solely attributable to the reform itself.

4.3. Empirical Strategy

To evaluate changes attributable to the reform, I estimate the relationship between fuel subsidy reductions and the hazard rate of exiting the fishery using two quasi-experimental approaches. Based on the structure of exogenous variations in the fuel subsidy payments, I 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. I 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 post-reform years. The details of these approaches are discussed below.

4.3.1. Difference in difference (DD). To measure the elasticity of exiting (buyback) decisions y_{it} with respect to annual subsidy payments s_{it}, consider the following DD design with a continuous treatment:

$$y_{it} = \beta \ln(s_{it}) + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t \mathbf{X}_i + u_{it},$$

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 interactive fixed effects $\nu_t \mathbf{X}_i$ 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. The linear transition probability model above is a linear approximation of the discrete-time conditional hazard function of vessel exit, where age fixed effects λ_{a_t} capture the baseline hazard at the age a_{it}.[1] The parameter of interest (β) represents the marginal effect of fuel subsidy payments on the probability of exit (or buyback), conditional on not exiting before year t.

It is important to note that β is identified by the one-time reduction in the baseline fuel subsidy standard brought about by the 2016 reform, which I argue below can be considered exogenous. In contrast, the initial allocation of fuel subsidies and year-to-year variation in fuel subsidies common across all vessels do not factor into the identification because they are soaked up by the vessel- and year-fixed effects, respectively. To see this, note that vessel i's' fuel subsidy in year t is determined by two components: $s^p_{i,t} = base^p_i \times adj^p_t$, where $p \in \{pre, post\}$ denotes whether year t occurs in the pre- or post-reform period (see Chapter 2 for a more comprehensive discussion of the components

[1]To see the equivalence, let $\mathcal{T}_i > 0$ be the life spell and a_{it} be the vessel age for vessel i. Let $h_{it} = h(a_{it}|\mu_{it})$ be the conditional hazard of exiting at the age a_{it} and μ_{it} be a vector of predetermined covariates. The discrete-time conditional hazard function h_{it} is also the conditional expectation function of y_{it}, since

$$\begin{aligned} h_{it} &= \Pr[a_{it} \leq \mathcal{T}_i < a_{i,t+1} \mid \mathcal{T}_i \geq a_{it}, \mu_{it}] \\ &= \Pr[y_{it} = 1 \mid y_{i,t-1} = 0, \mu_{it}] \\ &= \mathrm{E}[y_{it} \mid \mu_{it}], \end{aligned}$$

for which OLS can provide the best linear approximation.

that determine fuel subsidy payments). The first component $base_i^p$ refers to the vessel's baseline subsidy standard, which does not vary across years. The second component adj_t^p refers to an annual adjustment to each vessel's subsidy. Letting $I_t = \mathbf{1}\{t \geq 2016\}$ indicate the post-reform period, I can thus write the natural log of vessel i's fuel subsidy in year t as:

$$
\begin{aligned}
\ln(s_{it}) &= I_t(\ln(s_{it}^{post}) - \ln(s_{it}^{pre})) + \ln(s_{it}^{pre}) \\
&= I_t(\ln(base_i^{post} \times adj_t^{post}) - \ln(base_i^{pre} \times adj_t^{pre})) + \ln(base_i^{pre} \times adj_t^{pre}) \\
&= I_t(\ln(base_i^{post}) - \ln(base_i^{pre})) + \ln(base_i^{pre}) + I_t \ln(adj_t^{post}) + (1 - I_t)\ln(adj_t^{pre}) \\
&= I_t(-\Delta_i) + \ln(base_i^{pre}) + I_t \ln(adj_t^{post}) + (1 - I_t)\ln(adj_t^{pre}),
\end{aligned}
$$

where Δ_i denotes the reduction in vessel i's baseline fuel subsidy standard (the measure of treatment exposure). Thus, the common adjustments of fuel subsidies across all vessels, adj_t^p, get absorbed into the year fixed effect (γ_t), while the pre-reform baseline, $base_i^{pre}$, gets absorbed by the vessel fixed effects (c_i). Therefore, identification of β stems from reform-induced changes in the baseline fuel subsidy standard rather than year-to-year adjustments in fuel subsidy payments.

The main estimation equation for the DD design is thus

$$
y_{it} = \beta \Delta_i I_t + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t \mathbf{X}_i + u_{it}, \tag{4.1}
$$

where the parameter β captures the variation in y_{it} related to the persistent reduction in s_{it} brought by the reform, which represents fishers' long-term adjustments of exit decisions in response to a persistent change in the baseline subsidy payment. The interpretation for β is: a 1% reduction in the baseline fuel subsidy standard caused by the reform will, on average, increase the annual exit probability by β percentage points over the post-reform period.

I measure the change in vessel i's baseline fuel subsidy standard (Δ_i) as the reduction in the average annual fuel subsidy post-reform compared to that pre-reform:

$$\Delta_i = \log\left(\frac{\bar{s}_i^{pre}}{\bar{s}_i^{post}}\right) = \log\left(\frac{\text{Avg}_{t<2016}s_{it}}{\text{Avg}_{t\geq 2016}s_{it}}\right).$$

Δ_i therefore indicates a vessel's dose of treatment exposure to the reform: the higher Δ_i assigned by the new subsidy rule, the larger the income shock received by the vessel owner. In the DD strategy, the imposition of vessel-length thresholds in 2016 can be taken as an exogenous assignment of Δ_i across vessels. Before the subsidy reform of 2016, each trawler's eligible fuel subsidy per power only varies annually with diesel prices, while after 2016 the baseline subsidy standard is a predetermined variable by the vessel length, engine power, and gear type registered pre-reform. With the subsidy standard reform based on vessel classes, Δ_i is larger for trawlers just below the eligibility thresholds relative to those just above the threshold (Figure 4.1). The discontinuities in subsidy payments resulting from arbitrarily placed length thresholds and vessel length variation over horsepower serve as the cross-sectional variation in Δ_i to identify β.

The vessel features influencing the subsidy assignment can intrinsically correlate with the tendency to exit and the impacts of unobserved time-varying covariates, including fuel prices, sea conditions, and fishery stocks. The interactive fixed effects $\nu_t\mathbf{X}_i$ purge out omitted variable bias associated with vessel characteristics that may influence the exit decision differently across years, such as engine power, vessel length, total tonnage, and fishing operation. After the absorption of $\nu_t\mathbf{X}_i$, the exogenous variation left for identification primarily comes from the discontinuities in the post-reform subsidy assignments generated by the multiple vessel-length thresholds.

The causal interpretation of β as the average treatment effect in the DD model is built on the parallel trend assumption; hence, I explicitly test this assumption using an event study specification:

$$y_{it} = \sum_{j=2012}^{2019} \beta_j \Delta_i^{base} I_t^j + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t\mathbf{X}_i + u_{it}. \tag{4.2}$$

where $I_t^j = \mathbf{1}\{t = j\}$. If the assignment of treatment exposure is exogenous, we should observe that the trends in exit probability across vessels with different treatment exposure only diverge after the reform shock but not before. Since the identification stems from the one-time exogenous reduction in the baseline fuel subsidy standard, the event-study coefficients β_j capture year-specific responses to changes in the baseline fuel subsidies that occurred at the time of the reform.

4.3.2. Regression discontinuity difference-in-differences (RD-DD). Complementing the baseline continuous-treatment DD design, the primary merit of the RD-DD is its transparency. The RD design clearly defines the comparison groups and relies on the local continuity of potential outcomes at the vessel-length threshold for identification, where I can provide clear evidence to verify the identification assumption.

To estimate the treatment effect of subsidy payment on exit decisions, an ideal experiment would randomly assign vessels in a fleet to high-subsidy and low-subsidy groups and then compare the exit hazard between these two groups. The cross-sectional variation in the fuel subsidy level around the vessel-length threshold provides the random assignment I desire. The registered vessel length is determined at the construction time with an accuracy to the centimeter. Before 2016, trawlers received the same fuel subsidy per engine power each year. After the 2016 reform, trawlers over the threshold received substantially higher fuel subsidy payments than trawlers with the same power and gear just below the threshold. For the non-manipulation and local continuity of vessel length, vessels around the threshold should be similar and comparable so that the assignment of high and low subsidy standards is as good as random.

An RD-DD design is embedded in this quasi-experiment. Since the probability of receiving higher subsidy payments after the reform is abruptly higher for vessels with lengths just above the vessel-length thresholds, I can use a fuzzy-RD strategy to estimate the marginal treatment effect of subsidy payments on exit decisions. Moreover, as the vessel-length threshold is only imposed after the reform, I can conduct event studies for the treatment effect at the threshold before and after the reform and use pre-reform periods as placebo tests to verify the continuity of potential outcomes.

For the sake of transparency, the multiple-period fuzzy-RD starts from the reduced-form two-stage least squares (2SLS) estimation of the effect of the vessel-length (or treatment) thresholds on the probability of exit in each year. My primary specification uses local linear regression within a given bandwidth of the treatment threshold, and controls for the running variables (vessel length) on either side of the threshold. The RD-DD specification identifies the local treatment effect of the reform as the difference in the discontinuity before and after the reform:

$$y_{it} = \delta_{0t} + \delta_{10} d_i + \delta_{11} D_{it} + \delta_{2t} l_i + \delta_{3t} d_i \times l_i + \zeta_t \mathbf{X}_{it} + u_{it} \text{ if } |l_i| \leq h, \tag{4.3}$$

where d_i is an indicator for vessel length being above the threshold $d_i = 1\{L_i > \tilde{L}\}$, $D_{it} = d_i \times \mathbf{1}\{t \geq 2016\}$ is an indicator for being assigned with higher subsidy payments than others in the post-reform years, and l_i is the re-centered running variable $l_i = L_i - \tilde{L}$. The bandwidth h is specified by the optimal bandwidth choice. The parameters δ_{10} and δ_{11} in this RD-DD specification capture the pre-existing discontinuities and the event-associated difference in discontinuities at the threshold for the pre- and post-reform period, respectively.

Based on the reduced-form specification, the 2SLS specification for the fuzzy-RD is given as:

$$\ln(s_{it}) = \gamma_{0t} + \gamma_{10} d_i + \gamma_{11} D_{it} + \gamma_{2t} l_i + \gamma_{3t} d_i \times l_i + \nu_t \mathbf{X}_{it} + \epsilon_{it} \text{ if } |l_i| \leq h \tag{4.4}$$

$$y_{it} = \beta_{0t} + \beta_1 \ln(s_{it}) + \beta_{2t} l_i + \beta_{3t} d_i \times l_i + \mu_t \mathbf{X}_{it} + v_{it} \text{ if } |l_i| \leq h \tag{4.5}$$

where I use d_i and D_{it} to instrument for the subsidy payment s_{it} in the second-stage regression. The β_1 is the local average treatment effect of fuel subsidy on exit probability I aim to estimate.

I estimate both conditional and unconditional RD-DD specifications and control for year and age fixed effects in all estimations. For the conditional RD-DD specification, vessel features $\mathbf{X}_{it}$ include engine power, total tonnage, and fishing operation. While these covariates turn out not to be necessary for identification, they help increase the efficiency of the estimates. As with the estimation of the DD model, I cluster the standard error at the vessel level for inference.

Identifying assumptions. The key identifying assumption for the DD design is parallel trends in potential outcomes—i.e., any unobserved confounding factors must be time-invariant (Angrist and Pischke, 2009). Similarly, the key identifying assumption for the RD-DD design is that any unobserved confounding factors at the vessel-length thresholds must also be time-invariant (Grembi et al., 2016). I carefully consider the validity of these assumptions from a design-based perspective to ensure that the treatment assignment in the quasi-experiment is exogenous to potential outcomes, conditional on observed covariates.

I first rule out the threat that the reform designer intentionally imposed the subsidy standard based on unobservable characteristics underlying the post-reform exit tendency of vessels. As the policy declares, the post-reform subsidy standard is designed to be deterministic on the pre-reform vessel features. While the subsidy coefficients for gear types are selected with conservation targets, my specifications only utilize the arbitrary discontinuities of eligible subsidies across vessel-class thresholds for identification, which are generated without intention by design. The eligibility thresholds are evenly placed into continuous features to split vessel classes. Moreover, the baseline subsidy for each vessel class between thresholds is determined by the average of registered powers in 2014 for vessels in the corresponding class.

The remaining threats to the identifying assumptions are anticipation and self-selection into post-reform treatments. A few facts alleviate concerns over whether existing vessel owners can forecast the subsidy reform design in making exit decisions, and whether they can manipulate vessel features for higher subsidy payments.

First, the advent of fuel subsidy reform, especially the new subsidy standards based on vessel reclassification, is exogenous and unanticipated by vessel owners. Like many policies in China, the reform is designed in a "top-down" mode. The fuel subsidy level for the reform is issued by the MOA without community discussion or local trials. The "top-down" feature of this reform can be evidenced in the address at the National Fishery Work Conference of March 2016, where the minister of MOA specifically directed local governments to accelerate the submission of reform plans and to explain the policy to fishers (Ministry of Agriculture Fisheries Administration Bureau, 2016).

Second, reciprocal to the "top-down" mode is fishers' limited access to policy information. According to surveys in Zhejiang, most local vessel owners only have limited knowledge of fishery subsidy mechanisms and rely on local governments and communities for policy information (Songli et al., 2016). Moreover, the annual subsidy standards for all post-reform years were published all at once at the advent of the reform. Hence it is improbable that fishers had perfect foresight of future payment changes in advance of official decisions and responded to the reform long before the execution of the reform.

Third, subsidy eligibility based on technical dimensions is hard to manipulate for existing vessels. The annual fuel subsidy standard for a trawler is determined by its engine power, vessel length, and fishing gear registered on the license. Aside from the engineering difficulties, any technical modification of these features needs approval and inspection from the fishery and maritime departments.

Finally, the proactive policy design that protects against loopholes undercuts the incentives to manipulate vessel length. The fishery department of Zhejiang specifically mandated that for vessels modified after 2014, their subsidy would be capped by what they would otherwise be eligible for without these modifications (Zhejiang Province Ocean and Fisheries Bureau, 2016). The execution of this mandate is confirmed in the local announcements of the subsidies issued. Consistent with the incentive design, I observe few modifications within the license system after 2014 in the data. Indeed, I observe only 14 vessels in the sample whose length was modified during the sample, all of which occurred after 2014, the year used for determining fuel subsidy eligibility. Thus, these vessel-length modifications would not have altered a vessel's subsidy payments in the post-reform period.[2]

Anticipation effects. Although vessel owners were unlikely to have perfect foresight regarding fuel subsidy reductions prior to the execution of the reform, I cannot completely rule out that there was some anticipation of a policy change (even if it was uncertain). If vessel owners anticipated the policy, they may have changed their exiting behavior prior to the reform, thereby "contaminating" the pre-reform period—i.e., it wouldn't reflect true exiting behavior given the fuel subsidy payment at that time. Such behavior may explain the decrease in vessel exits and construction in 2015, the year before the reform.

To test whether possible contamination of the last pre-treatment year influences results, I drop 2015 from the analysis and re-estimate the event-study specification, measuring all year-specific treatment effects relative to 2014. These estimation results are presented in column (4) of Table

[2]Note that the estimates from the main specifications are virtually unchanged when I drop these vessels from the sample.

A.4 and exhibit very little change from the main results. Since anticipation of the policy before 2015 is highly unlikely, anticipation of the fuel subsidy reform does not likely influence the results.

Stable unit treatment value assumption (SUTVA). The interpretation of β as the marginal effect of a persistent reduction in fuel subsidies on a vessel's probability of exiting the fishery relies on the stable unit treatment value assumption (SUTVA). Formally, SUTVA requires the potential outcomes of any unit to be independent of the treatment status of other units (Rubin, 1980). In this case, the assumption requires that a vessel owner's potential exit decision, given a subsidy payment reduction, is independent of the subsidy payment reductions incurred by other vessel owners. Previous work has demonstrated the challenges of satisfying SUTVA when policy changes have general equilibrium effects (Heckman et al., 1998) or occur within dynamic systems with feedback across social and environmental dimensions (Ferraro et al., 2019). I investigate the possibility of such SUTVA violations in the study environment below and conclude that they are likely not an issue for my investigation.

For the sake of simplicity, I consider an idealized experiment in which vessel owners in a treatment group receive a subsidy reduction while vessel owners in a control group do not. This simplification makes it easier to conceptualize the possibility of a SUTVA violation while still being applicable to the more general setting in which all vessels are treated to varying degrees.

First, consider the possibility of a SUTVA violation through a "general equilibrium effect," whereby the subsidy reductions for treated vessels may spill over to the control vessels through the market for engine power quotas. In the pre-reform period, all engine power quotas are identical—each kW of quota receives the same subsidy payment and can be applied to any newly constructed vessel. Thus, we would expect the market for quota before the reform to be characterized by a single equilibrium price. In the post-reform period, each unit of quota for the treatment vessels receives a lower subsidy payment compared to the control vessels' quota. Thus, the treatment creates two markets for quota: one for the higher-valued quota owned by the control vessels and one for the lower-valued quota owned by the treated vessels. In equilibrium, we would expect the difference in price between these two markets to be equal to the net present value (in perpetuity) of the difference in the subsidy payments. Since the treatment created two separate markets for quota, subsidy reductions for the treated vessels do not influence the quota price, and thus the exit decisions, of the control vessels. Therefore, SUTVA is not violated.

Next, consider the possibility of a SUTVA violation through a "rebound effect," whereby the subsidy reductions for treated vessels may benefit the control vessels through improved fishing conditions as treated vessels retire their quota. While the retirement of vessels may improve the profitability of vessels that remain in the fishery as fishery conditions improve, this is not unique to the vessels in the control group. Indeed, any vessel in the control or treatment groups that remains in the fishery will experience the same improved fishing conditions. If would-be new or current vessel owners expect the same improved fishing conditions (given some expectation over fleet capacity reduction), then the inverse supply and demand curves for quota (Figure 3.1) will shift up by the same amount (equal to the net present value of improved fishing conditions over the expected life of a vessel) in the markets for both control vessel quotas and treated vessel quotas. Thus, we would expect the exit decisions of treated and control vessels to be equally impacted by expectations over improved fishing conditions, leaving the treatment effect independent of treatment assignment. Empirically, such an effect would be captured by the year fixed effects in the model, which are common across all vessels. This is consistent with my empirical strategy, where identification stems from the differential reduction in subsidy payments (or engine power quota prices) between the treated and control vessels. Thus, while the potential exit decisions of vessels may be impacted by a rebound effect, treatment and control vessels are all equally impacted, leaving the treatment effects unaffected.

