The effect of fuel subsidies on Chinese distant water fishing

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Abstract

Causal evidence on the effect of fuel subsidies on fishing activities is unavailable, despite the widespread belief among researchers and policymakers that fuel subsidies are one of the biggest causes of fisheries depletion. China's fishing fleet is the world's largest, and in 2016 the government changed its fuel subsidy policy for distant water vessels to one that increases with predetermined vessel characteristics. The policy features 25 thresholds at which subsidies discontinuously increase. Using a regression discontinuity design, we estimate that a 1% increase in fuel subsidy increases hours of fishing by 1.4%. We use these estimates to calculate how global fish populations would change if China reduced fuel subsidies.

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1 Introduction

The presence of subsidies is a fundamental determinant of the economics of distant water fishing. For example, half of global high seas fishing would not be profitable without subsidies (Sala et al., 2018). Fuel subsidies, which totalled $8 billion globally in 2018, attract particular attention because they lower the marginal cost of fishing (Sumaila et al., 2019). The importance of fuel subsidies in reducing the costs of fishing has led many researchers to suggest that fuel subsidies are a leading cause of fisheries depletion (Cisneros-Montemayor et al., 2022; Costello et al., 2021; Martini & Innes, 2018). But despite the near consensus on the connection between fuel subsidies and fisheries depletion, causal evidence on the effect of fuel subsidies on fishing does not yet exist.[1]

This paper fills that knowledge gap by applying a regression discontinuity design to the Chinese distant water fishing fleet. This fleet is "distant water" in the sense that it fishes inside the Exclusive Economic Zones (EEZs) of countries other than China, as well as on the high seas beyond any nation's jurisdiction. External validity occurs because China's distant water fleet dwarfs all others; Millage, Warham, Rubino, and Costello (2021) estimate it contains five times more vessels than the European Union's distant water fleet, the second-largest. Internal validity occurs because fuel subsidies discontinuously increase according to predetermined vessel characteristics.

Chinese distant water fishing has steadily expanded since March 1985, when China's first distant water fleet sailed to West Africa (Ministry of Agriculture and Rural Affairs of China, 2020). The government considers distant water fishing to be a strategic industry (Support and Strength China's Distant Water Fisheries Research Group, 2010). It advances several government objectives, such as China's "Go Global" industrial restructuring strategy; it increases domestic fish supply and food security; and it allows fishers to remain in the industry even as domestic fish stocks become exhausted (Ministry of Agriculture of China, 2007; Zeng, 2022). By the end of 2021, China had 177 legal distant water fishing firms and 2,559 distant water vessels, fishing in the EEZs of more than 40 other countries and in the high seas of the Pacific Ocean, Indian Ocean, Atlantic Ocean and Southern Ocean

[1] Sakai (2017) estimates the relationship between subsidies and fish stocks, rather than fishing effort. Their identification strategy compares countries with more and less subsidy to each other over time.

(Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2021; Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, National Fisheries Technology Extension Center and China Society of Fisheries, 2022; Ministry of Agriculture and Rural Affairs of China, 2020; Zeng, 2022). The distant water fleet caught 2.25 million tons in 2021—900 times more than in 1985—and earned 22.56 billion yuan ($3.5 billion) in revenue (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, National Fisheries Technology Extension Center and China Society of Fisheries, 2022; China Foreign Exchange Trade System, 2021; Ding, 2015).

We compile the first comprehensive data on the characteristics of Chinese distant water fishing vessels. Then we match vessels to fishing activity data inferred from vessel movements by the organization Global Fishing Watch (Kroodsma et al., 2018). Our regressions compare the hours of fishing by vessels who receive a larger marginal subsidy because they are just above a subsidy threshold to vessels who receive a smaller marginal subsidy because they are just below a subsidy threshold.

The estimated effects of fuel subsidies are large. We find that a 1% increase in fuel subsidy increases hours of fishing by 1.4%. However, this elasticity is somewhat imprecise. We obtain a more precise result when we estimate the effect of fuel subsidies on the distance vessels travel. We find that a 1% increase in fuel subsidies increases km traveled by 1.2%. The fuel subsidy policy we evaluate was in effect for six years. We therefore view these estimates as long-run elasticities, which other research has found to be an order of magnitude larger than short-run elasticities (Buchsbaum, 2022; Feehan, 2018).

We use our estimated elasticity of fishing with respect to fuel subsidies to simulate how global fish stocks would change if China reduced its distant water fuel subsidies. We account for the response of non-Chinese vessels to a reduction in Chinese fuel subsidies with an instrumental variables strategy. We use data on fish stock status from Costello et al. (2016) to explore predicted changes in overfishing status in 18 major ocean regions. We predict that a 50% reduction in Chinese distant water fuel subsidies would eliminate overfishing in the Southeast Pacific, the Antarctic Atlantic, and the Northwest Pacific, and it would substantially reduce overfishing in most other regions.

2 Institutional context

Along with 79 other countries, China subsidizes the fuel of its fishing vessels (Schuhbauer et al., 2020). China does so because its fishing industry is economically and strategically important. Six million people worked in fisheries full-time in China in 2021 (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, National Fisheries Technology Extension Center and China Society of Fisheries, 2022). The government particularly encourages distant water fishing because it contributes to China's food security,[2] "Marine Power Strategy", and its "Go Global" and "One Belt One Road" directives (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2017; Zeng, 2022).

Chinese fisheries fuel subsidies began in 2006 as a complement to China's economy-wide oil price reform.[3] In order to reduce the cost pressure caused by higher fuel prices, the government provided subsidies for vulnerable groups and industries, including fishers and fishing companies (National Development and Reform Commission of China, 2006). The Chinese government reforms its distant water fuel subsidy policy every five years as part of its Five-Year Plans, and it has separate fuel subsidy policies for distant water fishing vessels and for vessels that fish in its EEZ.[4] Vessels must be "flagged to" (registered in) China to receive fuel subsidies. The distant water fuel subsidy policies between 2006 and 2015 were mainly based on fuel prices and oil consumption.[5] Instead of achieving its original intent of protecting fishers when oil prices are high, the government came to view this subsidy formula, which awarded subsidies proportionally to oil consumption, as leading to undesirably high levels of subsidy expenditure, fuel consumption, and fishing (Ministry of Finance, 2016).

[2]The national government exempts import tariff and import value-added tax on self-caught aquatic products (and processed products) that are caught in the EEZs of other countries or on the high seas and shipped back to China by distant water fishing vessels (General Administration of Customs of China and Ministry of Agriculture of China, 2000). As a further incentive, some regions provide subsidies that increase with the quantity of aquatic products declared at customs (General Office of the People's Government of Fujian Province, 2021; Government of Fujian Province, 2014; Tianjin Municipal Committee of Agriculture and Rural Affairs, 2020).

[3]To reduce the price difference between domestic and international oil products, the government introduced a market-oriented reform for oil prices and increased domestic refined oil prices in 2006.

[4]2006 was the first year of the 11th Five-Year Plan. There have been four iterations of distant water fuel subsidies so far: 2006 to 2010, 2011 to 2015, 2016 to 2020, and 2021 to 2025, corresponding to China's 11th, 12th, 13th, and 14th Five-Year Plan periods.

[5]In 2007, the Ministry of Agriculture published the official formula (Department of Industrial Policy and Regulation, Ministry of Agriculture, 2021). This formula did not change between 2006 and 2015.

China reformed its fuel subsidy policy in 2016 with this concern in mind. We study the effects of the distant water fuel subsidy policy between 2016 and 2020 because that policy features numerous thresholds at which fuel subsidies discontinuously increase with vessel size (General Office of the Ministry of Agriculture of China, 2016). Distant water fuel subsidy policies between 2006 and 2015, and from 2021 to 2025, did not feature discontinuities according to vessel size (Department of Industrial Policy and Regulation, Ministry of Agriculture, 2021; General Office of the Ministry of Agriculture and Rural Affairs and General Office of the Ministry of Finance, 2021a).[6] Chinese fuel subsidies are ex post in that the amount of subsidy awarded for fishing in year t depends on the policy in year $t+1$. For example, the fuel subsidies vessels receive in 2015 depend on 2015 fishing activities and the 2016 policy. We exclude 2015 data from our primary analysis because vessels might not have known about the new policy when choosing how much to fish in 2015. We include 2020 data in our primary analysis because the 2016-2020 formula was used by most provinces to award subsidies that year.[7] We obtain similar results when we repeat our analysis with data between 2015 and 2020, and data between 2016 and 2019 (Section 5.3).

During our period of analysis, the fuel subsidy received by vessel i of gear (fishing method) type j in year t is

$$Subsidy_{ijt} = SubsidyStandard_t \times SubsidyFactor_j \times SubsidizedEnginePower_{ij} \times SubsidyDays_{it}$$

The subsidy standard is a time constant that changes each year.[8] The subsidy factor

[6]China ended explicit fuel subsidies from 2021 and replaced them with a "compliance award" based on the compliance rating scores of distant water fishing companies (General Office of the Ministry of Agriculture and Rural Affairs and General Office of the Ministry of Finance, 2021a). These compliance subsidies may also increase fishing because they are linear in "compliance hours" (e.g., hours of fishing in an authorized location).

[7]Zhejiang province was an exception (Zhejiang Provincial Department of Finance and Zhejiang Provincial Department of Agriculture and Rural Affairs, 2021). Most provinces used the 2016-2020 formula because they were not required to start applying the 2021-2025 formula until 2021 (General Office of the Ministry of Agriculture and Rural Affairs and General Office of the Ministry of Finance, 2021b; Ministry of Finance and Ministry of Agriculture and Rural Affairs, 2021a, 2021b).

[8]The subsidy standard was 2,610 in 2015 (Taicang Municipal Government, 2016), 1,808 in 2016 (Wenling Municipal Government, 2017), 1,645 in 2017 (Jiangbei District Government, 2019), 1,331 in 2018 (Jiangbei District Government, 2020), 1,331 in 2019 (Department of Agriculture and Rural Affairs of Liaoning Province, 2020), and 1,065 in 2020 (Department of Agriculture and Rural Affairs of Liaoning Province, 2020). Since the subsidy standard is the same in all regions of China in the same year, our data comes from the public data of specific regions. The downward trend in the subsidy standard is consistent with the national government's

is a constant that depends on the vessel's gear.[9] The discontinuities in subsidy amount occur because of the subsidized engine power term, which we explain when we introduce our empirical strategy in Section 4. Subsidy days are the minimum of authorized fishing days and "vessel monitoring system (VMS) days". Since (as we will explain) subsidy days roughly correspond to the number of days vessels fish, and the fuel subsidy is linear in subsidy days, the fuel subsidy policy could increase fishing because it reduces the marginal cost of fishing.

Each year, vessel owners (firms) request a number of authorized fishing days from the Ministry of Agriculture (MOA), as well as the areas in which their vessels will fish. Authorized fishing days do not bind subsidy days because the MOA approves requests as long as the firm and its employees are not on the Ministry's blacklist (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2020b; FAO, 2022; Ministry of Agriculture of China, 2003). VMS days refers to the number of days in which the MOA receives a minimum number of pings (messages) from vessels' VMS transponders.[10] Each ping from a vessel contains its identifying information, location, speed, and direction of travel. Between 2015 and 2019, the minimum ping rate was 6 per day and at least one ping every four hours (General Office of the Ministry of Agriculture of China, 2014a). In 2020, the MOA increased the minimum ping rate to 24 per day and at least one ping per hour (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2019). VMS days roughly correspond to days of fishing because pings must originate from vessels' authorized fishing areas in order to contribute toward vessels' subsidies (General Office of the Ministry of Agriculture of China, 2012).

We do not observe VMS pings because the MOA considers these data to be confidential. Instead, we define a subsidy day as a day in which we observe at least one ping from a vessel's Automatic Identification System (AIS) transponder, which are publicly available (Kroodsma et al., 2018). This measure likely underestimates the number of subsidy days, but by much less than if we applied the MOA's minimum VMS ping rate to the AIS data

desire to reduce the level of subsidy expenditures (Ministry of Finance, 2016).

[9] There are ten gears and four possible values of the subsidy factor, ranging from 0.00246 to 0.00492. Most vessels in our data have a subsidy factor of 0.00369.

[10] In cases where the countries visited by fishing vessels forbade vessel location surveillance equipment, Chinese distant water fishing vessels are required to install Automatic Identification System (AIS) transponders (General Office of the Ministry of Agriculture of China, 2014a).

(Figure A1). AIS tranponders transmit the same data to terrestrial receivers and satellites as VMS transponders, but they have worse reception than VMS. We calculate that the fuel subsidy for the median vessel-year is $181,610 (2016 USD) using this measure of subsidy days, but because our measure is an underestimate, the median vessel-year annual fuel subsidy is likely greater. We estimate that $181,610 is 10% of annual variable costs for the median vessel-year in our data (Sala et al., 2018). This underestimate of subsidy days affects our elasticity of fishing with respect to fuel subsidy received, but it does not affect our estimate of the effect of the fuel subsidy policy on fishing.

3 Data

By combining publicly-available data from international organizations and Chinese agencies, we identify and collect the characteristics of subsidized Chinese distant water fishing vessels. Then we match these characteristics with fishing activity data. The resulting panel data are at the level of vessel-month-year.

We begin by collecting data on mainland Chinese distant water fishing vessels from the seven Regional Fishery Management Organizations (RFMOs) that China belongs to.[11] For each RFMO vessel, we recorded the vessel's registry name and vessel characteristics, including gear, length, gross tonnage, engine power, and the year the vessel was built. Gross tonnage is a non-linear measure of a vessel's internal volume. When vessels have the same name in Chinese pinyin, but the Chinese characters name and other characteristics are different, we regard them as different vessels. In most RFMOs, vessels reported additional identification information such as previous name, Maritime Mobile Service Identity (MMSI), call sign, and International Maritime Organization (IMO) number. We also gathered data from RFMO websites on the species vessels target when they fish, vessels' authorized fishing

[11] According to the Chinese White Paper on the Compliance of China's Distant Water Fisheries 2020 (Ministry of Agriculture and Rural Affairs of China, 2020), China is also a member of the Southern Indian Ocean Fisheries Agreement (SIOFA). But because the SIOFA authorized vessels do not contain any fishing vessels from mainland China, we only collect data from the following seven RFMOs: Convention on Conservation of Antarctic Marine Living Resources (CCAMLR), Inter-American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), Indian Ocean Tuna Commission (IOTC), North Pacific Fisheries Commission (NPFC), South Pacific Regional Fisheries Management Organization (SPRFMO), and Western and Central Pacific Fisheries Commission (WCPFC) (CCAMLR, 2021; IATTC, 2021; ICCAT, 2021; IOTC, 2021; NPFC, 2021; SPRFMO, 2021; WCPFC, 2021).

area, freezer type (if the vessel has a freezing system), the firm the vessel belongs to, and the RFMOs the vessel is registered in. We combine these variables into a single dataset at the vessel-RFMO level.

Not all RFMO databases contain all of the above variables, especially vessel characteristics, and characteristics sometimes differ across RFMOs for vessels with the same identifiers. To include more vessels and vessel characteristics, we combine our RFMO data with data from Rongcheng, a hub of Chinese distant water fisheries.[12] The municipal dataset of Rongcheng is part of the Shandong Provincial Open Data Platform, which was developed in 2018 and contains 318 distant water fishing vessels registered in Rongcheng (Rongcheng Municipal Government, 2021). For the 99 vessels missing characteristics in the RFMO data but not in the Rongcheng data, regardless of whether they are registered with only one RFMO or in multiple RFMOs, we use the Rongcheng data to fill in missing characteristics. For the 68 vessels enrolled in multiple RFMOs and with conflicting characteristics across RFMO databases or between RFMO data and Rongcheng data, we use characteristics from the Rongcheng data.[13] We also added 104 vessels that are included in the Rongcheng database but not in the RFMO databases. We fill in missing fishing gear values for eight vessels with information from Chinese news reports and fishing firm websites.[14] We standardize all vessel lengths to meters and all engine powers to kilowatts. After removing duplicate vessels, we obtain data for 2,216 Chinese distant water fishing vessels.[15]

[12]Rongcheng is both a hub of Chinese distant water fishing vessels and a hub of distant water fishing firms. In 2020, Rongcheng had 307 distant water fishing vessels and 19 distant water fishing firms, compared to China's total of 2,705 distant water fishing vessels and 180 distant water fishing firms that year (Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2020a; Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, National Fisheries Technology Extension Center and China Society of Fisheries, 2021). Rongcheng is also the only distant water fishing hub in northern China, and it is the county-level city with the largest distant water fishing capacity in China.

[13]We believe that the Rongcheng data is more reliable than the RFMO data because their vessel characteristics data are the same as those used by the MOA to calculate fuel subsidies.

[14]Eight vessels have "other fishing vessels not specified" listed as their gear in the Rongcheng data: JINGYUAN616, LUWENYUANYU171, LUWENYUANYU172, LUWENYUANYU175, LUWENYUANYU176, LUWENYUANYU177, LUWENYUANYU178, TIANYUAN. We determined from Chinese news reports that the first seven vessels are squid jiggers and stick-held dip net for Pacific saury fishing vessels, and the last one is a squid jigger (Cong, 2014; Pan, 2015; Zhoushan Property Exchange Co., Zhoushan Jia Lian Auction Co., and Zhoushan Huali Auction Co., 2009). Seven vessels have missing gear in the RFMO data. According to Chinese news reports, FURONGHAI, FUYUANYU9818 and MINGKAI are factory stern trawlers in CCAMLR areas, and PINGTAIRONG131, ZHONGSHUI602, ZHONGSHUI606 and ZHONGSHUI607 are tuna longliners (Wang, 2022; Weng, 2021; Yuan, 2015).

[15]We have slightly fewer vessels in our data compared to the 2,705 legally authorized distant water fishing

We match these vessel characteristics data to fishing activity data from the organization Global Fishing Watch (GFW).[16] Most distant water fishing vessels have Automatic Identification System (AIS) transponders that send their movements to satellite and terrestrial receivers. GFW applies machine learning algorithms to predict fishing activity from AIS vessel movements (Kroodsma et al., 2018).

We downloaded the hours of fishing for all vessels flagged to (registered in) China between 2015 and 2020 because vessels must be flagged to China to receive fuel subsidies from the MOA. GFW also provides vessel characteristics data. However, in contrast to the RFMOs, which can obtain detailed vessel data from member countries based on compliance rules, some GFW vessel characteristics are machine-learning-predicted values (Kroodsma et al., 2018). We believe that RFMO vessel characteristics are more reliable than GFW's for this reason. We ignore GFW vessel characteristics data and only match our vessel characteristics data to GFW fishing hours data on the following vessel identifiers: registry name, MMSI (called SSVID by GFW), call sign and IMO.

For vessels that do not match perfectly on these four variables between the two datasets, we develop a matching criterion with two indices: the vessel name as the primary fixed matching index and other indicators as the flexible matching parameter with the priority MMSI > call sign > IMO. This matching criterion means we first match vessels by name and MMSI, then match unmatched vessels by name and call sign, and finally match remaining unmatched vessels by name and IMO. Figure B1 illustrates this process and states the number of vessels in each category.

