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Labor market impacts and responses: The economic consequences of a marine environmental disaster☆

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ABSTRACT

This paper examines the aggregate and distributional labor-market impacts of a large-scale marine environmental crisis caused by an industrial pollution in Vietnam. Combining labor force surveys with a novel satellite data on fishing-boat detection, the analysis finds negative and heterogeneous impacts on fishery incomes and employment, and uncovers interesting coping patterns. Satellite data suggest that the affected upstream fishers traveled north to unaffected area to continue fishing. These individuals thus bore a lower income damage. The affected downstream fishers, instead, were more likely to reduce fishing hours and work secondary jobs. The paper also finds evidence on a gradual decline in the damages on fishing intensity and fishery incomes, and a positive labor-market spillover to freshwater fishery.

1. Introduction

It was not until recently that the downsides of intensified industrialization have started gaining academic attention. One of the burgeoning topics is how increasingly frequent and severe industrial disasters have taken place around the world. Since the 1990s, the number of documented large-scale industrial disasters has increased by nearly five-fold (EM-DAT, 2017). According to the International Disaster Database from the Centre for Research on the Epidemiology of Disasters (CRED), the types of industrial disasters that nations experience include gas leaks, oil spills, nuclear explosions, and chemical contamination. These incidents often lead to disastrous environmental consequences with impacts felt for years. Developing countries, with laxer environmental standards and a strong desire to promote industries and attract foreign investment, are most likely to bear the brunt of these industrial disasters. Ironically, these countries usually lack the capacity to fully evaluate the causes and effects of disasters, hold perpetrators accountable, and provide timely assistance to the affected population. Existing studies on the effects of man-made environmental disasters in developing countries, due to capacity and budget constraints, and sometimes political sensitivities, are rare.

In this paper, we examine the labor-market impacts of *Formosa*,[1] an industrial marine pollution crisis that took place in Vietnam in April 2016 and disrupted fishery activities in the country's central coast. Our analysis leverages a novel source of high-resolution satellite data on night-time boat detection in Vietnam's marine exclusive economic zone (EEZ), and relates it to employment data from the Vietnamese labor force surveys. Exploiting both the industry-specific and location-specific

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[1] As later discussed, we refer to the disaster as *Formosa* following the name of the polluter that caused this marine pollution.

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natures of the *Formosa* shock, our identification strategy compares fishery workers that lived in the affected region to both non-fishery workers in the same area and other fishery workers outside the affected zone.

We estimate the impact of *Formosa* by employing a series of difference-in-differences estimations (DiD) using individual-worker data, and show that the disaster sharply reduced average fishery income by as much as 42 percent during the rest of 2016. Utilizing high-resolution, satellite-detected data on the prevalence of night-time fishing boats at the monthly interval, we additionally estimate the direct impact of *Formosa* on fishing activities, showing an average decline in fishing intensity of as much as 36 percent in the period immediately following the pollution breakout. Importantly, we find a large spatial variation in impact's magnitude. Our estimation indicates a more negative impact on fishery communities located downstream of the contaminated zone relative to those upstream and closer to safe waters. In addition, we show that the heterogeneous impact seems to have induced different labor-market coping responses. Satellite data suggests a strong northward movement in the fishing pattern of the affected upstream fishers. Being able to travel to safer fishing grounds allowed these workers to maintain the number of work hours. In contrast, fishers located downstream were more likely trapped inside the contaminated zone; their average income reduced by more than half in 2016. This adverse circumstance led to a significant reduction in fishery work hours and an increase in the likelihood of working secondary jobs. Quantile analysis further suggests a distributional impact across fishery income groups, indicating the strongest damage to fishers in the lowest income quantile.

Next, we study aspects of the disaster recovery by examining *Formosa* effects on both fishing intensity and fishery earnings over time. We find a gradual reduction in the size of disaster damage to both outcomes. Evidence shows that by the last quarter of 2016, while fishing activity in the affected region had largely recovered, average monthly fishery earnings were still only two-third of the pre-disaster period. Additionally, we examine potential spillover effects of *Formosa* to other related industries in the affected provinces. Among the industries deemed eligible for *Formosa* compensation by the government, we find positive earning spillovers to workers in the freshwater-fishery industry, especially those located downstream. Finally, in an extended discussion, we study the potential effect of the government's fishing-ban policy. Evidence from a spatial regression discontinuity design and a triple-differences analysis suggest some, albeit not statistically robust, effect of the ban, which aligns with our view that, rather than being strictly enforced, the ban served more as a mechanism through which the government communicated the severity of the incidence to the public.

Our paper focuses on evaluating the short-run, immediate impacts of *Formosa* on fishery workers, and how the affected fishers adapted to this extreme shock to their livelihoods, for at least two important reasons. First, fishery is the third-most dominant sector in Vietnam, accounting for 19.97 percent of the country's total agricultural GDP in 2016 and 9–10 percent total export revenues (General Statistics Office, 2016b). Fishery-related activities also make up a considerable share of the economics in the central Vietnam. At the four-digit Vietnam Standard Industrial Classification (VSIC) level, the single sub-industry of saltwater fishery accounts for 3.8 and 7.3 percent of total employment and income in coastal districts[2] of Ha Tinh, Quang Binh, Quang Tri, and Hue in 2015 (General Statistics Office, 2016a). Second, the Vietnamese fishery sector is characterized as being predominantly small-scale and concentrated in coastal near-shore waters (Pomeroy et al., 2009).[3] Due to this nature of the industry, majority of Vietnamese fishers face considerable restriction on the length and types of their fishing voyage. Fishery earnings are also highly vulnerable to uncertainties in fishing condition—from unfavorable climates to extreme, albeit rare, incidents like *Formosa*. Because we are interested in examining the immediate impact of the crisis, we confine the scope of the analysis to the period before any formal source of compensation was distributed, i.e., the rest of 2016.[4] The time frame of our analysis allows us to cleanly evaluate fishery economic damages and adaptation activities during the most urgent time, thereby providing insights related to the timing, effectiveness, and equality of assistance policies.

This study directly contributes to an emerging literature on the economic impacts of environmental disasters. Most of this literature has dealt with natural incidences. One common characteristic of natural disasters is their seasonality—hurricanes, floods, droughts, or earthquakes usually repeat in certain locations, and tend to take place during specific seasons of the year. Natural disasters are generally found to cause significant economic losses. Dell et al. (2014) provide a detailed overview of the literature.[5] Specific to the economic impacts in Vietnam, Benson (1997) finds that natural disasters have clear adverse effects on agricultural crop yields and infrastructure, which also influencing cropping decisions. Noy and Vu (2010) show that lethal disasters cause lower annual output growth, but could trigger short-run boost through an "investment-producing destruction" channel. Arouri et al. (2015) show that storms, floods, and droughts all have negative effects on Vietnamese household income and expenditure, and locations with higher mean expenditure and more equal expenditure distribution are more resilient to shocks. Groger and Zylberberg (2016) examine Typhoon Ketsana in 2009 and show that it triggered labor migration from inundated rural areas to urban cities, in turn enlarging the remittance flow to affected households.

Directly related to the labor market impacts on fishery industry, Chaijaroen (2019) shows that coral breaching—a climate-change phenomenon caused by abnormally high sea-surface temperature—has a negative impact on marine resources, and subsequently, fishery households' income and protein consumption in Indonesia. The paper also finds evidence of long-run adaptation mechanisms, in terms of workers'

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[2] District is a second-tier administrative unit, subordinated to a province.

[3] According to the most-recent comprehensive Fishery Country Profile report from the Food and Agriculture Organization, there were a total of 109 thousand fishing vessels in the country in 2003, of which 28 thousand were non-mechanized and 45 thousand were outboard motorized boats with engine power smaller than 20 hp—both of which can only fish strictly inshore (up to 4–5 nm from the coast). There were approximately 20 thousand medium-sized vessels with an average 50 hp per boat that fish mainly in shallow-water offshore. The rest were large vessels specializing in deep-water offshore fishing (FAO, 2005).

[4] As we will discuss subsequently, the government's official directive on compensating and subsidizing the *Formosa* victims—after going through several rounds of revisions—were officially passed into law and implemented in the first quarter of 2017. This monetary subsidy effectively represents a sizable, positive shock to the income of the affected fishers, which would potentially render a downward bias to the estimated impact of *Formosa* in our empirical setting.

[5] At the macro level, Strobl (2012) and Noy (2009) find that natural disasters typically cause a drop in output in developing countries. Natural disasters may also affect the behavior of individuals. For instance, Page et al. (2014) show that victims of the flood become more risk-seeking after a loss in Australia. In contrast, Cameron and Shah (2015) show that individuals living in villages that recently suffered a natural disaster such as a flood or earthquake exhibit more risk-aversion than individuals in other villages. In terms of the labor market's implications, Gray and Mueller (2012) find that natural disasters trigger labor migration. In the U.S., Belasen and Polachek (2009) find that workers' earnings increase up to 4 percent in hurricane-stricken counties while wages in nearby counties decrease. Also, workers in hurricane-hit counties migrate into neighboring areas.

adjustments in labor supply and industry switching. Our paper differs in the sense that we study the impulsive, short-run impacts on, and subsequent labor market responses of, local fishery communities to a breakout of a marine environmental crisis. Also in Indonesia, Axbard (2016) shows that climatic variability that affects local fishing conditions can influence fishers' decision to conduct crime (sea piracy) through an income opportunity channel.

Compared to the extended body of literature on the economic consequences of natural disasters and climatic variability, the evidence on impacts caused by man-made, industrially-driven disasters is scant. Unlike natural disasters, industrial disasters are consequences of human errors and mechanical malfunctions; in many cases, they are one-off events without any precedents. Anticipating the occurrence of such events are difficult, which often leads to serious challenges with the design of emergency responses and adaptation mechanisms. However, because of their unpredictability, research on industrial disasters, including this paper, can take advantage of more plausible identifying assumptions. Among industrial disasters, chemical spills, along with oil spills and radiation, are relatively rare but have caused larger damages.[6] Existing studies mainly focus on assessing the health and environmental impacts of large-scale industrial accidents. Radiation exposures following major nuclear power-plant accidents such as those at *Three Mile Island* in Pennsylvania in 1979, *Chernobyl* in Ukraine in 1986, or *Fukushima* in Japan in 2011, have been shown to elevate long-term cancer risks (Christodouleas et al., 2011), increase infant and childhood leukaemia (Petridou et al., 1996), and hurt long-term school outcomes (Almond et al., 2009). House prices and food prices in the exposed areas were also affected (Nelson, 1981; Tajima et al., 2016). Most similar to the Formosa disaster, oil-spill disasters have caused environmental damages to local marine ecosystems, which directly affect fishery and tourism industries. The damages have been documented for the *Exxon Valdez* on south-central Alaska (Cohen, 1995), the *Prestige* in Galicia (northwest Spain) (Garza-Gil et al., 2006), or the *Penglai* in the Bohai sea (northeast China) (Pan et al., 2015), along with associated studies on risk assessment analysis (Al-Majed et al., 2012; Wirtz et al., 2007; Liu et al., 2015). However, few studies have focused on industrial disasters in developing countries. As far as we know, we are the first to rigorously examine labor-market outcomes and document coping responses of the affected population in a developing country.

We contribute to the literature by evaluating economic impacts of *Formosa*, a marine pollution crisis in coastal Vietnam, on fishery workers. Our analysis particularly investigates the victims' responses to this extreme environmental shock. The results indicate large distributional impacts of *Formosa* on different local fishery communities and income groups, thereby providing an important implication to assistance polices that aim at supporting the victimized population.

The rest of this paper is organized as follows. Section 2 provides background information of the *Formosa* disaster in greater detail. Section 3 describes the data sources and our econometric specification. Section 4 presents the main empirical results of *Formosa* impacts on fishing intensity and fishery labor-market outcomes, along with a series of robustness and falsification exercises. Section 5 extends to the equally-important discussions on heterogeneous impacts, fishers' coping mechanisms, fishing recovery, spillover effects, and the potential impact of the fishing ban. Finally, Section 6 concludes.

2. The *Formosa* disaster

In early April 2016, widespread news were reported across all major Vietnamese and global media venues about a large-scale marine crisis, where tonnes of fish and other marine creatures died suddenly in mass and floated ashore along the coast of four provinces in central Vietnam: Ha Tinh, Quang Binh, Quang Tri, and Hue.[7] Shortly after, the main perpetrator was identified to be Formosa Ha Tinh Steel Corporation, whose malfunctioned underwater drainage system discharged heavy industrial waste containing phenol, cyanide and iron hydroxides—all are toxic chemical substances—into the ocean.[8,9] After initially denying responsibility, the company admitted guilt on June 30th, 2016, and agreed to settle for an immediate remedial compensation package worth US$500 million. It was three months after, on September 29th, 2016, when the government finally passed a directive advising on the bottom and cap of the affected individual's compensation package (Prime Minister of Vietnam, 2016). This directive would be further revised and adjusted in March 2017 before it officially went into law (Prime Minister of Vietnam, 2017).[10]

It is worth noting that, due to a variety of reasons including the intense political sensitivity surrounding the event,[11] there has not been any official and rigorous scientific assessments regarding the ecological damage caused by *Formosa*. Leaving aside debates on the precise severity of the *environmental* effect(s), this analysis investigates *Formosa*'s *economic* impacts on local coastal communities residing in the four affected provinces—those relying heavily on saltwater fishery for their livings. In May 2016, for the first time in history, the Vietnamese government announced a double-ban on both fishing activity and the processing and selling of seafood caught within 20 nautical miles of central Vietnam provinces, worrying that contaminated seafood in the region might not meet safety standards. The ban would eventually last six months and was lifted in September 2016. However, all near-shore (within 20 nautical miles) deepwater fishing activity continued to be restricted, and would only be lifted in May 2018, after the Health Ministry announced that seafood caught in the area had met safety standards and marine resources had recovered.