4.4. Main Results and Robustness

4.4.1. The DD Model. The event study coefficient estimates obtained from equation 4.2 are presented in figure 4.2. The plotted estimates capture the differential trend break by year across post-reform subsidy reduction rates relative to the baseline period of 2015. To ensure that the effect of fuel subsidy reduction is not confounded with other changes associated with vessel features, I additionally control for vessel length, engine power, total tonnage, and gear type in the specification, all interacted with time fixed-effects.

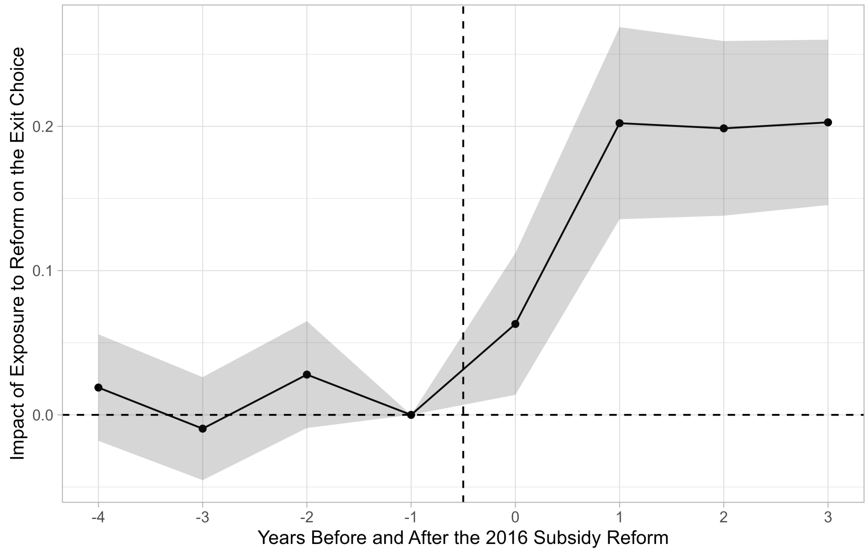

FIGURE 4.2. Year-specific marginal treatment effects of a one-percent reduction in fuel subsidy payments on the probability of exiting, relative to the baseline year 2015.

A clear pattern emerges from the event study plot. First, there is no evidence in the plot of systematic correlation between the post-reform subsidy reduction rate and the pre-reform trend in exit decisions, which lends us confidence in the parallel trend assumption. The differential trend breaks across vessel subsidy levels only emerge after 2016, with the vessels assigned with higher subsidy reduction rates also experiencing an increase in exit rate. Relative to the baseline period 2015, the percentage-point increase in the annual exit rate associated with a 1% lower annual subsidy payment is around 0.06 in the first year of the reform and 0.20 in the years later.

Table 4.3 presents the result of DD estimation for equation 4.1. Column (2) presents the estimates from the multiple-period DD specification, where common trends across different vessel features are controlled as in the event study specification. On average, in the post-reform period, a 1% reduction in the average annual fuel subsidy will cause the annual exit probability of a trawler in the fleet increase by 0.15 percentage points. This treatment effect corresponds to an elasticity estimate of 0.015, using the post-reform annual exit rate of 9.5%. Column (4) then estimates a two-period DD specification. Compared to the more flexible specifications in Column (2), the parsimonious two-period DD evaluates the overall treatment effect of the subsidy reduction during the 4 years of the post-reform period by ignoring the intraperiod dynamics. I estimate that a 1% reduction

Table 4.3. Marginal Effects of a One-Percent Fuel Subsidy Reduction on Vessel Exit

	Annual		Quadrennial	
	(1)	(2)	(3)	(4)
Fuel Subsidy	0.211^{***}	0.153^{***}	0.501^{***}	0.350^{***}
Reduction	(0.0128)	(0.0185)	(0.0279)	(0.0408)
Year-Gear FE	Yes	Yes	Yes	Yes
Year-Length FE	No	Yes	No	Yes
Year-Power FE	No	Yes	No	Yes
Year-Tonnage FE	No	Yes	No	Yes
R^2	0.148	0.168	0.481	0.509
ymean	0.0610	0.0610	0.222	0.222
Observations	50984	50984	14016	14016

Note: This table displays the difference-in-differences coefficient estimates of equation 4.1. The sample is defined as the large trawlers (≥24m) in Zhejiang province of China existent to the end 2011. For annual marginal effect estimates, the dependent variable is the annual exit indicator between 2012 and 2019; for quadrennial estimates, the dependent variable is the exit indicator before and after the 2016 reform. Standard errors in parentheses are clustered at the vessel level.
Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

in the average annual fuel subsidy will cause the quadrennial exit probability of a trawler in the fleet increase by 0.35 percentage points in the post-reform period. The corresponding elasticity is roughly 0.012 with the post-reform annual exit rate of 30.2%.

The inclusion of feature-specific common trends shrinks the marginal effect estimate. The preferred estimates in (2) and (4) are around one-fourth smaller than columns (1) and (3), for which I only control the year fixed effects across the gear type. The deflation in the estimates indicates that the interactive year fixed effects help reduce the potential bias from time-varying confounders while leaving a usable amount of exogenous variation in subsidy assignment for identification.

The treatment effect estimate in table 4.3 is robust in a variety of alternative specifications and sample selections. First, I reexamine the DD specification by substituting the vessel-level fixed effects with higher-level fixed effects for gear types or vessel classes to address the potential bias of applying DD for binary survival outcomes (Table A.4). Second, I include the interaction of year fixed effects with additional vessels features, such as fixed effects for year-age combinations (Table A.3). Finally, I mutate the sample by including all new vessels built before the reform and by extending the panel to the year 2020. The event study and the DD results are robust to the scale of fixed effects and the selection of observations.

4.4.2. The RD-DD Model. The core evidence of the RD-DD design is illustrated in figure 4.3, which visualizes the distribution of the average annual fuel subsidies and the exit choices for surviving vessels before and after the reform for vessels with length in the proximity to the 30m threshold. The vessel distribution is densest and most balanced around the 30m eligibility threshold, around which a 5m bandwidth contains 59% ($\frac{4489}{7649}$) of the full sample and a 2m bandwidth contains 24% ($\frac{1841}{7649}$). I do not find any other policies specifically targeting this threshold for existing vessels besides the new subsidy standard, making the subsample an ideal candidate for studying the fleet response to subsidy variations.

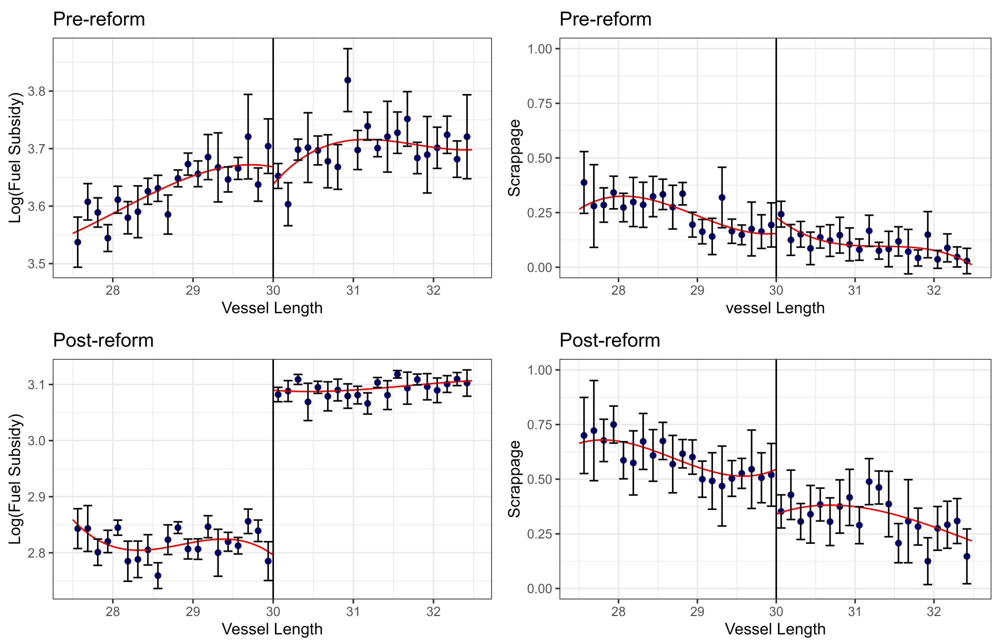

FIGURE 4.3. Average fuel subsidies (left) and vessel exit rates (right) as a function of vessel length (meters), before (top) and after (bottom) the fuel subsidy reform.

The right panel illustrates the first-stage variation for pre- and post-reform annual average fuel subsidies. As the pre-reform annual fuel subsidy standard per horsepower is uniform across trawlers, provided the local continuity of the engine power distribution, the subsidy payment to vessels should have no discontinuities across the post-reform length threshold. In contrast, with the imposition of the eligibility threshold, trawlers falling right to the 30m threshold can enjoy up to 36% more annual fuel subsidies payments than a trawler falling left with all else equal. [3] Corresponding to

[3]How important is this 36% arbitrary difference in subsidy income to the finance of bottom trawlers in the post-reform period? According to a field survey on trawling fishers conducted in Zhejiang province between 2018 and 2019, the

the shift in subsidy assignment, the left subplot presents the quasi-experiment evidence for vessel exit responses to the reform. Before the reform, there is no pre-existing discontinuities observed in the exit rate at the post-reform subsidy threshold within the fleet. The downward jump in the vessel exit rate at the 30m threshold only emerges after the execution of the new subsidy standard for 2016 reform.

The co-occurrence of discontinuities in fuel subsidy payments and exit choices at the eligibility threshold implies a strong linkage between the fuel subsidy and the exit decisions. Within the post-reform period, the exit probability for vessels just left of the threshold than their counterparts right to the threshold by 12 percentage points. Combined with the figure for the first stage, the Wald estimator for the local average treatment effect of post-reform subsidy payments from the figure is around 0.4, close to the previous DD estimate.

TABLE 4.4. First-stage and Reduced-form Estimations for the RD-DD Specification

	(1) log(Fuel Subsidy)	(2) Exit	(3) log(Fuel Subsidy)	(4) Exit
over30=1	-0.014*	0.018	0.001	0.019
	(0.006)	(0.010)	(0.001)	(0.010)
post16=1 × over30=1	0.294***	-0.069**	0.252***	-0.059**
	(0.017)	(0.021)	(0.003)	(0.021)
Year-Gear FE	No	No	Yes	Yes
Year-Power FE	No	No	Yes	Yes
Year-Tonnage FE	No	No	Yes	Yes
R^2	0.949	0.057	0.996	0.091
F	4413.02	71.60	247765.21	24.06
Observations	11958	11958	11958	11958

Note: This table displays the coefficient estimates of equations 4.3 and 4.4 from the regression-discontinuity difference-in-differences specification. The sample is defined as the large trawlers (≥24m) in Zhejiang province of China existent to the end 2011 within the optimal bandwidth (29-31m). Column (1) and (3) are first-stage estimates; column (2) and (4) are reduced-form estimates. Standard errors in parentheses are clustered at the vessel level.
Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Based on the visualized evidence, table 4.4 presents a formal estimation of the first-stage and reduced-form equations 4.4 and 4.3 respectively using the local linear regression with an optimally-selected bandwidth of 2 meters. The conditional and unconditional specifications present similar

production profit per harvested biomass for a bottom trawler is 0.52 RMB/kg on average. Meanwhile, the average income from fuel subsidy payments is 1.43 RMB/kg (Shen and Chen, 2022). A 36% increase in subsidy standard is equivalent to a 24% increase in total operating profit, or a 14% increase in operating cash flow, excluding the annual depreciation of fixed assets (1.72 RMB/kg). In years before 2018, when the baseline subsidy is higher, the ratio of subsidy income to the operating profit could be even higher.

evidence as the figure 4.3 and the F-statics of the first stage is convincingly large. The imposition of the threshold by the reform results in a roughly 30% local jump in average annual subsidy payments. In response to differential treatment, the exit rate for vessels just passing the threshold is six percentage points lower in the post-reform period.

Table 4.5. Marginal Effect of Fuel Subsidy on Vessel Scrappage from the RD-DD Specification

	Full sample		Post-reform sample	
	(1)	(2)	(3)	(4)
Log(Fuel Subsidy)	-0.184**	-0.158*	-0.176*	-0.156*
	(0.065)	(0.072)	(0.070)	(0.072)
Year-Gear FE	No	Yes	No	Yes
Year-Power FE	No	Yes	No	Yes
Year-Tonnage FE	No	Yes	No	Yes
R^2	0.066	0.091	0.064	0.093
ymean	0.074	0.074	0.114	0.114
Observations	11958	11958	5197	5197

Note: This table displays the two-stage least squares coefficient estimates of two-stage equations 4.4 and 4.5 from the regression-discontinuity difference-in-differences specification. The full sample is defined as the large trawlers (≥24m) in Zhejiang province of China existent to the end 2011 within the optimal bandwidth (29-31m). The dependent variable is the annual exit indicator between 2012 and 2019. For post-reform sample estimates estimates, the sample is redistricted to years after 2016. Standard errors in parentheses are clustered at the vessel level.
Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Finally, table 4.5 presents the 2SLS estimates for the marginal treatment effect of the fuel subsidy payments from the fuzzy-RD specification. Columns (1) and (2) present the unconditional and conditional RD-DD estimates. Column (3) and (4) presents the estimates using only the post-reform sample, in which case the RD-DD specification is reduced to the cross-sectional RD strategy. The similarity in these estimates for the local average treatment effect indicates the continuity in the pre-reform outcome and pre-determined covariates.

For robustness checks, figure A.4 plots the density of vessels across vessel length. There is no evidence of bunching around the thresholds, which is to be expected given the difficulty of adjusting the length of a vessel, the unanticipated nature of the reform (at the time of vessel construction), and the lack of any other length-based policies coinciding with the thresholds. We focus on the bandwidth surrounding the 30-meter threshold for the RD-DD design since it contains the majority of vessels along the vessel-length dimension. As a result, the RD-DD estimate at the 30-meter threshold is the most comparable to our DD estimate. We also estimate the RD-DD model at the

35- and 40-meter thresholds and find smaller effects of the fuel subsidy reform on vessel exiting rates (compared to the 30-meter threshold), which is consistent with the heterogeneous treatment effects for the DD model indicating larger vessels are less sensitive fuel subsidy reform (Table A.2).

In summary, through two different estimation strategies, there is considerable evidence that the subsidy reduction stimulated operating trawlers to exit the fleet—namely, a one-percent decrease in the post-reform annual average fuel subsidy leads to a significant increase in the annual exit probability of 0.15 percentage points. Comparing with the DD estimates capturing differential trend breaks at the time of the reform, the cross-sectional comparison of post-reform exit choices provides very close estimates of the marginal treatment effect. The closeness in estimates exploiting within- and between-unit variation suggests a strong parallel trend in the pre-reform exit risks for the DD strategy.

4.4.3. Vessel Buyback Decisions. 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. To quantify the impact of fuel subsidy reduction on fishers' willingness for buyback program participation, I estimate the treatment effect of fuel subsidy reductions on buyback choices in the post-reform period. I apply the baseline DD specification in the empirical strategy for observations between 2012 and 2019:

$$y_{it}^b = \beta^b \Delta_i^{base} I_t^{Post} + \lambda_{a_{it}} + \lambda_{a_{it}}^b + c_i^b + \gamma_t^b + \nu_t^b \mathbf{X}_i + u_{it}^b \tag{4.6}$$

The estimation result in table 4.6 shows that the fuel subsidy reduction increases fishers' willingness to participate in the buyback program. Over the reform period, each 1% decrease in mean fuel subsidy payment leads the the quadrennial buyback rate to drop by a percentile of 0.20, which is around half of the size of the treatment effect on scrap rate, 0.42. This result indicates that reform-induced exiting decisions are on average equally likely to be turned into a government buyback or a new vessel. The size of the estimate is consistent with the descriptive statics that each unit of

Table 4.6. Marginal Effect of a One-percent Fuel Subsidy Reduction on Vessel Buyback

	Annual		Quadrennial	
	(1)	(2)	(3)	(4)
Fuel Subsidy	0.0803***	0.0651***	0.202***	0.156***
Reduction	(0.00970)	(0.0140)	(0.0243)	(0.0350)
Year-Gear FE	Yes	Yes	Yes	Yes
Year-Length FE	No	Yes	No	Yes
Year-Power FE	No	Yes	No	Yes
Year-Tonnage FE	No	Yes	No	Yes
R^2	0.111	0.136	0.282	0.303
ymean	0.0207	0.0207	0.0751	0.0751
Observations	50984	50984	14016	14016

Note: This table displays the difference-in-differences coefficient estimates of equation 4.6. The sample is defined as the large trawlers (≥24m) in Zhejiang province of China existent to the end 2011. For annual marginal effect estimates, the dependent variable is the annual buyback indicator between 2012 and 2019; for quadrennial estimates, the dependent variable is the buyback indicator before and after the 2016 reform. Standard errors in parentheses are clustered at the vessel level.
Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

power quota released from the scrapped trawlers in the post-reform period has a 52% probability of being bought back.

4.5. Heterogeneity

To explore the heterogeneous exit and buyback decisions of fishermen in response to the subsidy reform, I allow β to vary over vessel features in the two-period DD specification:

$$y_{it} = \sum_{m=1}^{M} \beta_m V_i^m \Delta_i^{base} I_t^{post} + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t \mathbf{X}_i + u_{it} \tag{4.7}$$

$$y_{it}^b = \sum_{m=1}^{M} \beta_m^b V_i^m \Delta_i^{base} I_t^{post} + \lambda_{a_{it}}^b + c_i^b + \gamma_t^b + \nu_t^b \mathbf{X}_i + u_{it}^b \tag{4.8}$$

where β_m is the coefficient on the interaction of $\Delta_i I^{post}$ with indicators of vessel classification bins, where $V_i^m = \mathbf{1}\{\text{vessel class}_i = m\}$.