We first apply this procedure to the 2,202 vessels whose names appear in only one RFMO database. Then we manually match the remaining 14 vessels. In total, we are able to match 1,496 vessels to the GFW fishing data. If a vessel-year has observations in GFW data in

vessels at the end of 2020 mentioned in the Chinese Fisheries Statistical Yearbook. The reason for this is that our dataset only includes distant water fishing vessels from seven RFMOs and Rongcheng; we are missing distant water fishing vessels not present in these data. For example, vessels authorized to fish in another country's waters, and not in any regions managed by RFMOs, could be authorized by the MOA without being registered in an RFMO database.

[16]We matched our vessel characteristics data to the research version of GFW's fishing data, which is only available to GFW Research Partners, rather than the publicly available version of these data, because the research version contains more vessels. However, in our analysis we subset our data to vessels in the public version of GFW's data so that our results are reproducible.

some months but not in others, we add rows for those months to our panel data and assign fishing hours = 0. Finally, we subset vessels to those present in the publicly-available version of GFW's fishing data so that our analysis is reproducible. This filtering reduces the number of matched vessels to 1,340, of which 1,234 have a gear with a gross tonnage discontinuity.[17]

4 Empirical strategy

Recall from Section 2 that the annual subsidy in yuan for Chinese distant water fishing vessels is given by subsidy standard × subsidized engine power × subsidy factor × subsidy days. Subsidized engine power is the minimum of a vessel's engine power and its subsidized engine power ceiling. Vessels with higher gross tonnages (GT) have higher ceilings. Table B1 displays how vessels' ceilings of subsidized engine power depend on their gross tonnage and gear. Let c^{GT} be the nearest gross tonnage threshold for vessels given their gross tonnage and gear. Let c^{EP} be the subsidized engine power ceiling for vessels with gross tonnages below c^{GT}. To get more subsidy, vessels need to both have gross tonnages greater than c^{GT}, and have engine power (EP) greater than c^{EP}. Note that vessels register their characteristics with the government, who inspects vessels and verifies characteristics annually (Chinese Government, 1994, 2003; Ministry of Agriculture, 2013a).

There are therefore four types of vessels: those above or below their gross tonnage threshold, and those for which their ceiling of subsidized engine power would be binding or would be non-binding if they were below their gross tonnage threshold. Table 1 shows that we form the treatment group from vessels that meet these two requirements (T), and we form the control group from vessels who do not (C). We define "binding vessels" as those for which their ceiling of subsidized engine power would be binding and "non-binding" vessels as those for which their ceiling of subsidized engine power would not be binding.

Consider the following example. "Squid jiggers" are vessels whose fishing gear allows them to target squid. Squid jiggers with $GT \geq 300$ have a subsidized engine power ceiling

[17] Pacific saury vessels have only one ceiling of subsidized engine power: 2,200 kilowatts for vessels with gross tonnage above 1,400 (Table B1). All Pacific saury vessels have gross tonnage above 1,400, and there is no information on what the ceiling of subsidized engine power would be for Pacific saury vessels with gross tonnage below 1,400.

Table 1: Treatment status (T or C) depends on vessels' gross tonnage (GT) and engine power (EP)

		GT	
		Below	**Above**
EP	**Non-binding**	C	C
	Binding	C	T

of 750 kW, while squid jiggers with $GT < 300$ have a ceiling of 600 kW. In this example, $c^{GT} = 300$ and $c^{EP} = 600$. We can re-create Table 1 for this example: The vessel in the top right cell with EP = 500 and GT = 301 does not benefit from being above the GT threshold because its ceiling of subsidized engine power would not be binding if its GT was below 300. If instead the vessel had an engine power of 700, it would benefit from being just above its gross tonnage threshold.

Table 2: Example vessel corresponding to the four vessel types

		GT	
		Below	**Above**
EP	**Non-binding**	(500, 299)	(500, 301)
	Binding	(700, 299)	(700, 301)

In the regression analysis, we pool vessels across gears and gross tonnage thresholds because our data is sparse within each gear-gross tonnage threshold discontinuity. First, we identify the nearest gross tonnage threshold of each vessel and calculate its "gross tonnage distance", which equals the gross tonnage of a vessel minus its nearest gross tonnage threshold. In the Table 2 example, vessels in the left-side cells have a gross tonnage distance of -1 and vessels on the right-side cells have a gross tonnage distance of +1. This procedure normalizes gross tonnage thresholds (the cutoff) to 0. Then we calculate "normalized gross tonnage distance" by dividing gross tonnage distance by the width of the vessel's nearest gross tonnage threshold. Threshold width is half the distance to the next threshold.[18]

Normalized gross tonnage distance is the running variable in our primary specification.

[18] A threshold's width to the left may differ from its width to the right because distance to the below threshold may differ from distance to the above threshold. Relatedly, since a gear's minimum threshold has no threshold below it, we set its left threshold equal to its right threshold. Similarly, we set the right width of a gear's maximum threshold equal to its left width.

It is similar to a vessel's percentage distance to its nearest gross tonnage threshold. Figure 1 displays the transformation from (a) gross tonnage in levels to gross tonnage distance and (b) from gross tonnage distance to normalized gross tonnage distance. Figure 1(c) depicts the gross tonnage thresholds and widths for two gears: tuna purse seiners and squid jiggers, which we use to explain the difference between gross tonnage distance and normalized gross tonnage distance. Consider two vessels: a tuna purse seiner with a gross tonnage of 1,400 and a squid jigger with a gross tonnage of 480. The gross tonnage distance of the tuna purse seiner is -100 and the gross tonnage distance of the squid jigger is -20, while the normalized gross tonnage distance of both vessels is -0.2. When gross tonnage distance is the running variable, the tuna purse seiner will almost always be outside the optimal bandwidth, even though relative to the width of its threshold it is the same distance from its nearest threshold as the squid jigger. Normalizing gross tonnage distance gives large and small vessels a more equal opportunity to fall within the optimal bandwidth and contribute to our estimates because this running variable accounts for the tendency of large vessels to be in large bandwidths. By contrast, when (non-normalized) gross tonnage distance is the running variable, the gross tonnage in levels of most vessels within the optimal bandwidth is small. We prefer normalized gross tonnage distance as the running variable because it does not overweight small vessels.

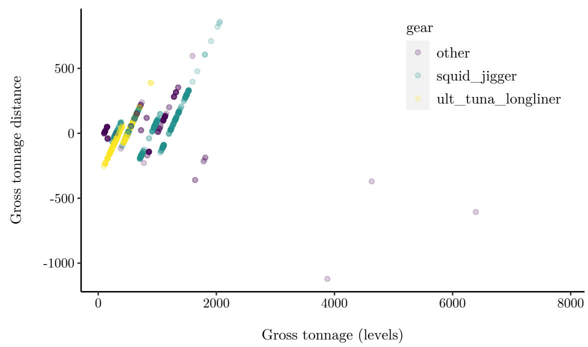
Our primary estimating equation is:

$$\begin{aligned} log(fishing\_hours_{ijt}) = {} & \beta_1 \mathbb{1}\{norm\_gt\_dist_{ij} > 0\} + \beta_2 norm\_gt\_dist_{ij} + \\ & \beta_3 norm\_gt\_dist_{ij} \times \mathbb{1}\{norm\_gt\_dist_{ij} > 0\} + \\ & \beta_4 gt_i + \beta_5 engine\_power\_kw_i + \beta_6 length\_m_i + \alpha_j + \epsilon_{ijt} \end{aligned} \tag{1}$$

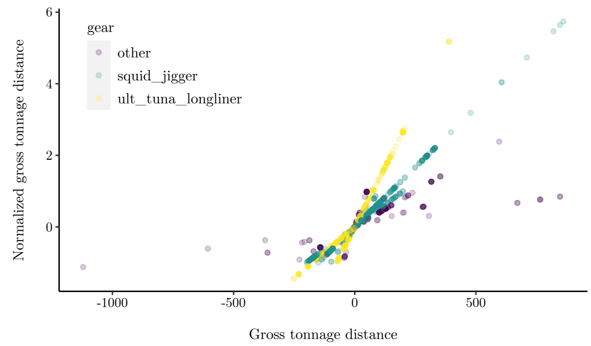
where i = vessel, j = gear, t = month-year, $log(fishing\_hours)$ is log hours of fishing, $norm\_gt\_dist$ is normalized gross tonnage distance, $\mathbb{1}\{norm\_gt\_dist_{ij} > 0\}$ equals 1 if the vessel's gross tonnage is greater than or equal to its nearest gross tonnage threshold and it equals 0 otherwise, gt is the vessel's gross tonnage in levels, $engine\_power\_kw$ is the vessel's engine power in kilowatts, $length\_m$ is the vessel's length in meters, α_j are gear fixed effects, and ϵ_{ijt} is the error term. The coefficient of interest is β_1, which measures the effect of being

Figure 1: Construction of normalized gross tonnage distance as running variable

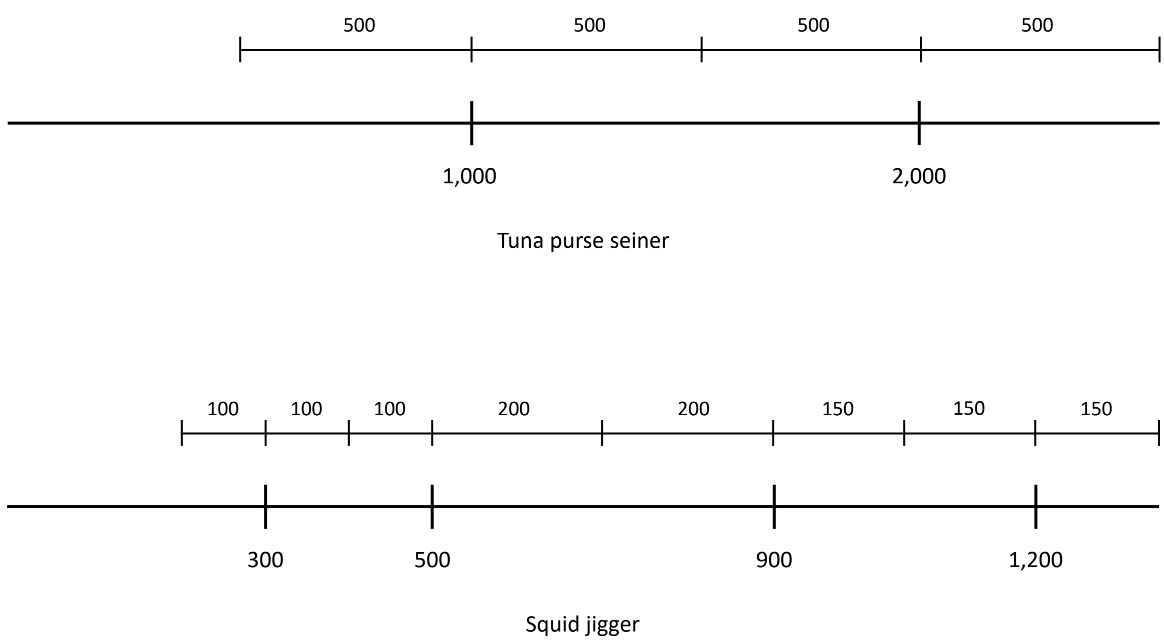
(a) Gross tonnage to gross tonnage distance



(b) Gross tonnage distance to normalized



(c) Gross tonnage thresholds and widths for two gears



Notes: (a) A vessel's gross tonnage distance (y-axis) equals its gross tonnage in levels (x-axis) minus its nearest gross tonnage threshold. (b) A vessel's normalized gross tonnage distance (y-axis) is its gross tonnage distance (x-axis) divided by the width of its nearest gross tonnage threshold. (c) Gross tonnage thresholds (larger font) and widths (smaller font) for two gears.

just above the gross tonnage threshold on fishing. We cluster standard errors at the vessel level because that is the level at which treatment is assigned (Abadie, Athey, Imbens, & Wooldridge, 2017).

Unless otherwise noted, we estimate all regressions with the default options of the rdrobust package in R (Calonico, Cattaneo, Farrell, & Titiunik, 2022). Using default options limits researcher degrees of freedom. The package's default options are: mean squared error-optimal bandwidth selection, a minimum of 10 unique values of the running variable inside the optimal bandwidth,[19] the same bandwidth above and below the gross tonnage threshold, local linear specification for the running variable, triangular kernel function, and local quadratic specification for the bias-correction. Our regression tables below report the three estimates that rdrobust reports by default: the conventional point estimate and conventional standard error, the bias-corrected point estimate and conventional standard error, and the bias-corrected point estimate and the robust bias-corrected standard error. Unless otherwise noted, we report Conventional RD estimates in the text because they remain the default estimators in applied microeconomics.

In addition to displaying point estimates and standard errors in table format, we visually reproduce every regression with the rdplot command from the rdrobust package. The resulting binned sample means and local linear conditional mean functions allow the reader to assess the variation of the dependent variable around the gross tonnage threshold. We specify three non-default options so that the difference in the intercepts between the two local linear conditional mean functions corresponds exactly to the conventional regression discontinuity point estimate. Those non-default options are: triangular kernel, local linear specification for the running variable, and the same optimal bandwidth from the corresponding regression table and column. Unless otherwise noted, we use default options in all other instances. The most important of these default options calculates the number of bins and the bin endpoints with the mimicking variance evenly-spaced method using spacings estimators (Calonico, Cattaneo, & Titiunik, 2015).

[19] If the optimal bandwidth results in fewer than 10 unique values of the running variable, then the package enlarges the bandwidth until 10 unique values occur within it.

5 Effects of fuel subsidies on fishing and distance traveled

5.1 Intensive margin effects

The policy we evaluate in this paper was publicly announced in 2016, and applied retroactively to 2015 fishing (General Office of the Ministry of Agriculture of China, 2016). Since vessels choosing how much to fish in 2015 might not have been aware of the new subsidy formula, our regressions include data between 2016 and 2020 unless otherwise noted. We obtain similar results when we re-estimate the effect of the policy using data between 2015 and 2020 (Section 5.3).

For similar reasons, our primary regressions exclude vessels built on or after 2016. These vessels could have chosen their characteristics with respect to fuel subsidy thresholds, whereas vessels built before 2016 could not have manipulated their characteristics in this way. We obtain similar results when we exclude vessels built on or after 2015 instead of 2016 (Section 5.3). In Section 5.2.3, we compare vessels built before 2016 to those built on or after 2016.

In Table 3 we estimate Equation 1 for different subsets of vessels built before 2016. In Column 1, we limit the sample to "binding vessels": vessels for which the engine power ceiling is binding. In this sample, vessels above their gross tonnage threshold receive more subsidy from being above it, and vessels below their gross tonnage threshold would have received more subsidy had they been above it. We find that the fuel subsidy policy increases monthly fishing hours by a statistically significant 0.594 log points (standard error = 0.246). We convert this large coefficient into an elasticity in Section 5.1.1. While this is our preferred estimate of the effect of the policy on fishing, we note that the other RD estimates of the subsidy policy impact ("Bias-corrected" and "Robust") are even larger in magnitude and are more precisely estimated.

Limiting the sample in Column 2 to "non-binding vessels"—those for which the engine power ceiling is not binding—provides a placebo test. The fuel subsidy policy should not increase fishing for these vessels because vessels in this sample do not receive more subsidy from being just above their gross tonnage threshold. The "effect" of the policy on these vessels is

Table 3: Effect of fuel subsidies on log hours of fishing

	Dependent variable: log(fishing hours)		
	(1)	(2)	(3)
Conventional	0.594	-0.170	-0.122
	(0.246)	(0.061)	(0.051)
Bias-Corrected	0.843	-0.206	-0.133
	(0.246)	(0.061)	(0.051)
Robust	0.843	-0.206	-0.133
	(0.283)	(0.064)	(0.058)
Bandwidth	0.203	0.380	0.459
N	1,050	7,976	13,849
Sample	Binding	Non-Binding	Both

Notes: In each regression, the unit of observation is a vessel-month-year, we cluster standard errors at the vessel-level, we use all default options from the rdrobust package, and we control for gear fixed effects, gross tonnage, length in meters, and engine horsepower. The data used to estimate the regression in Column 1 are Chinese distant water fishing (DWF) vessels built before 2016 for which the engine power ceiling is binding. In Column 2 the data are Chinese DWF vessels built before 2016 for which the engine power ceiling is not binding. In Column 3 the data are all Chinese DWF vessels built before 2016 (both binding and non-binding vessels).

slightly negative and it is much smaller in magnitude than the effect on binding vessels. The statistical significance of this effect vanishes when we implement a randomization inference procedure below.

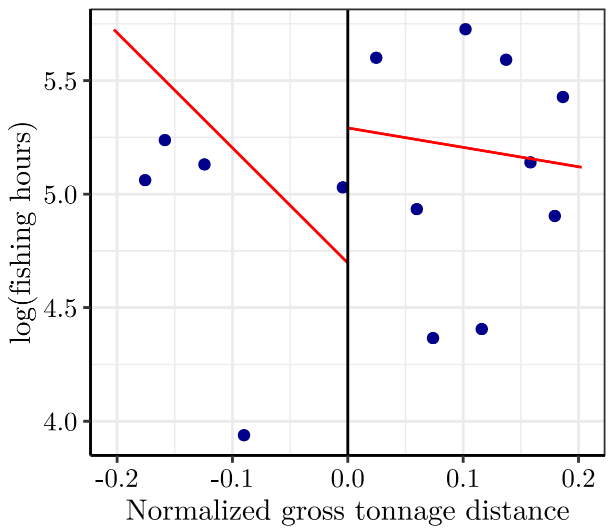
Column 3 estimates Equation 1 for all vessels, regardless of whether their engine power ceiling is binding. This specification labels vessels as treated if they are above their gross tonnage threshold, regardless of whether they receive more subsidy from being above their threshold. Note that the rdrobust package does not allow estimation of heterogeneous treatment effects in the sense of including both binding and non-binding vessels in the same regression and estimating separate treatment effects for each group. Since non-binding vessels are more numerous than binding vessels, the Column 3 coefficient is slightly negative. Its statistical significance does not survive randomization inference.