Fig. 1 shows the map of Vietnam (divided into provinces) with a focus on the study area. The shaded provinces in central Vietnam are those directly affected by *Formosa* according to the government: Ha Tinh, Quang Binh, Quang Tri, and Hue (from north to south). The location of Formosa steel plant is geo-coded and shown as the green asterisk on the southern tip of Ha Tinh province. The thick dashed line (in red) indicates the near-shore fishing-restricted zone demarcated by the government that was in effect for six months, between April and September

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[6] In the database EM-DAT, among hundreds of industrial disasters reported every year, only a handful of them are chemical spills, oil spills or radiation. However, the effects are disproportionately large. For chemical spills, oil spills and radiation, the average affected population per incidence since 1950 is around 18,000 people, while for other categories of industrial disasters (collapse, explosion, fire, gas leak, poisoning), the figure is about 3200 people (EM-DAT).

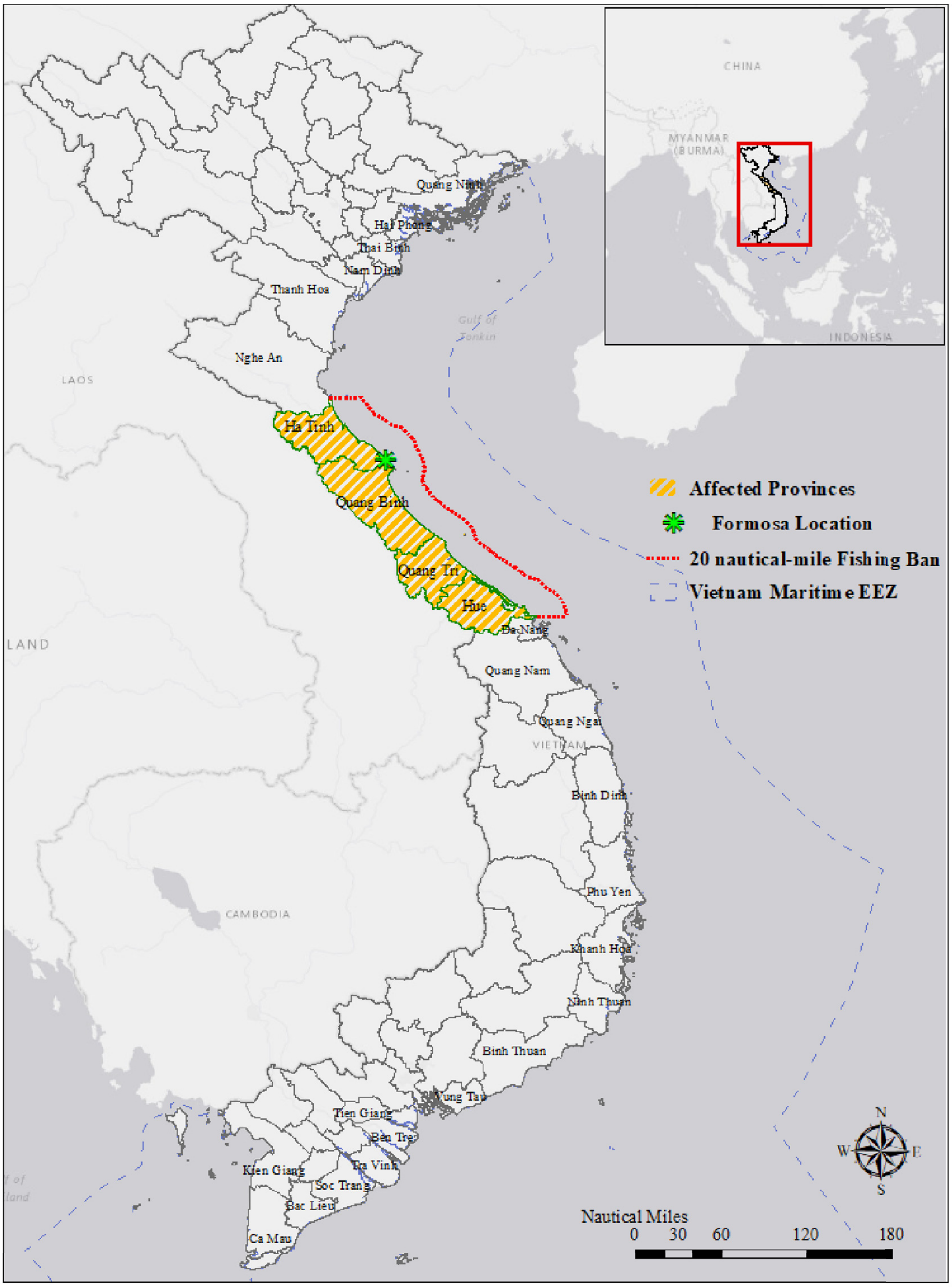
[7] For instance, see Vietnamnet (2016); Thanh Nien News (2016); ABC News (2016); The Guardian (2016); Reuters (2016); Fox News (2016), etc.

[8] The Formosa disaster was most likely unexpected. According to data from Dow Jones FACTIVA, there was no news article about Vietnam from both Vietnamese and global news outlets that contained both terms "Formosa" and "fish" up until April 2016. In April 2016 and May 2016, the number of articles mentioning "Formosa" and "fish" jumped to 80 and 117 respectively.

[9] Most assessments on the health of Vietnamese fisheries conclude that the country's ocean is currently being heavily overfished, and marine resources heavily over-exploited (Bojo, 2011). Only half a percent of Vietnam's Exclusive Economic Zone (EEZ) is designated (demarcated or proposed) as Marine Protected Areas (MPA), which are scattered across the country's coast (Marine Conservation Institute, 2020). The Vietnamese government in recent years have started taking stricter legal measures to protect marine resources, for instance, imposing larger penalties on marine exploitation activities that use illegal and destructive fishing gears (Prime Minister of Vietnam, 2013).

[10] See the detailed time-line pertaining to the Formosa environmental pollution incident in the Appendix.

[11] For instance, see BBC (2016); CNN (2017); Bloomberg (2016); New York Times (2016), etc.



Note: This figure shows the map of Vietnam, divided into 63 provinces (first-tier administrative units). The treated group (i.e., the *Formosa*-affected provinces) is shaded in orange and includes the provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue. The thick dash line (red) illustrates the 20 nautical-mile near-shore fishing-restricted region after *Formosa* took place. The thin dash line (blue) indicates Vietnam's Exclusive Maritime Economic Zone (EEZ).

Fig. 1. Map of Vietnam with a Focus on the Formosa Study Area.

2016.[12] The thin dash line (in blue) indicates the Maritime Exclusive Economic Zone (EEZ) of Vietnam.

3. Data and empirical methodology

3.1. Data and summary statistics

We use two main data sources to analyze the impact of *Formosa* on fishery workers in central Vietnam. We first collect labor-market

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[12] As mentioned earlier, this region also defines the *deepwater* fishing-ban zone which was effective until May 2018.

information from the Labor Force Surveys of Vietnam ("LFS") in 2015 and 2016. To measure fishing intensity, we rely on the Visible Infrared Imaging Radiometer Suite ("VIIRS"), which is a remotely-sensed, satellite imagery data product administered by the National Oceanic and Atmospheric Administration ("NOAA") and captures the luminosity of night-time light around the globe. We specifically utilize VIIRS′ Boat Detection Module ("VBD"), which processes worldwide night-time ocean light emitted from fishing boats to attract catch. Importantly, VBD also implements an automatic boat detection identification system that converts light intensity to boat counts. This algorithm enables us to obtain a monthly pixel-level panel dataset of fishing-boat counts, which serves as our proxy for fishing intensity, for the entire Vietnam's maritime EEZ between 2013 and 2016.

3.1.1. Vietnam labor force surveys

The Labor Force Survey is conducted annually by the General Statistics Office of Vietnam. The surveys in 2015 and 2016 include 689,747 and 814,611 individuals, respectively. LFS provides primary labor-market information (employment status, income and work hours) at a monthly basis. Household members are selected from a stratified random sampling representative by province and industry. The sample includes all family members of interviewed households. Importantly, in each survey year there is a representative sub-group of households randomly selected to be surveyed twice a year, with the first survey visit taking place in the first or second quarters, and the subsequent revisit taking place in the last two quarters. This unique feature of LFS allows us to rely on both a repeated cross-section (i.e., the pooled sample) and an individual-level panel (i.e., the re-surveyed sample) to estimate employment and income impacts of *Formosa*. Indeed, the advantage of the latter approach is that we can further control for individual-specific fixed effects, thereby accounting for all time-invariant factors—both observed and unobserved—that might simultaneously affect both treatment status (i.e., residing within the affected zone) and the labor-market outcomes. Also for the purpose of analysis, we restrict our sample to only working-age individuals between 18 and 70 years old.

We focus on the labor outcomes specifically in saltwater fishery industry and examine the changes in these outcomes before and after the *Formosa* incident. Our main sample includes all individuals who worked in the saltwater fishery industry before the disaster in 2016 (i.e., in Q1-2016). Thus, the fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue—the four *Formosa*-affected provinces—serve as the treatment group. As we will elaborate further, we exploit both the location-specific and industry-specific characteristics of *Formosa* to obtain two separate control groups. First, because *Formosa* took place strictly in the central provinces, we form a "geographic" control group consisting of non-affected fishers located in other coastal provinces. To avoid the concerns related to contaminated control units, we restrict to only fishery workers living in the southern provinces distant from Formosa, specifically between Phu Yen to Ca Mau (see Fig. 1). We explain the selection of Phu Yen as the main control group's "cutoff" in the next section. Second, the fact that *Formosa* mainly affected the fishery industry allows us to form an "industry" control group consisting of individuals living in the affected zone who worked in non-affected industries.[13]

The first panel in Table 1 presents descriptive statistics for the primary labor-market and observable characteristics of the saltwater fishery industry, using LFS 2015. The mean and standard deviation for each outcome variable are shown separately for all *Formosa*-affected fishers locating between Ha Tinh and Hue (i.e., the treatment group), all fishers in the control provinces (i.e., the geographic control group), and all workers in the unaffected industries between Ha Tinh and Hue (i.e., the industry control group). At the baseline, it is evident that fishery is a considerably more influential income-generating activity for individuals living in central Vietnam. On average, a central Vietnam fisher works over 62 h a week and earns 7.5 million VND in total monthly income (approx. 335 USD), compared to the respective figures of 55 h and 6.2 million VND of a southern (i.e., control) fisher, or 49 h and 4.4 million VND of a worker in the "control" industries (manufacturing, construction, and retail). Because of the arduous and labor-intensive condition, well over 90% of the fishers are male. More than a quarter of fishers in central Vietnam (more than a third of southern fishers) do not have any formal educational training and only less than 3% obtained high-school or college level education. Anecdotally, most fishers are born and raised in families that have been attached to fishery for generations. In addition to the summary statistics for the pooled sample in LFS 2015, Table A1(a) presents similar baseline descriptive statistics for individuals in the LFS 2016 panel sample.

Appendix Table A1(b) provides preliminary mean-comparison statistics indicating the negative impact of *Formosa* on fishery earnings in central Vietnam. The table compares pre-disaster (i.e., Q1-2016) and post-disaster (i.e., the rest of 2016) average monthly incomes, separately for 3 groups: 1) the treatment group, i.e., the fishery workers living in the *Formosa*-affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue; 2) the unaffected fishery workers living in southern provinces distant from Formosa, which we refer to as the "geographic" control group; and 3) the non-fishery workers living in the *Formosa*-affected provinces that work in other unaffected industries, referred to as the "industry" control group. The means-difference tests (last column) indicate drastic and statistically significant declines in average fishery incomes of the *Formosa*-affected individuals. In contrast, we do not observe any statistically meaningful changes in incomes of the "control" fishers.[14]

A crucial aspect of the DiD method is the validity of the parallel-trend assumption. Fig. 2 visually addresses this element; the figure plots pre- and post-Formosa movements of monthly average incomes, for each month between January 2015 and December 2016, separately for the fishery and control industries (construction, retail, manufacturing) within the provinces affected by *Formosa* (Ha Tinh, Quang Binh, Quang Tri, and Hue) as well as the unaffected/"control" regions (i.e., all provinces south of Phu Yen; separated into two regions roughly equal to the size of the treatment zone—1) Phu Yen to Binh Thuan and 2) Vung Tau to Ca Mau). While the line plots exhibit strong parallel trends between the treated (i.e., fishery in affected provinces) and both the "geographic" (i.e., fishery in unaffected regions) and "industry" control groups (i.e., unaffected industry in *Formosa*-affected provinces) during the pre-*Formosa* period, there is a visible downward deviation from trend for the treatment group, right after *Formosa* took place in April 2016, following a gradual trend-conversion for the subsequent months. In contrast to the income curve of the treated units, we observe a rather flat earning profile for all the control groups employed in our empirical setting across the entire analysis period.

3.1.2. Satellite data on boat detection

To measure the impact of *Formosa* on fishing activity, we use the Visible Infrared Imaging Radiometer Suite ("VIIRS"), which documents high-resolution night-time light luminosity at the Earth's surface. VIIRS is administered by the National Oceanic and Atmospheric Administration (NOAA). Specifically, we utilize a special Boat Detection Module of VIIRS ("VBD"), which detects the ocean's night-time light emitted from fishing boats.[15] VBD is jointly sponsored by the U.S. Agency for

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[13] We subsequently check for the validity of both control groups in several empirical exercises.

[14] In fact, there is an expected (insignificant) increase in the average fishery earnings of the unaffected southern fishers after the first quarter of 2016. This is because the fishing season usually takes place between May and November each year, as visually seen in Fig. 3.

[15] Night-time fishing often requires the emission of high-luminous light to attract catch.

Table 1
Descriptive baseline statistics for LFS and VBD samples.