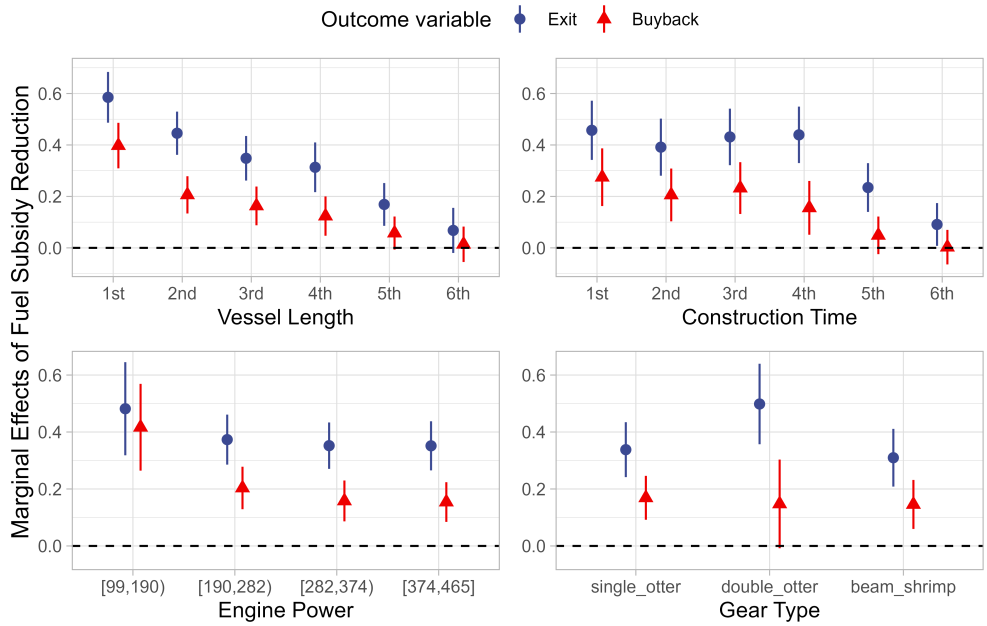

FIGURE 4.4. Estimates of heterogeneous treatment effects of a one-percent fuel subsidy reduction on quadrennial post-reform exit and buyback probabilities across quantiles or categories of vessel characteristics.

I first explore the heterogeneity over vessel size and vintage. I find that the fuel subsidy assignment has a significantly stronger impact on the exiting decisions for vessels in the lowest quantile of length and recency than those in the highest quantile. The small and old trawlers bear the highest pressure from the reduction in fuel subsidy payments to scrap and leave the fleet, while the impact on the largest and newest trawlers is almost insignificant. As predicted by the conceptual framework, the larger and newer trawlers in the fleet are more likely to be designed with higher technical efficiency and managed by more skilled skippers, and thus their operations are less subject to the change of subsidy income.

The heterogeneity of treatment effects is more stark for the buyback decisions. Sensibly, the treatment effect of subsidy reduction on the choice probability for buyback shrinks fast for vessels larger and newer. In the competition for the use of fishery resources, the smaller and older vessels are more vulnerable to the pressure of subsidy income decline and are more likely to be owned by aging fishers, who are also more inclined to be persuaded to leave exit through buyback. Lastly, old vessels are prioritized on the list of the buyback program when ranked along with other voluntary candidates for retirement.

I then explore the heterogeneity across gear types. I find that the post-reform scrappage decisions of double-otter trawlers are more sensitive to subsidy reduction compared with single-otter and beam trawlers. The double-otter bottom trawling used to be the dominant fishing method in the East China Sea fishery. However, with the depletion of demersal fish stocks, double-otter trawlers face higher pressure of profitability relative to other trawlers for the high fuel consumption. On the margin, the buyback decision of double trawlers is slightly less responsive to the variation in fuel subsidy payments, while on the baseline a higher proportion of scrapped double-otter trawlers joined the post-reform buyback program (62.5%) than other types of scrapped trawlers (51.0%).

In summary, the heterogeneity analysis shows that the capacity of small and old vessels are retired disproportionately faster by the fuel subsidy reduction. Consistent with the experiences of many other capacity decommissioning programs, the fishery subsidy reform first retires the vessels at the left tail of the technical efficiency distribution of the fleet. Therefore, while the reform successfully reduces the total physical capacity and modernizes the fleet, it may not have reduced the actual fishing intensity on the fishing grounds. I also find that the reform manages to mitigate the ecosystem harm if the trawl fleet by reducing the share of double-otter bottom trawlers, which have more severe impacts on seabed ecosystems.

I check the robustness of the results by estimating the event-study specification on separate subsamples of vessel features. I find consistent evidence when examining the heterogeneity in the estimates of post-reform trend breaks across subsamples (See Tables A.5, A.6, and A.7). The conclusions drawn from heterogeneous treatment effects are robust to the most flexible specifications.

4.6. Fleet Capacity Counterfactuals

The fuel subsidy reform simultaneously decreased fuel subsidy payments to vessel owners and increased the buyback price offered to vessel owners for retiring quota. I 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 (or not at all). Specifically, I consider the following counterfactual scenarios:

- *Counterfactual 1*: What would the number of vessel retirements have been if there had been no reforms at all?
- *Counterfactual 2*: What would the number of vessel retirements have been if only the buyback price had been raised and fuel subsidy payments continued to be determined by the pre-reform rule?
- *Counterfactual 3*: What would the number of vessel retirements have been if only the fuel subsidy payments had been reformed and the buyback price had remained at its pre-reform level?

These counterfactual scenarios are depicted in Figure 4.5. In the following sections, I discuss estimates of the number of vessel retirements that would have occurred in each counterfactual scenario and how I arrived at my conclusions. I then compare the number of vessel retirements across counterfactual scenarios to arrive at an estimate of the total impact of the fuel subsidy reform and a decomposition of the total impact across the decreased fuel subsidy payments and the increased buyback price. While counterfactual fleet capacities are primarily discussed in terms of vessel numbers below, I also compute corresponding impacts in terms of vessel engine power.

4.6.1. Counterfactual 1. In Counterfactual 1, I consider the number of vessel retirements that would have occurred if there had been no reforms at all—i.e., the buyback price would have remained at its pre-reform level (2,500 RMB/kW) and fuel subsidy payments would have continued to be determined using the same formulas in place during the pre-reform years. To determine the number of vessel retirements that would have occurred in the absence of any reforms, I rely on the model of the engine power quota market, which predicts that no vessel retirements will occur if the equilibrium quota price is greater than the buyback price. Historical exiting patterns support this claim. In the four years before the reform, the average price of engine-power quota ranged between 7,000-10,000 RMB/kW, compared to a buyback price of just 2,500 RMB/kW (Table S2). Accordingly, not a single vessel was retired through the buyback program. Thus, to determine the

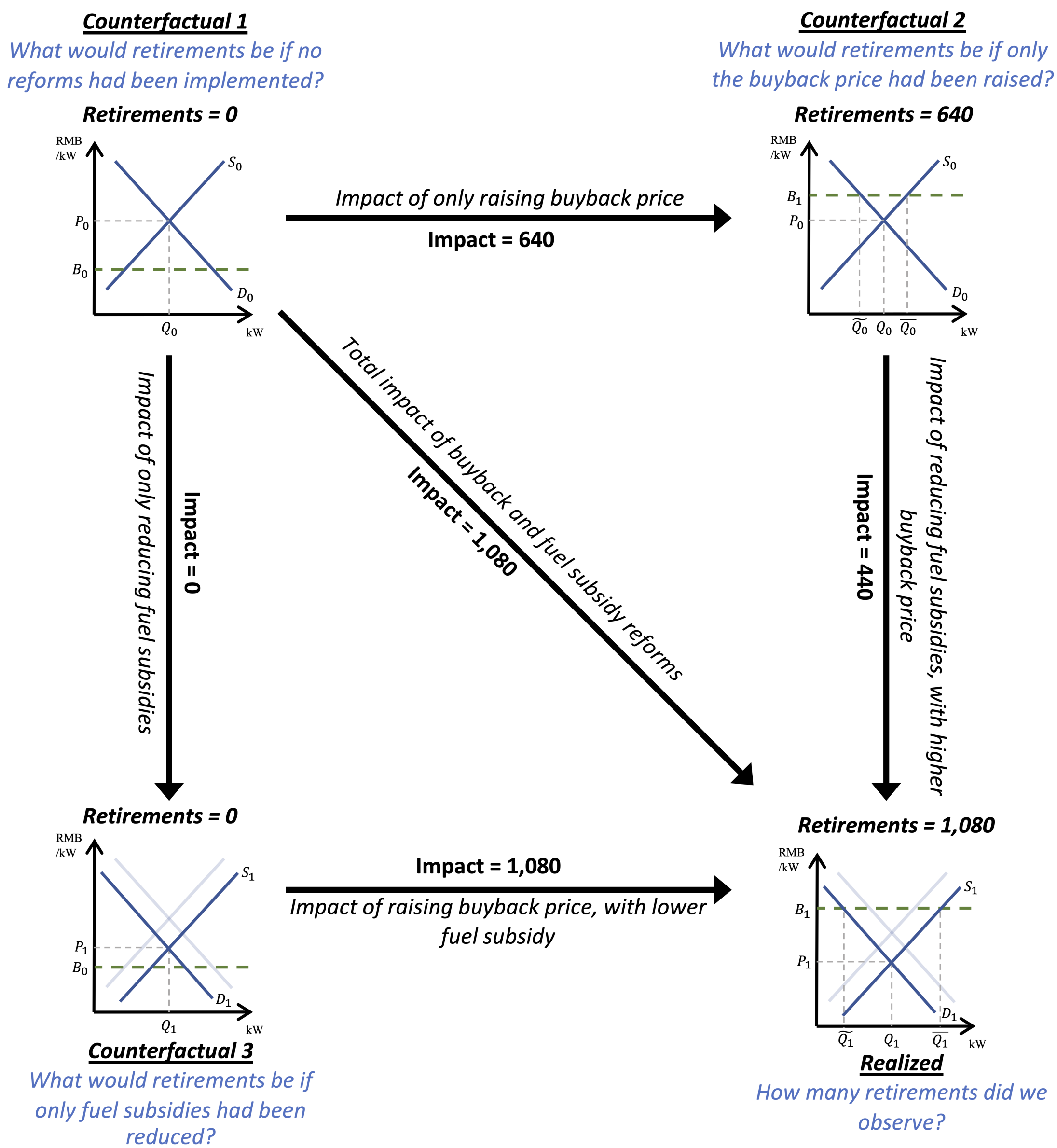

FIGURE 4.5. Graphical illustration of the counterfactual scenarios considered for decomposing the treatment effect of the fuel subsidy program reform. The number of vessel retirements (or buybacks) is estimated for each counterfactual scenario within the engine power quota market model (and, when applicable, within the difference-in-differences model). Comparing the number of vessel retirements across adjacent (i.e., not diagonal) counterfactual scenarios provides an estimate of one policy treatment in isolation from the others.

number of vessel retirements that would have occurred in the absence of any reforms, I need to estimate what the power quota price would have been in the post-reform years in the absence of any reforms.

Given the features of the cap-and-trade system, I assume that the value of the engine power quota includes the capitalization of expected fishing profits from the marginal vessel plus the expected income from fuel subsidy payments in perpetuity. This assumption is supported by the strong positive correlation between fuel subsidy payments and quota prices in the pre-reform years (Table 4.2). Based on the pre-reform subsidy calculation formula and the post-reform diesel prices, the counterfactual subsidy standard would have fallen from an average of 1,724 RMB/kW in the pre-reform years to an average of 1,100 RMB/kW in the post-reform years due to plunging fuel prices following 2015. Using a 20% discount rate, which is consistent with the interest rates offered by local financial institutions of fishing villages (Wang and Pan, 2016) and the literature estimating implicit discount rates for large investments (e.g. Hausman, 1979; Warner and Pleeter, 2001), this would equate to a reduction in the net present value of fuel subsidy payments of approximately 3,000 RMB/kW. Accordingly, we would expect the average power quota prices to fall from their 7,000-10,000 RMB/kW range in the pre-reform years to a range of 4,000-7,000 RMB/kW in the post-reform years. Once again, records of historical fuel subsidy payments and quota prices support this expectation. For example, between 2010 and 2011, the annual average fuel subsidy standard for Zhejiang province was 1,120 RMB/kW, approximating the counterfactual post-reform subsidy standard in the absence of any reform (1,100 RMB/kW), and the recorded average quota price ranged between 4,000-6,000 RMB/kW (Table 4.2).

Taking 4,000 RMB/kW as a lower bound for the counterfactual quota price, I conclude that there would have been no vessel retirements in the post-reform years in the absence of any reforms since the counterfactual quota price remains higher than the buyback price of 2,500 RMB/kW. That is, vessels would have continued to exit through the engine power quota market, and no retirements through the buyback program would have occurred, leaving fleet capacity unchanged.

4.6.2. Counterfactual 2. In Counterfactual 2, I consider the number of vessel retirements that would have occurred if the buyback price increased to its post-reform level (7,500 RMB/kW) but fuel subsidy payments continued to be determined as they had been during the pre-reform years. According to the model of the quota market for engine power, we would expect vessel retirements to occur through the buyback program if the buyback price is above the equilibrium quota price.

In Counterfactual 1, I conclude that the power quota price would have likely ranged between 4,000-7,000 RMB/kW in the post-reform years if fuel subsidy payments had been determined by their pre-reform rule. Thus, a buyback price of 7,500 RMB/kW would be expected to induce vessel retirements through the buyback program. The question is: by how much?

To answer this question, I turn to the estimate of β_m from the two-period difference-in-differences model (with heterogeneous treatment effects), which represents the marginal effect of a reduction in the baseline fuel subsidy standard on the probability of retiring a vessel through the buyback program during the post-reform period. Since the buyback price was increased simultaneously with a reduction in the baseline subsidy payments, β_m represents the marginal effect of a reduction in baseline fuel subsidy payments conditional on a buyback price of 7,500 RMB/kW. Thus, I can use the difference-in-differences model to estimate the counterfactual buyback rate by predicting the buyback rates for the post-reform years after replacing the observed fuel subsidies with the hypothetical fuel subsidies that would have existed had they been determined using the pre-reform rule. These predictions estimate the counterfactual buyback rates that would have existed if only the buyback subsidy had been raised.

Let the counterfactual fuel subsidy payment in the post-reform period be s_{it}^c. In the discussion of Counterfactual 1, I conclude that these subsidy payments would have fallen to an average of 1,100 RMB/kW. In comparison, the observed post-reform fuel subsidy s_{it}^c averages 880 RMB/kW and varies substantially across the fleet (388-1,338 RMB/kW). Notably, the counterfactual fuel subsidy level is within the empirical range of the observed post-reform subsidy payments, lending credibility to the internal validity of the predicted counterfactual buyback rates.

With the identified treatment effect β_m and the counterfactual fuel subsidy level s_{it}^c, the derivation of the predictors for the counterfactual fleet capacity is straightforward. In the potential-outcome framework, the counterfactual and observed buyback probability, y_{it}^c and y_{it}, respectively, in the post-reform period follows the relation:

$$\mathbb{E}\left[y_{it}^c - y_{it} \mid i \in m\right] = \beta_m \mathbb{E}\left[\ln(s_{it}^c / s_{it}) \mid i \in m\right],$$

which can be derived by substituting in the difference-in-differences equation for y_{it}^c and y_{it}. The counterfactual buyback rate for vessel class m can thus be consistently estimated as:

$$\hat{\mathbb{E}}\left[y_{it}^c \mid i \in m\right] = \text{Avg}_{i \in m}\left[y_{it} + \hat{\beta}_m \ln(s_{it}^c / s_{it})\right].$$

With the number of observations N_t, and the number of observations N_{mt} for vessel group m, the overall counterfactual buyback rate for vessels can then be estimated as:

$$\hat{\mathbb{E}}\left[y_{it}^c\right] = \sum_m \hat{\mathbb{E}}\left[y_{it}^c \mid i \in m\right] \frac{N_{mt}}{N_t}.$$

The counterfactual fleet capacity in terms of engine power can be computed similarly by replacing N_{mt} with $N_{mt} \times EP_{mt}$, where EP_{mt} represents the average engine power in vessel class m at time t.

Following this procedure, I estimate that the buyback rate would have been 9.7% (in vessel numbers) and 7.2% (in vessel engine power) in the post-reform period (relative to the average fleet size in the pre-reform period), or approximately 640 vessel retirements (127 MW of engine power quotas), if only the buyback price had been raised to 7,500 RMB/kW and the fuel subsidy payments had been determined according to their pre-reform rule.

4.6.3. Counterfactual 3. In Counterfactual 3, I consider the number of vessel retirements that would have occurred if the buyback price had remained at its pre-reform level (2,500 RMB/kW) but fuel subsidy payments were determined according to the reformed subsidy standard. As before, I rely on the engine power quota market model to determine the number of vessel retirements that would have occurred without any reforms. According to the model, we would expect vessel retirements to occur through the buyback program if the buyback price is above the equilibrium quota price. The challenge is thus determining what the quota price would have been if only subsidy payments had been reformed and whether it would have been below the pre-reform buyback price.

As discussed in Counterfactual 2, fuel subsidy payments were observed to be, on average, 880 RMB/kW in the post-reform period, which represents an 844 RMB/kW decrease from the average fuel subsidy payment of 1,724 RMB/kW observed in the pre-reform period. Using a 20% discount rate would equate to a reduction in the net present value of future fuel subsidy payments of approximately 4,000 RMB/kW. Accordingly, we would expect the average power quota price to fall from its 7,000-10,000 RMB/kW range in the pre-reform years to a range of 3,000-6,000 RMB/kW in the post-reform years. Once again, records of historical fuel subsidy payments and quota prices support this expectation. For example, in 2010, the annual average fuel subsidy standard for Zhejiang province was 747 RMB/kW, approximating the counterfactual post-reform subsidy standard in the absence of any reform (844 RMB/kW), and the recorded average quota price ranged between 3,500-4,000 RMB/kW (Table 4.2).[4]

Taking 3,000 RMB/kW as a lower bound for the counterfactual quota price, I conclude that there would have been no quota retirements in the post-reform years if only the fuel subsidy payments had been reformed since the counterfactual quota price remains higher than the buyback price of 2,500 RMB/kW. That is, vessels would have continued to exit through the engine power quota market and no quota retirements through the buyback program would have occurred, leaving fleet capacity unchanged.

Table 4.7. Post-reform Scrap and Buyback Rates Simulated Under Counterfactual Subsidy Policies

Period	Case	Avg. Fuel Subsidy (RMB/kW)	Buyback Price (RMB/kW)	Exit Rate in Fleet Size (%)	Buyback Rate in Fleet Size (%)	Exit Rate in Total Power (%)	Buyback Rate in Total Power (%)
Pre-reform	Obs	1724	2500	15.4 [14.6,16.2]	0	13.0 [12.4,13.7]	0
Post-reform	Obs	880	7000	30.2 [29.1,31.3]	16.4 [15.5,17.2]	26.8 [25.8,26.0]	14.1 [13.4,14.9]
Post-reform	CF1	1110	7000	19.4 [16.6,22.2]	9.71 [7.42,12.0]	14.9 [12.0,17.9]	7.22 [4.84,9.60]
Post-reform	CF2	1110	2500	<19.4	0	<14.9	0

Note: The estimated counterfactual rates of exit and buyback in the fleet with bootstrapped confidence intervals. CF1 represents the counterfactual scenario in which only the buyback price was raised but there was no reform to the fuel subsidy standard and CF2 represents the counterfactual scenario in which neither the buyback price was raised nor the fuel subsidy standard reformed. We also estimate the counterfactual exit and buyback rates in terms of total engine power.