Figure 2 reproduces the three regressions of Table 3 visually.[20] The binned sample means

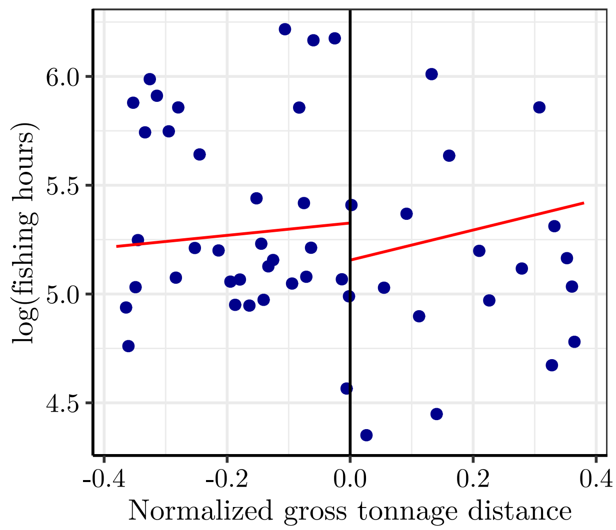
[20]The downward sloping running variable in Figure 2(a) is consistent with the relationship between gross tonnage and fishing in the period before the 2016 to 2020 fuel subsidy policy. For both vessels who will go on to become binding and vessels who will go on to become non-binding, there is a negative relationship

Figure 2: Effect of fuel subsidies on log hours of fishing, different subsets of vessels

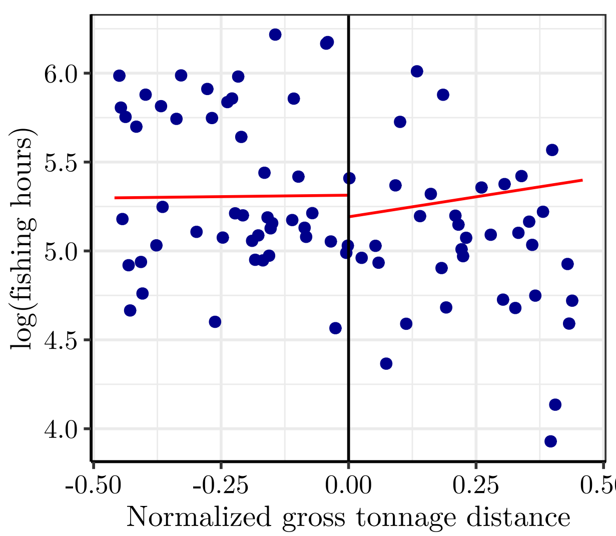
(a) Binding vessels



(b) Non-binding vessels



(c) All vessels



Notes: Points are binned sample means of log fishing hours (raw data) and lines are local linear conditional mean functions. These plots reproduce the three regressions in Table 3, with the difference in intercepts between the two regression lines in (a) corresponding to the conventional point estimate in Column 1, and so on.

between gross tonnage in levels and pre-period fishing hours (Figure A8).

(points) reveal large variation in raw fishing hours near the threshold. This variation suggests the numeric standard errors in Table 3 could overstate the precision of the point estimates. The raw data also raise the question of whether the large positive effect on the binding vessels is an artefact of a small number of influential points or of the particular bandwidth chosen by the mean squared error optimal-bandwidth selector.

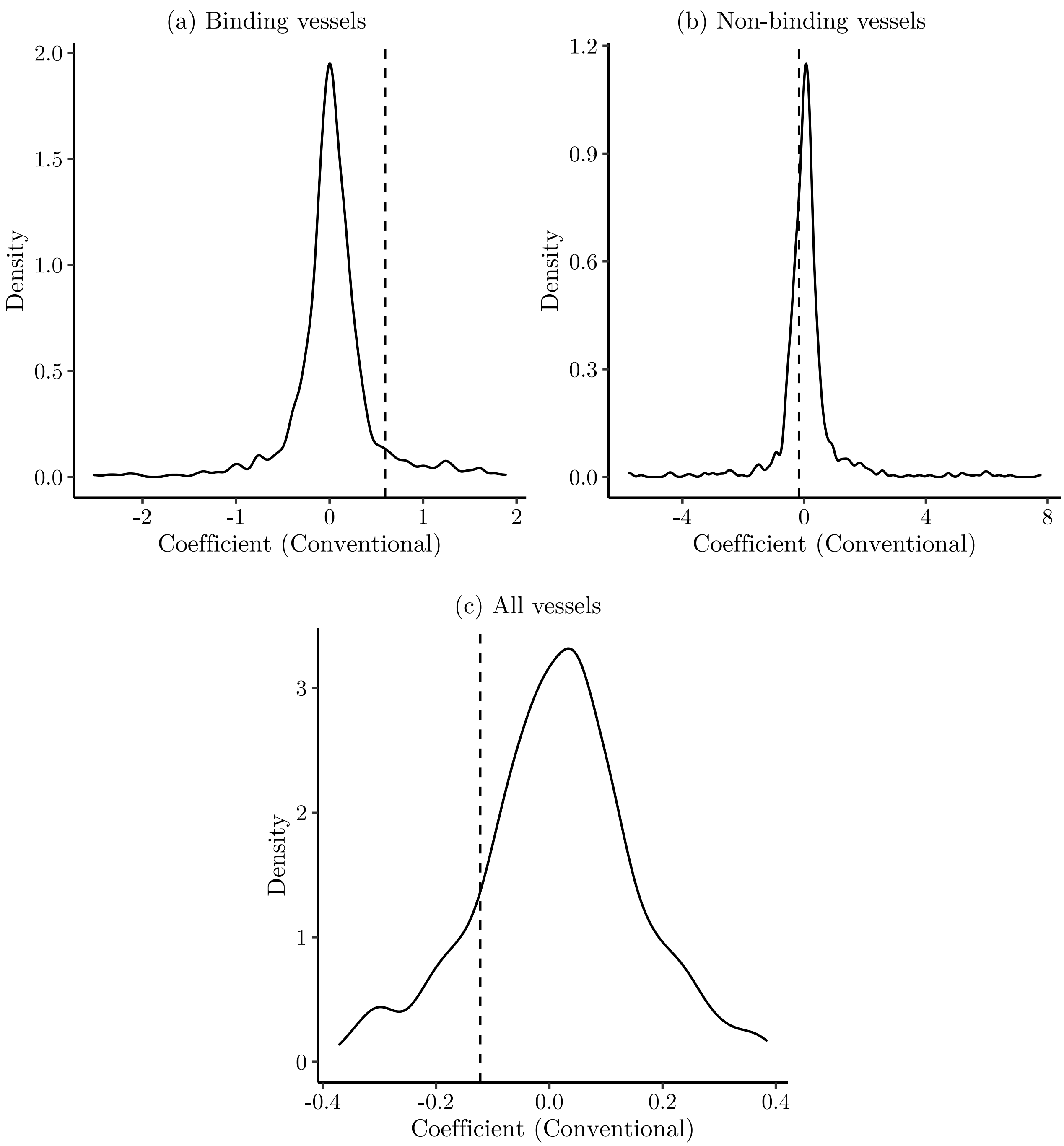
We believe the best way to address these concerns is with randomization inference. Our procedure randomly creates new gross tonnage and ceiling of subsidized engine power thresholds for each gear,[21] calculates the normalized gross tonnage distance of each vessel to these placebo thresholds, estimates Equation 1 using all default options from the rdrobust package, and saves the conventional and bias-corrected point estimates. We repeat this procedure 1,000 times and plot the distribution of placebo conventional point estimates against the true conventional point estimate in Figure 3. The numeric standard errors in Table 3 seem to overstate precision; the randomization inference p-value for binding vessels is 0.085 compared to 0.016.[22] The randomization inference p-values for non-binding vessels and all vessels are 0.700 and 0.838.

This modest precision could occur because vessels receive subsidy according to the number of transmissions they send per day, not the number of hours they fish. Distance traveled is a measure of vessel activity that may correspond more closely to vessels' subsidy incentives. It may also be measured with less error than fishing hours, which is a predicted value (Kroodsma et al., 2018). We re-estimate Equation 1 with log(distance traveled in km) as the dependent variable. In Columns 1 and 2 of Table 4, the data are binding vessels and in Columns 3 and 4 the data are non-binding vessels. In Columns 1 and 3 of Table 4, the bandwidth is the optimal bandwidth from when log fishing hours was the dependent variable

[21] We create placebo gross tonnage and ceiling of subsidized engine power thresholds as follows. For a given gear, identify the minimum over gross tonnage thresholds and vessels' gross tonnages in levels. For example, for squid jiggers the smallest gross tonnage threshold is 300 and the smallest vessel has a gross tonnage of 238, so the minimum gross tonnage threshold is 238. Identify the maximum gross tonnage threshold and the minimum and maximum ceiling of subsidized engine power thresholds in the same way. The maximum (minimum) ceiling of subsidized engine power threshold is the maximum (minimum) over ceiling of subsidized engine power thresholds and vessels' engine power. For example, for squid jiggers the largest ceiling of subsidized engine power threshold is 1,800 kW and the largest vessel has an engine power of 2,100 kW, so the maximum ceiling of subsidized engine power threshold is 2,100. Uniformly draw over this interval a number of thresholds equal to the number the gear has in the true fuel subsidy policy.

[22] The randomization inference p-value is the fraction of placebo estimates larger than the true estimate, while the p-value of 0.016 from Table 3 comes from a two-sided t-test.

Figure 3: Randomization inference effect of fuel subsidies on log hours of fishing, different subsets of vessels



Notes: Placebo conventional point estimates (solid lines) against true conventional point estimates (vertical dashed lines). We trim the top and bottom 2% of placebo conventional point estimates for legibility, but retain all placebo estimates when calculating p-values. The randomization inference p-values are (a) 0.085, (b) 0.700, and (c) 0.838.

Table 4: Effect of fuel subsidies on log distance (km) traveled

	Dependent variable: log(km traveled)			
	(1)	(2)	(3)	(4)
Conventional	1.107	38.657	-0.229	-0.229
	(0.260)	(0.226)	(0.046)	(0.046)
Bias-Corrected	1.368	43.888	-0.246	-0.255
	(0.260)	(0.226)	(0.046)	(0.046)
Robust	1.368	43.888	-0.246	-0.255
	(0.365)	(0.311)	(0.056)	(0.052)
Bandwidth	0.203	0.089	0.380	0.395
N	1,234	478	8,974	9,189
Sample	Binding	Binding	Non-Binding	Non-Binding
Table 3 Bandwidth	X		X	

Notes: In each regression, the unit of observation is a vessel-month-year, the dependent variable is log distance traveled in km, the running variable is local linear, the bandwidth is the same below and above the cutoff, the kernel function is triangular, standard errors are clustered at the vessel-level, and controls are gear fixed effects, gross tonnage, length in meters, and engine horsepower. The data used to estimate the regressions in Columns 1 and 2 are Chinese distant water fishing vessels for whom the engine power ceiling is binding and in Columns 3 and 4 the data are Chinese distant water fishing vessels for whom the engine power ceiling is not binding. In Columns 1 and 3, the bandwidth is from Columns 1 and 2 of Table 3. In Columns 2 and 4 the bandwidth selection procedure is mean-squared error optimal.

(Columns 1 and 2 of Table 3). Specifying the same bandwidth as when the dependent variable was log fishing hours enables direct comparison between estimated effects because they come from the same sets of vessels. In Columns 2 and 4 of Table 4, the mean squared error-optimal bandwidth selector chooses the bandwidth. Figure 4 reproduces Columns 1 and 3 of Table 4 visually.

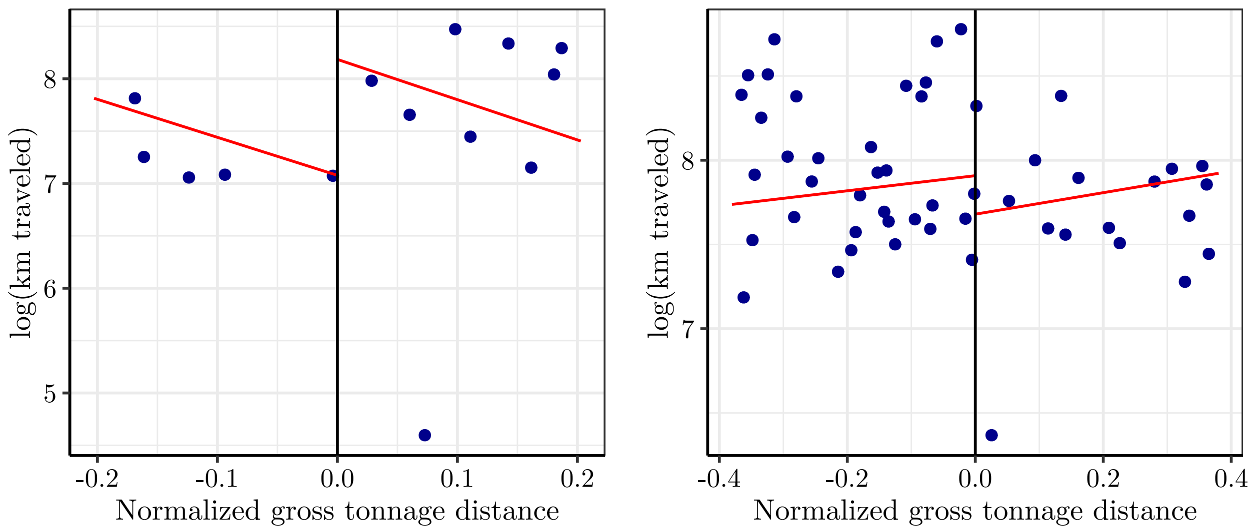
For binding vessels, the estimated effects of the subsidy program on distance traveled are larger in magnitude and more precise than the effects of the policy on fishing hours. We estimate that the fuel subsidy policy increases distance traveled by a vessel in a month by 1.107 log points (Column 1 of Table 4). The t-statistic is 4.3 and the randomization inference p-value is 0.041 (Figure A2).[23] We convert this point estimate into an elasticity in Section

[23] In instances like this one where we impose a bandwidth from a different regression, we follow the same procedure in the randomization inference. In this example, for a given run number (panel data created relative to a given random draw of gross tonnage and ceiling of subsidized engine power thresholds), the placebo

Figure 4: Effect of fuel subsidies on log distance traveled, different subsets of vessels

(a) Binding vessels

(b) Non-binding vessels



Notes: Points are binned sample means of log(distance traveled in km) and lines are local linear conditional mean functions. (a) and (b) reproduce the regressions in Columns 1 and 3 of Table 4, with the difference in intercepts between the two regression lines in (a) corresponding to the conventional point estimate in Column 1, and so on.

5.1.1. The estimate in Column 2 is implausibly large, perhaps because the optimal bandwidth is very small. As expected, there is no effect of the policy on distance traveled for non-binding vessels (Column 3); the randomization inference p-value is 0.808 (Figure A2). The large and relatively precise effect of the policy on distance traveled by binding vessels demonstrates that fuel subsidies change vessel behavior. In addition to (most likely) increasing fishing, fuel subsidies may be increasing the amount of time vessels spend searching for fishing grounds.

5.1.1 Elasticity of fishing and distance traveled with respect to fuel subsidy

We now convert the reduced form coefficients in Tables 3 and 4 into elasticities of fishing hours and distance traveled with respect to fuel subsidies. These elasticities help us interpret the magnitude of the reduced form coefficients, and the fishing elasticity is an input to our

regression discontinuity on log distance traveled uses the optimal bandwidth from the placebo regression discontinuity of the same run number on log fishing hours.

counterfactual scenario in Section 6.

First, we calculate the fishing elasticity by dividing the reduced form effect of the policy on log fishing hours by the first stage effect of the policy on log subsidy received. The reduced form is the effect on binding vessels that we report in Column 1 of Table 3. We estimate the first stage effect by replacing the dependent variable in Equation 1 with log subsidy received.

We calculate each vessels' monthly subsidy received by allocating their annual subsidy received proportionally to subsidy days. Subsidy days are the number of days in a month in which vessels have positive AIS hours. For example, if half of a vessel's subsidy days in 2017 occurred in January and half occurred in February, we would allocate half of the vessel's 2017 subsidy to January 2017 and half to February 2017. We convert subsidy amounts from nominal Yuan to 2016 USD.

Table 5 displays the estimates. The first stage effect of the policy on the amount of subsidy received is 0.437 log points (Column 2). In other words, binding vessels just above their nearest gross tonnage threshold receive 55% more fuel subsidy on average than binding vessels just below their nearest gross tonnage threshold. Figure 5(a) displays this regression visually. The elasticity of fishing hours with respect to fuel subsidy received is 1.359. While the conventional first stage and elasticity estimates are large in magnitude, neither are statistically different from zero when we apply our randomization inference procedure. The randomization inference p-values are 0.259 and 0.149 (Figure A3). We therefore view these estimates as suggestive evidence that the elasticity of fishing with respect to fuel subsidies may be larger than 1. Our estimates could be imprecise because we estimate fuel subsidies with different transponder data than the regulator uses (Section 2).

Second, we perform a similar procedure to estimate the elasticity of distance traveled with respect to fuel subsidy received. Columns 4 to 6 of Table 5 display the reduced form, first stage, and elasticity estimates. As in Column 1 of Table 4, we apply the optimal bandwidth from when fishing hours was the dependent variable. There are more observations than when we estimate the fishing hours elasticity because of vessel-months with positive distance traveled and subsidy received but zero fishing hours. The two first stage estimates differ for this reason.[24] The first stage is more precise in this specification (t-statistic is 4.3

[24] The reduced form coefficient differs slightly from the estimate in Column 1 of Table 4 for a similar reason.

Table 5: Elasticities of fishing hours and distance traveled with respect to subsidy received

	log(fishing hours)			log(km traveled)		
	RF	FS	Elasticity	RF	FS	Elasticity
	(1)	(2)	(3)	(4)	(5)	(6)
Conventional	0.594	0.437	1.359	0.977	0.821	1.190
	(0.246)	(0.103)	(0.647)	(0.250)	(0.189)	(0.409)
Bias-Corrected	0.843	0.497	1.696	1.159	0.929	1.248
	(0.246)	(0.103)	(0.607)	(0.250)	(0.189)	(0.370)
Robust	0.843	0.497	1.696	1.159	0.929	1.248
	(0.283)	(0.153)	(0.772)	(0.305)	(0.283)	(0.502)
Bandwidth	0.203	0.203	0.203	0.203	0.203	0.203
N	1,050	1,050	1,050	1,227	1,227	1,227

Notes: In each regression, the data are binding vessels built before 2016, the unit of observation is a vessel-month-year, we cluster standard errors at the vessel-level, we use default options from the rdrobust package, and the control variables are gear fixed effects and the gross tonnage in levels, length in meters, and engine horsepower of each vessel. RF (reduced form) is the effect of the policy on log fishing hours (Column 1) or log distance traveled (Column 4), FS (first stage) is the effect of the policy on log fuel subsidy received, and elasticity is the reduced form divided by the first stage. We calculate the elasticity standard errors with the delta method. We use the reduced form optimal bandwidth in estimating the first stage so that the set of vessels used to calculate the instrumental variables elasticity is the same.

and randomization inference p-value is 0.077). We estimate that the elasticity of distance traveled with respect to fuel subsidy received is 1.190. This result is somewhat imprecise (t-statistic is 2.9 and randomization inference p-value is 0.184). Figure A4 displays the placebo randomization inference coefficients against the true first stage and elasticitiy coefficients.