	Fishery industry Formosa provinces		Control provinces			Control industry Formosa provinces		
	Mean	S.D.	Mean	S.D.	Dif. [p-val]	Mean	S.D.	Dif. [p-val]
Panel I. Labor Characteristics: Individual Level (Labor Force Survey 2015)								
Total Monthy Income ('000 VND)	7475.4	8294.5	6232.0	12,073.8	0.05	4502.2	3180.4	0.00
Monthly Income from Main Job ('000 VND)	7396.3	8321.3	6191.7	11,976.7	0.05	4357.7	3104.4	0.00
Work Hours (per week)	62.11	15.03	54.47	13.49	0.00	48.66	10.34	0.00
Having A Second Job (%)	12.71	33.35	2.82	16.56	0.00	18.80	39.07	0.00
Age	39.52	12.73	37.46	11.01	0.00	39.58	11.27	0.93
Gender:								
Male (%)	98.53	12.04	92.28	26.69	0.00	58.13	49.34	0.00
Female (%)	1.47	12.04	7.72	26.69	0.00	41.87	49.34	0.00
Educational Attainment:								
No Training (%)	26.65	44.27	42.90	49.50	0.00	7.28	25.98	0.00
Primary School (%)	38.88	48.81	41.27	49.24	0.36	21.94	41.38	0.00
Secondary School (%)	31.54	46.52	12.79	33.40	0.00	37.26	48.35	0.02
High School (%)	2.93	16.90	2.12	14.40	0.30	21.05	40.77	0.00
College (%)	0.00	0.00	0.93	9.58	0.05	12.48	33.05	0.00
Observations	409		2268			8256		
Panel II. Fishing Intensity: Boat Detection (VBD 2013–2015)								
Boat Detection Likelihood (%)	59.13	49.16	39.78	48.94	0.00			
Number of Boats Detected	4.62	8.20	3.33	7.84	0.00			
Sea Surface Temperature (SST; Celsius)	26.35	3.34	28.25	1.95	0.00			
Precipitation (mm)	209.78	234.99	192.20	180.15	0.00			
Observations (grid-month)	25,560		84,960					

Note: This table presents the descriptive baseline statistics for the primary fishery characteristics—using data from the Labor Force Survey 2015 (Panel I), and fishing intensity—using monthly-interval satellite data from VIIRS Boat Detection module 2013–2015 (Panel II). "Control industries" refers to manufacturing, construction and retailling industries. "Formosa provinces" refers to observations belong to the four Formosa-affected provinces (Ha Tinh, Quang Binh, Quang Tri, and Hue). "Control provinces" refers to observations belong to all provinces south of Phu Yen, i.e., distant from the Formosa-affected region. 1 USD ≈22,550 VND (Vietnam Dong) as of December 31st, 2015. In Panel II, "Boat Detection Likelihood" refers to the probability that at least one boat is detected in a pixel-month. "Number of Boats Detected" refers to the total number of boats detected in a pixel-month. A pixel's resolution is 10-mile-square. The sample VBD sample is restricted to near-shore pixels (≤ 20 nm from the coasts).

International Development, NOAA, and the World Bank. The project collects and processes remote-sensing images from the Suomi National Polar-orbiting Partnership (Sunomi-NPP) satellite. Joint Polar Satellite System (JPSS) is the new generation polar-orbiting operational environmental satellite system in the U.S. The VIIRS itself is the primary imager on Sunomi-NPP.[16] Elvidge et al. (2015) discuss details of the technical algorithm and validation of VBD.

The use of night-time light brightness as a measure of economic activity has become increasingly popular in economic research. However, the majority of work have relied on *land-based* data products from VIIRS, or more popularly, from an older satellite's sensor suites—the Meteorological Satellite Program–Operational Line Scan (DMSP-OLS). These land-based products provide information on light detection of lighting from cities, towns, and villages, and thus has been shown as a reliable proxy for growth outcomes (see Donaldson and Storeygard (2016) for a comparative study on this literature). Our analysis, instead, is one of a few existing studies within the economic discipline that use VBD—an *ocean-based* data product—as a measure for fishing activities.[17] This remotely-sensed data source is highly suitable for our setting, since we study the impact of *Formosa* on coastal small-scale fishery in Vietnam, where, unlike the case of developed countries' fisheries, majority of fishing boats are not equipped with sophisticated GPS tracking technologies such as automatic identification system (AIS) or vessel monitoring system (VMS). In fact, in a study where VBD boat detection was cross-matched with VMS-equipped vessels in near real time, Hsu et al. (2019) show that VBD predicts actual fishing activities with high level of accuracy, especially for the major gear types that deploy and operate lights to attract catch such as squid fishing, lift net, and purse seiners—all are highly prevalent in Vietnam and other countries with small-scale marine fisheries.

For the purpose of this analysis, we use the monthly VBD products published by NOAA for the period between 2013 and 2016.[18] This data source provides the temporal average of all daily boat detection for each month, with a spatial resolution of 742 m × 742 m footprint.[19] We then spatially aggregate the detection data into each 10-mile-square geo-grid cells that, together, spans Vietnam's entire Maritime Exclusive Economic Zone. The chosen resolution of 10-mile-square grid allows us to better capture the effect for different fishing grounds across the entire country's coastal area. It covers a marine space granular enough to detect micro changes in fishing activity's patterns (e.g., within-province fishing grounds' migration). Nevertheless, this footprint still spans a sufficiently large marine segment, which allows us to be less concerned

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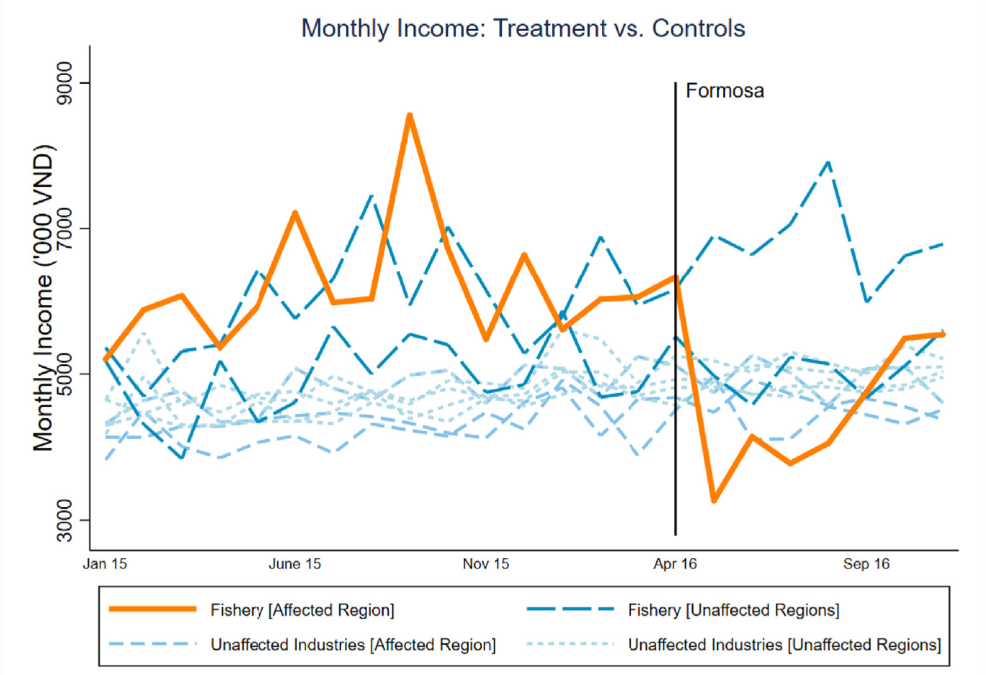
[16] We collect the raw-, raster-formatted VBD's light intensity and boat detection data at https://ngdc.noaa.gov/eog/viirs/download_boat.html.

[17] The only existing economic study that we are aware of is Yuan (2018), which uses VBD to study the compliance to seasonal fishing ban policies in China.

[18] As subsequently discussed, our main empirical setting employs three full years of pre-treatment observations (2013–2015) to capture potential seasonality effects in fishing activities in different coastal regions. It is noticed that 2013 is the first year with available VIIRS data for all twelve months in the year.

[19] According to Elvidge et al. (2018), the monthly VBD product, which gives monthly-average boat detection per night—addresses each of the three criteria that could be potential concerns for higher-frequency intervals: lunar cycle effect, seasonal variation, and cloud cover. The monthly VBD data mitigates lunar cycle effects and improve the cloud-free boat-detection capability. It should also be noted that monthly temporal averaging is widely used in economic analyses to mitigate seasonal effects on economic and fisheries data (Burkhauser et al., 2000; Garza-Gil et al., 2006; Neidell, 2004).



Note: This figure plots the pre- and post-Formosa movements of monthly average incomes (in '000 VND), for each month between January 2015 and December 2016, separately for the fishery and control industries (construction, retail, manufacturing) within the provinces affected by *Formosa* (Ha Tinh, Quang Binh, Quang Tri, and Hue) as well as the unaffected/"control" regions (i.e., all provinces south of Phu Yen; separated into two groups—1) Phu Yen to Binh Thuan and 2) Vung Tau to Ca Mau).

Fig. 2. Comparison of Income Trends: using Labor Force Surveys 2015–16.

with issues about spatial auto-correlation or spurious boat detection.[20]

The second panel (Panel II) in Table 1 presents fundamental statistics of the two VBD outcome variables related to fishing intensity that we study in this paper: 1) *fishing prevalence*, i.e., boat-detection likelihood, which is the probability that at least a boat was detected inside a particular grid in a given month and, thus, provides information regarding the *extensive* margin of the *Formosa* impact; and 2) *fishing density*, i.e., the number of boats detected in each grid, which captures the *intensive* margin. Our study sample is restricted to near-shore marine region within 20 nautical miles from the country's coast. The three-year baseline grid-month statistics from VBD 2013–2015 indicate that near-shore fishery actions are considerably greater in the central coast, both intensively and extensively. On average, 59 percent of near-shore water in central Vietnam are fished every month, while the respective boat-detection likelihoods in the control (southern) provinces are 40 percent. Likewise, there are approximately 4.6 boats detected per night within each of the 10-mile-square pixel in the treatment provinces, compared to the average 3.3 boats detected per grid in the control area. It is also noted that these statistics on fishing intensity are consistent with the LFS labor-market information; recall from Panel I of the table that saltwater fishers in the central provinces have a greater baseline average workload relative to those in the control provinces. In terms of the climate covariates, sea-surface temperature in the central and southern coasts (which closely reflects overall air temperature in these regions) are highly moderate year-round. The average monthly sea-surface temperature in central Vietnam is over 26.4 Celsius degree (with 3.3° S.D.), slightly cooler than in the south (28.2 Celsius degree with a 1.9° S.D.). Central coasts also experience higher monthly average rainfall than the south (209 mm relative to 192 mm per month).

Fig. 3 provides evidence supporting the parallel trend assumption in near-shore fishing intensity (i.e., boat counts) between the treatment (left) and control zones (right). In this figure, we plot the aggregate monthly boat counts for all the months between 2014 and 2017, separately for the two groups.[21] Even under the apparent existence of fishing seasonality, it is clearly visible that 2016 was an anomalous period with low monthly boat counts in the affected region (left panel). The number of boats captured in the peak month of July 2016 was just above 4,000, compared to that of greater than 6000 in other years. While this sharp downward deviation is noticeable in the treatment zone, it is not the case for the control region; the 2016 near-shore average monthly boat counts in the southern provinces seemed to closely follow its yearly pattern.

In Fig. 4, we further discuss several initial visual observations from the fishing-boat detection data. This figure presents a side-by-side comparison between two raw satellite snapshots from VIIRS′ VBD images. In each of the two panels, we process the original raster-formatted data published by the NOAA for the two months of May 2016 (right; i.e., the month immediately after the *Formosa* breakout) and May 2015, re-sampling the light maps into 10-mile-square grids covering the entire

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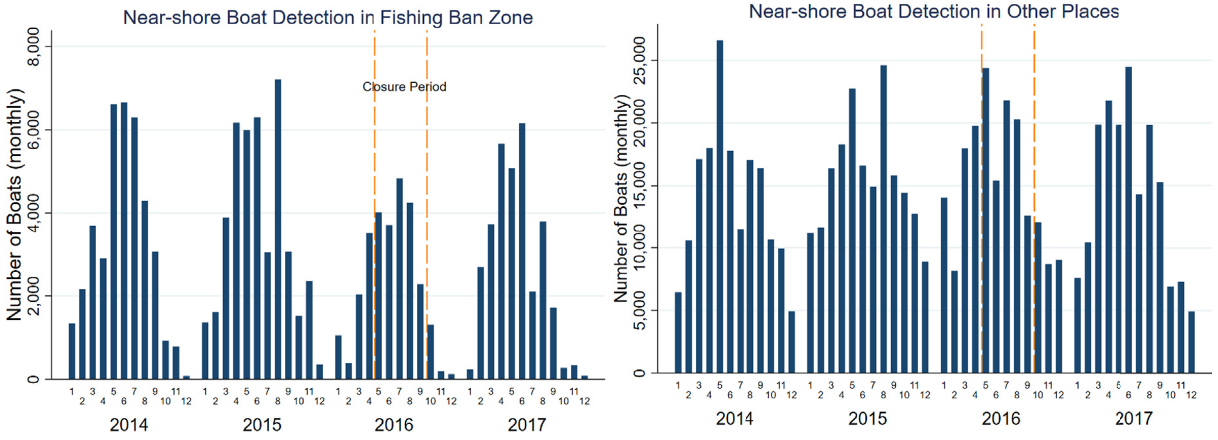
[20] It is also noted that there is no official between-province marine boundary in Vietnam. To ease result interpretations (i.e., in connecting results between VBD and LFS datasets), we mechanically constructed spatial cutoffs between each pair of coastal provinces by extending their terrestrial borders outward to the ocean. We then assign marine pixels to each province utilizing these mechanically constructed marine boundaries.

[21] Notice that our main regression exercises only focus on estimating the immediate impact of *Formosa*, hence restrict to a 2013–2016 sample. This also provides consistency with the LFS sample. For robustness purposes, we subsequently discuss estimates using an extended sample of monthly observations between April 2012 and May 2018 in the Appendix.



(a) Near-shore Boat Detection - Ban Zone (b) Near-shore Boat Detection - Other Zone

Note: This figure plots the pre- and post-Formosa movements of fishing intensity, measured by total monthly boats detected, for every months in 2014-2017. The left panel shows statistics for the treatment area, i.e., the 20 nautical-mile restricted fishing zone along the coast of the affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue. the right panel shows statistics for the control area, i.e., near-shore fishing zone along the coast of the Southern provinces distant from Formosa—from Phu Yen to Ca Mau.