4.6.4. Impacts of the Reform. Given the conclusions for the counterfactual scenarios above, I can now derive the vessel/quota retirement impacts associated with the various components of the fuel subsidy reform.

[4]Note that 2008 also had an average fuel subsidy payment of similar magnitude to the counterfactual scenario with a lower range of observed quota prices (Table 4.2). However, the fuel subsidy payment rule was not formalized until 2009, making future subsidy payments more uncertain at the time. Moreover, catch-per-unit-effort (CPUE) was considerably lower in 2008 than in the post-reform period. Thus, the quota prices observed in 2008 are likely smaller than what we would expect in the counterfactual scenario.

What's the total impact of the reform on vessel/quota retirement? To determine the total impact of the fuel subsidy reform on vessel/quota retirements, I need to compare the observed number of vessel retirements in the post-reform period with the counterfactual number of vessel/quota retirements that would have occurred in the absence of any reforms. In Counterfactual 1, I conclude that there would have been no vessel/quota retirements in the absence of any reforms since the equilibrium quota price would be higher than the buyback price. Thus, I estimate the total impact of the reform over the four years following the reform (2016-2019) to be 1,080 vessel retirements or 249MW of engine power quotas, which equates to a 16.4% (14.1%) decrease in vessel numbers (engine power) relative to the average fleet size in the pre-reform years (Table 4.7). That is, all 1,080 vessel retirements and 249MW of engine power quota retirements observed in the post-reform period are attributable to the fuel subsidy reform.

What's the impact of the buyback reform on vessel/quota retirement? To determine the impact of the increased buyback price on vessel/quota retirements, I need to compare the counterfactual number of vessels/quotas that would have retired in the post-reform period if only the buyback price had been raised (Counterfactual 2) with the counterfactual number of vessel retirements/quotas that would have occurred in the absence of any reforms (Counterfactual 1). In Counterfactual 1, I conclude that there would have been no vessel retirements in the absence of any reforms since the equilibrium quota price would be higher than the buyback price. In comparison, I conclude that the 640 vessels and 127MW of engine power quotas would have retired if only the buyback price had been raised in Counterfactual 2. Thus, I estimate the impact of only raising the buyback price over the four years following the reform (2016-2019) to be 640 vessel (127MW quota) retirements, which equates to a 9.7% (7.2%) decrease relative to the average fleet size in the pre-reform years (Table 4.7). This implies that the remaining 440 vessels (122MW quotas) associated with the total impact of the reform are due to the reformed fuel subsidy payments.

What's the impact of the fuel subsidy reform on vessel/quota retirement? To determine the impact of reforming the fuel subsidies alone on vessel/quota retirements, I need to compare the counterfactual number of vessels/quotas that would have retired in the post-reform period if only the fuel subsidy payments had been reformed (Counterfactual 3) with the counterfactual number of vessel/quota retirements that would have occurred in the absence of any reforms (Counterfactual

1). In Counterfactual 1, I conclude that there would have been no vessel/quota retirements in the absence of any reforms since the equilibrium quota price would be higher than the buyback price. Similarly, I conclude that no vessels/quotas would have retired if only the fuel subsidy payments had been reformed in Counterfactual 3. Thus, I estimate the impact of only reforming the fuel subsidy payments over the four years following the reform (2016-2019) to be 0 vessel retirements (or no change relative to the average fleet size in the pre-reform years).

4.7. 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 unravel how removing subsidies impacts fisheries. In this chapter, I utilize an unprecedented dataset and a unique natural experiment where subsidies were actually reduced to estimate how subsidy reductions affected the trawl fleet in China's Zhejiang province. This 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 (Young et al., 2018).

The main empirical results show that removing 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 comprised of fuel subsidy payments, as indicated by a survey of trawling vessel owners (Shen and Chen, 2022). 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 the 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 re-entering 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 I 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 re-invoking 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 non-fishing 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 (Costello et al., 2021).

In the natural experiment considered here, the simultaneous reduction in fuel subsidies and increase in buyback prices led to an increase in the exit rate of vessels. During the four pre-reform years, approximately 15% of the fishermen in the sample exited by selling their power quota to new entrants. During the four post-reform 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 the 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 without the buyback program, vessel exit decisions would not have likely translated into any fleet capacity reduction. Indeed, even with the buyback program in place, if buyback prices had remained at their pre-reform level, there would have been no post-reform capacity reduction. This is because pre-reform buyback prices (2,500 RMB/kW) had been set below the prevailing post-reform power quota prices of 6,000-9,000 RMB/kW. 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 subsidy reductions alone are not likely to have any effect on fleet capacity in limited entry fisheries unless they are accompanied by complementary policies that ensure that exit decisions translate into fleet capacity reduction actions.

Removing subsidies is only a first step towards sustainable fisheries. But subsidy removal may be neither necessary nor essential for sustainability. The end goal of subsidy removal is surely to reduce fishing mortality in overharvested fisheries. But as argued above, subsidy removal alone does not guarantee capacity reduction. Moreover, fishing capacity, as measured by vessel numbers or total engine power, is only one of many factors determining fishing mortality, such as fishing time, number of fishers, and the technical efficiency of vessels. If the desire is to rebuild fisheries or hold them at sustainable levels, managers must either control fishing mortality directly (e.g., through a total allowable catch) or control all factors in the harvest production process. 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 (Sakai, 2017).

In China's case, it is not immediately clear how reduced fleet capacity will translate into harvests and the status of fish stocks. On the one hand, conservation gains from reduced fleet capacity could be eroded by transitioning 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 (Sun et al., 2023), 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 (Costello, 2017; Szuwalski et al., 2017).

In general, as the preceding discussion demonstrates, subsidy removals and buyback programs can be effective tools for fleet capacity reduction, provided that they are tailored to the policy context at hand; however, they should not be viewed as long-term solutions to sustainability challenges for fisheries. Importantly, simply reducing fleet capacity does not address the underlying incentives of remaining vessel owners to over-invest in unregulated dimensions of the harvesting production process, and without direct control over fishing mortality, overfishing can persist (Homans and Wilen, 1997; Holland et al., 1999; Weninger and McConnell, 2000). At best, such tools should be viewed as short-term aids in transitioning to a more sustainable governance system that addresses the root of overfishing concerns, rather than the symptoms. It remains to be seen how the management of China's post-reform fisheries will evolve and how complementary policies will foster the "ecological economy" goals of a sustainable fishery.

CHAPTER 5

Beyond the Trawl Fishery: Impacts of Fuel Subsidy Reform on the Gear Structure of the Offshore Fishing Fleet of China

5.1. Introduction

The fishing industry in China is a critical sector that requires careful management to ensure the sustainable utilization of marine resources while supporting the livelihoods of coastal communities. The government has adopted differentiated management schemes for vessels of varying sizes, with a particular focus on medium and large fishing vessels (MLFVs). These vessels play a dominant role in the harvest composition, making their capacity management a crucial concern for fishery managers.

In this Chapter, I evaluate the impact of the 2016 fisheries subsidy reform on the fleet dynamics of the offshore fisheries fleet in Zhejiang province, China. Building upon the treatment effect heterogeneity of fuel subsidy on the exit choice of trawlers demonstrated in the previous chapter, my research quantifies the restructuring effect of this heterogeneity on the fishing fleet in response to the reform.

To achieve this, I construct an entry-exit model of fishing power and simulate the counterfactual fleet structure in the absence of the fuel subsidy reform. By employing counterfactual analysis, I quantify the role of profitability as a key driver of capacity adjustment in light of the reform of fishing subsidies. My findings reveal that the 2016 fuel subsidy reform not only accelerated overall capacity reduction but also incentivized the substitution of high-intensity fishing gears, such as trawlers, with less intensive and more selective gears like gill nets, longlines, and crab pots.

The significance of this study lies in its contribution to understanding fleet heterogeneity in the design of fisheries reform. By expanding the scope of the impact evaluation to encompass the entire offshore fisheries as a complex system of mixed fisheries, my research provides critical insights into the role of fleet heterogeneity in shaping the outcomes of subsidy reform. Additionally, my investigation sheds light on the intricate relationship between subsidy reduction and gear structure optimization, offering valuable guidance for policymakers seeking to balance conservation goals and coastal communities' socio-economic needs.

The Chapter is structured as follows. Section 5.2 provides background on the regulatory environment in China's offshore marine fisheries and the trends in fishing fleet gear structure of Zhejiang province. Section 5.3 details the data source and summarizes the fleet dynamics between 2011 and 2020. Section 5.4 describes the empirical model to simulate the counterfactual fleet gear structure. Sections 5.5 present the main empirical results and counterfactual analysis. Section 5.6 discusses and concludes.

5.2. Institutional Background

5.2.1. Taxonomy of fishing vessels by size. As per the fishing license regulation published in 2018, MLFVs in China are classified as vessels with a registered length of no less than 12 meters. Among these vessels, those with a length of no less than 24 meters are further categorized as large vessels. Conversely, vessels with a length below 12 meters fall under the classification of small fishing vessels (SFVs). [1] MLFVs constitute a significant portion of China's registered marine fishing vessels, accounting for approximately 35% of the total fleet. Furthermore, they represent a substantial share of the total fishing power, comprising around 90% of the collective fishing power across all vessels. As such, MLFVs hold a dominant position in the fishing industry, making their capacity management of paramount importance for fishery managers in China.

The distinction between MLFVs and SFVs in China extends beyond their length classification. MLFVs serve primarily as high-power motorized vessels, operated for commercial fisheries, and are often associated with larger-scale and industrial fishing operations. On the other hand, SFVs are commonly utilized by artisanal and small-scale fishermen who engage in traditional and subsistence fishing activities. The contrasting nature of MLFVs and SFVs in terms of their fishing operations

[1]In the fishing license regulation published in 2018, small fishing vessels are vessels with a length less than 12m and engine power less than 44.1kW, while the new regulation in 2018 abandoned the criteria on engine power.

and scale highlights the importance of tailored management approaches to address the specific needs and challenges faced by each category (See Figure A.5).

To achieve a balance between conserving fishery resources and safeguarding subsistence fisheries, the Ministry of Agriculture (MOA) in China has implemented and reinforced differentiated management schemes for fishing vessels of varying sizes. As part of these schemes, specific regulations have been put in place to govern the fishing activities of different categories of vessels.

For instance, vessels over 12m in length are restricted to fishing outside the designated *prohibited fishing zone line for motor trawlers*, which is an area designated for offshore fisheries in China. On the other hand, small fishing vessels are confined to operating within the nearshore fishing grounds within the specified boundary. This tailored approach to fishing zone allocation ensures that different vessel sizes are appropriately directed to specific fishing areas, optimizing resource utilization and minimizing potential conflicts.

In addition to managing the fishing zone, the MOA also closely supervises vessel construction activities of MLFVs. Specifically, the MOA strictly regulates the engine power quota for medium and large vessels in each province. In 2017, the MOA further mandated that the engine power quota cannot be converted or transferred between small fishing by construction or any other means. This policy ensures that each province's fleet of MLFVs is managed as a limited-entry fleet, effectively controlling the overall fishing capacity of the offshore fisheries.

5.2.2. Management of the offshore fishing fleet. In view of the dominating role of MLFVs in the harvest composition, the capacity management of the MLFV fleet is of particular importance for fishery managers. On the one hand, in the reform of 2016, the MOA specifically set the MLFV capacity reduction target for local governments in addition to the total capacity reduction target. This move emphasized the importance of managing the size of the MLFV fleet as a key performance indicator for local fishery managers, underscoring the importance of optimizing the fleet's capacity to maintain ecological balance and resource sustainability.

In addition to the cap-and-trade management of fishing power, fishery managers in China's offshore fisheries have recognized the diverse and mixed-fisheries nature of fishing operations. Different fishing activities exhibit significant variations in catchability and spatiotemporal behavioral characteristics. To address this complexity, multiple measures have been adopted to improve the gear structure of offshore fleets. These measures include direct control over gear adoption and mesh size, restricting the share of juveniles in landings, differential timing of summer moratoriums, and revising fuel subsidy standards associated with fishing gears.

As an example, prior to 2023, trawlers and stownet vessels were subject to a summer fishing moratorium that commenced one and a half months later than other fishing gears. Conversely, angling gears, such as longline or squid jigging, enjoyed the privilege of fishing throughout the entire year without any seasonal restrictions. By focusing on the improvement of gear structure, these efforts aim to promote a more selective and sustainable fishing practice and improve the harvest quality of landings while minimizing potential negative impacts on marine ecosystems.

5.2.3. Gear structure in the fishery of Zhejiang province. The East China Sea (ECS) area is the most productive fishing ground in China, where trawling is the primary method for wild capture. Targeting a broad spectrum of species, the capacity of trawlers boomed throughout the 1990s because of the extreme efficiency of the gear type. It rose to be the dominant gear in the offshore fishery production of China and Zhejiang, contributing one-half of the marine harvest by weight for China and two-thirds for Zhejiang.

While the trawl fishery in the ECS has historically been the most productive, fishers within the fleet have been confronted with declining fishing profits in recent years. This decline can be attributed to various factors, including the depletion of fish resources, rising fuel and labor costs, and the fuel-intensive nature of trawler operations. Furthermore, the harvest in the ECS trawling fishery has been adversely affected by the degradation of valuable fish stocks, leading to an increasing proportion of the catch consisting of less economically viable species such as "trash fish" and invertebrates.

In response to these challenges, fisheries managers in China have implemented stricter regulations, including more stringent summer moratoriums and restrictions on the landing of juvenile fish, as well as the closure of fish meal factories along the coast to protect juvenile fish populations.

Simultaneously, the growth in consumer income has resulted in an increased willingness to pay for high-quality, attractively marketed wild-caught fish products.

Faced with evolving resource and market conditions, an emerging trend is observed in Zhejiang, where more fishers are transitioning away from trawlers and towards more selective fishing gears such as gill net and longline (See figure 5.1). This shift is driven by the desire to adapt to changing market demands and conserve fish resources while maintaining economic viability.

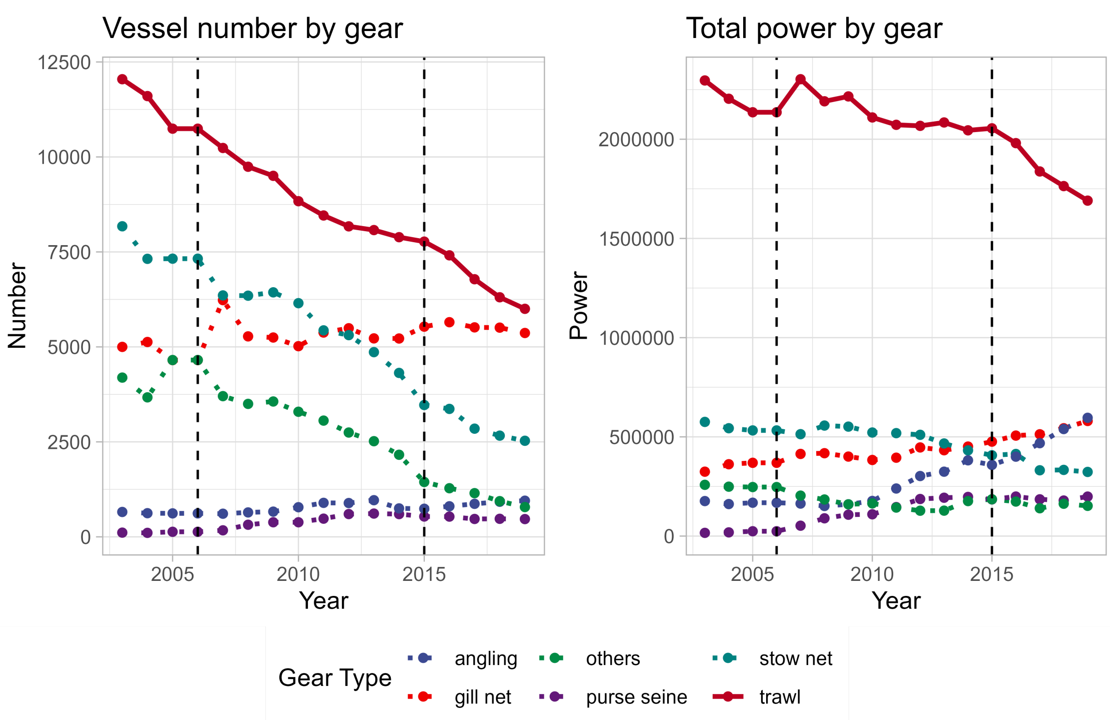

FIGURE 5.1. The evolution of fleet capacity by gear types in Zhejiang province from the Chinese Fishery Yearbook

The reduction in fuel subsidies since 2016 has also played a significant role in accelerating this transition. However, a novel and policy-relevant challenge that remains unexplored pertains to distinguishing the specific impact of the fuel subsidy reform from the pre-reform momentum and influence of other contemporaneous gear control policies.

5.3. Data Description

To reconstruct the historical stock of fishing vessels between 2011 and 2020, I collected registry records of almost all MLFVs in the MFVDMS database of Zhejiang province and applied the data-compiling procedure in the previous Chapter to the registry and license records. I select all vessels with vessel length $\geq 12m$ and engine power $\geq 44.1kW$ as the sample for analysis if the main gear on the licenses is identified as one of the following: trawl, gill net, seine net, stow net, angling, and pot/trap. I compute the fuel subsidy eligibility based on the licensed vessel characteristics based on the public documents published by the Zhejiang government on fisheries subsidies.

Figure 5.2 demonstrate the evolution of the MLFV fleet in Zhejiang province between 2011 and 2020, summarized from the compiled dataset. As shown, the 2016 reform managed to reverse the trend of capacity creeping since 2011 and induced a sharp decrease in total fishing power operating in offshore fisheries. Decomposing the fleet by length, we observe that the fleet reduction was mostly contributed by the massive retirement of vessels less than 30m after 2016. In contrast, the increase in the exit of vessels over 35m was negligible and was over-compensated by the entry of new vessels. Together, the size structure of the fleet was shifted to be dominated by large vessels over 30m.