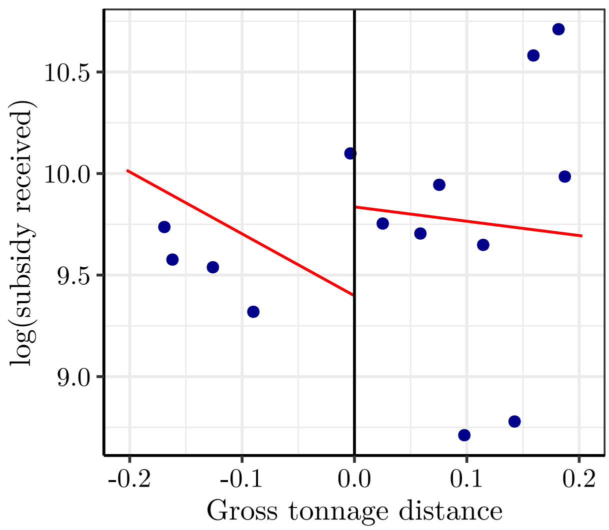
These estimates could be large because they are long-run elasticities; the fuel subsidy policy we evaluate was in effect for six years. In the context of electricity consumption, Buchsbaum (2022) and Feehan (2018) estimate long-run price elasticities that are an order of magnitude larger than previously estimated short-run price elasticities.

Note that our calculation of fuel subsidies received by vessels depends on our definition of

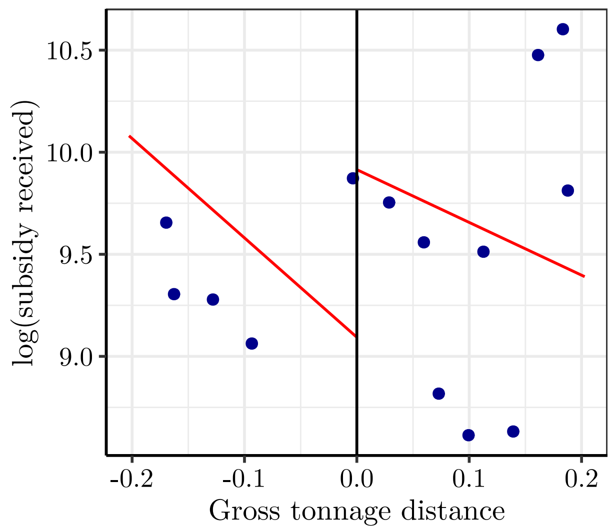
GFW calculates distance traveled from non-public, vessel movement point data. We use the public version of GFW's AIS data when allocating subsidies to the monthly level. Due to the log transformation of the dependent variables, to remain in the data used to estimate Columns 4 to 6 of Table 5, the vessel-month-year must have positive distance traveled in the non-public data and positive AIS hours in the public data. Only the first condition must be true to remain in the data used to estimate Column 1 of Table 4.

Figure 5: Effect of policy on fuel subsidy received (first stages)

(a) Fishing specification



(b) Distance traveled specification



Notes: Points are binned sample means of log(fuel subsidy). (a) and (b) reproduce the Column 2 and Column 5 regressions of Table 5, with the difference in intercepts between the two regression lines corresponding to the conventional point estimate. Lines are local linear conditional mean functions.

a subsidy day as one in which we observe at least one AIS ping from a vessel. This definition is different from the regulator's (the MOA), which depends on the number of VMS pings the regulator receives (which we do not observe). Mismeasurement of subsidy days would bias our first stage and elasticity estimates if we differentially underestimate subsidy days with respect to gross tonnage thresholds. We do not find evidence of differential underestimation, which suggests that underestimating subsidy days does not bias our estimated first stage or elasticity.[25]

[25] We re-estimate Equation 1 with the difference in official and estimated subsidy days as the dependent variable. The data are aggregated to the annual level to match the level at which we observe official subsidy days from Putuo district, Zhoushan, in Zhejiang province. Our test is underpowered because these data are for 273 vessels for 2020 only. The coefficient of 1.5 is small in magnitude compared to the mean official subsidy days (302) and it is statistically insignificant.

5.2 Extensive margin effects

In addition to increasing fishing on the intensive margin, fuel subsidies could increase the likelihood of fishing at all. We estimate the effects of fuel subsidies on the probability of fishing in a month in Section 5.2.1 and on measures of entry and exit in Section 5.2.2. Then in Section 5.2.3 we assess the "super extensive" margin by testing whether vessels built after the policy was announced are more likely to be just above a subsidy threshold, compared to vessels built before the policy was announced.

5.2.1 Probability of fishing in a month

We re-estimate Equation 1 with a new dependent variable: an indicator that equals 1 if a vessel has positive fishing hours in a month and equals 0 otherwise. In Table 6, we estimate Columns 1 and 2 with the subset of binding vessels and Columns 3 and 4 with the subset of non-binding vessels. In Columns 1 and 3, we impose the same bandwidths from when log fishing hours was the dependent variable so that the vessels used to estimate the regressions are the same. In Columns 2 and 4 we do not impose bandwidths and instead apply the mean-squared error optimal bandwidth procedure.

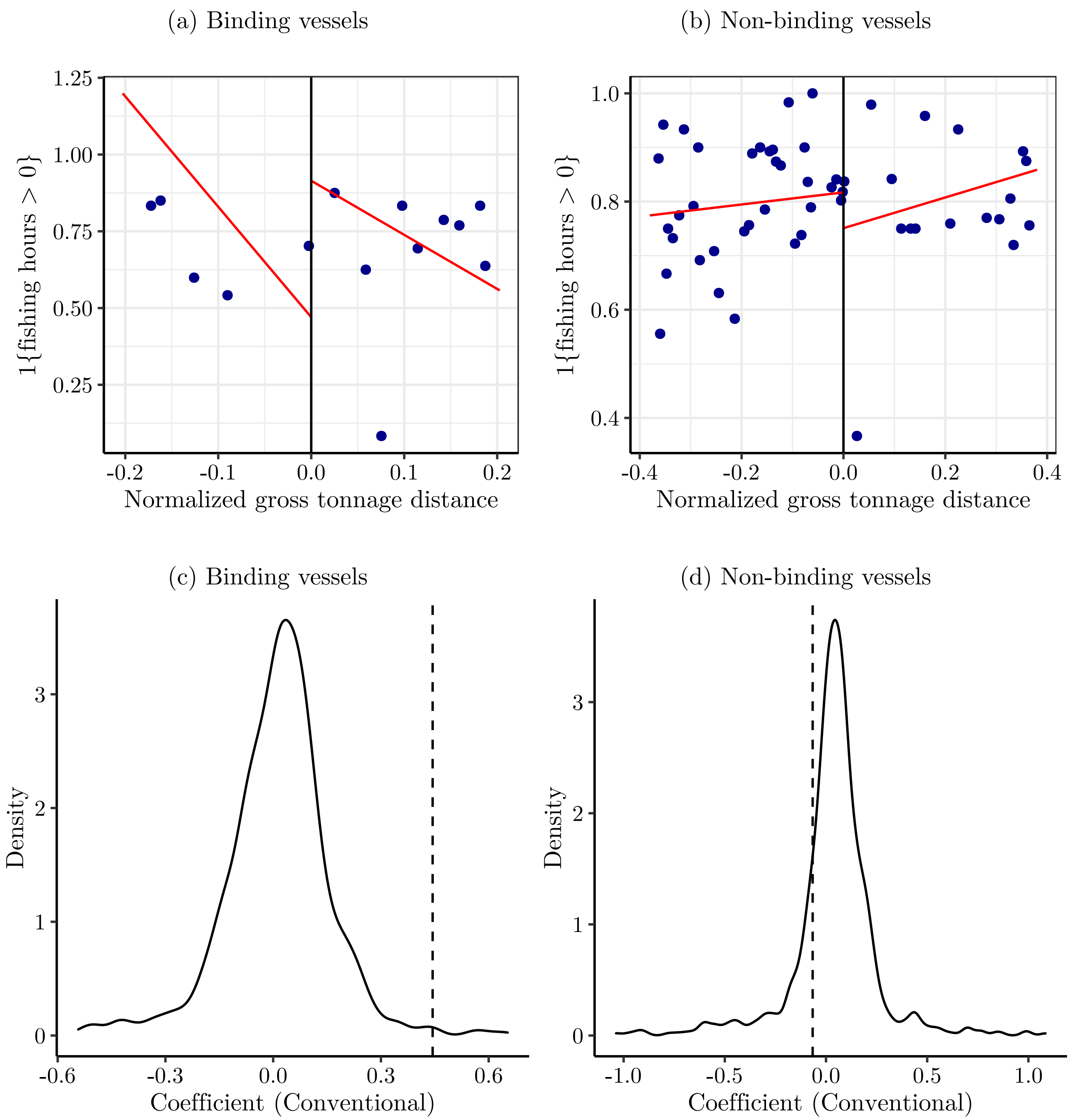
We estimate that fuel subsidies increase the probability of fishing in a given month by 44.4 percentage points (Column 1). This effect is large compared to the 70% average probability of fishing in a month. It is also precisely estimated (t-statistic is 4.4 and randomization inference p-value is 0.028). The Column 2 coefficient is implausibly large—twice as large as the mean of the dependent variable—perhaps because the optimal bandwidth is very small. We find no effect of the policy on non-binding vessels (Columns 3 and 4). The coefficients are one to two orders of magnitude smaller than the coefficients for binding vessels, and their randomization inference p-values are large (0.809 and 0.831). Figure 6 displays the Column 1 and 3 regressions and distributions of randomization inference placebo coefficients. These results suggest that fuel subsidies significantly increase fishing on the extensive margin.

Table 6: Effect of fuel subsidies on indicator for fishing in a month

	Dependent variable: 1{fishing hours > 0}			
	(1)	(2)	(3)	(4)
Conventional	0.444	1.387	-0.066	-0.089
	(0.100)	(0.117)	(0.017)	(0.018)
Bias-Corrected	0.587	1.905	-0.085	-0.101
	(0.100)	(0.117)	(0.017)	(0.018)
Robust	0.587	1.905	-0.085	-0.101
	(0.139)	(0.137)	(0.021)	(0.021)
Bandwidth	0.203	0.154	0.380	0.275
N	1,500	1,020	9,876	6,912
Sample	Binding	Binding	Non-Binding	Non-Binding
Table 3 Bandwidth	X		X	
Mean dep. var.	0.700	0.686	0.808	0.809

Notes: In each regression, the unit of observation is a vessel-month-year, the dependent variable is an indicator for positive fishing hours, the running variable is local linear, the bandwidth is the same below and above the cutoff, the kernel function is triangular, standard errors are clustered at the vessel-level, and controls are gear fixed effects, gross tonnage, length in meters, and engine horsepower. The data used to estimate the regressions in Columns 1 and 2 are Chinese distant water fishing vessels built before 2016 for whom the engine power ceiling is binding and in Columns 3 and 4 the data are Chinese distant water fishing vessels built before 2016 for whom the engine power ceiling is not binding. In Columns 1 and 3, the bandwidth is from Columns 1 and 2 of Table 3. In Columns 2 and 4 the bandwidth selection procedure is mean-squared error optimal.

Figure 6: Effect of fuel subsidies on indicator for fishing in a month



Notes: In (a) and (b), points are binned sample means of a positive fishing hours indicator and lines are local linear conditional mean functions. These plots reproduce Columns 1 and 3 of Table 6, with the difference in intercepts between the two regression lines in (a) corresponding to the conventional point estimate in Column 1, and so on. (c) and (d) display the distribution of placebo conventional point estimates (solid line) against the true conventional point estimate (vertical dashed line) from (a) and (b). We trim the top and bottom 2% of placebo conventional point estimates for legibility, but we retain all placebo estimates when calculating p-values. The randomization inference p-values are (c) 0.027 and (d) 0.809.

5.2.2 Entry and exit

Next we examine whether fuel subsidies affect entry into and exit from the fishery. We estimate regressions of the following form:

$$\begin{aligned} Y_{ij} = {} & \beta_1 \mathbb{1}\{norm\_gt\_dist_{ij} > 0\} + \beta_2 norm\_gt\_dist_{ij} + \\ & \beta_3 norm\_gt\_dist_{ij} \times \mathbb{1}\{norm\_gt\_dist_{ij} > 0\} + \\ & \beta_4 gt_i + \beta_5 engine\_power\_kw_i + \beta_6 length\_m_i + \alpha_j + \epsilon_{ij} \end{aligned} \tag{2}$$

where Y_{ij} is a measure of entry or exit for vessel i of gear type j and all other variables are as defined in Equation 1. Note that Equation 2 is identical to Equation 1 except for the different dependent variable and the absence of t subscripts. We collapse our data to a vessel-level cross-section for this analysis because we want to estimate whether a vessel ever enters or exits, regardless of how often they fish. These regressions use binding vessels only, but they do not require vessels to have been built before 2016 (because being built on or after 2016 is one of our measures of entry). We no longer cluster standard errors at the vessel-level since there is only one observation per vessel. We instead estimate standard errors with the heteroskedasticity-robust nearest neighbor variance estimator because that is the default method in the rdrobust package (Calonico, Cattaneo, Farrell, & Titiunik, 2022).

Our first measure of entry is an indicator that equals 1 if the vessel was built on or after 2016 and equals 0 otherwise (Column 1 of Table 7).[26] The coefficient is positive, which is consistent with entry, but it is imprecise (t-statistic is 2.3 and randomization inference p-value is 0.247). The visual reproduction of this regression, Figure 7(a), does provide some suggestive evidence in the form of the leftmost point just above the threshold. Binding vessels just above their nearest threshold are more likely to have been built after the policy was announced than nearby vessels (other points), but the difference is not statistically significant. We explore the potential for constructing vessels just above subsidy thresholds in greater detail in Section 5.2.3.

Column 2 of Table 7 uses a different measure of entry as the dependent variable: an

[26] The mean-squared error optimal bandwidth is so small that the regression results in an error. We therefore impose the optimal bandwidth from Column 1 of Table 3 to estimate this regression.

Table 7: Effect of fuel subsidies on entry and exit

	Dependent variable:		
	$1\{\text{Built} \geq 2016\}$	$1\{\text{First year} \neq 2016\}$	$1\{\text{Last year} \neq 2020\}$
	(1)	(2)	(3)
Conventional	0.097	0.074	-0.113
	(0.043)	(0.179)	(0.119)
Bias-Corrected	0.181	-0.098	-0.119
	(0.043)	(0.179)	(0.119)
Robust	0.181	-0.098	-0.119
	(0.126)	(0.224)	(0.145)
Bandwidth	0.203	0.201	0.423
N	79	79	176
Mean dep. var.	0.432	0.186	0.236

Notes: In each regression, the unit of observation is a vessel, the running variable is local linear, the kernel function is triangular, the bandwidth is the same below and above the cut-off, standard errors are heteroskedasticity-robust nearest neighbor, and the control variables are gear fixed effects and the gross tonnage, length in meters, and engine horsepower of each vessel. Data are Chinese distant water fishing vessels for whom the engine power ceiling is binding.

indicator that equals 1 if the first year we observe a vessel in the GFW data is *not* 2016. The indicator equals 0 if 2016 is the first year we observe a vessel in the GFW data. We again estimate a positive but statistically insignificant effect of fuel subsidies on entry.

Finally, we measure exit with an indicator that equals 1 if the last year we observe a vessel in the GFW data is not 2020. The indicator equals 0 if 2020 is the last year we observe a vessel in the GFW data. We do not find evidence of exit; while the coefficient is slightly negative it is not statistically different from zero.

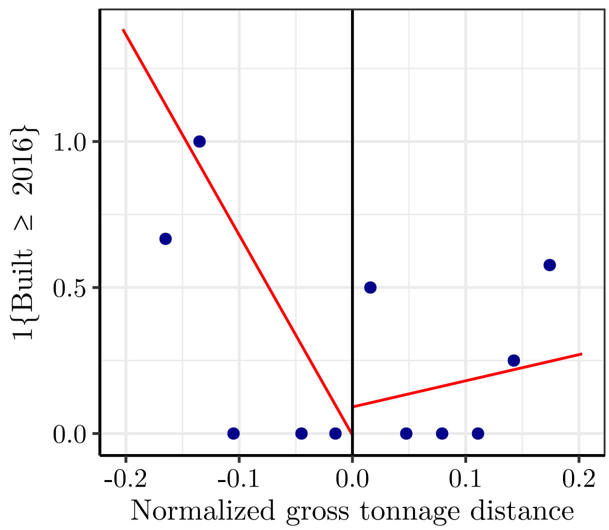
5.2.3 Comparing vessel characteristics before and after policy

23% of vessels in our data were built during or after 2016.[27] Though the regulator banned the entry of new distant water fishing vessels in 2013, firms may scrap their vessels and rebuild them (Ministry of Agriculture, 2013b). We compare the distance to the nearest gross tonnage threshold of vessels built before 2016 and of vessels built on or after 2016.

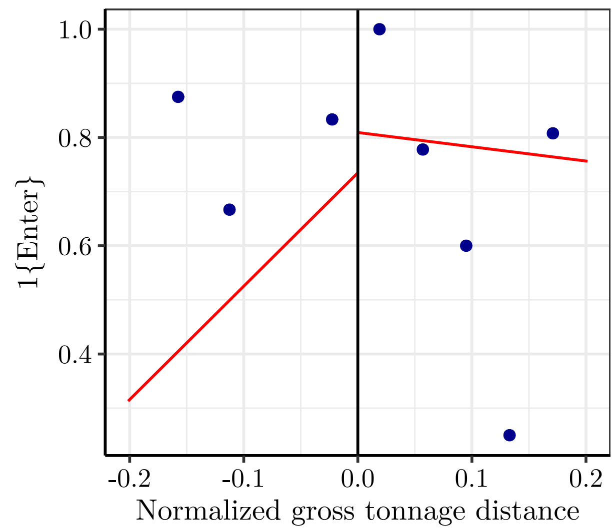
[27] The 43.2% reported in Column 1 of Table 7 is the mean of this variable within the optimal bandwidth.

Figure 7: Effect of fuel subsidies on entry and exit

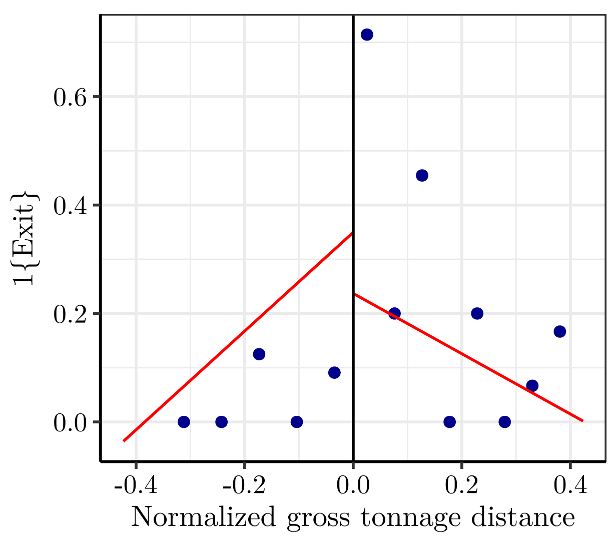
(a) 1{Built $\geq$ 2016}



(b) 1{First year $\neq$ 2016}



(c) 1{Last year $\neq$ 2020}



Notes: Points are binned sample means of the dependent variable (subfigure title) and lines are local linear conditional mean functions. These plots reproduce the three regressions in Table 7, with the difference in intercepts between the two regression lines in (a) corresponding to the conventional point estimate in Column 1, and so on.