Fig. 3. Comparison of Fishing Intensity: using VIIRS Boat Detection data.

marine space within the maritime EEZ of Vietnam.[22] The brighter pixels in these figures represent fishing grounds with higher boat density. One could visually notice the impact of *Formosa* on fishing intensity by contrasting the two snapshots. First, while near-shore fishing boats were densely detected along the coast of all central provinces in May 2015, this region experienced a marked decrease in boat density during the first month when *Formosa* took place (May 2016), especially in the near-shore region from Ha Tinh to Hue—the directly affected area. *Formosa* seemed to also affect major offshore fishing grounds (further out from the 20 nm fishing ban zone) of Quang Binh, Quang Tri and Hue, where the brightest cluster of densely-fished area became significantly dimmer. Interestingly, the coastal area north of Ha Tinh seems to experience a significant *increase* in brightness after the incident, suggesting a level of fishing concentration in this area after *Formosa* took place. As we will discuss empirically in the next section, this observation on the transition of fishing grounds from within to outside the contaminated zone (to the northern sites) offers a direct explanation to the large geographic distribution of the disaster's impact.

3.2. Econometric specification

To causally estimate the impact of *Formosa*, we employ two different data sets: 1) the Labor Force Surveys 2015–2016 (LFS), which provides information on fishery earnings and employment, and 2) VIIRS Boat-Detection Module, which provides satellite data on boats detected at night in coastal Vietnam. To analyze the LFS, we perform a set of difference-in-differences (DiD) regression analysis of the form:

$$y_{im} = \alpha_0 + \alpha_1(treat_i \times post_m) + X_{im} + \theta_m + \varepsilon_{im} \tag{1}$$

where the subscripts refer to an individual i surveyed in month m in 2016.[23] y_{im} is the dependent variable at the individual level. We investigate the effect of *Formosa* on several primary fishery earnings and employment, including monthly fishery and total incomes, weekly work hours, and the probability of working secondary jobs. The standard DiD treatment indicator term is

$$treat_i = \begin{cases} 1, & \text{if the individual is a fishery worker living in} \\ & \quad \text{Formosa} - \text{affected provinces} \\ 0, & \text{if the individual belongs to one of the} \\ & \quad \text{“control}'' \text{ groups.} \end{cases}$$

As mentioned, our analysis exploits both the location-specific and industry-specific characteristics of *Formosa*. Therefore, we measure the disaster's impact by employing two separate sets of control groups in all subsequent regressions:

1. Geographic control group: all individuals who worked in saltwater fishery before May 2016 and lived in the non-affected region. We purposefully narrow the geographic location of your preferred control group to only the southern provinces distant from the Formosa's location in order to mitigate any possibility that part of the control group could be contaminated due to potential spillovers of *Formosa*. Specifically, we include all fishery workers living in the southern provinces between Phu Yen and Ca Mau. We select this control set for several reasons. First, the coastal province of Phu Yen is over 900 km south of *Formosa*'s location, which equivalently gives us a geographic buffer of over 300 nautical miles (sea distance) and 600 km (land distance) from Hue—the southernmost of the four government-declared *Formosa*-affected provinces—so that geographic spillover is much less of a concern. Second, we visually cross-check our expectation by looking at NOAA's ocean currents data; according to Figure OA1 (Online Appendix), the downward current flowing through central Vietnam reverses its trend when getting to Da Nang—a province located north of Phu Yen—flowing out to the east and then northward. The flow of toxin appears to stop at the coast of Da Nang, which validates our geographical control group starting from Phu Yen to the South. In the subsequent sections of the paper, we further discuss multiple results from separate exercises including geographic control's robustness test, province-specific impacts, and undifferenced event-study, which helps additionally support the validity of our empirical design.
2. Industry control group: all individuals who worked in *Formosa*-unaffected industries before May 2016 and lived in the affected region. To identify unaffected industries, we cross-check on dif-

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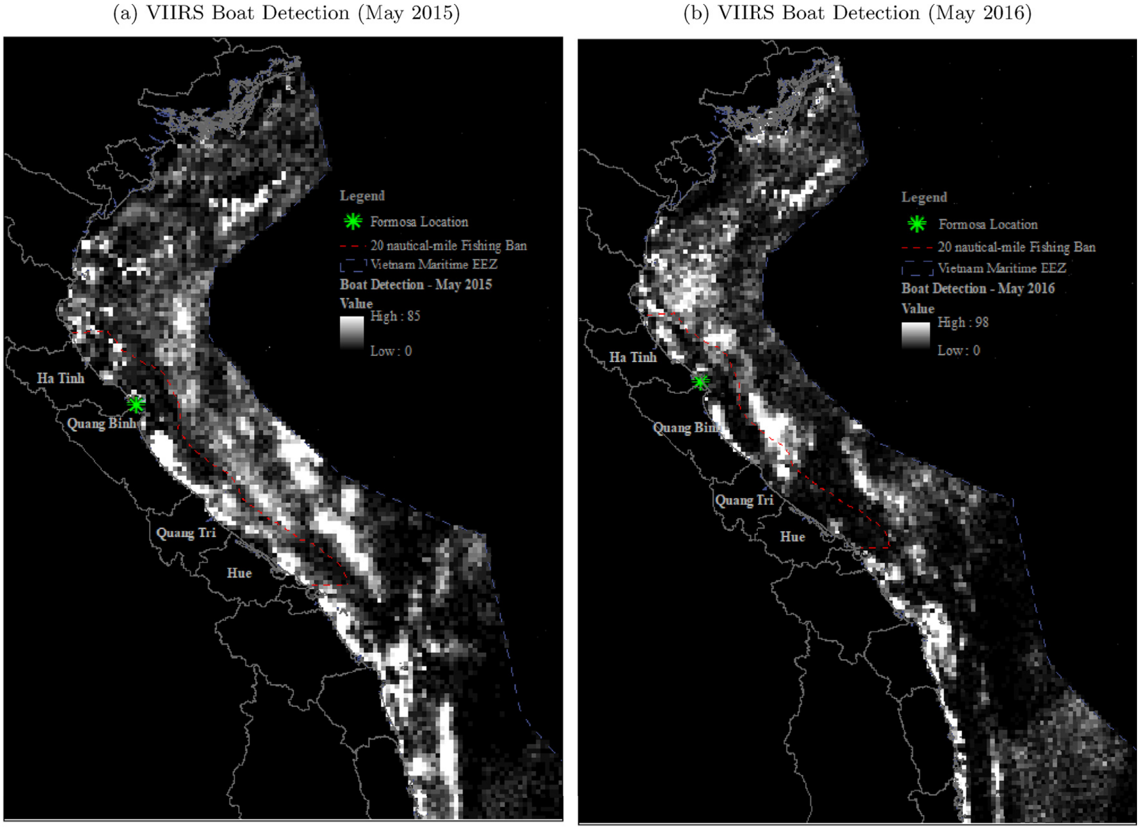
[22] Note that each of these pixel stores a monthly composite daily-averaged boat counts, made feasible by the VIIRS's automatic boat detection identification capability.

[23] In addition to the main sample, we also report a placebo test using LFS 2015, where we impose a hypothetical "event" in April 2015.



(a) VIIRS Boat Detection (May 2015)

(b) VIIRS Boat Detection (May 2016)

Note: This figure presents two snapshots of raw satellite images from VIIRS Night-light Boat Detection Module for the Vietnam Maritime EEZ (Formosa-focused), in May-2015 (left panel) and May-2016 (right panel). Grid pixels are re-sampled to 10-mile-square resolution (i.e., the resolution used in the main analysis). The brighter the pixel, the more night-time fishing boats detected (monthly average).

Fig. 4. Comparisons using VIIRS Night-light Boat Detection: Raw-data Plots.

ferent government's official sources regarding *Formosa* compensation/subsidy programs. In the main analysis, we adopt three major industries that are arguably the most *unaffected*, including manufacturing, construction, and retail.[24] An advantage of employing the industry control group is that it can more reasonably address the Stable Unit Treatment Value Assumption (SUTVA)—a common concern with DiD design.[25] Indeed, estimation results that are robust across both the geographic and industry control-group specifications would further safeguard the SUTVA validity.

$post_m$ is a binary variable indicating May 2016 or after. We also control for individual-specific covariates, X_{im}, which include gender, ethnicity, age, and level of education. θ_m represents the month-specific fixed effects, which absorb any unobserved monthly variations affecting the country-wide fishery industry. In the industry control group specification, we further control for 4-digit industry-specific fixed effects. Finally, ε_{im} represents idiosyncratic standard errors clustered at the district-level.

To estimate Equation (1), we employ all 2016 LFS individuals who self-identified his/her primary occupation as saltwater fisheries workers. Thus, this is a repeated cross-sectional approach, where *Formosa* impacts are derived from the income and workload differences between treated and control *cohorts* across time (i.e., before and after *Formosa*).[26] As discussed in Section 3.1.1, our analysis also makes use of a special LFS sample where a representative subgroup of households are randomly selected to be surveyed twice a year. This feature allows us to estimate an individual-level panel:

$$y_{im} = \alpha_0 + \alpha_1(treat_i \times post_m) + \sigma_i + \theta_m + \varepsilon_{im} \tag{2}$$

Equation (2) differs in which it additionally includes individual-specific fixed effects σ_i, which capture all time-invariant individual-level factors, including unobserved characteristics (e.g., innate ability).[27],[28]

Switching to the estimation with VBD data, we run DiD regressions of the primary form:

$$y_{cpmy} = \beta_1(treat_c \times post_{my}) + \gamma_c + \lambda_{my} + \pi_{pm} + X_{cpmy} + \epsilon_{cpmy} \tag{3}$$

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[24] Our estimates remain highly robust when we adopt workers in each of the three separate industries as the "control group", as visualized from Fig. 2.

[25] We provide an empirical evidence in the Appendix section that supports the validity of this assumption.

[26] For the specification using geographic control groups, the cohorts are fishery workers within and outside the *Formosa*-affected provinces. For the specification using industry control group, the cohorts are fishery and workers in control industries within *Formosa*-affected provinces. Also, we further report a robustness exercise in which we combine both LFS 2015 and 2016 for the repeated cross section approach.

[27] Note that the individual-specific covariates, X_{im}, are controlled for with the inclusion of σ_i.

[28] We define a worker's industry based on his/her response in Q1-2016 (i.e., in the first survey, before the *Formosa* event). In the subsequent individual-panel analysis, we include only individuals whose occupation remain the same between the two LFS 2016 surveys. Including individuals who "switch" industries does not change the impact estimates in any meaningful way. The result from this sample is available upon request.

where the subscripts refer to a 10-mile-square grid cell c located within the marine zone of province p, and stores the monthly-aggregate boat-detection value in month m in year y. Thus, the outcome variable y_{cpmy} provides a measure for fishing intensity at each 10-mile-square fishing grounds, spanning the entire Vietnam EEZ. We focus on two measures of fishing intensity: 1) boat detection likelihood (extensive margin); and 2) aggregate boat counts (intensive margin). The DiD treatment indicator term is

$$treat_c = \begin{cases} 1, & \text{if the grid is located within } \textit{Formosa} - \text{affected provinces} \\ 0, & \text{otherwise} \end{cases}$$

γ_c represents the grid-specific fixed effects, which capture time-invariant unobserved characteristics within each 10-mile-square fishing grid. λ_{my} represents the month-by-year fixed effects, which absorb the month-specific and year-specific single fixed effect terms, and essentially control for any monthly unobserved variations affecting country-wide fishing activities. π_{pm} represents the province-by-month fixed effects, which captures the existence of seasonality effects (e.g., monthly climates) specific to each of the 24 coastal provinces. In the most comprehensive model, we further control for two within-province variations in weather and ocean conditions that might affect fishing effort and fish availability, X_{cpmy}, namely the grid-specific precipitation and sea surface temperature (SST).[29] Finally, ϵ_{cpmy} represents idiosyncratic standard errors adjusted for heteroskedasticity and autocorrelation (i.e., HAC-robust) (Newey and West, 1987), where the serial correlation is allowed up to 6 months.[30]

The estimated coefficients of interest in these Equations are α_1 and β_1, which measure the differential changes in fishery earnings and intensity after *Formosa*, in the central coastal provinces (i.e., the treatment zone) relative to the unaffected provinces.

4. Overall impacts of *Formosa*

In this section, we present the empirical results from estimating *Formosa* impacts on the affected fishery communities. We separately investigate the damages caused to fishery earnings and employment, as well as to fishing intensity in the region. Using LFS, we estimate a massive and significant reduction to fishery income. This evidence is corroborated with a clear decline in both fishing prevalence and intensity, as measured by VBD boat detection data. We provide our perspectives regarding the policy implications of the results throughout the discussion. Finally, we probe our findings with a series of validity and falsification tests, from which we observe no “hypothetical” effects of *Formosa* on the unaffected provinces and/or industries, or before the accident actually took place.

4.1. Impact on labor outcomes in saltwater fisheries

Table 2 presents the DiD estimates for our primary indicator of economic well-being—fishery monthly incomes. We consider two earning measures: 1) monthly income from the primary occupation (columns 1 and 3) and 2) total monthly income from all sources (columns 2 and 4). In all regressions, the treatment group consists of pre-event saltwater fishers located in the affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue. As mentioned, we employ simultaneously two control groups in all subsequent regressions. In Panel A, the counterfactuals are pre-event fishers located in the unaffected coastal provinces. To avoid concerns related to potential spillover effects of *Formosa* to nearby regions, we restrict the sample to only the southern provinces distant from Formosa, i.e., from Phu Yen to Ca Mau (see Fig. 1). In Panel B, the counterfactuals are workers located within the *Formosa*-affected region who were employed in non-affected industries. As mentioned, we purposefully select industries that are arguably the most *unrelated* to the marine pollution crisis, namely manufacturing, construction, and retail. In addition to presenting the results across different control group adoptions, we also report the impact estimates across two empirical specifications: repeated cross-section (columns 1–2) and individual-level panel (columns 3–4). We also include a triple-differences specification that takes into account both geographic and industry variations in Panel C.