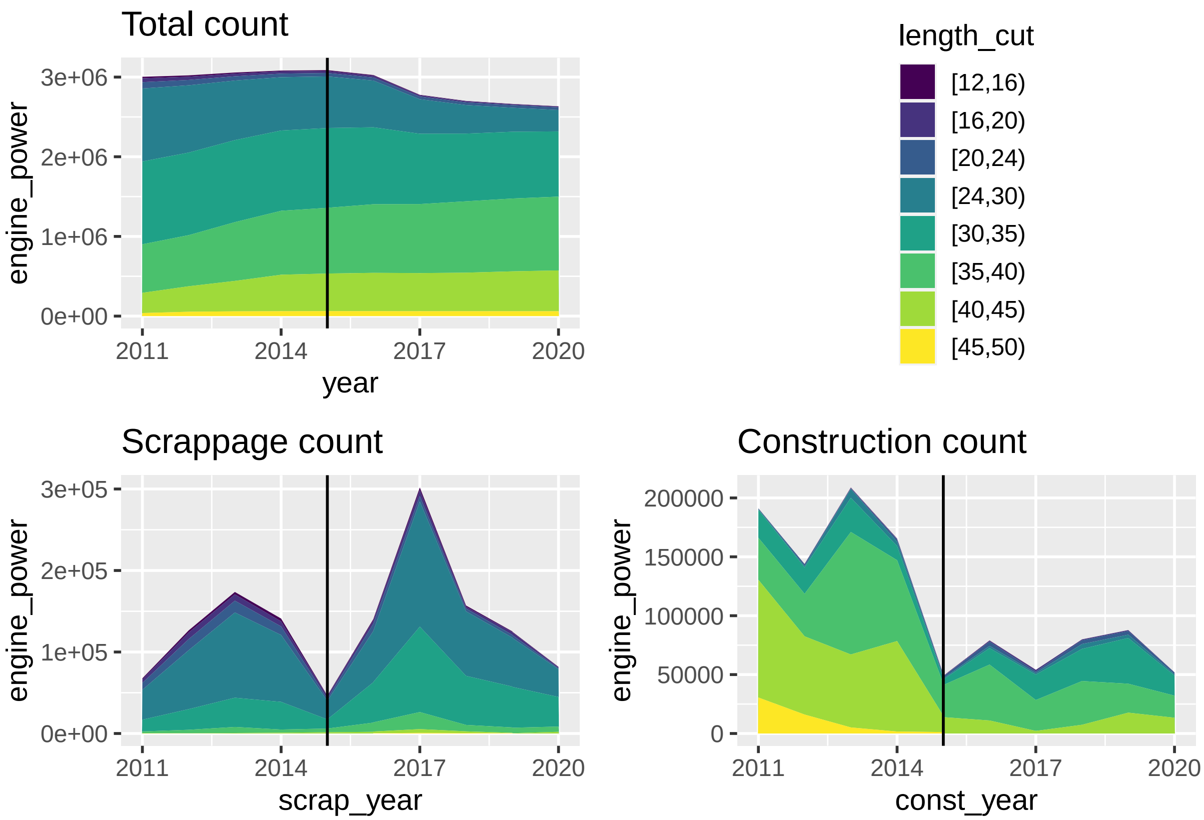

FIGURE 5.2. The evolution of the MLFV fleet capacity by vessel length in Zhejiang province from MFVDMS records

Besides reducing the fleet capacity through the retirement of smaller vessels, the subsidy reform also had subtle but important impacts on the gear structure and, most prominently, the share of trawling power in the offshore fisheries. The offshore fisheries of the ECS are dominated by trawlers, which are classified into beam trawlers and bottom trawlers. While beam trawlers target mainly shrimps, bottom trawlers can target demersal species, and they generally harvest a broad spectrum of species. While the bottom trawl fleet has continually been the most productive in the ECS regarding total tons of harvest, most of its harvest nowadays is so-called "trash fish" and invertebrates rather than economically high-valued consumer market fish. The bottom trawl fishery has been criticized for its high fishing intensity, low selectivity, scraping of bottom sediment, and destruction of sea-floor habitat. As a result, a large amount of administrative effort has been spent on confining the growth of the bottom trawl fleet, including extending the fishing moratorium and decreasing fishing subsidies.

FIGURE 5.3. The evolution of the MLFV fleet capacity by vessel length in Zhejiang province from MFVDMS records

Besides trawl net, gill net is increasingly the most important fishing gear, and most of the gillnet vessels in the offshore fisheries of East China Sea use drift nets. Deep-water drift gillnet vessels have been adopted by fishers in Zhejiang province to target high-valued pelagic finfish for their superior gear selectivity since the 1990s. While the trawling fisheries are declining due to the reduced biomass and stricter gear and season restrictions in recent years, gillnet vessels have gained popularity thanks to the market's growing appetite for high-quality, fresh fish.

The advantages of gillnet relative to trawlers becomes more evident with the subsidy reform in 2016, which revised the subsidy amount assigned to each gear. As shown in Table 5.1, by considering the impact on fisheries sustainability, the designer of the reform sharply reduced the subsidy

Table 5.1. Subsidy Coefficients and Vessel Counts by Gear Type of the MLFV Fleet in Zhejiang

Gear_type	Subs_coef_pre	Subs_coef_post	Restricted	vsl_cnt_2015	vsl_cnt_2020
single_stow	0.328	0.164	Yes	816	559
other_stow	0.328	0.300	No	160	125
angling	0.328	0.400	No	89	134
pot_trap	0.451	0.250	No	453	355
gill_net	0.451	0.360	No	2946	3055
double_trawl	0.480	0.300	Yes	1297	745
other_trawl	0.480	0.350	No	6085	4732
single_seine	0.492	0.246	Yes	492	399
other_seine	0.492	0.394	No	47	48

coefficient for gears of restricted use and promised to halt the subsidization of harmful gears after 2020. Echoing the design of the subsidy reform and the gear restriction in vessel construction, the reduction in the power of trawlers contributes most of the total fleet capacity reduction, while the power of gillnet vessels continued to increase. Overall, the preference shift observed in both scrappage and construction patterns led to a more ecologically desirable gear structure with better overall selectivity following the reform.

5.4. An Entry-exit Model

Under the cap-and-trade management of fishing power for MLFVs, the Zhejiang government prohibited the inter-provincial purchase of fishing vessels to achieve the capacity control target. Consequently, the fleet dynamics within Zhejiang province are primarily influenced by the exit of fishing power through vessels being scrapped and the entry of fishing power through vessel construction. The total power used for fishing vessel construction should be equal to the total power of scrapped vessels not retrieved by the government buyback program.

Table 5.2. Engine Power Flow for Each Vessel Investment Activity: Pre- and Post-reform

Post16	Scrappage	Boughtback	Construct	Nonbuyback
FALSE	486034	255	435829	485778
TRUE	724825	394937	359429	329888

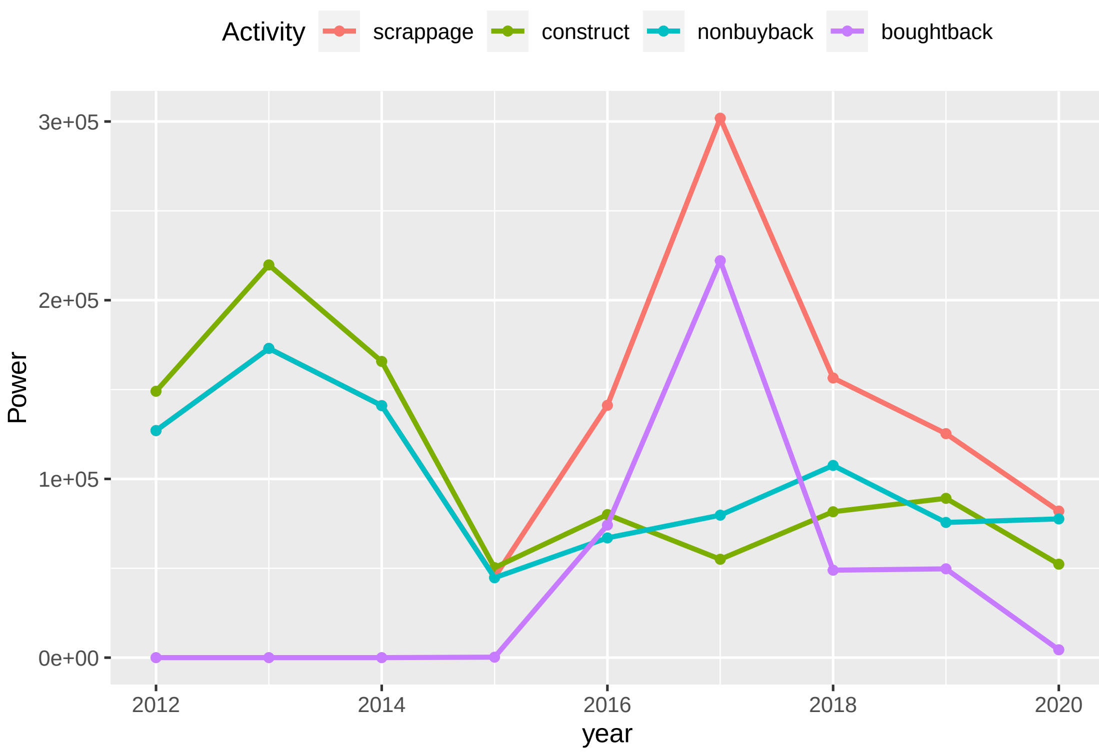

Figure 5.4. Engine Power Flow for Each Vessel Investment Activity by Each Year

Figure 5.4 and Table 5.2 present a comprehensive overview of the evolution of vessel entry, exit, and buyback activities, demonstrating their interconnections within the cap-and-trade system and the influences of 2016 subsidy reform on fishers' entry and exit decisions. Before the reform, vessel entry slightly exceeded vessel scrappage, likely due to the conversion of power quota from SFVs to MLFVs, resulting in a gradual increase in the total power of the offshore fleet. However, the 2016 reform, with its buyback program and fuel subsidy reduction, caused a significant shift in this trend. The large gap between increased scrappage and reduced construction activities resulted in a net reduction in fleet power.

Moreover, the figure highlights the pivotal role of the buyback program in capacity reduction within this limited-entry fishery. The "double-control" system design ensured that the power used for vessel construction was approximately equal to the power exiting through scrappage and not bought back. This balance was further emphasized by prohibiting engine power consolidation from inshore vessels to offshore vessels after 2015. The reduction in vessel construction can be attributed to the reform's activation of the buyback program, preventing around half of the exiting power from re-entering the fishery through new vessels.

To simulate the fleet dynamics without the fuel subsidy reform, a model must consider both vessel entry and exit components, which are closely linked by the cap-and-trade management of fishing power. Once the counterfactual vessel exit and entry patterns are identified, I can comprehensively depict the counterfactual fleet capacity and understand its evolution over time. Therefore, in order to simulate the fleet dynamics without the fuel subsidy reform, we need two components in the model, namely vessel entry and exit, which are linked by the cap-and-trade management of fishing power. Once the counterfactual vessel exit and entry are each identified, we are ready to depict a full story of the counterfactual fleet capacity.

In the vessel exit component, I first utilize the exogenous variation in fuel subsidy assignment brought by the 2016 fuel subsidy reform to identify the treatment effect of fuel subsidy on vessel exit and buyback decisions for each class of fishing vessel. Similar to Chapter 1, the exit choice for the vessel owner can be modeled with

$$y_{it} = \beta \log(FS_{it}) + \lambda_{a_{it}} + c_i + \gamma_t + \nu_t \mathbf{X}_i + u_{it}, \tag{5.1}$$

Where y_{it} is the indicator for exit or buyback, FS_{it} is the eligible amount of fuel subsidy, and a_{it} is the vessel age for vessel i at time t. c_i and γ_t are the fixed effects for vessel classes and time, respectively. I also include interactive fixed effects $\nu_t \mathbf{X}_i$ to capture unobserved time-varying impacts correlating with vessel characteristics. With the treatment effect β identified, I can simulate the counterfactual vessel exit by adjusting the fuel subsidy level FS_{it} to the counterfactual level without the fuel subsidy reform.

The primary consideration in this exercise is the proper classification of fishing vessels in preparation for estimating heterogeneous treatment effects. Primarily interested in the impact of the reform on the gear adoption in the fleet, I divide the sample by the licensed fishing gear. Due to highly unbalanced shares of fishing gears among the MLFV fleet, I further divide trawlers into three subcategories (double-otter, single-otter, and beam-shrimp trawlers) while combining the longline, jigging, and pot-trapping vessels into one category——"hook-trap", to make the sample size suitable for estimation. Lastly, as wood-hulled vessels have a drastically different tendency for retirement from steel-hulled vessels, the wooden vessels are set aside as an individual class in estimation. Together, I have eight classes of fishing vessels in the model simulation.

The second component of the model simulates vessel entry into the fleet. Given that the total amount of fishing power for vessel construction is determined by vessel exits, the rest of the problem is to determine the impact of subsidies on the flow of fishing power into each vessel class. The investment problem of would-be enterers then is choosing the type of vessels to construct. At the market level, the individual discrete choices add up to the shares of fishing power devoted to each class of fishing vessels, which is often modeled with an aggregated multinomial logit model:

$$\ln\left(s_{jt}\right) = \beta FS_{jt} + \alpha p_{jt} + \text{ Other Controls } + \xi_{jt}, \tag{5.2}$$

where s_{jt} is the share of power flowing to vessel class j in time t, while FS_{jt} and p_{jt} are the fuel subsidy and profit expected to be earned from the corresponding construction project.

However, the estimation is challenging in my setting, even with exogenous assignment of the fuel subsidy. First, it is hard to measure the actual subsidy eligibility for vessels constructed after 2014. Due to the local mandate in Zhejiang province that fuel subsidies for new vessels after the reform be limited by the subsidy for vessels replaced, it is impossible to compute the actual subsidy amount without further data to track the source of power quota for each new vessel. Second, sequential bans on the construction of harmful gear implemented following the subsidy reform make the variations in share changes after the reform very noisy for identification. Third, as the fuel subsidy coefficients attached to gears were designed to reflect the vessel fuel costs, the impact of fuel subsidy changes is hard to be disentangled with the differential impact of varying fuel costs for different gear types. Lastly, the sparsity of new vessels, in comparison with complex post-reform classifications of vessels for differential vessel regulations and subsidy standards, leads to severe information loss in estimation when observations of zeroes in the outcome variable are automatically dropped.

In the absence of reliable structural behavioral parameters identified in the simulation of counterfactual vessel entry to various gear types, I have to impose a simplified assumption that the share of power flowing to each gear type in the post-reform period would be like the share pre-reform, had fuel subsidy coefficients to each gear type not been revised by the reform. More specifically, I assume that the "independence of irrelevant alternatives" (IIA) assumption always holds for gear types available for construction, which means once an alternative is removed by the gear ban, the share will be proportionately diverted to other available gear types.

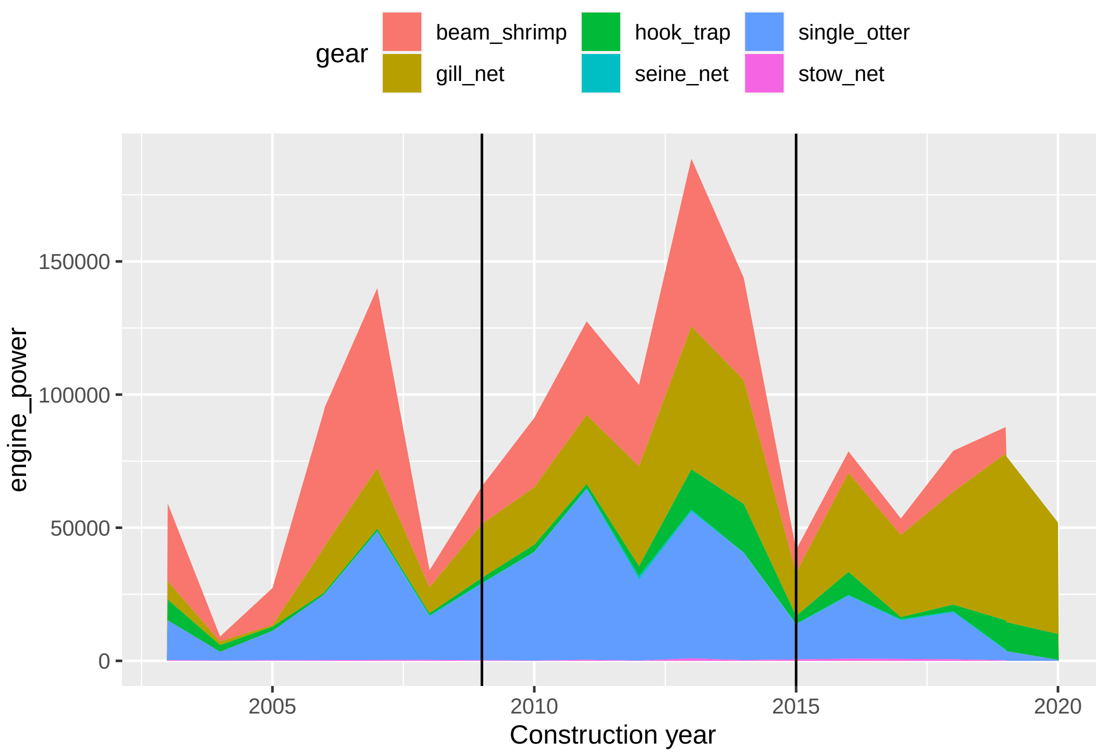

FIGURE 5.5. Engine power for Vessel Construction of Unrestricted Gears by Each Year

The extrapolation of the pre-reform gear preference to the post-reform period, though crude and arbitrary, is supported by descriptive evidence showing that the power share of different gear types in vessels constructed before 2016 remained relatively stable (Figure 5.5). This stability in gear choice is consistent with my understanding of the gradual shift in skill sets of local skippers due to the aging workforce, limiting their options for gear selection in the short term. Additionally, I compared the eligible fuel subsidy per power for vessels constructed just before and after 2016 based on the post-reform standard. The analysis did not reveal any systematic selection of vessel classes with higher fuel subsidy margins by fishers during the post-reform period (Figure 5.6). Despite the limitations of this assumption, it serves as a reasonable starting point for the counterfactual analysis of the fleet dynamics without the fuel subsidy reform.