The regulator began two other policies in 2014 and 2015 that partially overlap with the fuel subsidy thresholds: a one-time renovation and reconstruction subsidy, and a vessel standardization regulation.[28] These regulations do not invalidate our estimates of the effect of fuel subsidies on fishing because our results are robust to excluding vessels built after these regulations would have affected vessel construction decisions (Section 5.3). But they do prevent us from interpreting differences in gross tonnage distances as due entirely to the 2016-2020 fuel subsidy policy. Among vessels built on or after 2015, the median renovation and reconstruction subsidy received is \$571,679, compared to the median annual fuel subsidy of \$181,610 (both 2016 USD). Examining these distributions is nonetheless informative for assessing our focus on vessels built before 2016 in Sections 5.1 and 5.2.1.

Figure 8 plots the normalized gross tonnage distance distribution for all vessels, regardless of whether their engine power ceiling is binding, because the fuel subsidy policy may affect the characteristics of all vessels.[29] Vessels built before 2016 are discontinuously more likely to have gross tonnage just *below* their gross tonnage threshold (Figure 8a).[30] By contrast, there is no discontinuous difference at the threshold in the density of vessels built on or after 2016 (Figure 8b). The t-statistic on the difference in these two discontinuities is 2.2. Firms seem to have responded to the regulator's suite of regulations by reconstructing larger vessels, including vessels that will be eligible to receive larger fuel subsidies.

5.3 Robustness checks

If the regulator chose subsidy thresholds to award more subsidy to the vessels they expected would fish most, then our estimates of the effect of fuel subsidies on fishing are upward biased.

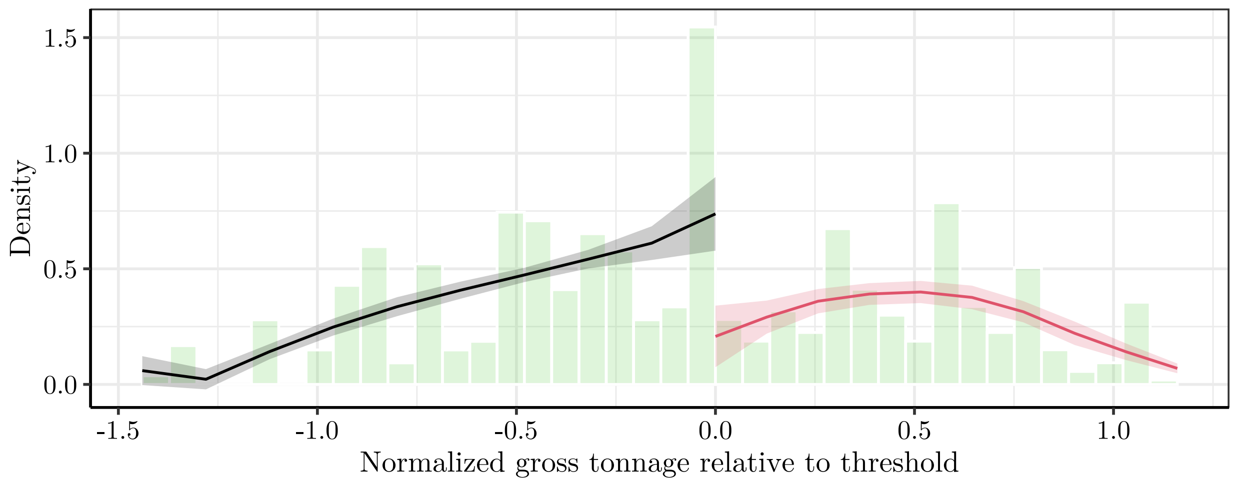
[28]Vessels built on or after 2015 are eligible for the renovation and reconstruction subsidy, which depends on gear, gross tonnage, and vessel length (General Office of the Ministry of Agriculture of China, 2016). The vessel standardization regulations began in 2014 and they specify gear-specific standards for vessel characteristics like width (General Office of the Ministry of Agriculture of China, 2014b, 2015). The regulator updated these standards in 2017, 2018, and 2021 (General Office of the Bureau of Fisheries of the Ministry of Agriculture and Rural Affairs of China, 2018, 2021; General Office of the Ministry of Agriculture of China, 2017).

[29]We created these figures with the rdplotdensity command from the rddensity package (Cattaneo, Jansson, & Ma, 2021). We used all default options with one exception: we set the local polynomial order used to construct the bias-corrected density estimators as 2 (default = 3). This change causes the confidence intervals to be conventional rather than bias-corrected.

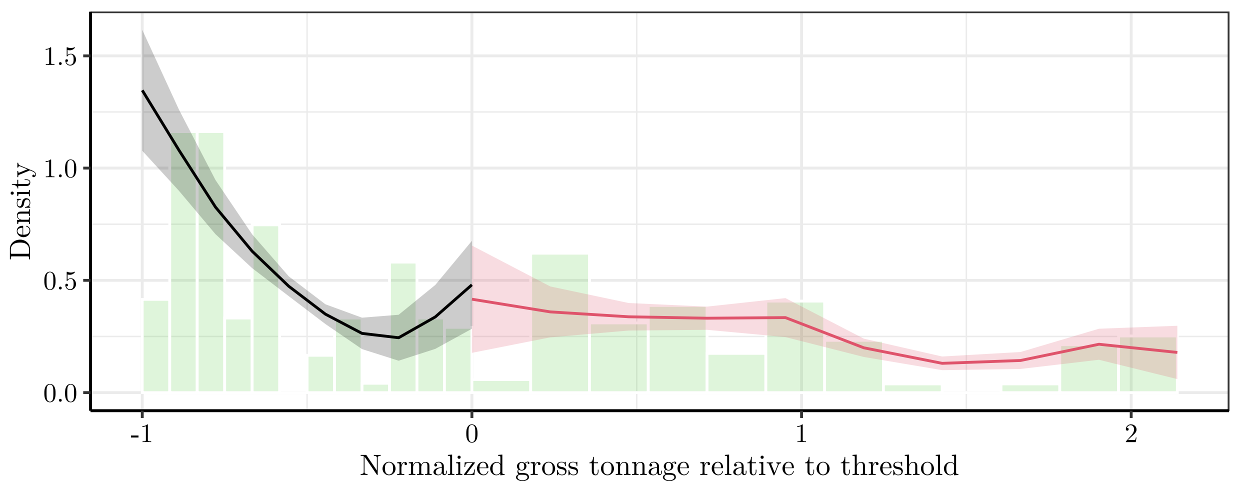
[30]However, there is no discontinuous difference in the density of binding vessels built before 2016 (Figure A5).

Figure 8: Distribution of vessels' normalized gross tonnage distances by year of construction

(a) Vessels built before 2016



(b) Vessels built on or after 2016



Notes: Bars are binned vessel densities (one observation per vessel), lines are local quadratic estimators of density, and shaded regions are 95% confidence intervals for the density of (a) vessels built before 2016 and (b) vessels built on or after 2016. The x-axis is vessels' normalized gross tonnage distance.

We explore the likelihood of this scenario with pre-period fishing data. Between 2006 and 2014, fuel subsidies for distant water vessels were linear in engine power and independent of gross tonnage (Department of Industrial Policy and Regulation, Ministry of Agriculture, 2021). GFW fishing data begins in 2012. As a placebo test, we re-estimate Equation 1 on log monthly fishing hours between 2012 and 2014 by "soon-to-be binding" vessels—those with gear, gross tonnage, and engine power such that their engine power became binding under the 2016-2020 fuel subsidy policy. We exclude 2015 data from this test because some firms may have been aware of the fuel subsidies policy that was applied to calculate 2015 subsidies, even though the policy was not officially announced until 2016 (General Office of the Ministry of Agriculture of China, 2016). Pre-period fishing hours by soon-to-be binding vessels are slightly *lower* among vessels who will be just above 2016-2020 fuel subsidy thresholds (Table A1 and Figure A6). This negative and statistically insignificant coefficient provide evidence against the hypothesis that more-subsidized vessels would have fished more than less-subsidized vessels even in the absence of fuel subsidies (randomization inference p-value is 0.669).

If less-subsidized vessels fish less because of the 2016 to 2020 fuel subsidy policy, then the Stable Unit Treatment Value Assumption (SUTVA) would be violated. One way this SUTVA violation could occur is if more-subsidized vessels decreased the fish available for less-subsidized vessels to catch. We consider this scenario by plotting log monthly fishing hours between 2012 and 2020 for binding and non-binding vessels above and below their nearest gross tonnage thresholds (four groups). To support the hypothesis of a SUTVA violation, fishing by the two groups of non-binding vessels and fishing by binding vessels below their nearest gross tonnage threshold should be decreasing between 2016 and 2020. In fact, fishing by all three groups is constant during this period, providing evidence against the SUTVA violation hypothesis (Figure A7).

We assess robustness to our preferred specification in Table 8. All of the regressions estimate a variant of Equation 1 on the subset of binding vessels. Our results are similar to our preferred specification in Column 1 of Table 3 in that the coefficients are all large and positive.

In Column 1 of Table 8, we find that the effect of the policy remains large and positive when we require vessel to have been built before 2015 instead of 2016. Excluding the 66 vessels (5%) built in 2015 ensures that no vessels in this regression manipulated their characteristics with respect to fuel subsidy thresholds. In Column 2, we obtain a similar result when we subset the data to between 2016 and 2019, instead of 2016 to 2020, since 2020

Table 8: Effect of fuel subsidies on log hours of fishing, alternative specifications

	Dependent variable: log(fishing hours)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Conventional	0.77	0.79	4.58	0.64	1.19	0.20	1.74	0.49	0.47
	(0.24)	(0.20)	(0.27)	(0.25)	(0.22)	(0.22)	(0.28)	(0.26)	(0.36)
Bias-	1.16	1.58	3.00	0.85	1.63	0.30	1.74	0.71	0.56
Corrected	(0.24)	(0.20)	(0.27)	(0.25)	(0.22)	(0.22)	(0.28)	(0.26)	(0.36)
Robust	1.16	1.58	3.00	0.85	1.63	0.30	1.74	0.71	0.56
	(0.31)	(0.23)	(0.33)	(0.32)	(0.26)	(0.29)	(0.34)	(0.33)	(0.46)
Bandwidth	0.194	0.190	0.146	0.203	0.197	51.570	0.148	0.203	0.321
N	1,050	715	737	1,143	1,050	3,485	700	1,050	506
Table 3 BW				X				X	

Notes: In each regression, the data are Chinese distant water fishing vessels for which the engine power ceiling is binding, we cluster standard errors at the vessel-level, we use default options from the rdrobust package, and we control for gear fixed effects, gross tonnage, and engine horsepower. All Columns except for 7 and 8 also control for vessel length. Columns 4 and 8 impose the bandwidth from Column 1 of Table 3. Column 1 excludes vessels if they are built on or after 2015, Column 2 excludes 2020 data, Columns 3 and 4 include 2015 data, and Column 5 includes year fixed effects. The running variable in Column 6 is (non-normalized) gross tonnage distance. The data used to estimate Column 9 are aggregated to the annual level.

was a transitional year between policy regimes (Section 2). In Columns 3 and 4, we subset the data to between 2015 and 2020, since the fuel subsidy policy we evaluate was applied ex post to 2015 fishing. The Column 3 coefficient is implausibly large, perhaps because the mean-squared error optimal bandwidth is small. When we re-estimate the regression with the optimal bandwidth from Column 1 of Table 3, we obtain a coefficient that is nearly identical to the coefficient from our preferred specification.

Next, in Column 5 we include year fixed effects. Year is a potentially relevant control because fuel subsidies dependent on a time constant that changes each year. Our coefficient roughly doubles compared to our preferred specification. The regression in Column 6 replaces the running variable with non-normalized gross tonnage distance. The coefficient remains positive but decreases by about half compared to our preferred specification. In Columns 7 and 8 we exclude vessel length as a control variable. Excluding any of the other control variables—gear fixed effects, gross tonnage, and engine horsepower—would violate our identifying assumption because these variables determine treatment status. The Column 7 coefficient is quite large, perhaps because the mean-squared error optimal bandwidth is small. When we re-estimate the regression with the optimal bandwidth from Column 1 of Table 3, we obtain a similar coefficient to the one from our preferred specification. Finally, in Column 9 we aggregate the data to the annual level. Precision decreases, but the magnitude of the coefficient remains similar to our preferred specification.

6 Fuel subsidies and overfishing

In this section, we seek to predict the changes in overfishing that would ensue if China were to reduce its distant water fuel subsidies. For example, how would overfishing status change if China were to halve its subsidy allocations? When a fish stock experiences overfishing, we mean that the current level of fishing pressure (F) is higher than the fishing pressure that would produce the maximum sustainable yield (F_{msy}). A common measure of overfishing is the ratio F/F_{msy}, where $F/F_{msy} > 1$ implies overfishing, $F/F_{msy} = 1$ implies biologically sustainable fishing, and $F/F_{msy} < 1$ implies fishing could increase without threatening the long-term persistence of the stock. One could use our estimate of the elasticity of fishing hours with respect to fuel subsidies to simulate the response of Chinese vessels to changes in fuel subsidies. However, a reduction in fishing effort by Chinese vessels would likely be followed by an increase in fishing by non-Chinese vessels. Accounting for this response requires an elasticity of fishing by non-Chinese vessels with respect to fishing by Chinese vessels.

6.1 Estimating the elasticity of fishing by non-Chinese vessels with respect to fishing by Chinese vessels

Estimating this elasticity is not trivial because fishing effort by both fleets is likely jointly determined. We attempt to overcome this challenge by employing an instrumental variables approach that leverages the Chinese New Year as a source of variation that exogenously affects fishing by Chinese vessels, but does not otherwise affect fishing by non-Chinese vessels.

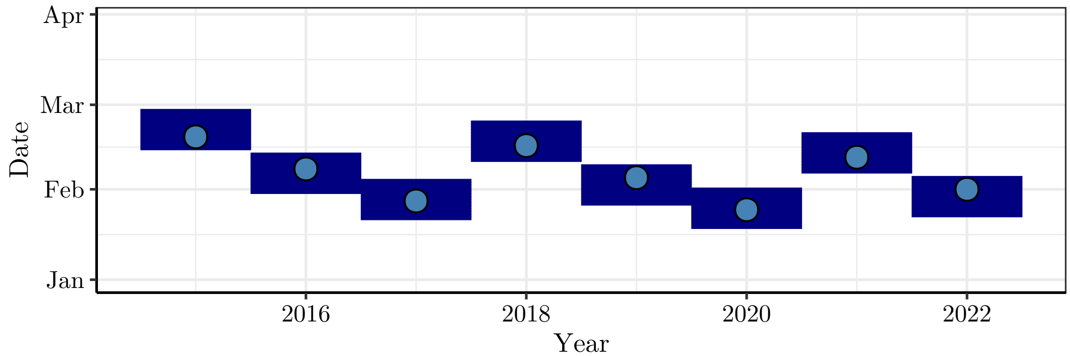


Figure 9: Visual representation of the date in which the Chinese New Year occurs (point), and the weeks for which $CNY_t = 1$ (blue polygons).

The instrument is relevant: every year Chinese fishers rest during the Chinese New Year, leading to detectable decreases in fishing effort worldwide (Kroodsma et al., 2018). The instrument is excludable because it plausibly only affects fishing by non-Chinese vessels through the reduction of fishing effort by Chinese vessels.

We begin by building a panel of weekly fishing effort by Chinese vessels and other vessels (*i.e.* non-Chinese vessels). We then construct an indicator variable CNY_t that takes the value $CNY_t = 1$ for weeks immediately before and immediately after the Chinese New Year, and $CNY_t = 0$ otherwise. For example, in 2016 the Chinese New Year occurred on February the 8th. The 5th and 6th weeks of 2016 have a value of $CNY_t = 1$ and all other weeks in 2016 have a value of $CNY_t = 0$ (Figure 9). Finally, we limit our sample to observations occurring during the first 13 weeks of each year (2015 to 2022)[31] and data from Food and Agriculture Organization (FAO) Regions where Chinese fishing accounts for at least 10% of total fishing activity across all years (Table 9). FAO Regions excluded from this analyses either have no fishing effort from Chinese-flagged vessels (Arctic Sea, NW Atlantic, NE Pacific, Mediterranean, NE Atlantic), or are far away from China so vessels are less likely to return to port during the Chinese New Year. In either case, the instrument is less relevant for these FAO Regions.

[31]We restrict our analysis to 2015-2022 because data quality in AIS improved after 2015. We retain only the first 13 weeks of a year to ensure we include the range of dates over which the Chinese New Year occurs while maintaining a similar number of non-Chinese New Year weeks before and after the Chinese New Year (Figure 9).

Table 9: Mean proportion of fishing effort applied by Chinese vessels in each FAO Region (2015-2020).

Ocean Group	FAO Region (Code)	% of fishing by Chinese vessels
Atlantic	Arctic Sea (18)	0.00%
	Atlantic, NW (21)	0.00%
	Med. and Black Sea (37)	0.00%
	Atlantic, NE (27)	0.00%
	Atlantic, SE (47)	1.04%
	Atlantic, West Central (31)	4.80%
	Atlantic, East Central (34)*	17.97%
	Atlantic, SE (41)*	31.89%
Indian	Indian Ocean, East (57)	7.80%
	Indian Ocean, West (51)*	17.35%
Pacific	Pacific, NE (67)	0.00%
	Pacific, SE (81)	2.47%
	Pacific, West Central (71)*	25.54%
	Pacific, East Central (77)*	27.75%
	Pacific, SE (87)*	67.14%
	Pacific, NW (61)*	74.47%
Southern	Pacific, Antarctic (88)	2.10%
	Atlantic, Antarctic (48)*	27.75%
	Indian Ocean, Antarctic (58)*	33.83%

*FAO regions included in the elasticity analysis.

We define our first-stage equation as:

$$log(\text{CHN fishing hours}_t) = \alpha \text{CNY}_t + \gamma_t + \epsilon_t \tag{3}$$

where we regress log hours of fishing by Chinese vessels in week t ($log(\text{CHN fishing hours}_t)$) on our indicator variable for weeks immediately before and after the Chinese New Year (CNY_t). γ_t are year fixed effects and ϵ_t is the error term. Identification comes from the difference between the lunar calendar, which determines the Chinese New Year, and the Gregorian calendar. The Chinese New Year occurs on the second new moon after the winter solstice, which is usually between January 21 and February 20 (Figure 9). We calculate cluster-bootstrapped standard errors at the year-level since year is the level at which treatment is assigned and there are a small number of years in our data.

The second-stage equation estimates the relationship between fishing by non-Chinese vessels and fishing by Chinese vessels:

$$log(\text{non-CHN fishing hours}_t) = \beta log(\widehat{\text{CHN fishing hours}_t}) + \gamma_t + \epsilon_t \tag{4}$$

where $log(\text{non-CHN fishing hours}_t)$ are the log hours of fishing by non-Chinese vessels and $log(\widehat{\text{CHN fishing hours}_t})$ is a predicted value from Equation 3. The parameter of interest is β, the elasticity of fishing effort by non-Chinese fishing vessels with respect to fishing effort by Chinese vessels.