Overall, our estimation using LFS 2016 indicates a large and statistically significant decline in fishery monthly incomes caused by *Formosa*, with the magnitude ranging from 30 percent in the repeated cross-sectional regressions (columns 1–2) to approx. 45 percent under the individual panel specification (columns 3–4). The fact that fishery income reduced by almost a half after the crisis indicates how destructive the disaster was. In the subsequent section, we further discover that the impact does not distribute evenly across the four provinces, and that depending on their location within the contaminated zone, the affected fishers either coped with the shock by traveling longer distance to safe fishing grounds with an inevitable cost, or had to substitute fishery hours with working secondary jobs.[31]

4.2. Impact on satellite-detected fishing activities

Having shown a significant decline in average fishery earnings during the immediate period after *Formosa* took place, we next provide corroborating evidence on the damage caused to fishing intensity in the contaminated zone. Building upon the initial visual inspection discussed in Figs. 2 and 4, we empirically estimate the causal impact of *Formosa* under a DiD setting using VBD boat detection data. We use a balanced panel of monthly marine grids from 2013 to 2016, with each cell resampled to a 10-mile-square resolution. We focus on two key measures of fishing intensity, including 1) boat detection prevalence—the average likelihood that a grid was occupied with at least one boat in a given month) and 2) boat detection density—log of number of boats detected per day in a given grid-month. While the first measure communicates the causal impact at the extensive-margin, the second does so at the intensive-margin.

Table 3 reports the estimated DiD coefficient $\widehat{\beta}_1$, which illustrates the ATE of *Formosa* on fishing prevalence and density in the demarcated 20 nm near-shore fishing-restricted zone until the end of 2016. We further test for the robustness of our estimation under various specifications controlling for different sets of fixed-effects and weather/ocean condition covariates. In each set of regressions, we employ a control group that consists of all near-shore grids in coastal provinces located south of Phu Yen. Consistent to what we initially observe in Figs. 2 and 4, it is evident from Table 3 that near-shore fishing within the *Formosa*-affected zone declined significantly. All DiD estimates are statistically significant at the 99% confidence level. The empirical result suggests a robust reduction in average boat detection density (i.e., the intensive margin) of up to 22 percent, and a reduction in boat detection likelihood (i.e., the extensive margin) of close to 6 percentage points.[32]

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[29] We obtain the raw raster data for precipitation (0.1 × 0.1° resolution) from the National Aeronautics and Space Administration’s Precipitation Processing System (PPS). Sea surface temperature (SST) raw raster data (4 × 4 km resolution) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite from the NASA Ocean Biology Processing Group (OBPG) provider. We resampled both data to the same resolution level as the base VBD data set (10 mile square) and overlaid all rasters to obtain our final data set.

[30] All results are robust to adjusting the number of serial correlation’s lags; see Table OA1.

[31] In Online Appendix Table OA2, we present results using an alternative cross-section analysis in which we pool LFS 2015 and LFS 2016 together (thereby enlarging the pre-event period to all months in 2015 and the first quarter of 2016). The impact estimates remain highly robust in magnitude and the level of significance.

[32] The estimates remain robust when controlling for the squares of precipitation and/or SST (Online Appendix Table OA3).

Table 2
Impact on fishery income.

	Income (main job)	Total income	Income (main job)	Total income
	Repeated cross-section		Individual-level panel	
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
treat × post	−0.297***	−0.298***	−0.433***	−0.441***
	(0.093)	(0.093)	(0.063)	(0.062)
Observations	2477	2477	872	872
R-squared	0.253	0.249	0.122	0.125
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes
[Panel B] Industry control group				
fishery × post	−0.301***	−0.299***	−0.460***	−0.464***
	(0.050)	(0.049)	(0.056)	(0.058)
Observations	7991	7991	2100	2100
R-squared	0.310	0.294	0.067	0.078
Industry Fixed Effects	Yes	Yes	No	No
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes
[Panel C] Triple-difference analysis				
treat × fishery × post	−0.388***	−0.378***	−0.453***	−0.456***
	(0.080)	(0.078)	(0.062)	(0.063)
Observations	45,744	45,744	12,622	12,622
R-squared	0.307	0.298	0.018	0.020
Industry Fixed Effects	Yes	Yes	No	No
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table shows the impact of Formosa on fishery income (monthly; '000 VND; log-transformed) in 2016. "Treat" indicates saltwater fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue. "Post" indicates May-2016 or after. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e., distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e., manufacturing, construction, and retail) living in the four Formosa-affected provinces. Columns 1–2 report results using a sample consisting of all individuals identified as saltwater fishery workers (for Panel A) and workers in the control industries (for Panel B) before May-2016. Columns 3–4 report results using a sub-sample restricting to only individuals who were surveyed twice in the Labor Force Survey 2016—before and after May-2016. Panel C reports the estimated coefficients of the triple-interaction term that takes into account both geographic and industry variations. Standard errors are clustered at the district level.

Note that we accommodate for the portion of "unlit" grids (i.e., those detected with no boats) in the log specification of boat density measure by adding a constant of ones to boat counts before the transformation. We refer to this specification in the main result tables as "modified log" value. In Online Appendix Table OA4, we report the additional DiD results adopting two other forms of the boat detection outcomes, including boat counts in level and unmodified logarithm. We also conduct a robustness exercise in Appendix Table A2, where it is shown that impact estimates remain negative and significant when employing several alternative geographic control groups (e.g., restricting to lower-southern provinces, upper-northern provinces, as well as unrestricted set of all-except-treated provinces).

4.3. Validity and falsification tests

4.3.1. Validity of the parallel-trend assumption

Recall that a crucial assumption underlying the difference-in-differences approach is that units of the treatment and control groups follow a "parallel trend", so that outcomes of the control would reasonably serve as counter-factuals for the treated units after *Formosa* took place. We have discussed descriptive evidence from Figs. 2 and 3, and Appendix Table A1(b). Specifically, we show that both measures of fishery income (Fig. 2) and boat density (Fig. 3) in the treatment and control groups seem to follow a common monthly pre-trend. Additionally, in Table A1(b), while we detect a significant reduction in means between the pre- and post-treatment earning averages for *Formosa*-affected fishery workers in 2016, we find no such statistical differences for the control groups. In this sub-section, we conduct additional empirical exercises to further support the validity of the parallel-trend assumption.

In the first exercise, we perform a placebo test using the baseline data from LFS 2015, and generate a fictional event in April 2015. Because this entire time frame predates the actual *Formosa* disaster, we do not expect any impact on the fishery industry in the central coast (i.e., in Ha Tinh, Quang Binh, Quang Tri, and Hue). Panel A in Appendix Table A3 documents the DiD estimates under this placebo test. It is evident that relative to the control group, the differential change in fishery incomes before and after April 2015 are statistically indistinguishable from zero.

Table 3

Impact on fishing density and prevalence: Using Satellite's boat detection.

	Boat-detection Intensity (modified log)			Boat-detection Probability (%)		
	(1)	(2)	(3)	(4)	(5)	(6)
treat X post	-0.134^{***}	-0.223^{***}	-0.187^{***}	-0.0473^{***}	-0.0594^{***}	-0.0534^{***}
	(0.0167)	(0.0159)	(0.0161)	(0.00760)	(0.00723)	(0.00768)
Precipitation (mm)			-0.00015^{***}			-0.00006^{***}
			(0.00002)			(0.00001)
sea-surface temperature (Celsius)			0.0125^{***}			0.00713^{***}
			(0.00193)			(0.000992)
Observations	147,360	147,360	144,290	147,360	147,360	144,290
R-squared	0.529	0.623	0.624	0.445	0.519	0.519
Grid-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Coast-ID X Month Fixed Effects	No	Yes	Yes	No	Yes	Yes

HAC-robust standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table reports estimates of the impact of *Formosa* on fishing activity within the fishing-restricted zone (i.e., within 20 nautical miles of the coasts of Ha Tinh, Quang Binh, Quang Tri, and Hue). Each observation is a 10-mile-square grid-month georeferenced from VIIRS's boat-detection data set. The sample includes all monthly observations between 2013 and 2016. *Post* indicates May-2016 or after. The reported outcome variables include log-transformed monthly aggregate boat counts in each grid (columns 1–3) and the probability that the grid was detected with at least a boat in that month (columns 4–6). The control group includes all grid-month observations located within 20 nautical miles of the southern coastal provinces between Phu Yen and Ca Mau (i.e., provinces distant from the *Formosa*-affected region). All standard errors are robust-adjusted to heteroskedasticity and autocorrelation (up to six lags) (i.e., HAC-robust).

In Panel B of Table A3, we provide a direct test for the validity of the "industry control group" in the main DiD analysis. Recall from Table 2 that individuals who lived in the *Formosa*-affected provinces and worked in manufacturing, construction and retail serve as the counterfactuals for fishery workers, the average monthly earnings of these individuals should not be affected by *Formosa*. We test for this hypothesis by comparing these individuals' before-after earning differentials to that of workers living in provinces unaffected by *Formosa* who also work in the same industries.[33] The estimation result suggests that *Formosa*, indeed, did not seem to affect earnings in these industries in any statistically meaningful way.

We repeat an identical falsification exercise for fishing activity's outcomes (i.e., boat detection likelihood and density) in Appendix Table A4, using an antecedent sample of grid observations for the months between 2012 and 2014, in which a fictional event is imposed hypothetically in April 2014. Everything else remains similar to the regressions in Table 3. As can be seen, all of the estimated DiD coefficients are small and statistically insignificant across various specifications, except for columns 5–6. In these columns, $\widehat{\beta_1}$ was actually *positively* estimated; however, the estimate is small in magnitude (1.5 percent) and only marginally significant at the conventional levels.

In an additional exercise, we show results for undifferenced event-studies that use separate VBD sample for the treated (Ha Tinh, Quang Binh, Quang Tri, Hue) and control (southern provinces—Phu Yen to Ca Mau) areas. Specifically, the single-difference model is modified from Equation (3), omitting the binary indicator $Treat_c$ and month-specific fixed effects λ_{my}. The reported coefficient β_1 is associated with the time indicator $Post_{my}$. To make the before-after comparison more rigorous, we restrict the sample to only the months between April and September from 2014 to 2016—the fishing-prime season in most of Vietnam—with April-September 2016 being the *Formosa*-impacted period. Table OA5 shows that, compared to the previous years, fishing activities detected in VBD decrease significantly for the treated areas (all six estimates are highly negative and significant) and do not increase for the control areas (all estimates are small in magnitude, all but one estimates (Panel B, column 6) are statistically non-significant).

Finally, in Appendix D, we present a formal statistical test for the pre-treatment parallel income trend between treated and control groups. The result of the exercise indicates that one cannot statistically reject the null hypothesis that treatment and control trends are parallel during the pre-*Formosa* period. Readers are referred to Table D1 and Appendix D for the detailed discussion of the test.

4.3.2. Falsification tests with permutation inferences

Given that we obtain a highly significant and robust set of impact estimates in Tables 2 and 3, it is hard to believe that these are spurious outcomes. However, we are still interested in empirically testing for this potential. From an econometric perspective, is there a possibility that the effects shown are simply outcomes of "the luck of the draw" that is entirely unrelated to *Formosa*? We show that such "lucky draw" is highly unlikely to materialize. We take randomly three to five provinces within the unaffected coastal region. We then assign a "treatment" status to these randomly-picked unaffected provinces and a "control" status to the rest. We then replicate the DiD regressions similar to equations (1) and (2)) with fishery incomes and boat density using these falsified treatment and control groups. We perform this permutation inference test with 1000 iterations, and plot the distributions of the estimated coefficients and their respective t-statistics in Fig. 5. For both fishery income and fishing density, the distributions of these falsified estimates exhibit strong normality centered at 0. The large majority of these coefficients are also imprecisely estimated, as indicated by the small magnitudes (in absolute term) of the majority of the t-values.[34] As indicated by the red vertical lines in each of the

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[33] For consistency with the earlier exercise, we also restrict the control group to individuals living in coastal provinces from Phu Yen to Ca Mau.

[34] We select randomly between three to five provinces in each iteration due to the fact that, depending on the geographical characteristics of each coastal provinces, the associated provincial marine space can vary widely—some provinces have larger/smaller coast lengths than others. For robustness check, we also experimented with the random treatment selection of one to five provinces and obtained highly identical results. Note that we remove Ha Tinh, Quang Binh, Quang Tri, and Hue from the all iterative samples to prevent contaminated effect.

panels, the estimated values obtained from the earlier regressions using the four *actually* affected provinces as the treatment group are complete left-tail outliers. This suggests that the causal impacts captured in Tables 2 and 3 are not likely to be randomly regenerated.

5. Heterogeneous impacts & coping mechanisms, fishing recovery, spillover effects, and the fishing ban

In this section, we turn to focus on the heterogeneous impacts on, and different coping mechanisms of, the victimized fishery workers. We corroborate evidence from both satellite (VBD) and labor force survey (LFS) data. First, we discover that *Formosa* impact is heterogeneous by fishery income group and location. We also show that, depending upon where fishers were located, these individuals likely responded differently to the shock. Those who could feasibly travel to safe grounds likely did so to sustain fishing activities. In contrast, fishers who were likely "trapped" inside the contaminated zone chose to substitute fishery work-hours with having secondary jobs. Next, we look at disaster recovery, examining the *Formosa* impacts on both fishing intensity and fishery income by quarters. We find a gradual reduction in disaster damage to both outcomes, even though the impact on earnings still remained sizable in the last quarter of 2016. In addition, we study potential spillover effects of *Formosa* on related industries, and find evidence suggesting an increase in freshwater fishery earnings. Finally, in an extended exercise, we examine the potential effect of the government's five-month fishing-ban policy. Under both a regression discontinuity design and a triple-differences analysis, we find no evidence on the effect of the policy in various localized areas around the ban's spatial threshold.

5.1. Heterogeneous impacts and coping mechanisms

To motivate our discussion on the coping mechanisms of fishery workers following *Formosa*, we first provide evidence that the impact of the crisis is highly heterogeneous by location. In Table 4, we split the treatment provinces into two separate groups by geographic location: Ha Tinh and Quang Binh (i.e., the "upstream" group), and Quang Tri and Hue (i.e., the "downstream" group). There exists a stark difference on how *Formosa* affected fisheries. In terms of the impact on incomes, the estimated ATE size (i.e., the size of average income reduction) for the downstream fishers is found to be between 10 and 15 percentage points larger than that for the upstream counterparts, suggesting a more severe impact of *Formosa* on the economic well-being of the fishers living downstream. In each regression, we further report the p-value associated with a one-sided t-test, where the null hypothesis is that the *Formosa* impacts are equal across upstream and downstream provinces. According to the p-values, null hypothesis is rejected at the conventional level (10%) for three out four regressions that include individual fixed-effects. The p-values of the last test (Panel A; column 4) is 0.107.