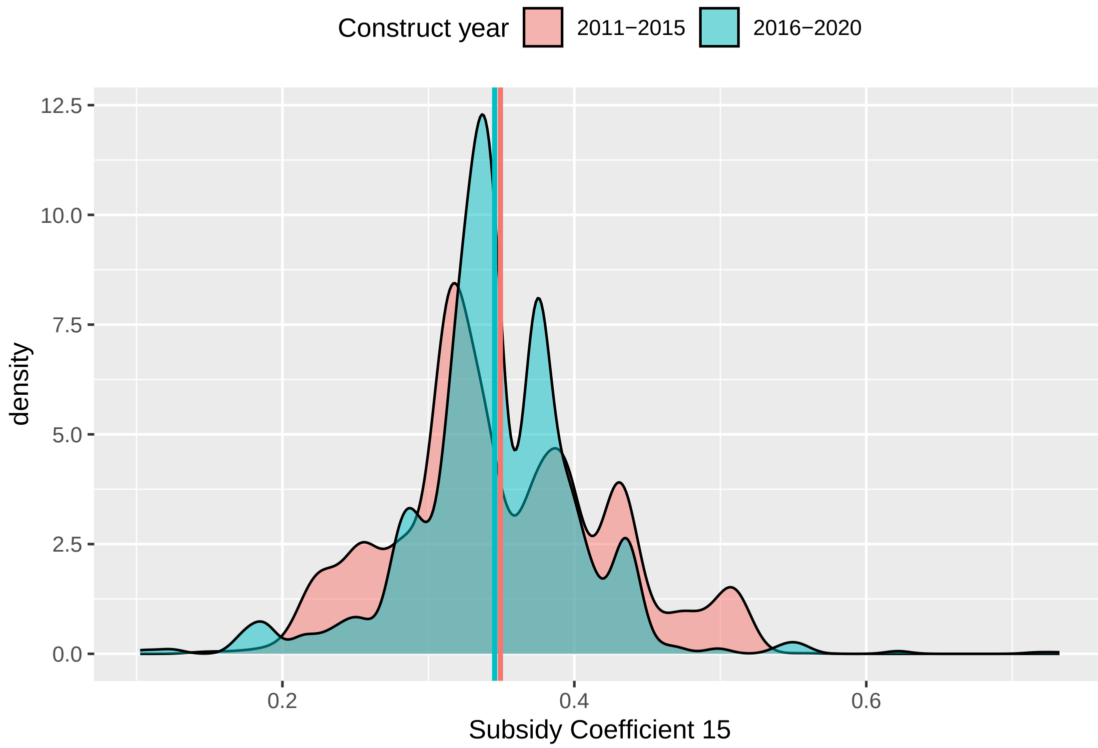

FIGURE 5.6. Distributions of Actual Subsidy Coefficients under the 2016 Fuel Subsidy Standard for Vessel Constructed Before and After the Reform

In summary, given the absence of clear variations in constructors' gear choice response to the fuel subsidy, I assume that the power share of gears would follow the pre-reform trend if the reform had not occurred for counterfactual simulation. As a sensitivity test, I also simulated the vessel entry using the observed post-reform gear type share. Conceptually, the potential outcomes of gear share could lie somewhere between these two scenarios.

I present the estimated treatment effects of fuel subsidies on vessel exit and buyback for existing vessels until 2012 in Figure 5.7. Notably, there is significant heterogeneity across vessel gear types in their responses to fuel subsidy reductions, with double-otter trawlers exhibiting the largest treatment effect. Based on the estimated average treatment effect and counterfactual average fuel subsidy, a back-of-the-envelop calculation indicates that the fuel subsidy reform has the most substantial impact on double-otter trawlers and the least impact on gillnet vessels (see Table A.8).

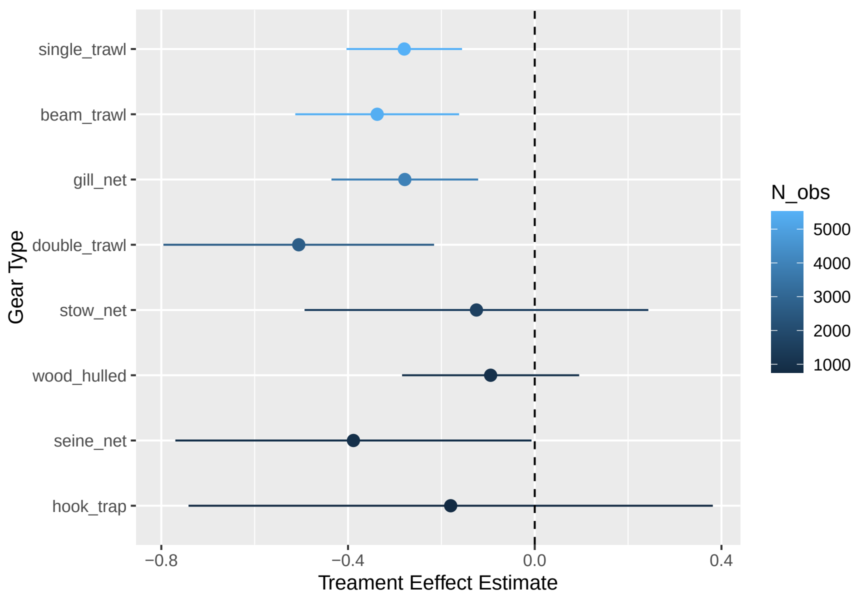

FIGURE 5.7. Estimated Treatment Effects of Fuel Subsidy on Vessel Exit by Gear Type with 95% CIs. See Table A.8 for details.

Based on the estimated treatment effects, I simulate the counterfactual scrappage and buyback between 2016 and 2019 assuming a fuel subsidy standard of 2312RMB/MT and pre-reform subsidy coefficients adopted. Comparing **Exit_Obs** and **Exit_CF** in Figure 5.8, the fuel subsidy reduction increased the total exit by over one third, and the reduction is mostly contributed by the exit of trawlers, in particular pair trawlers. The disproportionate pressure of subsidy reduction in the survival of pair trawlers is not surprising, considering the harshly reduced subsidy coefficient for restricted gears and the sensitivity of its profit margin to the fuel cost and subsidy income.

Using the counterfactual buyback rate, I simulate counterfactual entry flow **Const_CF1** and **Const_CF2** in Figure 5.8, which respectively use the pre-reform power share and post-reform power share for gear types. Comparing with **Const_Obs**, the reduction in vessel exit also leads to slight shrinkage in total power available for vessel construction.

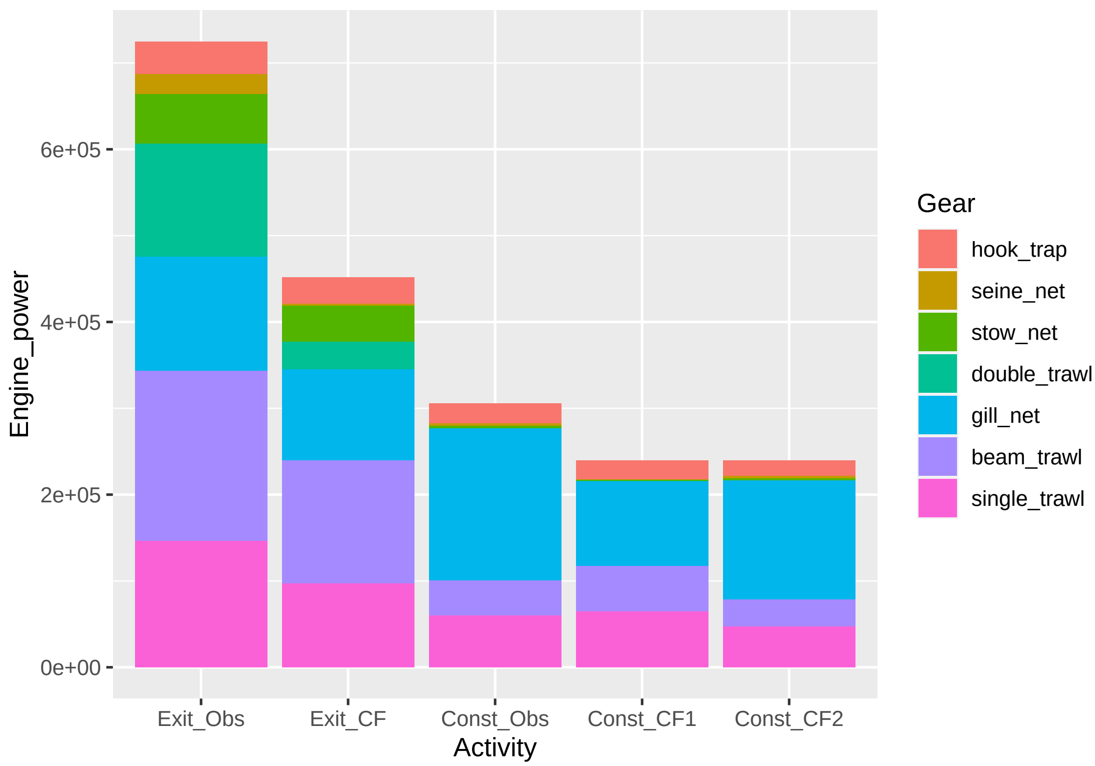

FIGURE 5.8. Simulated Counterfactual Entry and Exit Assuming No Reform in Fuel Subsidy Standard

Combining the simulated exit and entry flows, CF1 and CF2 in Figure 5.9 present the counterfactual gear structure at the end of 2019, assuming no reform on fuel subsidies. CF1 utilizes the pre-reform share to simulate the vessel entry to different gear types, while CF2 uses the post-reform share of vessel entry.

The simulated results demonstrate that the revision and reduction of the subsidy reform in 2016 partially contributed to the reduction in fishing power, while it was solely responsible for the shift in the gear structure. By comparing the Observed and Counterfactual scenarios for the fleet power in

2019 (the left panel), we observe that the subsidy reduction significantly reduced the total capacity. The remaining capacity reduction can be largely attributed to the buyback programs.

Similarly, by comparing the Observed and Counterfactual scenarios for the fleet structure in 2019 (the right panel), we find that the subsidy reduction predominantly improved the gear structure by reducing the power share of double-otter bottom trawlers and increasing the share of gill nets. Notably, the simulated results demonstrate that, without the fuel subsidy reform, the gear structure in 2019 would have been very similar to 2015, even with the gear ban on vessel construction in place. Thus, the shock of the subsidy reform on the stock of vessels is the primary factor driving the restructuring of the fishing fleet in the short-term period I am simulating.

Despite the observed insensitivity of the simulated power distribution among gear types to the assumption chosen for vessel entry flows, a trend exists in the comparison of **Const_CF1** and **Const_CF2** in Figure 5.8, that the share of power allocated to gillnet vessels appears to increase relative to trawlers in the post-reform period. While this differential trend in gear share of new vessels may not currently dominate the transient dynamics I am simulating, it is reasonable to project that, with the complete ban on the construction of bottom trawlers after 2019, gillnets will likely become the predominant gear choice for new fishing vessels, hastening the transition in the gear structure.

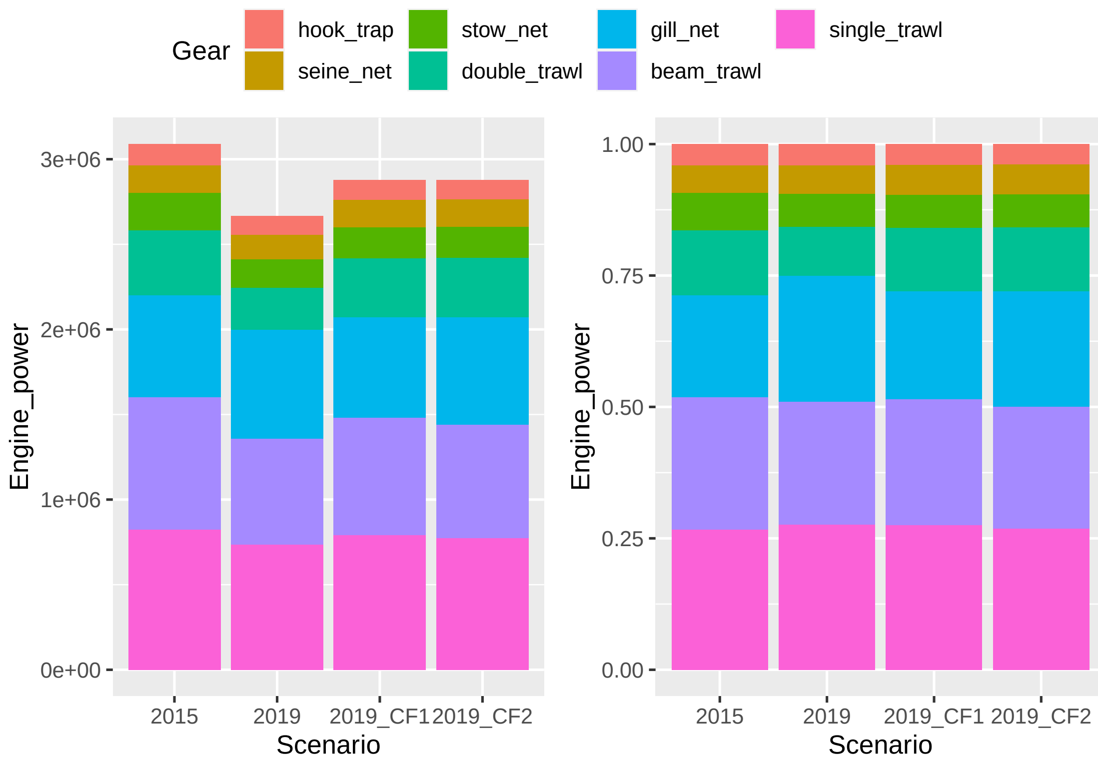

FIGURE 5.9. Simulated Counterfactual Fleet Capacity and Gear Structure Assuming No Reform in Fuel Subsidy Standard

5.6. Discussion

Overcapacity has been the main driver of fishery resource degradation in China since the 1980s. Excessive fishing capacity leads to over-competition in fishery resource exploitation, exacerbates the insufficiency of monitoring and enforcement, and ultimately results in low returns to fishers as rents are dissipated. The growth in fishing capacity and the degradation in fishery resources conspire to push the fishers to "fish down the food web" for "trash fish", which are mainly small fishes at early life stages, trophic levels, and economic value in the harvest (Sun et al., 2023). These low-value fishes are not harvested for direct human consumption but are mainly diverted into fish meals for the large aquaculture industry in China. According to a study by Chinese fishery biologists, about half of the species collected in samples of "trash fish" are potentially higher economic valued fish but caught too soon (Zhang et al., 2020). While indiscriminate fishing continues to supply aquatic proteins, the resulting trophic cascade is detrimental to the marine ecosystem health and the profitability for fishers (Szuwalski et al., 2017).

While the reduction in total fishing power is essential to address high fishing intensity, an equally significant yet subtle aspect is to curtail the widespread use of indiscriminate fishing methods employed by fishers. In the East China Sea fisheries, bottom trawlers contribute to most low-valued harvested fish. The forcible scraping of the seabed by the enormous fleet of bottom trawlers not only indiscriminately takes away any fishable species under the water but also damages the fishing ground for other more selective fishing operations despite the differential timing in summer closure (Hilborn et al., 2023; Girardin et al., 2015). The indiscriminate harvest structure also hinders implementing more scientific species-based management strategies (Wo et al., 2022). The task faced by the fishery managers thus is to accelerate the pace of fishers to shift to less harmful gears.

In this study, the counterfactual analysis demonstrates that the economic incentives designed through the subsidy reform successfully led to a significant increase in the share of deep-water gillnet vessels and a decrease in the use of trawlers in China's offshore fisheries within a span of only four years following the reform. My findings indicate that, compared to gear restrictions on construction, the reshaping effect on the existing fleet has been the more prominent driving force behind the shift in gear structure. However, in the long term, the paradigm shift in the gear choice of entering vessels will continue to influence the composition of the fishing fleet as the initial shock of fuel subsidy reduction gradually fades.

More importantly, while the observed short-run impact of subsidy reform on the fleet structure may facilitate the shift in harvest structure, the fundamental and lasting improvement will require further proactive actions by fisheries managers that apply "ecological civilization" principles to fisheries management. For the sustainable management of mixed fisheries and the ecosystems they rely on, more refined and comprehensive management measures should be considered as the next step in fishery reform efforts in China.

CHAPTER 6

Conclusion

The motivation for this thesis stems from the ongoing policy discourse surrounding global fisheries subsidies, a persistent topic that has engaged fisheries researchers and policymakers for decades. In recent years, advocacy over subsidy reforms has resulted in new policy practices embraced by global fisheries managers. At the onset of this research, WTO member states were in the final stages of negotiations, which were initiated in 2001, to reach the first agreement to limit the use of harmful fisheries subsidies. By the completion of this thesis, the WTO Agreement on Fisheries Subsidies had been officially adopted during the 12th Ministerial Conference (MC12) and received formal acceptance from several major fishing nations, including China and the United States.

Despite the hard-won achievement of reaching a global consensus on a partial ban on fisheries subsidies, significant uncertainty exists over how these policy changes will affect global fisheries. The benefits of removing harmful subsidies, specifically their impact on alleviating overcapacity and overfishing, have primarily been promoted with theoretical analyses under the assumption of open-access fisheries institutions. Empirical analysis of the real-world consequences of subsidy removal in a regulated institutional environment is lacking (Sakai et al., 2019). Additionally, although there are concerns that harmful fisheries subsidies contribute to the overexploitation of high-seas fisheries, recent estimates suggest that only a small portion of these subsidies, approximately \$1 billion out of \$22.2 billion, are directed towards supporting high-seas fishing. The majority of the harmful subsidies, approximately \$15.9 billion, are used to support domestic fishing fleets within the Exclusive Economic Zones (EEZs) of subsidizing nations (Skerritt et al., 2023). EEZ fisheries, enabled under the United Nations Convention on the Law of the Sea (UNCLOS), are subject to active regulation by coastal states with property rights (Englander, 2019). The uncertainties surrounding the impacts of subsidy removal in fisheries with domestic regulatory institutions hinder the formation of a more sweeping agreement for the complete removal of harmful subsidies across each country's domestic waters.

In this thesis, I take advantage of a unique opportunity to assess the real-world impact of a large-scale fisheries subsidy reduction in China, the world's largest fishing nation. China is also the world's largest user of domestic subsidies, mainly through its fuel subsidy program implemented in 2006. This Chinese case study 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, enabling a clean identification of the reform's treatment effect on fleet capacity. Second, China's fuel subsidy reform occurred within an institutional setting that embodies the complexity of the policy environments in which many future subsidy reforms are likely to occur. This setting encompasses not only fuel subsidies but also other policy instruments such as a cap-and-trade program for engine power, a buyback program to encourage exit and fleet capacity reduction, gear regulations, and open-season restrictions. This real-world policy environment provides a rich context for analyzing the mechanics of subsidy reduction and offers practical insights into the global implications of banning harmful subsidies.

A central lesson from this study is not just the robust empirical evidence confirming the conventional argument that fuel subsidy removal will increase vessel exit rates. Rather, it's the understanding of how other policy elements condition the effects of fuel subsidy reduction. In this case study, an understanding of the impact of fuel subsidy reduction can only be made within the broader context of the "double-control" system for managing fishing capacity, which resulted in a cap-and-trade market for fishing vessel engine power quota. Additionally, the buyback program introduced a buyback price that enticed fishers exiting the industry to retire their engine power quota rather than sell it to new entrants in the power quota market. Since fishing profit and subsidy income actively influence the capitalized market value of engine power as a form of production capital, the implications of fuel subsidy reduction for Chinese fisheries are clear: when fuel subsidy reductions effectively push the engine power quota price below the buyback price, vessel retirement will be triggered by activating buyback program participation by exiting fishers and capacity will decline. Conversely, if the engine power quota price from exiting fishers remains higher than the buyback price, that quota will be retained within the "double-control" system, albeit potentially shifting quota from marginal fishermen squeezed out by subsidy reductions to more competitive fishermen with a greater willingness to remain in the industry.