Table 10 displays these estimates. The first stage effect of the Chinese New Year on fishing effort by Chinese vessels is -0.502 log points (Column 2). This coefficient is statistically significant and implies a reduction of 40% of fishing effort by Chinese vessels during the Chinese New Year, corroborating previous findings by Kroodsma et al. (2018). Our F-statistics are large as well. Our reduced form and instrumental variables coefficients are negative, indicating that Chinese fishing reduces non-Chinese fishing, but the coefficients are small in magnitude and they are not statistically different from zero (Columns 1 and 3). Nonetheless, the naive OLS regression of log fishing hours by non-Chinese vessels on log fishing hours by Chinese vessels and year fixed effects in Column 4 demonstrate the utility of our instrumental variables strategy. The naive coefficient is positive and statistically significant, even though it is unlikely that Chinese fishing has a positive causal effect on non-Chinese fishing. By contrast, our IV estimate of -0.012 for this elasticity has the sign we expected.

We also concede that the Chinese New Year only causes short-term variation in Chinese fishing effort. As such, our approach estimates the immediate response of non-Chinese fishing vessels to fishing effort by Chinese vessels. Non-Chinese vessels might respond more in the long-term (e.g., if fish biomass of over-fished stocks[32] were to increase as a result of lower fishing effort). The possibility of a larger response by non-Chinese vessels implies that our below estimates of changes in F/F_{msy} should be interpreted as upper bounds. However, we note that not accounting for the response of non-Chinese vessels at all would result in even greater upward bias. (For example, compare the middle and bottom panels in Fig 11A, or

[32] Overfished stocks are those for which current biomass is below the biomass that would produce maximum sustainable yield.

Table 10: Elasticity of fishing hours by non-Chinese vessels with respect to fishing effort by Chinese vessels. The first column reports the reduced form (RF), the second column reports the first stage (FS), the third column reports the elasticity estimated by two-stage least squares (TSLS), and the fourth column reports the elasticity estimated via ordinary least squares.

	RF	FS	TSLS	OLS
α	0.006	-0.502		
	(0.016)	(0.050)		
β			-0.012	
			(0.032)	
log(CHN)				0.411
				(0.097)
Num.Obs.	111	111	111	111
R2	0.576	0.466	0.568	0.709
Cragg-Donald F	27.178 (DF = 1 , 109)			
Wald-test	88.507 (DF = 1 , 109)			

Standard errors are clustered by year and estimated via bootstrapping with 10,000 resamples.
All specifications include fixed effects by year.

the gray and colored bars in Fig 11B.)

6.2 Calculating changes in F/F_{msy}

We now proceed to calculating the change in overfishing that would result from a reduction in Chinese distant water fuel subsidies. Specifically, we consider five policy changes that would reduce the subsidy by 10%, 20%, 30%, 40%, and 50%. We follow the same approach as McDermott, Meng, McDonald, and Costello (2019), who calculate changes in overfishing that would arise from a "blue paradox" using catch-weighted F/F_{msy} values by FAO Region. Our values of F/F_{msy} for 4,718 stocks come from Costello et al. (2016), which we pair with GFW data on fishing by Chinese and non-Chinese vessels aggregated to the FAO-level.

For each policy scenario, we first use our elasticity estimate from Table 5 to calculate the predicted change in fishing effort by Chinese vessels in each FAO Region, and the corresponding change in F/F_{msy}. Based on these changes, we then use our elasticity estimate from Table 10 to calculate the change in fishing effort by non-Chinese vessels in each FAO

Region, and the corresponding change in F/F_{msy}. Finally, we calculate the percent change in F/F_{msy} by FAO Region by comparing the new F/F_{msy} in each scenario to the current rate of overfishing.

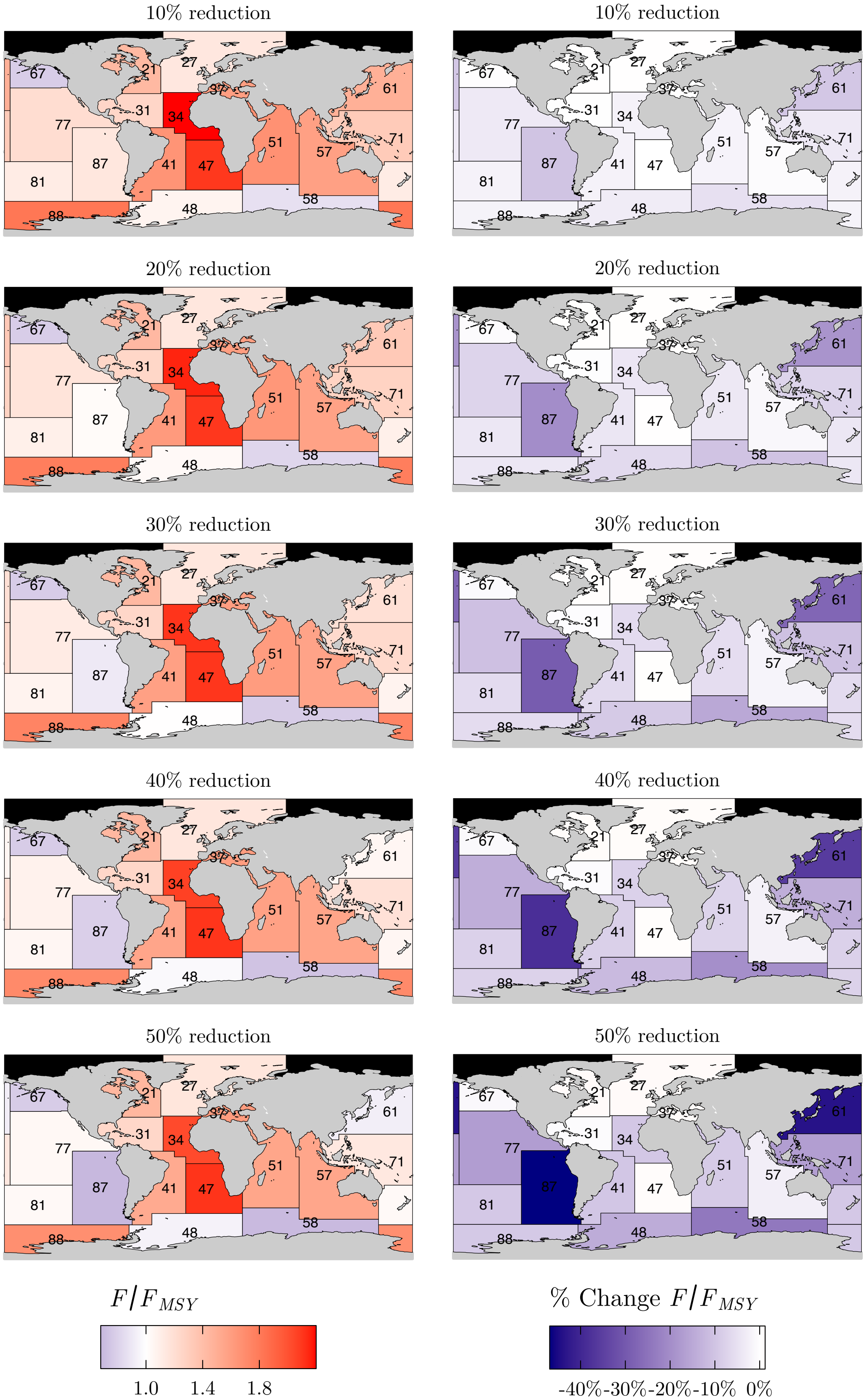
Consider the following example for a 50% reduction in subsidies and FAO Region 87 (Southeast Pacific), where Chinese vessels accounted for 77.2% (1.53 million hours) of fishing in 2020. The current fishing pressure is $F/F_{msy} = 1.28$. With an elasticity of 1.359 and a 50% reduction in Chinese fuel subsidies, we calculate the reduction in fishing effort by Chinese vessels as $((1 - 0.5)^{1.359} - 1) \times 100 = -61.01\%$. In the absence of a response by other vessels, a 61% reduction by vessels that account for 77% of the effort in the region implies a 47% reduction in total fishing effort. Affecting only the numerator in the F/F_{msy} ratio, this reduction in fishing effort would imply $(1 - 0.47) \times F/F_{msy} = 0.677$. However, this value of $F/F_{msy} = 0.677$ represents an upward biased estimate, as it does not yet account for the response of other vessels. To incorporate that change, we leverage our elasticity estimate of effort by non-Chinese vessels with respect to effort by Chinese vessels of -0.012. As stated above, Chinese vessels would reduce their effort by 61%, which means non-Chinese vessels would increase their effort by 1.14%, resulting in a net reduction of 46.8% in fishing pressure and bringing F/F_{msy} to 0.681.

6.3 Changes in F/F_{msy}

Today, 16 of the 18 FAO Regions included in our analysis are subject to overfishing. We explore five alternative policy interventions and find that a 10% reduction in subsidies would not change the number of FAO Regions experiencing overfishing (Fig 10), but that it could lead to a reduction in up to 10.3% in overfishing for some regions (*e.g.* the Southeast Pacific [FAO Region 87]). However, a 50% reduction in Chinese distant water fuel subsidies would move three FAO Regions (The Southeast Pacific [87], the Antarctic Atlantic [48], and the Northwest Pacific [61]) below the overfishing threshold of $F/F_{msy} = 1$ and result in a further reduction of fishing effort in other regions by up to 46.8%. Figure 10 shows the changes in overfishing by FAO Region for the five scenarios of subsidy reduction. Using the stock-level data, we can also calculate the proportion of stocks that would be subject to overfishing under each scenario. Currently, 64.5% of stocks experience overfishing. A 10% reduction in fuel subsidies to China's distant water fishing fleet would see this overfished fraction decrease to 63.8%, while a more ambitious 50% reduction in subsidies would result in 61% of stocks experiencing overfishing.

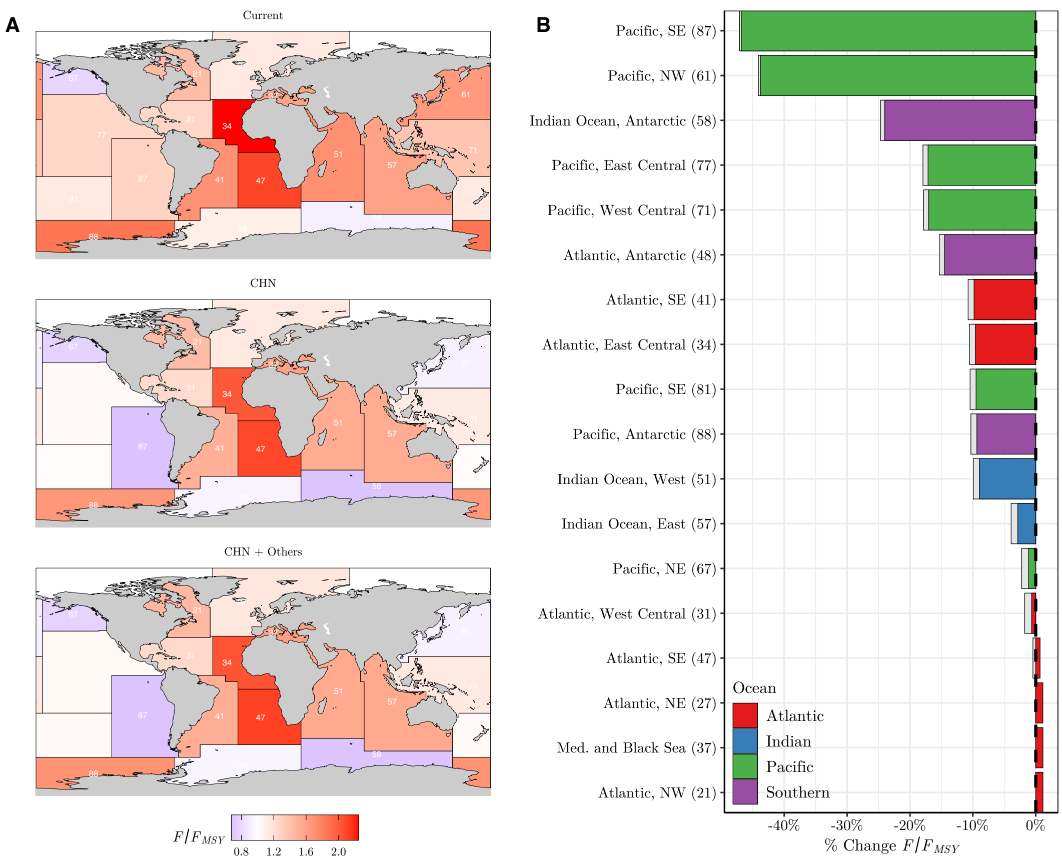
In Figure 11A we focus on the 50% reduction in subsidies scenario. We display the current F/F_{msy} in each FAO Region, the F/F_{msy} that results from changes in fishing effort by Chinese vessels under a 50% reduction in subsidies, and the F/F_{msy} after other vessels increase their effort following the effort reduction from Chinese vessels. We predict the largest decreases in overfishing in FAO Regions in the Pacific Ocean, where Chinese vessels account for large shares of fishing effort. For FAO Regions with little fishing effort by Chinese vessels, the proportional increase in fishing effort by non-Chinese vessels would lead to an increase in overfishing of up to 1.2%. These regions occur in the Atlantic, where European vessels dominate fishing (McCauley et al., 2018).

Figure 10: Absolute (left) and relative (right) changes in overfishing (F/F_{msy}) for 18 FAO Regions under five subsidy reduction scenarios



Notes: The numbers on the map correspond to the FAO Region Code.

Figure 11: Overfishing (F/F_{msy}) for 18 FAO Regions under a 50% reduction in Chinese distant water fuel subsidies



Notes: (A) current F/F_{msy} (top; from Costello et al. (2016)), the F/F_{msy} that would result from changes in fishing effort by Chinese vessels (middle), and the net change in F/F_{msy} accounting for the response by non-Chinese vessels (bottom). Panel B shows the percentage change in F/F_{msy} by FAO Region. The gray portion of the bars correspond to the middle panel of A; they indicate the percentage change in F/F_{msy} in the absence of a response by non-Chinese vessels to a change in fishing effort by Chinese vessels. The bar colors indicate ocean, and the bar order is by the fraction of fishing effort in the FAO Region that Chinese vessels account for in 2020.

7 Discussion

In this paper we provide the first causal evidence that fuel subsidies increase fishing. We do so in a context with external validity—the world's largest distant water fleet—and internal validity—a regression discontinuity design based on non-manipulable, predetermined vessel characteristics. We estimate large effects from fuel subsidies: a 1% increase in fuel subsidies increases hours of fishing by 1.4% and distance traveled by 1.2%. We demonstrate that reductions in fuel subsidies to China's distant water fishing fleet could reduce —but not eliminate—overfishing in most FAO Regions. These results suggest that researchers and policymakers are right to emphasize fuel subsidies in discussions of fisheries policy reform.

In June 2022, the WTO adopted the "Agreement on Fisheries Subsidies", which prohibits signatory countries from subsidizing vessels that fish for depleted stocks or engage in Illegal, Unauthorized, and Unregulated (IUU) fishing (WTO, 2022). This agreement is the second ever reached, on any subject, at the WTO. China has already updated its distant water fuel subsidy to comply with the WTO agreement (General Office of the Ministry of Agriculture and Rural Affairs and General Office of the Ministry of Finance, 2021a).

While historic, the WTO agreement is narrow in the types of subsidies it limits. Data do not usually exist to demonstrate that stocks in low- and middle-income countries are depleted, and IUU fishing is only one contributor to fisheries depletion. Depletion depends on the total quantity of fishing, not the fraction of fishing that is legal. By demonstrating the large effect of fuel subsidies on the total quantity of fishing, our findings suggest that further, more ambitious subsidy reform could result in large ecological gains. Opportunities exist in the 80 countries that subsidize the fuel of their fishing vessels, and in the ongoing "second wave" WTO negotiations on fisheries subsidies (Schuhbauer et al., 2020; WTO, 2022).

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Online Appendix

The effect of fuel subsidies on Chinese distant water fishing

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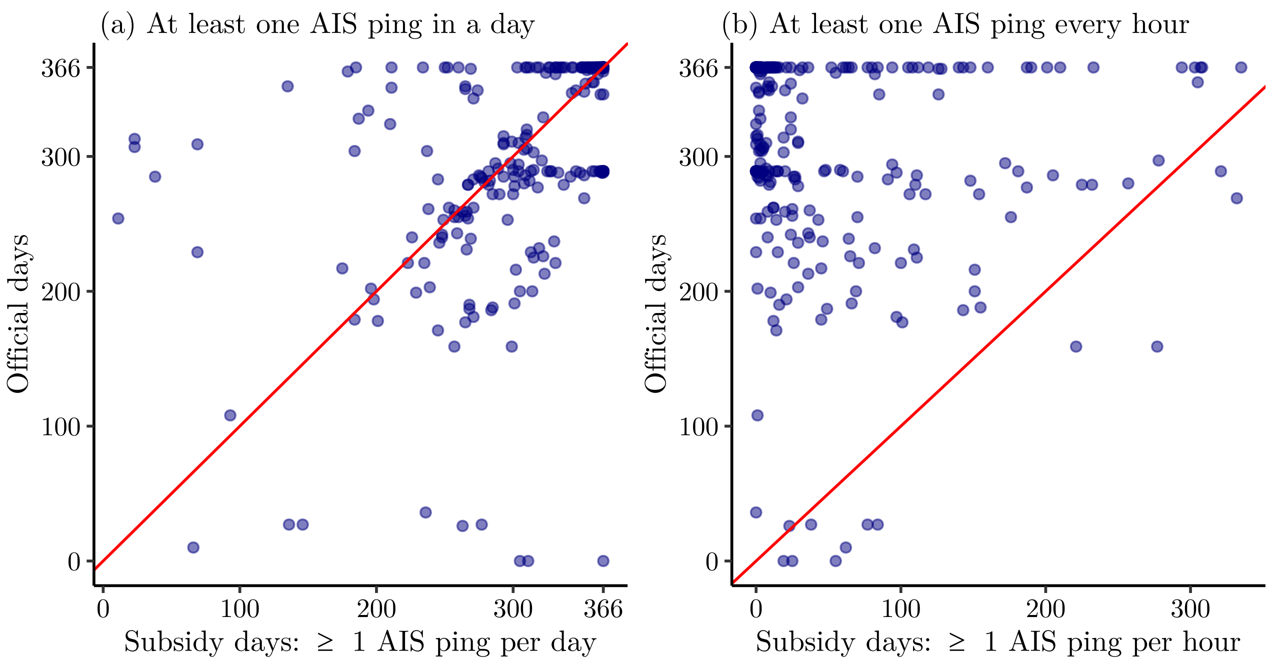
December 22, 2022