Our estimation result on the unequal distribution of *Formosa* effect based on the location of the affected fishers is rather surprising and should directly inform the design of assistance programs. According to Decision 1880/QD-TTg dated September 29, 2016 from the Vietnamese central government, the *Formosa* compensation criteria for affected saltwater fishery relied solely on fisher's boat ownership and the boats' engine power (i.e., whether the fisher had a boat, whether the boat was motorized, and if so, the horse-power of its engine), *uniformly* across Ha Tinh, Quang Binh, Quang Tri and Hue.[35] Besides the geographically homogeneous subsidy, the assistance program by the government also did not take into account fishery income heterogeneity. Indeed, in an extended exercise that we report in Appendix Table A5, we use a quantile analysis to estimate the impact margins across fishery income quantiles. The result from Table A5 indicate that the impact was the most destructive for fishers with the lowest income, followed by those in highest quantiles, and finally the medium income-earning groups. For example, we find that the average monthly earnings of fishers at the bottom 10% of income dropped by over 70 percent. These are likely low-skilled fishers who would be most vulnerable to job losses.

Returning to the analysis on the discrepancy in the geographic distribution of earning impacts, we now investigate satellite information. Recall from the initial observation in Fig. 4, there seems to be a transition in fishing grounds (i.e., the bright pixel clusters) from within the contaminated zone to the "safe" region located north of Ha Tinh. An explanation for this altered fishing pattern pertains to the southward flow of the ocean; toxic substances discharged by *Formosa* in Ha Tinh were likely spread south along the current (hence affecting also Quang Binh, Quang Tri, and Hue), leaving the marine region north of Ha Tinh uncontaminated. Therefore, what is shown in Fig. 4 nicely corresponds to a rational expectation in fishery response: we would expect fishers located near the safe water, i.e., the upstream individuals who lived in Ha Tinh and Quang Binh, to travel north to continue fishing. However, going north is perhaps not an equally convenient option for the downstream fishers, given how far away they are located. Traveling there to fish is certainly much more costly, if not impossible, provided that the majority of these individuals are small-scale fishers. This difference in relocation feasibility likely attributed directly to the large geographic distributional impact of *Formosa*. Furthermore, it might have also triggered different responses in the fishery labor market, as we discuss subsequently.

To more formally examine how fishers coped with *Formosa*, we empirically estimate a province-by-province ATEs on fishing intensity along the coast of each of the northern and central provinces in Vietnam. To remain consistent with the regression tables, we employ the same restricted control group consisting of fishery workers located in Phu Yen to Ca Mau, where we argued that fishing activity was unaffected by the disaster. Fig. 6 plots the DiD estimated coefficients and their 95% confidence intervals for each provinces from Quang Ninh to Binh Dinh, using all 10-mile-square grid observations located within 20 nautical miles from shore. Panel A illustrates the impact on fishing density, measured by log-transformed monthly-aggregate boat counts. Panel B illustrates the impact on fishing prevalence, measured by the indicator for boat-detection likelihood in each grid. The detailed results corresponding to this figure are provided in Online Appendix Table OA6.

Both Panels A and B show that the directly-affected area between Ha Tinh and Hue suffered the most dramatic impacts. Consistent with the ATEs estimated in Table 3, we find reductions of over 20 percent in fishing density and close to 10 percentage points in fishing prevalence in this region. It can also be seen that the crisis did not just affect fishery communities located inside the fishing-restricted zone, but also the nearby regions. The spillover effect is noticeable in the southern adjacent area including Da Nang and Quang Nam, where both fish-

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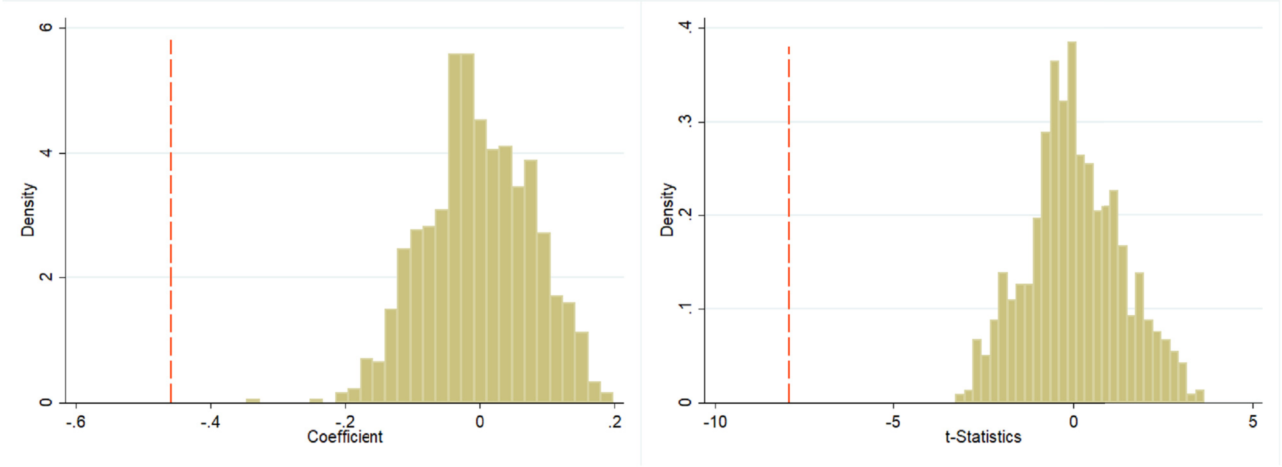
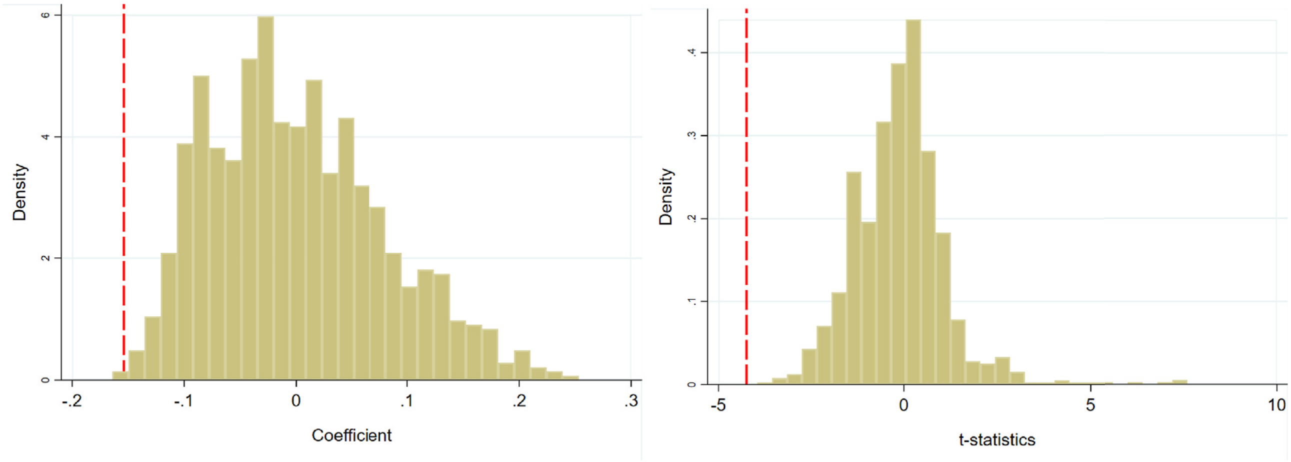
[35] According to Decision 1880/QD-TTg, the maximum length of compensation was six months from April 2016 to September 2016. In addition to saltwater fishery, six other affected industries in Ha Tinh, Quang Binh, Quang Tri and Hue provinces were compensated, including aquaculture, salt production, coastal fishery business activities, fishery logistics services, tourism and coastal trade service, purchasing and temporary storage of aquatic products. Compensation was paid to the affected people out of the total $500 million USD remedial compensation package from Formosa Steel Plant.



(a) **A1**: Coefficient values – Monthly Income

(b) **A2**: t-statistics – Monthly Income



(c) **B1**: Coefficient values – Boat Detection

(d) **B2**: t-statistics – Boat Detection

Note: This figure presents the results from a falsification exercise consisting of two permutation tests for 1) monthly fishery income (Panel As) and 2) fishing intensity (i.e., log of number of boats detected) (Panel Bs). Each iteration randomly assigns hypothetical treatment status to between 3 and 5 unaffected provinces. Panel A1 and B1 plot the distributions of coefficient values from the 1,000 replications, following Equation 1. Red lines indicate the coefficient values obtained from Table 2 (for Panel A1) and Table 3 (for Panel B1), where the treatment status is assigned to the actual four affected provinces (Ha Tinh, Quang Binh, Quang Tri, and Hue). Panel A2 and B2 plot the distributions of the corresponding t-statistics.

Fig. 5. Falsification Exercise: Permutation Tests.

ing density and likelihood were negatively affected.[36] The impact does seem to dissipate for regions further away south, and becomes small and statistically insignificant starting from Quang Ngai.

Turning to the spillover effects in the northern provinces, Fig. 6 exhibits an interesting pattern that corresponds to what is observed in Fig. 4. The panels illustrate a large and significant *increase* in fishing intensity in all of the coastal provinces north of *Formosa*. The positive spillover effect is the strongest in Nghe An, the northern neighboring province of Ha Tinh. Taken together, the findings in Fig. 6 provide certain suggestive evidence reinforcing our hypothesis for a coping mechanism in fishery pattern: the fishers capable of traveling to uncontaminated fishing zones did likely resort to this option in order to sustain fishing as an income-generating activity.[37]

There are two immediate follow-up questions: 1) among the affected fishers, who were more likely to travel to safe fishing grounds to continue fishing? and 2) from the labor-market standpoint, do fishers respond differently, depending on the possibility of relocation?

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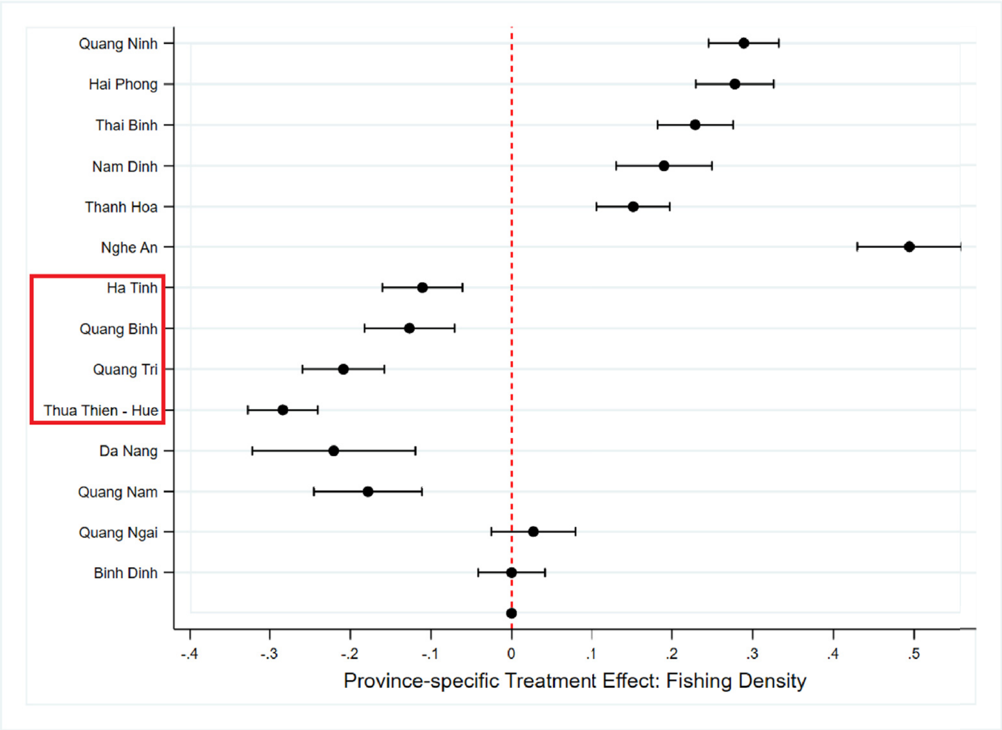
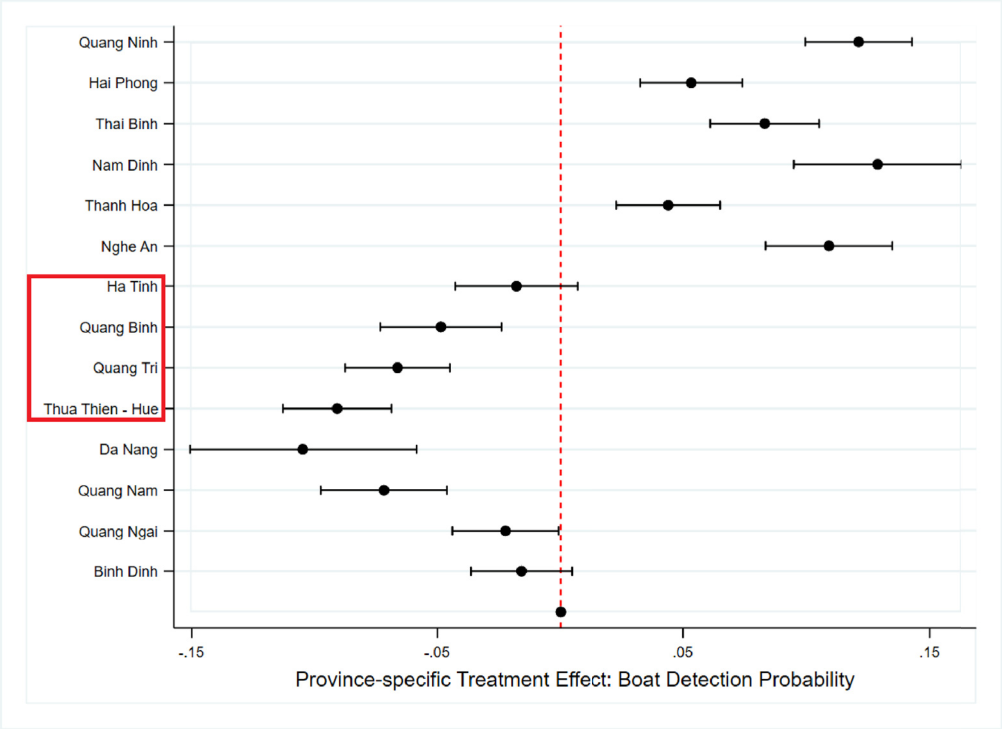
[36] Notes that there is no official boundary for the maritime zones at the provincial-level. In this paper, we loosely define a province's water boundary as a horizon line extended from the intersection between its land border line and the shore. The grids located within this defined boundary are considered the marine zone belonging to that province.