In this context, it can be seen that the proper design of an exit channel for fishers becomes as crucial for fleet capacity control as fuel subsidy reduction. In the subsidy reform program of China, this was made possible by redirecting the savings from reduced fuel subsidies into the buyback program, effectively repurposing the subsidies to incentivize vessel exit while assisting fishermen in transitioning to non-fishing occupations. In doing this, Chinese authorities not only established a mechanism for reducing fleet capacity but also addressed one of the significant political obstacles to subsidy reforms, namely, the short-term costs imposed on fishermen as their subsidy payments are reduced. Indeed, the counterfactual analysis in Chapter 4 implies that subsidy reductions alone may not guarantee any capacity reduction. In the Chinese case, if buyback prices had remained at their pre-reform level, they would have been below the post-reform power-quota prices that would likely have existed if only the fuel subsidies had been reduced. Exiting vessels would then have preferred selling their power quotas on the market to potential entrants rather than surrendering them to authorities through the buyback program.

Throughout my investigation, the rise and fall in engine power quota prices in Chinese fisheries serve as a vivid illustration of how fishers' economic decision-making actively reacts to adjustments in fisheries subsidy policies. These dynamics underscore the intricate interplay between subsidies, local regulatory measures, and the functioning of capital markets. This scenario highlights a cautionary note in subsidy reform design: a simplistic approach to subsidy removal, without considering the economic incentives driving local fishermen, is likely to generate unintended socioeconomic costs or fail to achieve the intended policy objectives.

Another significant insight gained from evaluating the subsidy reform is the finding of heterogeneous responses of fishers to the subsidy reduction. Older, smaller, and less technically efficient vessels are notably more likely to exit under the pressure of fuel subsidy reduction, leading to a shift in the post-reform fleet towards newer, larger, and more powerful fishing vessels. This targeted pressure on marginal vessels aligns with the interests of fishery managers in China, who aim to accelerate the modernization of the domestic fishing fleet and reduce operational risks at sea, primarily attributed to outdated and less robust vessels. However, this shift in fleet distribution raises questions regarding the actual impact of capacity retirement on fishing mortality. As the least efficient producers exit first through vessel buyback or replacement, the actual reduction in harvesting capacity will likely fall below the nominal reduction in physical fleet capacity(Pascoe and Coglan, 2000). Furthermore, the heterogeneous impacts of subsidy reduction accelerated the reshaping of the gear structure in China's offshore fisheries. While this momentum had emerged before the reform with the rise in the premium for high-quality consumable fish and the decline in the profitability of trawling fisheries, the reduction and redesign of fuel subsidies, coupled with other gear control measures, further exerted pressure on bottom trawlers' retirement and encouraged the adoption of more selective gear.

Taken together, the findings from this thesis suggest that while subsidy reductions may contribute to addressing the overcapacity problem, their ultimate impact on fisheries sustainability, fishers' livelihoods, and food security requires further examination through subsequent studies. This underscores the importance of not viewing subsidy removal as a panacea for fisheries sustainability but, at best, as a foundation for further steps in the reform process.

Beyond the global lessons about the prospects for subsidy reform efforts, the initiative behind this research also lies in its potential contribution to inform the quest for improved management of Chinese fisheries. Similar to many other developing nations, China's fisheries suffer from reliance on indirect controls on inputs rather than direct output controls or property-rights-based institutions (Su et al., 2020). As the world's largest marine capture fishery, China's fisheries are often noted for the extensive nature of its marine management system, marked by numerous challenges faced by fishery managers. One of the most distinguishing features has been the sheer number of fishers and vessels relying on marine capture fisheries, a scale leading to significant depletion of near-shore resources. Efforts to curb capacity growth began in the 1990s, primarily involving fleet power and season-length caps. More substantial reforms were only seen after the 13th Five-Year Plan beginning in 2016, which aimed at an ecologically motivated transition in ocean and coastal zone management. The fisheries subsidy reform examined in this thesis was conceived as a crucial part of this transition. Benefiting from a "top-down" approach, the plan went through a rapid nationwide implementation beginning in 2016.

This thesis project was initiated as a fundamental inquiry comparing China's early stagnation in capacity control within its fisheries sector up to 2015 with the regime shift that occurred following the proposal of the 13th Five-Year Plan. Until very recently, the scarcity of high-quality, openly accessible fisheries data, coupled with the historically limited transparency in fisheries management, has hindered in-depth empirical micro-studies of China's fisheries management like that of this thesis. Thanks to the government's recent embrace of digital transformation and transparency, I had the opportunity to investigate a rich and unique administrative dataset of fishing vessel registries in China's pivotal fishing province. Access to the dataset enabled me to recover and conduct a detailed analysis of fleet dynamics, combined with an extensive review of academic literature, policy documents, and valuable insights gained from interviews with industry practitioners.

To better understand China's fisheries management system, a significant contribution of this thesis lies in the identification and formal description of the cap-and-trade management of fishing power (i.e., the "double-control" system), which drives the engine power quota market. While local fishery managers have noticed the pattern of price movements in this market, its structure and operation have not been thoroughly described and researched before. Utilizing theories of cap-and-trade markets, I develop a unified framework for analyzing capacity management and fisheries subsidy policies in China, providing a nuanced understanding of participants' incentives within the dynamics of fisheries management. Indeed, the design of China's subsidy reform program, which is embedded within the double-control system, reflects fishery managers' admirably sophisticated understanding of the economic incentives that drive fishery participants' entry and exit and their strategic use of regulatory instruments to achieve management objectives of fleet capacity control and gear structure improvement.

Despite ongoing efforts to retire excess and harmful capacity, and increasingly stringent effort restrictions following the 2016 reform, the sustainable management of fisheries resources in China will most likely necessitate the implementation of comprehensive output control management. While complex management systems like catch share programs may not be immediately feasible for China's vast and intricate fisheries, the success of the subsidy reform demonstrates that gradual improvements can be achieved through well-designed policies and enlightened "top-down" implementation. Shifting market preferences are further driving the transition towards well-managed, commercially viable fisheries that provide essential ecosystem services (Crona et al., 2020). Extending beyond the registry and transaction records employed in this research, the broader implementation of electronic vessel monitoring systems and the obligatory reporting of fishing logs will further augment the availability and quality of data for fisheries management in China. This enhanced data landscape holds significant promise for advancing both scientific inquiries and policy development. In this regard, the potential for the field of marine resource management science in China is bright, offering a wealth of opportunities to gain deeper insights into fisheries dynamics, sustainability, and effective governance through future research.

APPENDIX A

Supplement Tables and Figures

Supplementary tables

Table A.1. Comparison of the fleet dynamics recovered in the MFVDMS sample with the Yearbook report for Zhejiang trawlers

	Trawlers: Fishery Yearbook		Trawlers: Sample (MFVDMS)				Large trawlers: Sample (MFVDMS)			
Year	Fleet Size (No.) (1)	Total Power (MW) (2)	Fleet Size (No.) (3)	Total Power (MW) (4)	Size to Yearbook Ratio (3)/(1)	Power to Yearbook Ratio (4)/(2)	Fleet Size (No.) (5)	Total Power (MW) (6)	Size to Yearbook Ratio (5)/(1)	Power to Yearbook Ratio (6)/(2)
2011	8459	2072.63	7950	1994.46	0.94	0.96	7685	1964.48	0.91	0.95
2012	8173	2067.46	7864	2000.59	0.96	0.97	7646	1976.92	0.94	0.96
2013	8075	2084.51	7779	2016.82	0.96	0.97	7613	2000.48	0.94	0.96
2014	7888	2044.89	7652	2021.57	0.97	0.99	7533	2011.34	0.95	0.98
2015	7771	2055.01	7617	2025.58	0.98	0.99	7515	2017.23	0.97	0.98
2016	7410	1980.35	7321	1967.82	0.99	0.99	7252	1962.29	0.98	0.99
2017	6781	1837.58	6571	1796.40	0.97	0.98	6506	1791.21	0.96	0.97
2018	6306	1763.85	6211	1717.48	0.98	0.97	6151	1712.73	0.98	0.97
2019	6002	1690.52	5913	1652.72	0.99	0.98	5860	1648.37	0.98	0.98

Table A.2. Reduced-form and 2SLS Estimations for the RD-DD Specification at 30m, 35m, and 40m cutoffs

	Annual Exit					
Cutoff tested $\tilde{L}$	30m		35m		40m	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Reduced form						
over_cutoff=1	0.0184	0.0187	0.000796	-0.00224	0.000689	0.0000917
	(0.0107)	(0.0104)	(0.00360)	(0.00338)	(0.000570)	(0.000404)
post16=1×over_cutoff=1	-0.0687**	-0.0588**	-0.0193*	-0.0121	0.00136	0.000879
	(0.0214)	(0.0210)	(0.00981)	(0.00950)	(0.00493)	(0.00461)
Panel B. 2SLS estimation						
log(Fuel Subsidy)	-0.184**	-0.158*	-0.0653*	-0.0614	0.00949	0.0128
	(0.0653)	(0.0718)	(0.0324)	(0.0383)	(0.0302)	(0.0590)
Year-Gear FE	No	Yes	No	Yes	No	Yes
Year-Power FE	No	Yes	No	Yes	No	Yes
Year-Tonnage FE	No	Yes	No	Yes	No	Yes
Bandwidth h	1.0	1.0	2.6	2.6	1.3	1.3
Observations	11958	11958	11684	11684	4899	4899

Robust Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Bandwidths h for multiple cutoffs are specified using MSE-optimal bandwidth selector (Cattaneo et al., 2020).

Table A.3. Robustness of Effects of Fuel Subsidy On Vessel Exit to Covariate Inclusion

	Annual Exit			
	(1)	(2)	(3)	(4)
log(Fuel_Subsidy)	-0.215	-0.189	-0.151	-0.151
	(0.0131)	(0.0175)	(0.0191)	(0.0203)
Year×Gear	Yes	Yes	Yes	Yes
Year×Power	No	Yes	Yes	Yes
Year×Length	No	No	Yes	Yes
Year×VesselAge	No	No	Yes	Yes
Year×CityPort	No	No	No	Yes
Year×LBDRatio	No	No	No	Yes
R^2	0.150	0.169	0.179	0.192
Observations	50471	50471	50471	50471

Robust Standard errors in parentheses

Table A.4. Robustness of the DD specification to the level of fixed effects

	Exit			
	(1)	(2)	(3)	(4)
Panel A. Annual effect				
post16=1 × log_exposure	0.129***	0.124***	0.153***	0.159***
	(0.0173)	(0.0174)	(0.0165)	(0.0174)
R^2	0.101	0.117	0.328	0.347
Observations	50984	50984	50984	44447
Panel B. Quadrennial effect				
post16=1 × log_exposure	0.356***	0.336***	0.350***	
	(0.0521)	(0.0492)	(0.0408)	
R^2	0.260	0.297	0.711	
Observations	14016	14016	14016	
Panel C. Event study				
year=2012 × log_exposure	-0.00618	0.000383	0.00954	-0.0173
	(0.0218)	(0.0218)	(0.0212)	(0.0259)
year=2013 × log_exposure	-0.0128	-0.00937	-0.0119	-0.0410
	(0.0267)	(0.0263)	(0.0201)	(0.0256)
year=2014 × log_exposure	0.0414	0.0396	0.0293	0
	(0.0263)	(0.0257)	(0.0203)	(.)
year=2015 × log_exposure	0	0	0	
	(.)	(.)	(.)	
year=2016 × log_exposure	0.0609*	0.0599*	0.0607*	0.0358
	(0.0268)	(0.0268)	(0.0246)	(0.0268)
year=2017 × log_exposure	0.192***	0.189***	0.201***	0.177***
	(0.0347)	(0.0343)	(0.0319)	(0.0331)
year=2018 × log_exposure	0.155***	0.151***	0.197***	0.180***
	(0.0312)	(0.0310)	(0.0295)	(0.0311)
year=2019 × log_exposure	0.133***	0.132***	0.203***	0.189***
	(0.0290)	(0.0292)	(0.0282)	(0.0302)
R^2	0.102	0.117	0.328	0.347
Observations	50984	50984	50984	44447
Classification FE	No	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Excluding 2015	No	No	No	Yes

Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

TABLE A.5. Event Study Estimation for Subsamples of Vessels Above or Blow the Median Length (31m)

	Annual Exit					
	Length < 31m			Length ≥ 31m		
	(1)	(2)	(3)	(4)	(5)	(6)
year=2012 × log_exposure	0.0328	0.0267	0.00426	-0.00591	-0.00261	-0.00970
	(0.0417)	(0.0418)	(0.0402)	(0.00997)	(0.0101)	(0.0133)
year=2013 × log_exposure	0.0306	0.0271	0.0371	-0.00693	-0.00440	-0.0159
	(0.0480)	(0.0479)	(0.0379)	(0.0123)	(0.0115)	(0.0128)
year=2014 × log_exposure	0.0123	0.00822	0.0193	0.00830	0.00846	-0.00112
	(0.0510)	(0.0503)	(0.0391)	(0.0133)	(0.0131)	(0.0125)
year=2015 × log_exposure	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)
year=2016 × log_exposure	0.119*	0.120*	0.106*	0.0439*	0.0449*	0.0524**
	(0.0483)	(0.0486)	(0.0453)	(0.0178)	(0.0176)	(0.0172)
year=2017 × log_exposure	0.232***	0.233***	0.228***	0.152***	0.153***	0.178***
	(0.0685)	(0.0680)	(0.0633)	(0.0264)	(0.0262)	(0.0247)
year=2018 × log_exposure	0.158*	0.155*	0.180**	0.0646**	0.0706**	0.124***
	(0.0633)	(0.0629)	(0.0606)	(0.0238)	(0.0237)	(0.0233)
year=2019 × log_exposure	0.140*	0.136*	0.177**	0.0464*	0.0546**	0.122***
	(0.0694)	(0.0694)	(0.0675)	(0.0193)	(0.0193)	(0.0199)
Classification FE	No	Yes	Yes	No	Yes	Yes
Individual FE	No	No	Yes	No	No	Yes
Observations	23679	23679	23400	26792	26792	26775

Robust Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

TABLE A.6. Event Study Estimation for Subsamples of Vessels With Vintage Above 2001 or Blow 1995

	Annual Exit					
	Vintage ≤ 1995			Vintage ≥ 2001		
	(1)	(2)	(3)	(4)	(5)	(6)
year=2012 × log_exposure	-0.0702	-0.0558	0.0531	-0.0105	-0.0137	-0.0220
	(0.0566)	(0.0555)	(0.0511)	(0.0100)	(0.0114)	(0.0162)
year=2013 × log_exposure	-0.116	-0.106	-0.0578	-0.00972	-0.0127	-0.0189
	(0.0651)	(0.0636)	(0.0468)	(0.0142)	(0.0148)	(0.0160)
year=2014 × log_exposure	-0.0134	-0.0116	-0.00993	0.0259	0.0220	0.0141
	(0.0611)	(0.0599)	(0.0479)	(0.0187)	(0.0174)	(0.0165)
year=2015 × log_exposure	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)
year=2016 × log_exposure	0.0633	0.0624	0.0612	0.0116	0.0117	0.0148
	(0.0635)	(0.0627)	(0.0581)	(0.0224)	(0.0224)	(0.0219)
year=2017 × log_exposure	0.228**	0.226**	0.237**	0.109***	0.109***	0.116***
	(0.0846)	(0.0832)	(0.0775)	(0.0328)	(0.0317)	(0.0306)
year=2018 × log_exposure	0.121	0.109	0.171*	0.0739**	0.0804**	0.1000***
	(0.0846)	(0.0841)	(0.0794)	(0.0257)	(0.0259)	(0.0253)
year=2019 × log_exposure	0.119	0.109	0.186**	0.0777**	0.0871**	0.117***
	(0.0721)	(0.0725)	(0.0699)	(0.0293)	(0.0293)	(0.0288)
Classification FE	No	Yes	Yes	No	Yes	Yes
Individual FE	No	No	Yes	No	No	Yes
Observations	15019	15019	14826	19847	19847	19843

Robust Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.7. Event Study Estimation for Subsamples of Vessels by Gear Type

	Annual Exit					
	Single-otter		Double-otter		Beam-shrimp	
	(1)	(2)	(3)	(4)	(5)	(6)
year=2012 × log_exposure	0.00771	-0.00489	-0.0372	0.0888	0.0197	0.0238
	(0.0256)	(0.0454)	(0.0793)	(0.101)	(0.0442)	(0.0567)
year=2013 × log_exposure	-0.00235	-0.0161	-0.0489	0.000568	0.00570	0.00341
	(0.0318)	(0.0454)	(0.0934)	(0.101)	(0.0458)	(0.0566)
year=2014 × log_exposure	0.0588*	0.0417	0.0369	0.0501	0.0126	0.00629
	(0.0291)	(0.0456)	(0.103)	(0.102)	(0.0423)	(0.0569)
year=2015 × log_exposure	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)
year=2016 × log_exposure	0.0509	0.0508	0.0377	0.0324	0.101*	0.104
	(0.0286)	(0.0459)	(0.122)	(0.105)	(0.0423)	(0.0575)
year=2017 × log_exposure	0.215***	0.226***	0.265*	0.276*	0.144*	0.169**
	(0.0436)	(0.0463)	(0.127)	(0.111)	(0.0611)	(0.0582)
year=2018 × log_exposure	0.104**	0.154**	0.457**	0.517***	0.0714	0.129*
	(0.0334)	(0.0474)	(0.141)	(0.119)	(0.0539)	(0.0603)
year=2019 × log_exposure	0.119***	0.186***	0.117	0.224	0.102*	0.184**
	(0.0356)	(0.0479)	(0.125)	(0.130)	(0.0505)	(0.0616)
Classification FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	No	Yes	No	Yes	No	Yes
Observations	19720	19640	9439	9374	21312	21161

Robust Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.8. Treament Effect estimates and Average Fuel Subsidies by Gear Type

Gear	$\hat{\beta}$	CI_min	CI_max	N	$\overline{FS}_{Obs}$	$\overline{FS}_{CF}$	$\Delta\log(\overline{FS})$	Shock
gill_net	-0.28	-0.44	-0.12	3931	174052.51	216674.6	-0.22	0.06
single_trawl	-0.28	-0.40	-0.16	5515	226342.27	287274.9	-0.24	0.07
beam_trawl	-0.34	-0.51	-0.16	5406	222197.08	279273.8	-0.23	0.08
stow_net	-0.12	-0.49	0.24	1605	91280.69	176812.2	-0.66	0.08
hook_trap	-0.18	-0.74	0.38	756	145346.89	235285.4	-0.48	0.09
seine_net	-0.39	-0.77	-0.01	953	187966.11	332011.8	-0.57	0.22
double_trawl	-0.51	-0.80	-0.22	2677	183516.97	320872.8	-0.56	0.28

Note: The estimation results of equation 5.1 for each gear types for counterfactual analysis. $\hat{\beta}$ is the estimated coefficient of on $\log(FS)$. CI_min and CI_max are the estimated 95% CIs for β. N is the number of observations for each regression. $\overline{FS}_{Obs}$ and $\overline{FS}_{CF}$ are the observed and counterfactual average fuel subsidies per vessel in the post-reform period. $\Delta\log(\overline{FS}) := \overline{FS}_{Obs} - \overline{FS}_{CF}$ measures the fuel subsidy reduction by the reform. Shock is calculated as $\hat{\beta} \times \Delta\log(\overline{FS})$, measuring gross impact of subsidy reform on exit rate of the vessel type.