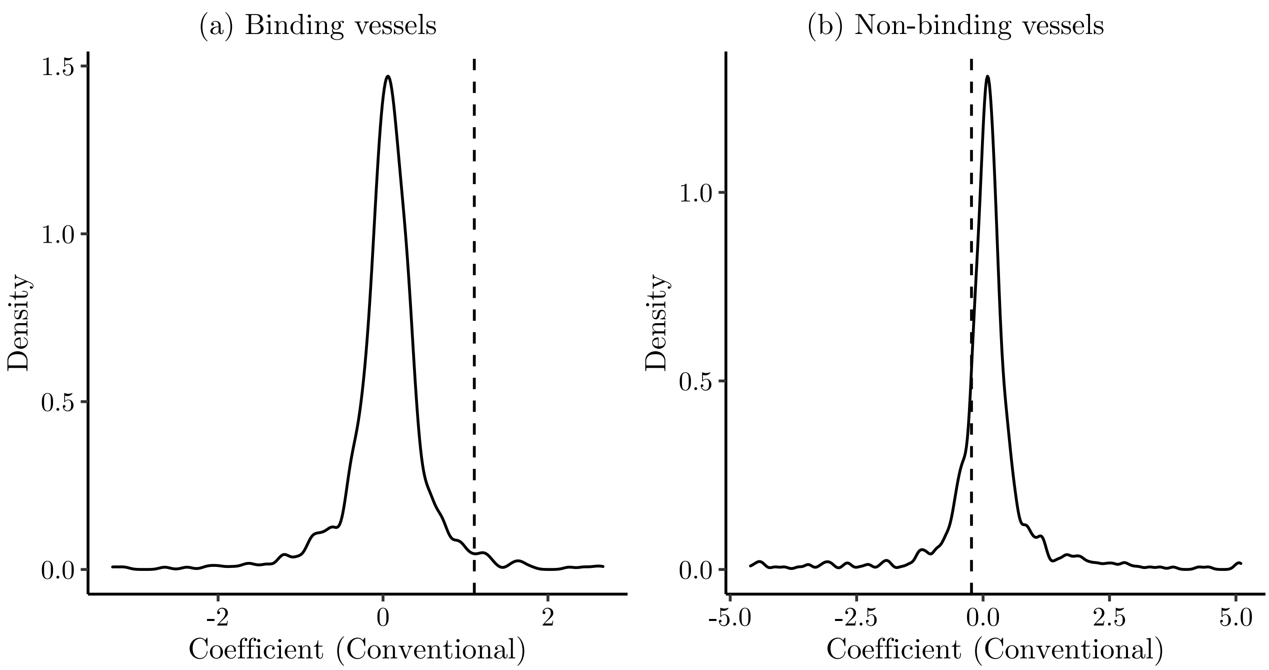
A Figures and Tables

Figure A1: Comparison of two definitions of subsidy days



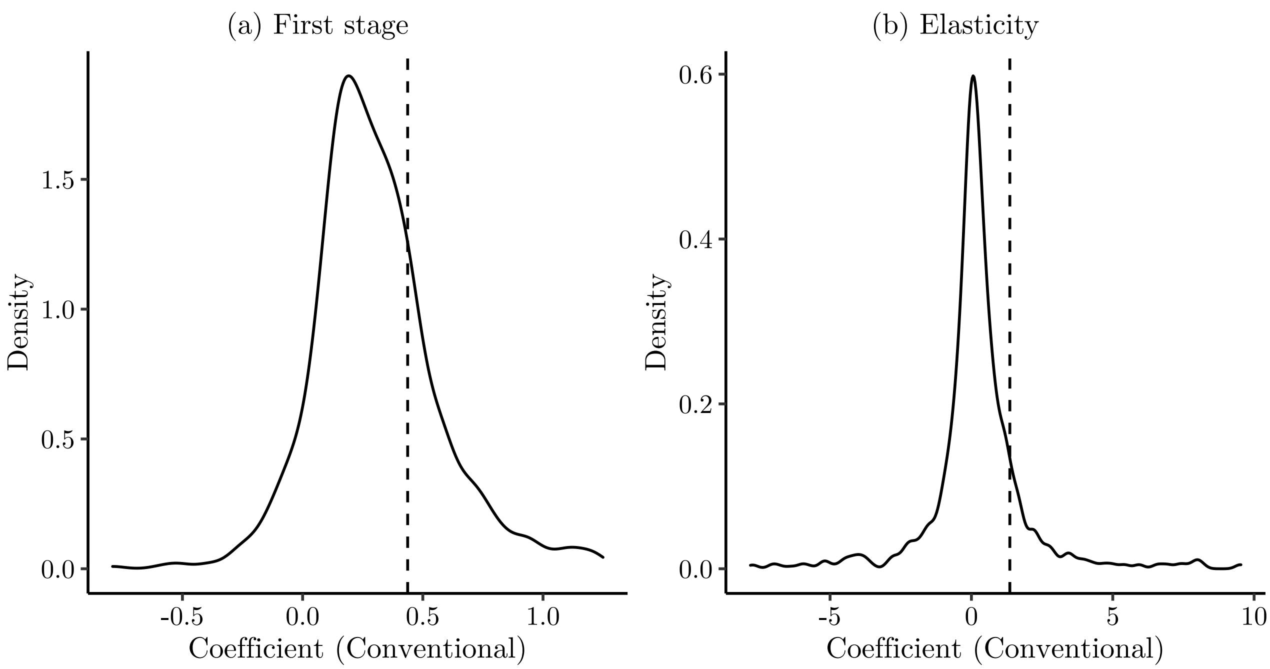
Notes: We obtained subsidy days for 273 vessels in 2020 from the regulator in Putuo district, Zhoushan, in Zhejiang province (y-axis). We compare these official subsidy days, which are based on VMS data we do not observe, to two definitions of subsidy days based on AIS data that we do observe. A subsidy day is one in which we observe (a) at least one AIS ping from the vessel that day or (b) at least one AIS ping from the vessel every hour that day. The former measure has a closer correspondence to official subsidy days, so we use it as our measure of subsidy days when calculating the annual fuel subsidy received by each vessel.

Figure A2: Randomization inference effect of fuel subsidies on log distance traveled in km, different subsets of vessels



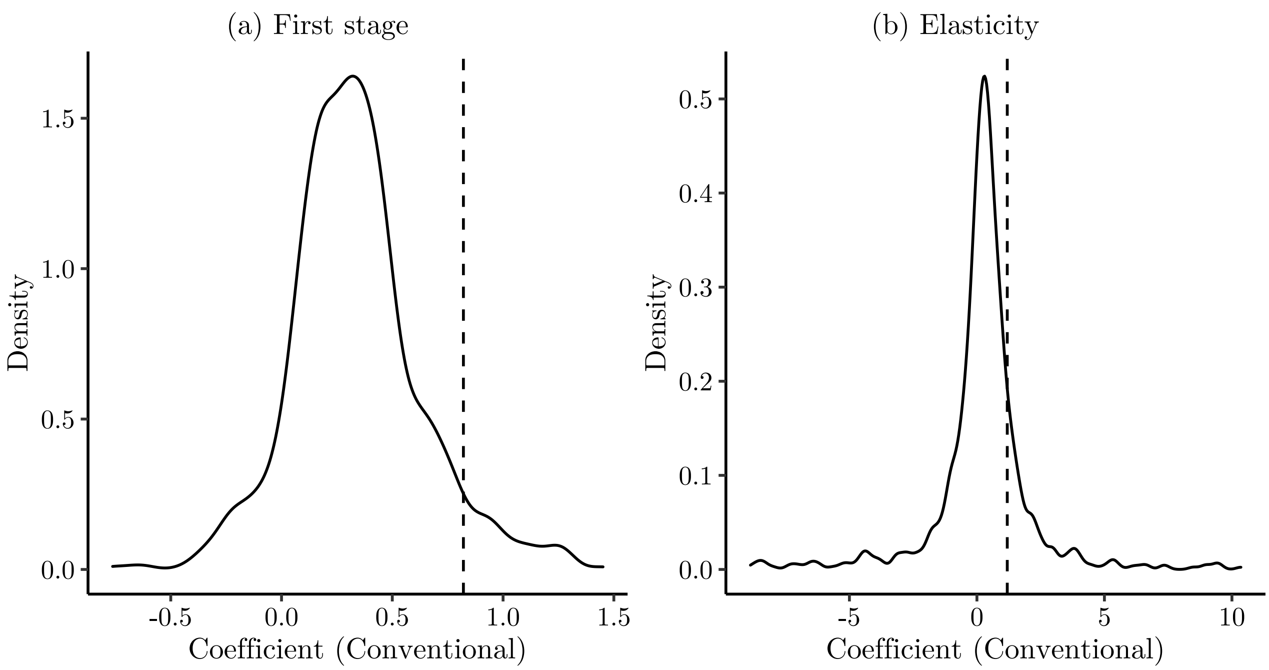
Notes: Each subfigure displays the distribution of placebo conventional point estimates (solid line) against the true conventional point estimate (vertical dashed line). We trim the top and bottom 2% of placebo conventional point estimates for legibility, but we retain all placebo estimates when calculating p-values. The randomization inference p-values are (a) 0.041 and (b) 0.808.

Figure A3: Randomization inference elasticity of fishing with respect to fuel subsidies



Notes: Each subfigure displays the distribution of placebo conventional point estimates (solid line) against the true conventional point estimate (vertical dashed line). We trim the top and bottom 2% of placebo conventional point estimates for legibility, but we retain all placebo estimates when calculating p-values. The dependent variable in (a) is log monthly fuel subsidy received and in (b) it is the placebo reduced form coefficient (effect of policy on log fishing hours) divided by the placebo first stage coefficient from the same random thresholds run. The randomization inference p-values are (a) 0.259 and (b) 0.149.

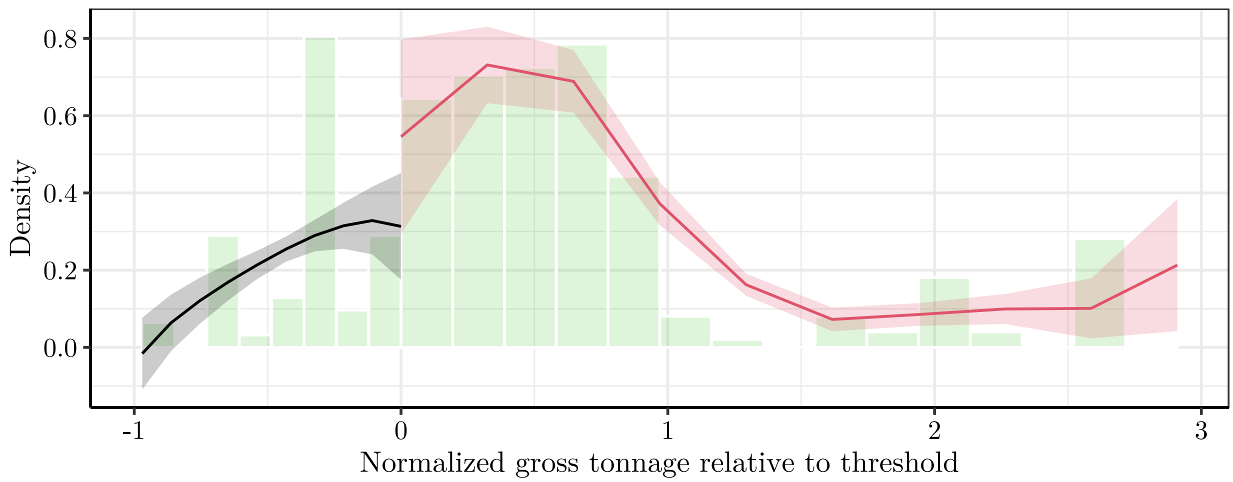
Figure A4: Randomization inference elasticity of distance traveled with respect to fuel subsidies



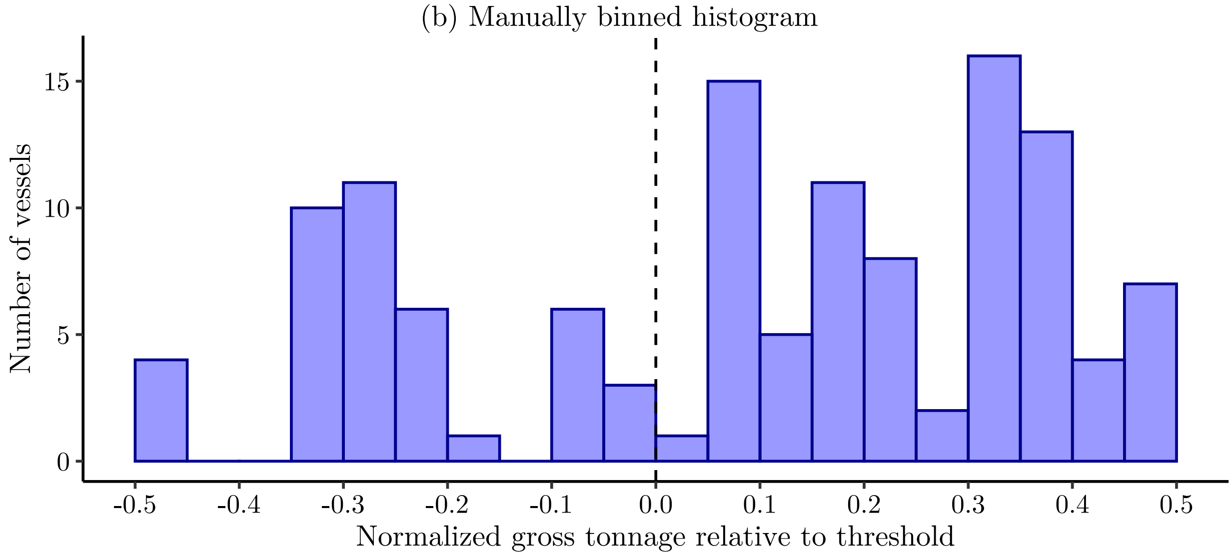
Notes: Each subfigure displays the distribution of placebo conventional point estimates (solid line) against the true conventional point estimate (vertical dashed line). We trim the top and bottom 2% of placebo conventional point estimates for legibility, but we retain all placebo estimates when calculating p-values. The dependent variable in (a) is log monthly fuel subsidy received and in (b) it is the placebo reduced form coefficient (effect of policy on log distance traveled) divided by the placebo first stage coefficient from the same random thresholds run. The randomization inference p-values are (a) 0.077 and (b) 0.184.

Figure A5: Normalized gross tonnage distance distribution for binding vessels built before 2016

(a) Density test



(b) Manually binned histogram



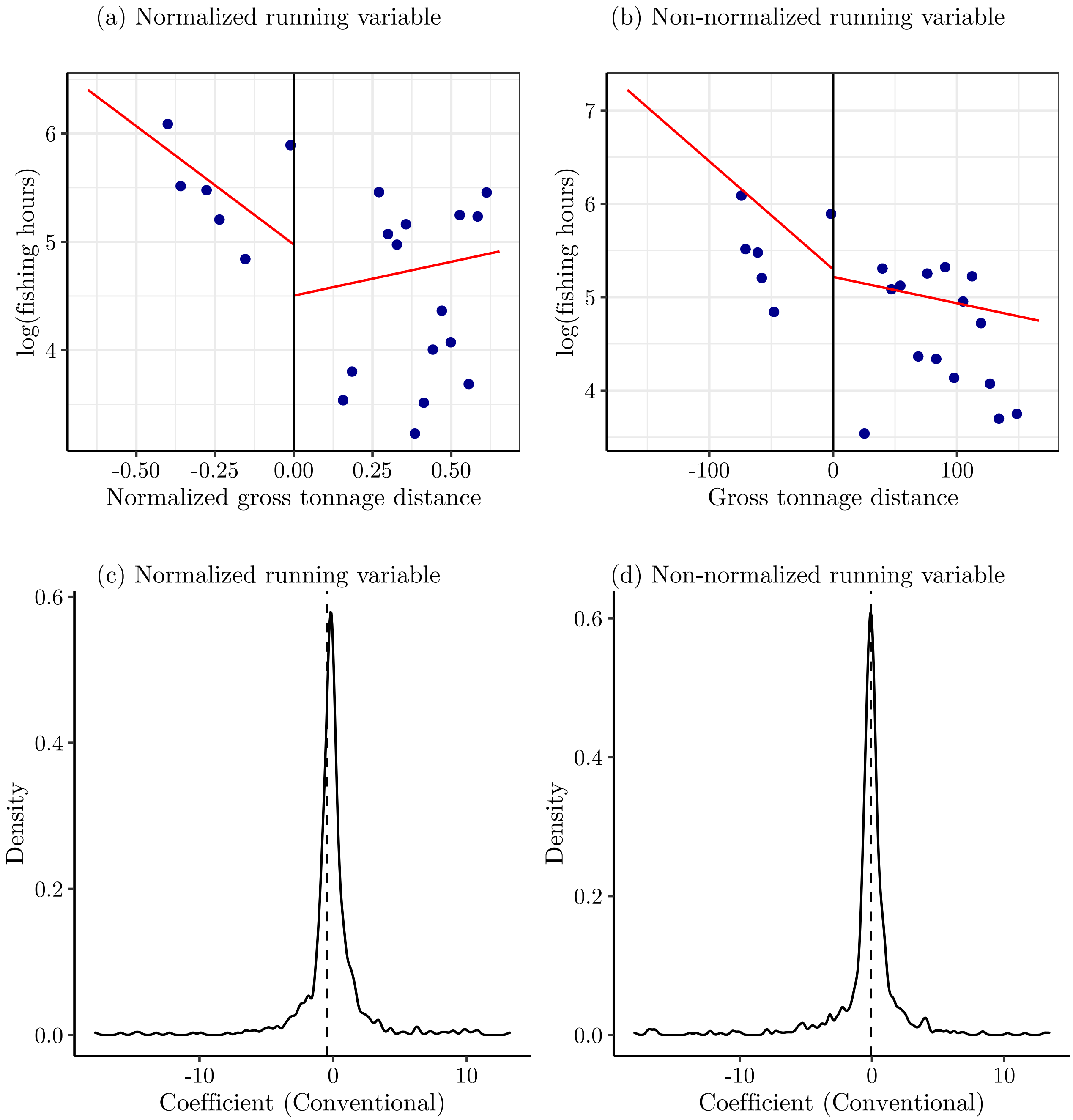
Notes: Data for both plots are the normalized gross tonnage distance of binding vessels built before 2016. In (a) bars are binned vessel densities (one observation per vessel), lines are local quadratic estimators of density, and shaded regions are 95% confidence intervals for the density. We created (a) with the rddensity package (Cattaneo, Jansson, & Ma, 2021). (b) is a histogram in which we have manually chosen the bin width to be 5 for all bins and the range of data to be between -0.5 and 0.5.

Table A1: Placebo RD on pre-period log hours of fishing

	(1)	(2)
Conventional	-0.473	-0.082
	(0.236)	(0.104)
Bias-Corrected	1.182	0.164
	(0.236)	(0.104)
Robust	1.182	0.164
	(1.283)	(0.222)
Bandwidth	0.653	166.163
N	755	911
Normalized running variable	Yes	No

Notes: The data are fishing between 2012 and 2014 by Chinese distant water vessels whose characteristics are such that their engine power ceiling will be binding under the 2016-2020 fuel subsidy policy. In each regression, the unit of observation is a vessel-month-year, we cluster standard errors at the vessel-level, we use all default options from the rdrobust package, and we control for gear fixed effects, gross tonnage, length in meters, and engine horsepower. The running variable is normalized gross tonnage distance in Column 1 and (non-normalized) gross tonnage distance in Column 2. The Column 2 bandwidth is mean-squared error (mserd) optimal. The Column 1 regression initially resulted in an error because the mserd optimal bandwidth is too small. We set the Column 1 bandwidth proportional to the Column 2 bandwidth and the ratio of those bandwidths in regressions on 2016 to 2020 data (Column 1 bandwidth equals Column 2 bandwidth times Column 1 of Table 3 bandwidth divided by Column 5 of Table 8 bandwidth).