[37] In a supplementary exercise, we perform two additional DiD regressions that take into account the nearshore grid samples within (1) Ha Tinh & Nghe An (i.e., utilizing the northern perpendicular cutoff segment) and (2) Hue & Da Nang (i.e., utilizing the southern perpendicular cutoff segment). We find that the DiD estimates are highly negative and significant in (1), suggesting strong negative impacts in fishing activity in Ha Tinh relative to Nghe An after Formosa took place. In contrast, the estimates are small in magnitude and not statistically robust in (2), suggesting a weak difference in fishing activity between Hue and Da Nang after *Formosa*. These results are available upon request.

(a) Panel A: Fishing Density



(b) Panel B: Fishing Prevalence



Note: This figure plots the province-specific impact estimates on fishing density (Panel A; log-transformed monthly-aggregate boat counts) and fishing prevalence (Panel B; probability of boat detection) for all coastal provinces from Quang Ninh (northern-most) to Binh Dinh (adjacent to the control group). The control group consists of all coastal provinces between Phu Yen and Ca Mau (i.e., provinces distant from the *Formosa*-affected region). The sample includes all grid-month observations from 2013 to 2016. Whiskers indicate 95% statistical intervals.

Fig. 6. Province-specific Treatment Effects.

Table 4
Heterogeneous impacts on fishery incomes by location.

	Income (main job)	Total income	Income (main job)	Total income
	Repeated cross-section		Individual-level panel	
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
(HaTinh & QuangBinh) × post	−0.251**	−0.259**	−0.413***	−0.427***
	(0.103)	(0.104)	(0.067)	(0.068)
(QuangTri & Hue) × post	−0.439**	−0.421**	−0.536***	−0.516***
	(0.187)	(0.187)	(0.056)	(0.056)
Observations	2477	2477	872	872
R-squared	0.254	0.250	0.123	0.126
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes
P-value for mean dif. *t*-test	0.169	0.205	0.042	0.107
[Panel B] Industry control group				
(HaTinh & QuangBinh) × post	−0.276***	−0.279***	−0.438***	−0.448***
	(0.059)	(0.057)	(0.063)	(0.066)
(QuangTri & Hue) × post	−0.429**	−0.400**	−0.573***	−0.545***
	(0.160)	(0.161)	(0.029)	(0.029)
Observations	7991	7991	2100	2100
R-squared	0.311	0.294	0.067	0.078
Industry Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes
P-value for mean dif. *t*-test	0.190	0.242	0.013	0.059

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Note: This table shows the heterogeneous impact of Formosa on fishery income (monthly; '000 VND; log-transformed) in 2016, separately for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Thua Thien-Hue) Formosa-affected regions. "Post" indicates May-2016 or after. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e., distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e., manufacturing, construction, and retail) living in the four Formosa-affected provinces. Columns 1–2 report results using a sample consisting of all individuals identified as saltwater fishery workers (for Panel A) and workers in the control industries (for Panel B) before May-2016. Columns 3–4 report results using a sub-sample restricting to only individuals who were surveyed twice in the Labor Force Survey 2016—before and after May-2016. In each regression, a one-sided *t*-test's p-value is provided, where the null hypothesis is that *Formosa* impacts are equal across upstream and downstream provinces. Standard errors are clustered at the district level.

The pattern in Fig. 6 continues to provide empirical evidence. As we already discussed, among the four affected provinces, those located upstream—in Ha Tinh and Quang Binh—were likely to possess better adapting options due to their proximity to the uncontaminated fishing grounds north of Ha Tinh. In contrast, the options for the downstream fishers in Quang Tri and Hue were much more limited: transporting north, especially for those operating small boats and mainly fish near-shore, was much more cost-ineffective due to the distance.[38] Going south to fish near-shore was also not prospective when seafood consumers were also reluctant to purchase products caught in this region, citing the concern with potential southward spillover of the contaminated water. These downstream fishers, then, had to make the hard choices; to stay in fishing, they had to travel more distantly and cost-ineffectively, no matter north- or south-ward.[39] Otherwise, the only other prospect is to obtain secondary jobs away from fishing activities. Indeed, the latter is what we empirically observe in Table 5.

Table 5 presents the ATE estimates for two dependent variables directly related to the labor-market responses: 1) weekly work hours in saltwater fishery and 2) the probability of having secondary jobs (in the surveyed month). To get at the heterogeneous responses, we continue to split the *Formosa*-affected sample into upstream (Ha Tinh & Quang Binh) and downstream provinces (Quang Tri & Hue). The empirical results obtained in Table 5 strongly corroborate our overall hypothesis on fishers' labor-market coping mechanisms. Consistently estimated across the choices of control groups, the downstream fishers in Quang Tri and Hue—those who were likely "trapped" inside the contaminated zone—responded to *Formosa* by reducing their weekly fishing workload by approximately 29 h. This massive and significantly estimated reduction in workload amounts to almost a half of total baseline weekly work hours (62 h; see Table 1) and reflects how disastrous *Formosa* was to fishery employment in this region. In stark contrast, and consistent with the hypothesis that upstream fishers could transition to the northern safe waters, we find a slight increase in the fishery workload of these individuals after *Formosa*. Albeit imprecisely estimated, this increase of approximately 1.7 h is consistent with the potentially longer travel duration that these fishers have to make, if they indeed resort to the option of traveling to safe fishing locations. It might have been the case that this extra travel cost and, perhaps, the unfamiliarity with new fishing grounds directly factor into a reduction in earnings that we saw in Table 2. Finally, because upstream fishers were likely to find a way to continue fishing, we do not observe any significant changes in the likelihood that these individuals look for secondary jobs. However, the sizable reduction in downstream fishery workload seems to trigger another channel of employment response that these individuals resorted to. In column 2, we find an approximately 14-percentage-point increase in the likelihood that fishers located in Quang Tri and Hue had secondary jobs outside fishery. While we do not observe in the data the type of secondary jobs these workers performed, it is likely that the

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[38] Besides the higher transportation cost, fishers would also have to worry about inflated expenses related to the preservation of seafood's freshness—a crucial factor of the selling price.

[39] In terms of traveling to safe zones, these fishers either have to make their ways further down south to Binh Dinh or Phu Yen—areas far away from *Formosa*, or up to the distant northern zones.

Table 5
Labor-market responses: Fishery workload and having secondary jobs.

	Weekly workload (1)	Having extra Jobs (2)
[Panel A] Geographic control group		
(HaTinh & QuangBinh) × post	1.227	−0.122
	(1.917)	(0.093)
(QuangTri & Hue) × post	-28.825^{***}	0.138^{***}
	(1.085)	(0.020)
Observations	872	872
R-squared	0.240	0.066
Month Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
P-value for mean-dif. *t*-test	0.000	0.005
[Panel B] Industry control group		
(HaTinh & QuangBinh) × post	1.728^{*}	−0.114
	(1.017)	(0.091)
(QuangTri & Hue) × post	-29.548^{***}	0.141^{***}
	(0.678)	(0.016)
Observations	2100	2100
R-squared	0.124	0.015
Industry Fixed Effects	Yes	Yes
Month Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
P-value for mean-dif *t*-test	0.000	0.004

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Note: This dependent variables are 1) fishery work hours per week (column 1), and 2) the probability that the affected fisher worked extra jobs (column 2). The heterogeneous labor-market responses are shown for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Thua Thien-Hue) Formosa-affected regions. "Post" indicates May-2016 or after. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e., distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e., manufacturing, construction, and retail) living in the four Formosa-affected provinces. All regressions include month and individual fixed effects. In each regression, a one-sided *t*-test's p-value is provided, where the null hypothesis is that *Formosa* impacts are equal across upstream and downstream provinces. Standard errors are clustered at the district level.

jobs are menial in characteristics, given the low average educational background of most fishers.[40]

5.2. Impact recovery and spillover effects

Having presented the dramatic impact of *Formosa* on fishery earnings, employment choices, and fishing intensity, we now turn to the discussions on the damage recovery and potential spillover effects on other industries.

Table 6 presents empirical evidence for the recovery on fishing density (Panel A) and prevalence (Panel B) after *Formosa*. The empirical setting is identical to what is shown in Table 3, with the only exception being the ATEs estimated separately for each quarters after April 2016. Relative to the pre-treatment period, and consistent across alternative control group adoptions, we find pronounced reductions in fishing density by between 33 and 44 percent, and in fishing prevalence by approximately 9–13 percent. The substantial negative effects lingered to the last quarter of 2016, where the negative impact magnitudes are estimated to drop by two-third (The paired t-tests for mean comparisons reject impact equality between Q2-Q3 and Q2-Q4 at 99% confidence level in all eight regressions).

Correspondingly, Table 7 presents the impact recovery on fishery incomes. Again, we follow the same empirical setting similar to that in main regressions in Table 2, except for the quarterly ATEs estimation. The empirical result also suggests a clear declining trend in negative average treatment effects; while *Formosa* is estimated to have caused as much as a 65 percent reduction in fishery income in the second quarter of 2016, the effects decreased to approximately a half in the last quarter, and are statistically indistinguishable from 0 in the "pooled" specifications. Interestingly, the paired t-tests suggest that damage reduction is only statistically significant in the pooled regressions (p-values are smaller than 0.1 in columns 1 and 2), while not so in the individual-panel exercise. Overall, while it is encouraging to observe a rapid impact recovery, the fact that fishery earnings still declined by over 30 percent half-a-year after *Formosa* for individuals who stayed in the saltwater fishery industry (as reflected from columns 3 and 4), and especially when fishing activities have almost resumed to the normal rate (recall from Table 6), shows how devastating the disaster was.

Next, we investigate the potential spillover effects of *Formosa* on other industries. Recall that we have shown in Table A3 (Panel B) that *Formosa* did not seem to have any effect on the highly-unrelated industries such as manufacturing, construction and retail— which facilitates our adoption of workers in these industries as reliable counterfactuals to saltwater fishery workers. We now pay attention to the potential spillovers to individuals employed in other industries that have a higher level of linkages to fishery (Table 8). We examine four industries, including freshwater fishery, husbandry, restaurants and lodging. On the one hand, freshwater fishery and husbandry are industries that produce direct substitute products to saltwater seafood; hence it is reasonable to expect certain spillover effects of *Formosa*, most likely through a supply-determinant channel such as substitute-product pricing. On the other hand, restaurant and lodging are selected because of the potential damage to the coastal tourism industry. In fact, together with saltwater

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[40] See the descriptive statistics for "Educational Attainment" in Table 1.

Table 6
Impacts on fishing intensity and prevalence by quarters.

	(1)	(2)	(3)	(4)
[Panel A] Outcome Variable: Boat-detection Intensity (modified log)				
treat X [Q2-2016]	−0.364***	−0.363***	−0.439***	−0.333***
	(0.0240)	(0.0244)	(0.0280)	(0.0233)
treat X [Q3-2016]	−0.226***	−0.184***	−0.473***	−0.310***
	(0.0283)	(0.0291)	(0.0326)	(0.0277)
treat X [Q4-2016]	−0.0532**	−0.108***	−0.437***	−0.128***
	(0.0208)	(0.0218)	(0.0276)	(0.0201)
Observations	147,360	100,272	65,568	219,984
[Panel B] Outcome Variable: Boat-detection Probability (%)				
treat X [Q2-2016]	−0.0919***	−0.103***	−0.134***	−0.0931***
	(0.0103)	(0.0110)	(0.0131)	(0.00990)
treat X [Q3-2016]	−0.0640***	−0.0518***	−0.165***	−0.0857***
	(0.0124)	(0.0131)	(0.0150)	(0.0119)
treat X [Q4-2016]	−0.0215*	−0.0426***	−0.176***	−0.0481***
	(0.0113)	(0.0119)	(0.0142)	(0.0109)
Observations	147,360	100,272	65,568	219,984
Grid-specific Fixed Effects	Yes	Yes	Yes	Yes
Month-specific Fixed Effects	Yes	Yes	Yes	Yes
Coast-ID X Month Fixed Effects	Yes	Yes	Yes	Yes
Climate Covariates	Yes	Yes	Yes	Yes
Control Group	Main Specification	Lower Southern	Upper Northern	All But Treated

HAC-robust standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Note: This table shows estimates of the quarterly impacts of *Formosa* on fishing activity within the fishing-restricted region (i.e., within 20 nautical miles of the coasts of Ha Tinh, Quang Binh, Quang Tri, and Hue). Each observation is a 10-mile-square grid-month georeferenced from VIIRS's boat-detection data set. The sample includes all monthly observations between 2013 and 2016. *Post* indicates May-2016 or after. The reported outcome variables include log-transformed monthly aggregate boat counts in each grid (Panel A) and the probability that the grid was detected with at least a boat in that month (Panel B). Columns 1 to 4 reports estimates from the specifications that employ the control groups (coastal provinces) from Phu Yen to Ca Mau (column 1), from Vung Tau to Ca Mau (column 2), from Quang Ninh to Thai Binh (column 3) and from all other provinces except for the four affected (column 4). All standard errors are robust-adjusted to heteroskedasticity and autocorrelation (up to six lags) (i.e., HAC-robust). The paired t-tests for mean comparisons reject equality in Q2-Q3 and Q2-Q4 at 99% confidence level in all eight regressions.

fishery, restaurant and lodging are among the sub-industries eligible for several *Formosa* compensation schemes, as documented in the government's official reports (VOA, 2016).[41]

As Table 8 indicates, there seems to be a positive spillover to the earnings in freshwater fishery in provinces where *Formosa* had the strongest impact (i.e., Quang Tri and Hue). This spillover effect is robust to the adoption of both geographic (columns 1–4) and industry control groups (columns 5–8), as well as different levels of added fixed effects. The estimated ATEs range between 20 and 25 percent increase in monthly income for the freshwater fishery workers, and are likely due to the positive demand shock for freshwater seafoods after the breakout of *Formosa*—prices of the saltwater-substituted products soared when the demand for them elevated. However, unlike the case of freshwater fishery, we do not find any robust and consistent evidence suggesting spillover on the earnings of workers employed in husbandry, restaurant, or lodging.[42]

5.3. Effect of the fishing ban

Another important policy-relevant question surrounding the *Formosa* crisis is to understand potential impacts of the fishing-ban policy imposed by the government between May and September 2016—one that, if existed, should serve as a competing mechanism explaining the decline in fishing activity within the Formosa-affected zone. Recall that the Formosa disaster erupted in April 2016, followed by a five-month fishing ban for the entire 20 nm near-shore water along the coast of Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue. Understanding whether the ban affected fishing behaviors or not would allow us to elucidate the necessity of this enforcement policy itself, as well as to shed more light on understanding the magnitude of the disaster. In Appendix C, we empirically rely on two alternative empirical approaches to study the effects of the ban, including a spatial regression discontinuity design (RD) and a triple-difference analysis. Readers are referred to Appendix C for detailed discussion and results.