Supplementary figures

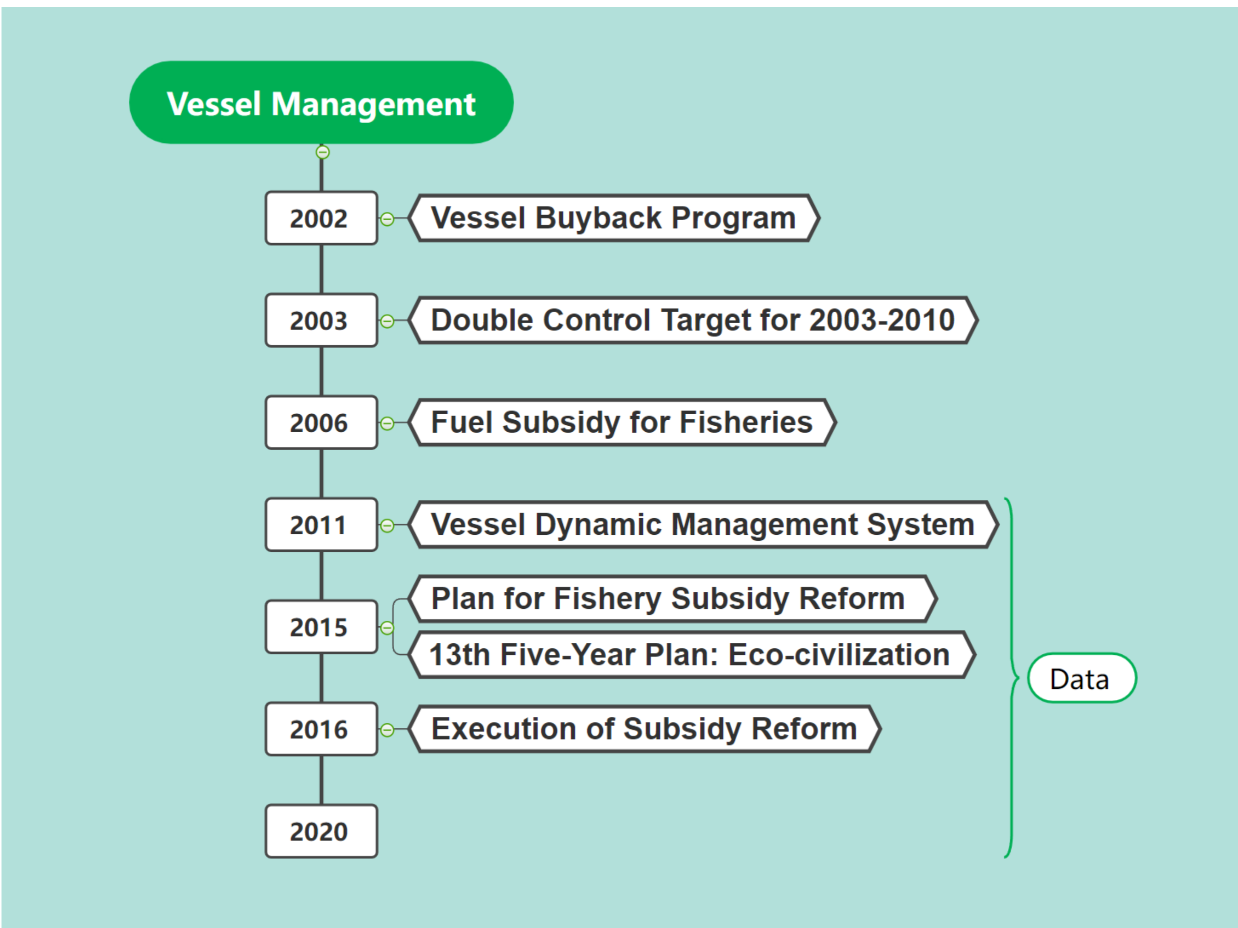

FIGURE A.1. Timeline of reforms in fisheries capacity management and subsidy policies in the domestic marine fishery of China.

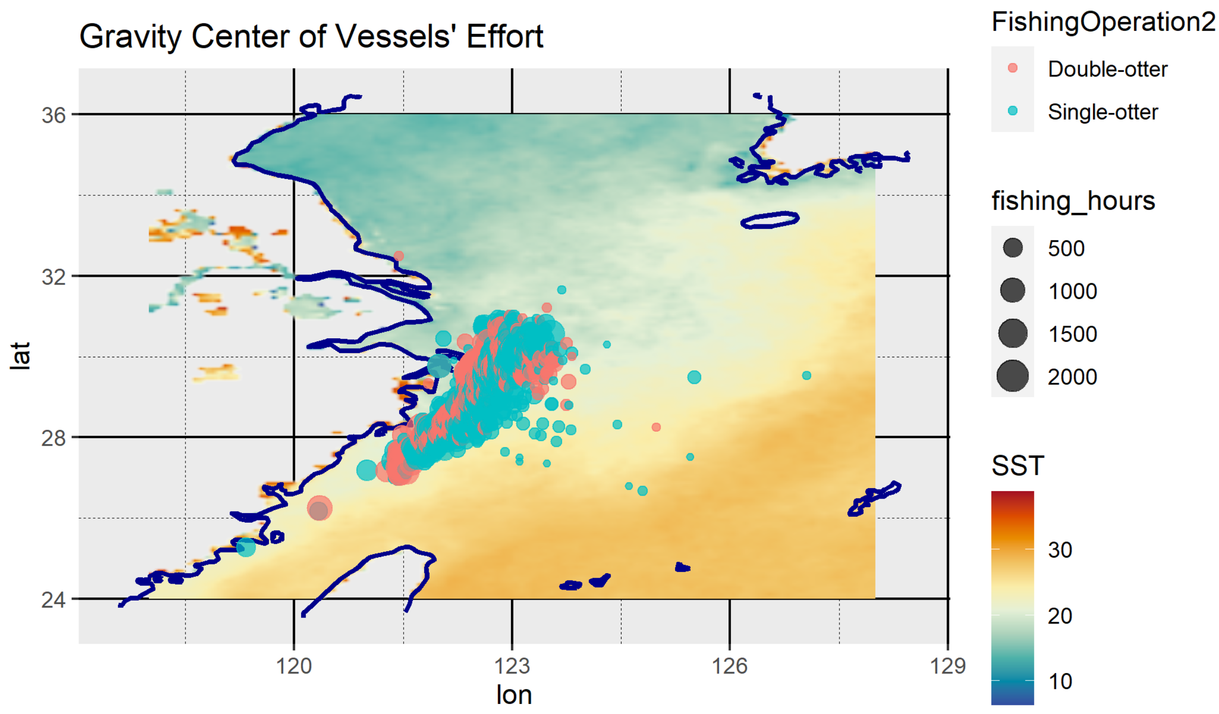

FIGURE A.2. The Distribution of fishing effort for the otter-trawl fleet managed by Zhejiang province between 2012 and 2016. The fishing effort data is curated from the Global Fish Watch `https://globalfishingwatch.org/`. Annual Average Sea Surface Temperature ($^{\circ}F$) is curated from NOAA `https://psl.noaa.gov/`.

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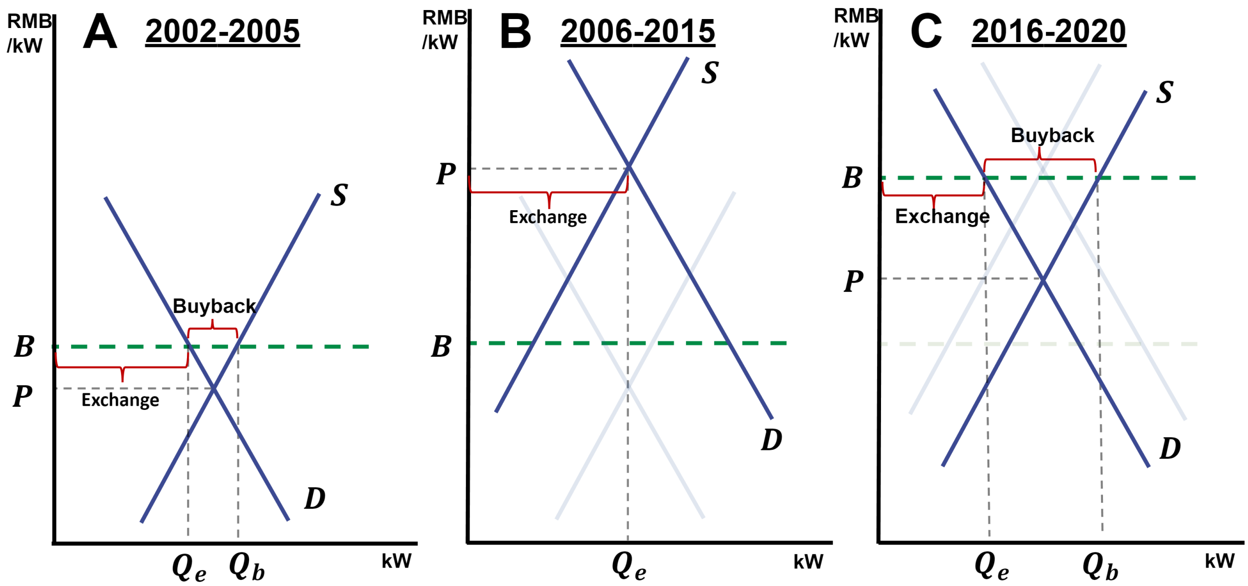

FIGURE A.3. The cap-and-trade market for engine power quota under different fuel subsidy policy regimes. With no buyback subsidy, the equilibrium price (P) and exchange of quota (Q_e) are determined by the intersection of the demand (D) and supply (S) curves (*SI Appendix*). Before the fuel subsidy program (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.

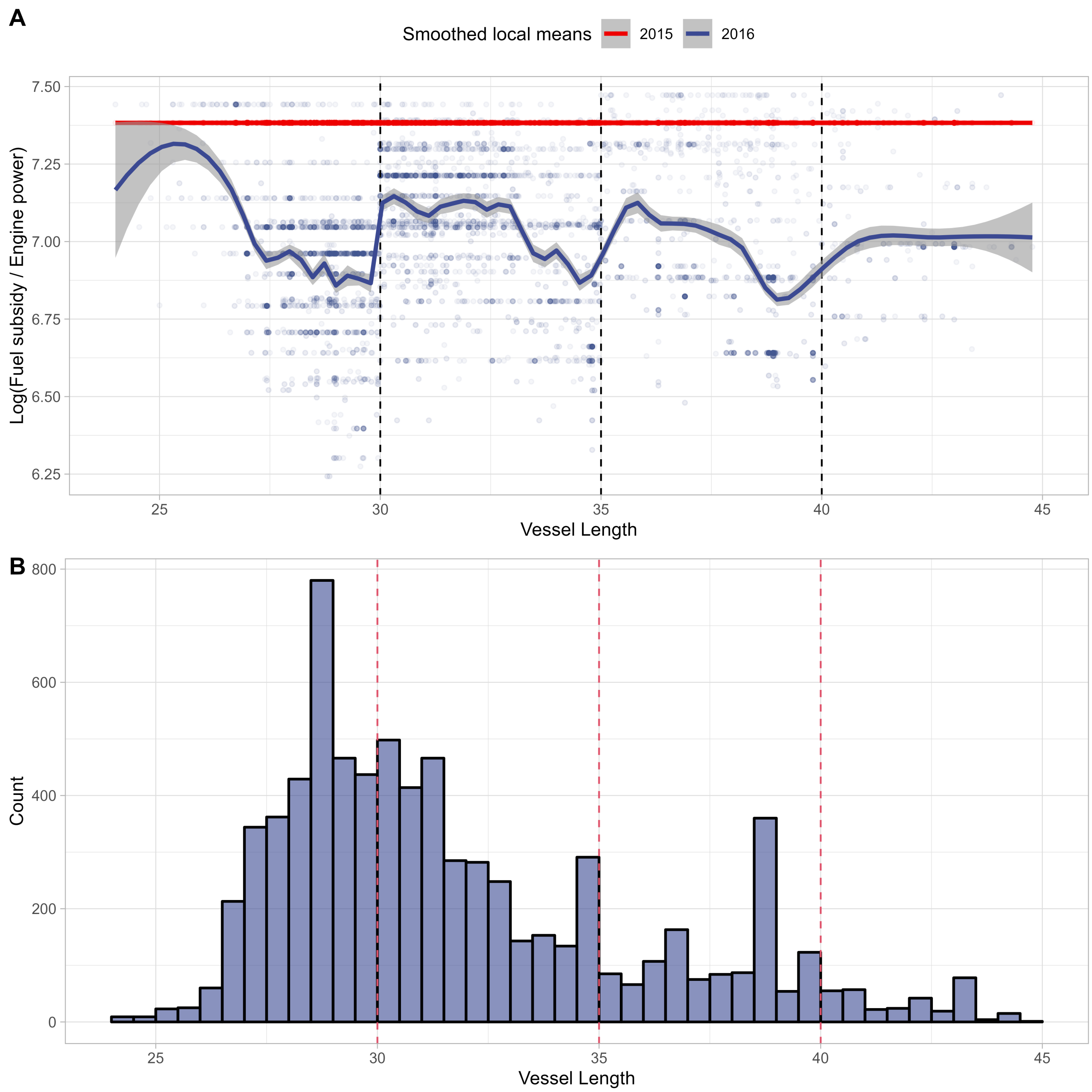

FIGURE A.4. Distributions of fuel subsidies and trawling vessels across vessel length. Panel A is the scatter plot of fuel subsidy payments per kW of engine power for all large trawling vessels in 2015 and 2016. Smoothed local means are fitted by a local linear regression (LOESS). Dashed lines are vessel length thresholds of vessel classifications for post-reform subsidy eligibility. Panel B is the histogram of vessel length for all large trawling vessels manufactured by 2011, with left-closed bins of 0.5m width.

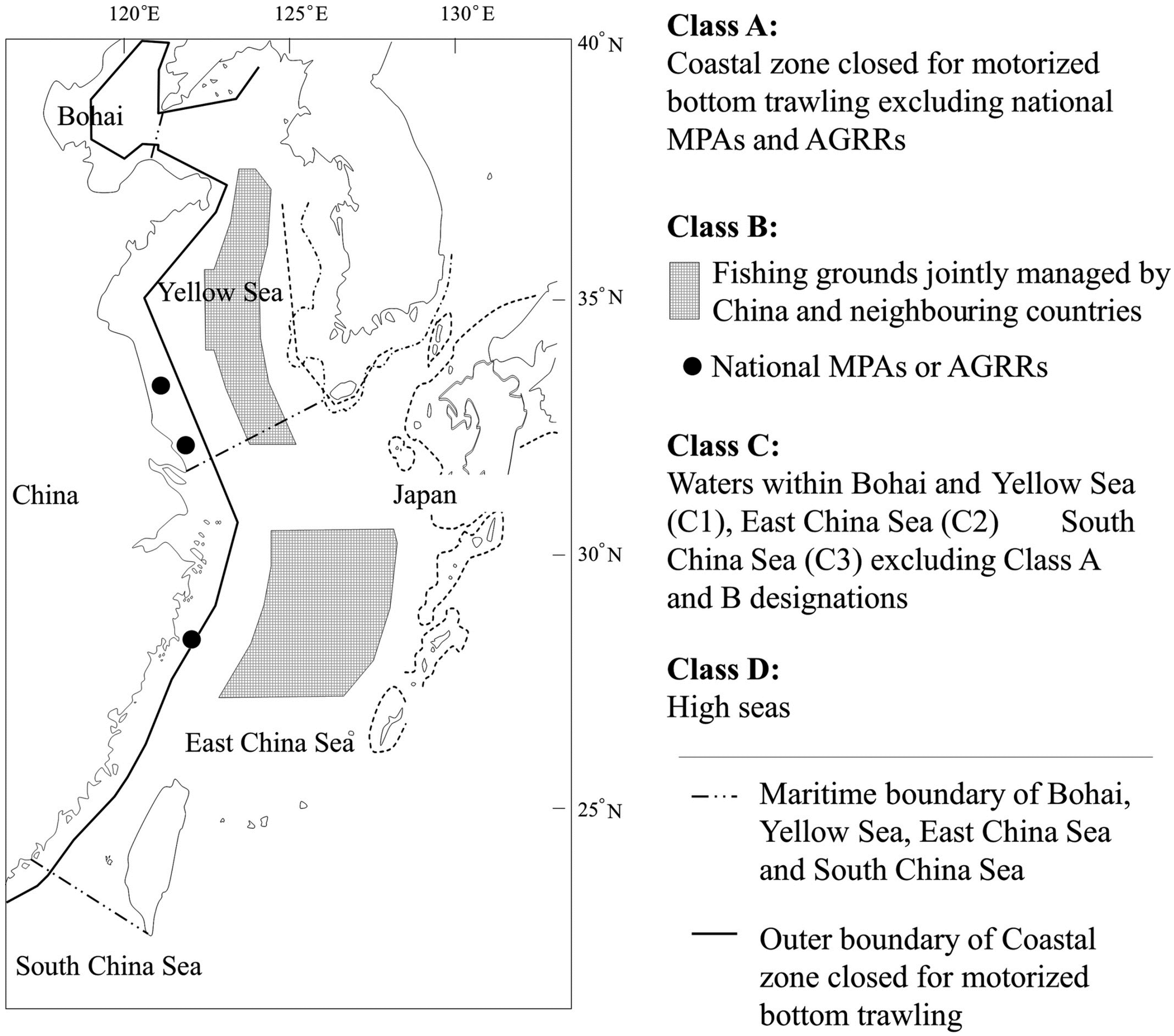

Figure A.5. Schematic diagram of spatial division of China's marine fisheries areas, source: Su et al. (2020). For domestic fishing vessels registered in Zhejiang province, small fishing vessels (SFV, vessels with $L < 24m$) can only operate in Class A waters and cannot operate across provincial boundaries, while medium and large fishing vessels (MLFV, vessels with $L \geq 24m$) approved for operations in Class B or Class C are only allowed to fish within the East China Sea area and not allowed to enter Class A waters without special permit.

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