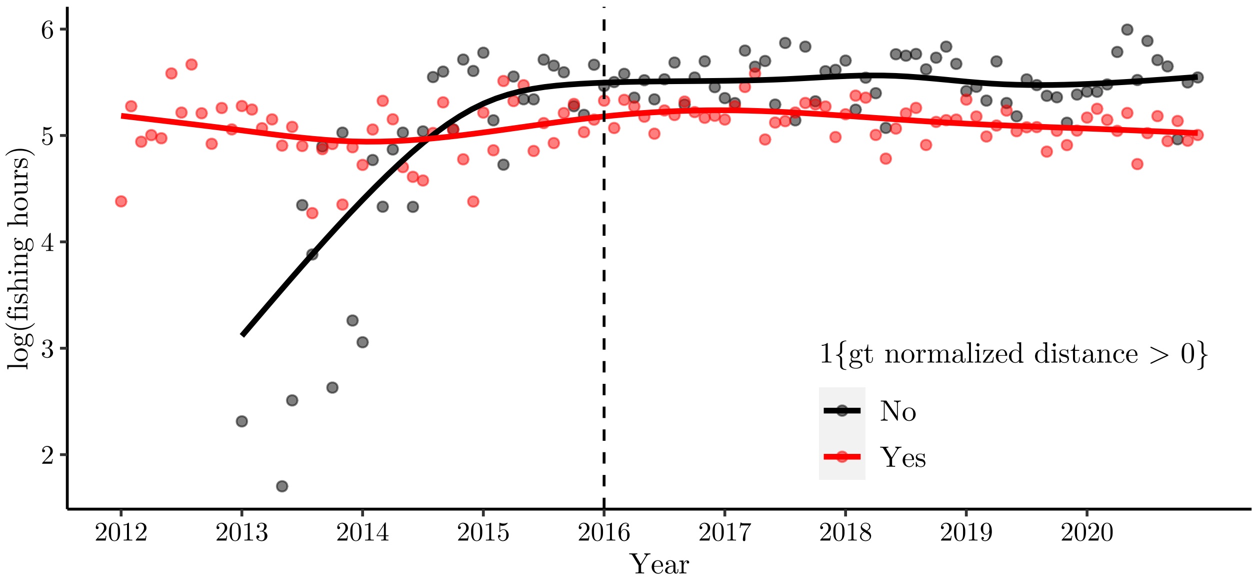
Figure A6: Pre-period placebo test



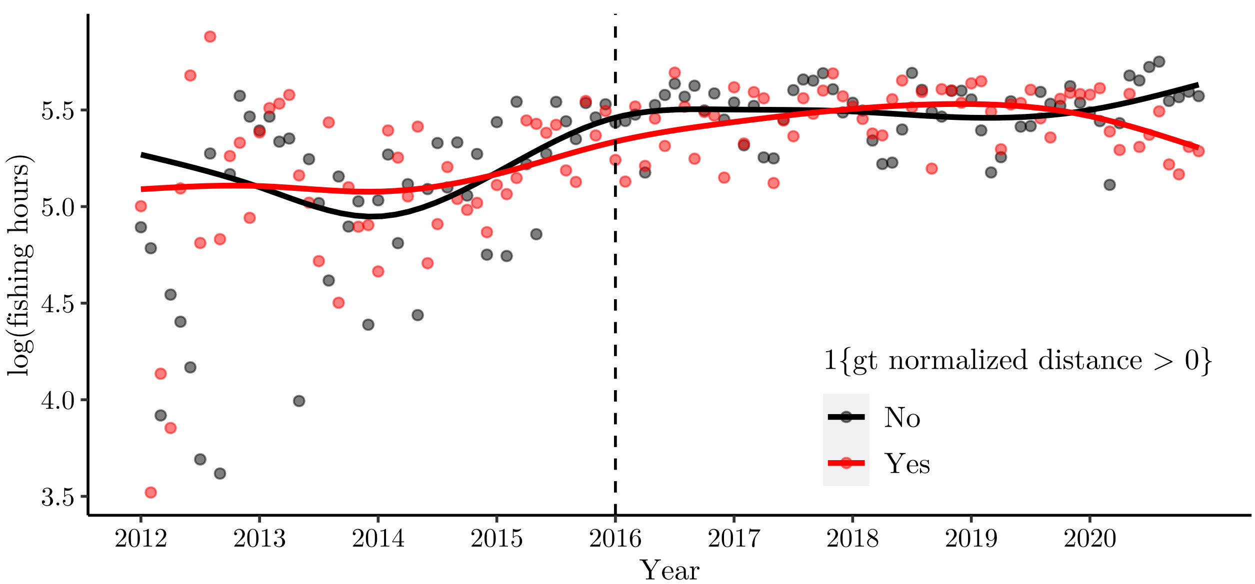
Notes: (a) and (b): Points are binned sample means of log(fishing hours) and lines are local linear conditional mean functions. These plots reproduce the two regressions in Table A1, with the difference in intercepts between the two regression lines in (a) corresponding to the conventional point estimate in Column 1, and so on. (c) and (d) display the distribution of placebo conventional point estimates (solid lines) against the true conventional point estimates (vertical dashed lines) from (a) and (b), respectively. We trim the top and bottom 2% of placebo conventional point estimates for legibility, but we retain all placebo estimates when calculating p-values. The randomization inference p-values are (c) 0.669 and (d) 0.488

Figure A7: Log monthly fishing hours over time

(a) Binding vessels

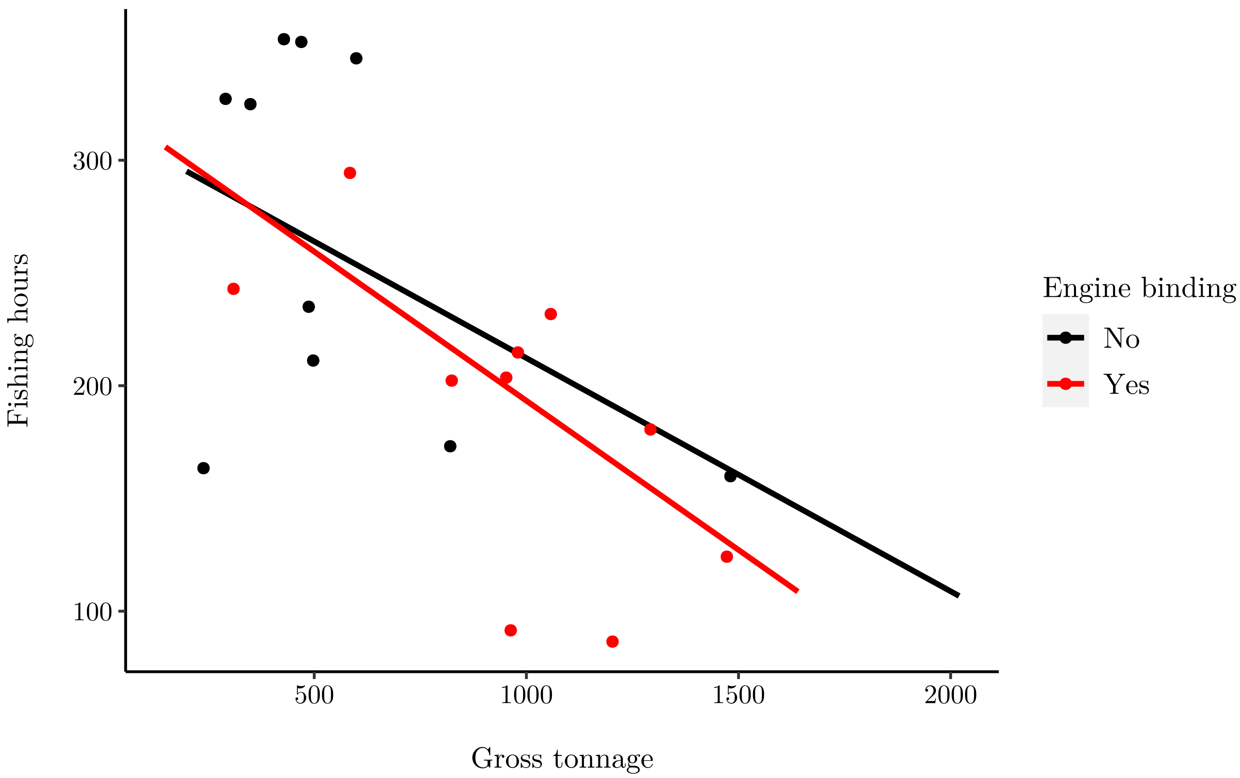


(b) Non-binding vessels



Notes: Points are average log monthly fishing hours for (a) binding and (b) non-binding vessels below (black) and above (red) their nearest gross tonnage threshold. We subset the data to vessels built before 2016 to facilitate comparison with our primary regressions. Lines are generalized additive model fits through vessel-level (non-averaged) log monthly fishing hours. Fishing hours are sometimes low or missing before 2015 because satellite coverage was poor before 2015.

Figure A8: Relationship between pre-period monthly fishing hours and gross tonnage



Notes: Linear monthly fishing hours between 2012 and 2014 (y-axis) and gross tonnage in levels (x-axis). Points are decile bins, but lines are drawn through the entire data. We exclude 2015 fishing data since vessels choosing how much to fish in this year might have been aware of the 2016-2020 policy. Engine binding calculated with respect to 2016-2020 policy. Of the 1,234 Chinese distant water fishing vessels that we matched to GFW data and that are of a gear with a gross tonnage discontinuity, only 405 have positive fishing hours between 2012 and 2014. We exclude from this plot's data 9 vessels with gross tonnage greater than 4,000 tons to improve legibility and because these vessels are not near a gross tonnage discontinuity.

B Data appendix

In order to calculate vessels' subsidies, we need to determine their gear. We do so as follows:

1. "Tuna purse seiner" and other "purse seiner": if the gear is tuna purse seiner, or if the gear is purse seiner and the target species of the vessel contains tuna, we classify the vessel as a tuna purse seiner. If the gear is purse seiner or light purse seiner, we classify it as other purse seiner.

2. "Large factory trawler (including Antarctic krill fishing and processing vessels)", "double-deck trawler and trawler fishing on high seas" and "other trawler": because all CCAMLR vessels are stern factory trawlers, if the gear is "stern factory trawler ", then we classify the vessel's gear as such. Since both double-deck trawlers and high sea trawlers can be assigned to the category "double-deck trawler and high sea trawler", we only need to find if a trawler is a double-deck trawler or a high sea trawler. If the gear is trawler or single trawler, and the authorized area contains "high seas", then we classify the vessel as a high seas trawler. For non-high sea trawlers, we use Chinese media to determine which vessels are double-deck trawlers. If no news reports are available for a vessel, we classify it as an "other trawler". the vessel is assumed as a non double-deck trawler and high sea trawler. If at the end of this process a trawler belongs to neither "large factor trawler" nor "double-deck trawler and trawler fishing on high seas", we classify it as "other trawler".

3. Pacific saury (Cololabis saira) fishing vessel: we classify vessels as such if their target species contains the word "SAP" (Pacific saury).[33]

4. Squid jigger: if vessels' gear contains "squid jigger", we classify them as such.

5. "Ultra-low temperature tuna longliner (ULT)" and other "tuna longliner". In order to distinguish the two categories, we first need to identify all tuna longliners. Vessels with

[33] In the acronym SAP, SA refers to saury and P refers to Pacific.

the gear "tuna longliner" are tuna longliners, as are vessels with the gear "longliner" or "drifting longliner" and the target species containing "albacore" or "tuna". For vessels with the gear "longliner" or "drifting longliner", but missing values in the "target species" column, we infer tuna longliners based on RFMO membership. ICCAT, IATTC and IOTC longline vessels are all tuna longliners. We identified other tuna longliners from Chinese media.[34]

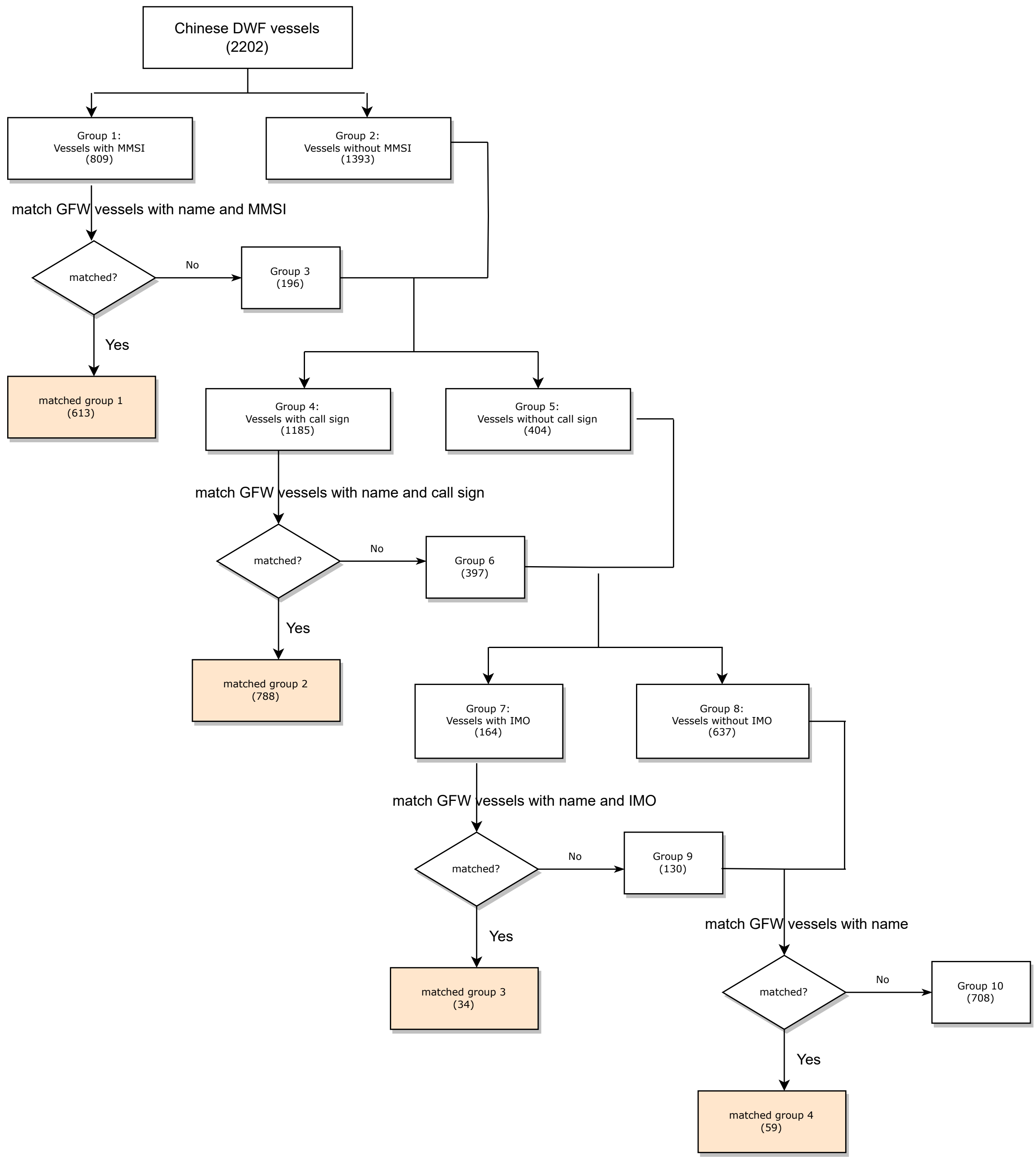
Then, we use three data sources to determine if a tuna longliner is a ULT tuna longliner: Chinese media reports, reports and announcements from publicly-listed Chinese fishing firms, and the websites of unlisted Chinese fishing firms.[35] We also identified tuna longliners as ULT based on their freezer types: "blast" or "blast and ice" or "plate". We classify the remaining tuna longliners as (non-ULT) "tuna longliner" because we could not find any evidence that they are ULT.

6. Other vessels (set net, gillnet, fishing, baskets and pots, etc): we classify vessels as such if their gear is "pot vessel".

[34]For example, the WCPFC vessel "YUEXIAYU90093" from the website http://www.shuichan.cc/news_view-189092.html.

[35]The annual reports and announcements of publicly-listed Chinese fishing firms, such as CNFC Overseas Fisheries Co., contain the identities of firms' ULT tuna vessels. We checked the websites of non-listed fishing firms, such as Penglai Jinglu Fisheries Co., Ltd., Zhejiang Ocean Family Co., Ltd., Dalian Ocean Fishing Co., Ltd., and Shandong Zhonglu Oceanic Fisheries Co., Ltd., to determine which of these firms' tuna longliners are ULT.

Figure B1: Flow chart of the matching process between vessel characteristics dataset and GFW dataset



Notes: The 2,202 Chinese DWF vessels are the vessels whose names appear only once in the vessel characteristics dataset, including 2,098 vessels in RFMO data and 104 vessels in Rongcheng data. The number in parentheses below each group is the corresponding number of vessels. The matched subsidized vessels include all vessels from Matched Group 1 to Matched Group 4.

Table B1: Ceiling of subsidized engine power

Gear	Gross tonnage	Ceiling of subsidized engine power (kW)
Tuna purse seiner	$\geq$ 2000	3650
	1000-1999	2800
	$\leq$ 999	1800
Ultra-low temperature (ULT) tuna longliner	$\geq$ 500	1200
	350-499	1000
	$\leq$ 349	800
Tuna longliner	$\geq$ 400	1000
	200-399	750
	100-199	550
	$\leq$ 99	300
Squid jigger	$\geq$ 1200	1800
	900-1199	1500
	500-899	1000
	300-499	750
	$\leq$ 299	600
Pacific saury	$\geq$ 1400	2200
Large factory trawler	$\geq$ 7000	8000
	5000-6999	6500
	3000-4999	5500
Double-deck trawler and trawler fishing on high seas	$\geq$ 1500	3500
	1000-1499	3000
	700-999	2500
	500-699	1800
	300-499	1500
Trawler	$\geq$ 500	1200
	300-499	1000
	200-299	900
	100-199	600
	$\leq$ 99	300
Purse seiner	$\geq$ 1000	1500
	500-999	1200
	200-499	900
	$\leq$ 199	550
Other vessels	200-500	750
	$\leq$ 199	550

Notes: Large factory trawler includes Antarctic krill fishing and processing vessels. "Other vessels" includes set net, gillnet, baskets, and pots.

References

Cattaneo, M. D., Jansson, M., & Ma, X. (2021). *rdrobust: Manipulation Testing Based on Density Discontinuity* [R package version 2.2]. https://cran.r-project.org/web/packages/rddensity/rddensity.pdf