Overall, the findings from both the RD and triple-difference analyses suggest that the fishing ban had some effects[43] but was perhaps

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[41] Together with saltwater fishery, restaurant, and lodging, the other compensation-eligible sub-industries include salt manufacturing and fishery services. However, we do not observe sufficient sample of workers in these two sub-industries in the labor force surveys.

[42] In addition to examining spillover to non-saltwater fishery industries, we study potential geographic income spillover to saltwater fishery in nearby provinces in Online Appendix Table OA7. The result indicates a negative spillover to fishery income in the southern provinces immediately adjacent to Hue (Da Nang to Quang Ngai). Statistically significant estimates dissipated in Binh Dinh.

[43] This is consistent with the literature. Elvidge et al. (2018) find that in the Philippines, fishing boat activity declined immediately and significantly following fishery closures. Similarly, Yuan (2018) finds that China's seasonal fishing bans are effective to achieve sustainable fishery.

Table 7

Impacts on fishery income by quarters.

	Income (main job)	Total income	Income (main job)	Total income
	Repeated cross-section		Individual-level panel	
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
treat × [Q2-2016] (α_1)	-0.526^{***}	-0.524^{***}	-0.558^{***}	-0.585^{***}
	(0.156)	(0.156)	(0.127)	(0.121)
treat × [Q3-2016] (α_2)	-0.306^{***}	-0.302^{***}	-0.426^{***}	-0.421^{***}
	(0.105)	(0.106)	(0.086)	(0.085)
treat × [Q4-2016] (α_3)	−0.064	−0.076	-0.317^{***}	-0.318^{***}
	(0.106)	(0.100)	(0.111)	(0.107)
Observations	2477	2477	1688	1688
R-squared	0.259	0.255	0.066	0.069
P-value for t-test H_0: $\alpha_1 = \alpha_2$	0.065	0.061	0.388	0.278
P-value for t-test H_0: $\alpha_2 = \alpha_3$	0.037	0.046	0.361	0.386
[Panel B] Industry control group				
treat × [Q2-2016] (α_1)	-0.631^{***}	-0.628^{***}	-0.628^{***}	-0.650^{***}
	(0.110)	(0.109)	(0.116)	(0.113)
treat × [Q3-2016] (α_2)	-0.311^{***}	-0.307^{***}	-0.458^{***}	-0.446^{***}
	(0.084)	(0.085)	(0.080)	(0.078)
treat × [Q4-2016] (α_3)	0.009	0.009	-0.318^{***}	-0.315^{***}
	(0.090)	(0.084)	(0.098)	(0.096)
Observations	7991	7991	4502	4502
R-squared	0.315	0.299	0.046	0.047
P-value for t-test H_0: $\alpha_1 = \alpha_2$	0.009	0.010	0.229	0.156
P-value for t-test H_0: $\alpha_2 = \alpha_3$	0.006	0.005	0.259	0.282
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table shows the impact of Formosa on fishery income (monthly; '000 VND; log-transformed) for each subsequent quarters after the start of Formosa incident in April 2016. "Treat" indicates saltwater fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e., distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e., manufacturing, construction, and retail) living in the four Formosa-affected provinces. Columns 1–2 report results using a sample consisting of all individuals identified as saltwater fishery workers (for Panel A) and workers in the control industries (for Panel B) before May-2016. Columns 3–4 report results using a sub-sample restricting to only individuals who were surveyed twice—before and after May-2016. Standard errors are clustered at the district level. The t-test are two-tailed.

not the only factor influencing the decline in near-shore fishing activity within the *Formosa*-affected region. There are at least two sensible explanations. First, logistically enforcing a strict no-take zone that spans over 200 miles along the coasts of the four affected provinces for an extended period of time would be prohibitively costly. This is the reason why our estimated decline in fishing activity—albeit substantial in magnitude—was not completely one hundred percent. Secondly, it is reasonable to believe that fishers and seafood consumers could expect and/or fear the spillovers of the contamination zone into nearby areas, due to either movement of fish stocks or the spatial spread of the toxic chemicals. This is supported by our finding on the heterogeneous spatial impacts on both fishing activity and incomes between the northern (Ha Tinh and Quang Binh) and southern (Quang Tri and Hue) affected provinces. Our view is that the ban announcement served more as a guidance through which the government could emphasize the severity of the contamination to the fishers and the public. The actual reduction in fishing activities—–as estimated from the VBD regressions—in our view, was also enforced 1) directly by the marine contamination which damaged fish stocks and 2) indirectly by the discontinuous reduction in consumers' demand for (potentially unsafe) seafood caught within the affected zone. We note that disentangling these two mechanisms is an empirically interesting exercise but is outside the scope of this paper. The government's policy mix of a fishing ban combined with a compensation program charged to the polluter could provide useful lessons for other developing countries.

6. Conclusion

Among major industrial disasters, oil spills, chemical spills and radiation rarely happen but have disproportionately larger effects. According to the EM-DAT database, since 1950s, these disasters only account for 8.5 percent of all industrial disasters but are responsible for about 43 percent of affected people. This paper examines the economic impacts of a large-scale marine pollution disaster on the employment and earnings of a local fishery community. The *Formosa* incident, in which toxic wastewater was discharged into the ocean and damaged an entire ecosystem in the central coast of Vietnam in 2016, presented a special case study for how the affected communities— saltwater fishers—coped with the negative shock. We combine a novel satellite data capturing night-time light detected from fishing boats with the fishery earnings and labor-market information provided by the labor force surveys. We show that the disaster reduced incomes by as much as 46 percent for the immediate period after the *Formosa* breakout. We further provide evidence indicating heterogeneous impacts by location and fishery income distribution, which might have induced different coping mechanisms. Upstream fishers who live closer to safe fishing grounds were likely to travel there and continue fishing, as shown by the intensified fishing activities in those regions after the incident took place. In contrast, downstream fishers, who live far away from safe waters, experienced more dramatic impact on average earnings. In terms of the labor-market responses, we find that

Table 8
Spillover effects to labor outcomes in other (relevant) industries.

	Geographic control group				Industry control group			
	Income (main job)	Total income	Income (main job)	Total income	Income (main job)	Total income	Income (main job)	Total income
	Repeated cross-section		Individual-level panel		Repeated cross-section		Individual-level panel	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Freshwater Fishery Industry								
(HaTinh & QuangBinh) × post	−0.156	−0.177	0.051	0.053	−0.057	−0.058	−0.036	−0.033
	(0.200)	(0.163)	(0.149)	(0.150)	(0.126)	(0.108)	(0.128)	(0.132)
(QuangTri & Hue) × post	0.226***	0.192***	0.263**	0.256**	0.205**	0.195**	0.207**	0.195***
	(0.071)	(0.073)	(0.116)	(0.097)	(0.085)	(0.076)	(0.082)	(0.065)
Observations	4408	4408	1426	1426	7941	7941	2094	2094
P-value for mean-dif. *t*-test	0.032	0.017	0.110	0.101	0.055	0.083	0.055	0.061
Panel B: Husbandry Industry								
(HaTinh & QuangBinh) × post	−0.015	−0.018	0.030	0.003	−0.030	0.007	0.049	0.037
	(0.056)	(0.052)	(0.061)	(0.051)	(0.032)	(0.031)	(0.069)	(0.047)
(QuangTri & Hue) × post	0.068	0.043	−0.079	−0.109	0.180***	0.080**	−0.090	−0.128*
	(0.063)	(0.063)	(0.075)	(0.086)	(0.038)	(0.037)	(0.059)	(0.065)
Observations	8980	8980	2570	2570	9769	9769	2404	2404
P-value for mean-dif. *t*-test	0.292	0.409	0.239	0.239	0.000	0.037	0.101	0.032
Panel C: Restaurant Industry								
(HaTinh & QuangBinh) × post	−0.206	−0.200	−0.063	−0.038	−0.050	−0.026	−0.158**	−0.127
	(0.138)	(0.142)	(0.049)	(0.067)	(0.062)	(0.060)	(0.073)	(0.090)
(QuangTri & Hue) × post	−0.040	−0.023	−0.006	0.006	−0.035	−0.016	−0.018	−0.004
	(0.040)	(0.042)	(0.039)	(0.042)	(0.045)	(0.043)	(0.045)	(0.047)
Observations	6225	6225	1892	1892	8287	8287	2184	2184
P-value for mean-dif. *t*-test	0.242	0.227	0.340	0.566	0.798	0.863	0.083	0.214
Panel D: Lodging Industry								
(HaTinh & QuangBinh) × post	−0.155	−0.151	0.093	0.092	−0.012	−0.026	0.040	0.047
	(0.238)	(0.237)	(0.084)	(0.087)	(0.124)	(0.120)	(0.062)	(0.060)
(QuangTri & Hue) × post	0.002	−0.005	0.038	0.036	−0.089	−0.082	−0.024	−0.017
	(0.062)	(0.061)	(0.060)	(0.061)	(0.096)	(0.093)	(0.054)	(0.053)
Observations	1331	1331	430	430	7766	7766	2024	2024
P-value for mean-dif. *t*-test	0.516	0.543	0.558	0.560	0.511	0.619	0.414	0.404
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes	No	No	Yes	Yes

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table shows the distributional impact of Formosa on the labor income (monthly; '000 VND; log-transformed) of individuals working in other relevant industries (i.e., those deemed eligible by the government for official Formosa compensation), separately for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Hue) Formosa-affected provinces. Panel A, B, C, and D report estimates using respective samples of workers in Freshwater Fishery, Husbandry, Restaurant, and Lodging, with the treated individuals working in (Ha Tinh & Quang Binh) and (Quang Tri & Hue). The control group consists of individuals working in the same industry who lived in unaffected provinces. Standard errors are clustered at the district level. The *t*-test are two-tailed.

these individuals substitute work hours in fishery with working secondary, non-fishery jobs. Both coping mechanisms are shown to help mitigate the income losses, even though far from entirely. We also find that the income damage to fishery diminished over time, even though it remained sizable and statistically significant at the end of 2016. Finally, we discover a positive spillover income effect on the freshwater fishery industry, which produces seafood's substitute products.

Examining the impact of *Formosa* on the affected population, and how these victims cope with the extreme shock, is relevant to the design of assistance policies. Fishers, on average, have lower education, work longer hours and have higher income than workers in other industries, making them vulnerable to negative employment shocks. In addition, we find that *Formosa* might have had an uneven earnings effect on the victims and affected the lowest income the most. It is also evident that *Formosa* did not just affect saltwater fishery in the four provinces located within the contaminated zone, but also the nearby regions and other industries as well. These findings provide valuable lessons for designing effective and equitable assistance programs.

CRediT author statement

Trung Hoang: Conceptualization; data analyses; writing; editing. **Duong Le:** Conceptualization; data analyses; writing; editing. **Ha Nguyen:** Conceptualization; data analyses; writing; editing. **Nguyen Vuong:** Conceptualization; data analyses; writing; editing.

Appendix

A. Additional result tables

Table A1(a)
LFS 2016's Summary Statistics for the Re-surveyed Sample.

	Fishery industry					**Control industry**		
	Formosa provinces		**Control provinces**			**Formosa provinces**		
	Mean	S.D.	Mean	S.D.	Dif. [p-val]	Mean	S.D.	Dif. [p-val]
Labor Characteristics: Individual Level (Labor Force Survey 2016)								
Total Monthy Income ('000 VND)	6972.5	5001.0	6031.3	4838.7	0.19	4786.6	3115.7	0.00
Monthly Income from Main Job ('000 VND)	6891.5	5042.5	5975.7	4837.1	0.20	4,647,4	3067.5	0.00
Work Hours (per week)	65.09	12.55	56.61	10.41	0.00	49.37	9.54	0.00
Having Secondary Job (%)	18.87	39.50	3.13	17.44	0.00	19.06	39.29	0.97
Age	36.60	11.29	36.93	10.77	0.84	40.37	11.02	0.02
Gender:								
Male (%)	100.00	0.00	95.30	21.19	0.11	60.98	48.80	0.00
Female (%)	0.00	0.00	4.70	21.19	0.11	39.02	48.80	0.00
Educational Attainment:								
No Training (%)	28.30	45.48	37.86	48.57	0.18	6.02	23.79	0.00
Primary School (%)	41.51	49.75	44.65	49.78	0.66	24.27	42.89	0.00
Secondary School (%)	18.87	39.50	13.32	34.02	0.28	34.80	47.66	0.02
High School (%)	7.55	26.68	2.61	15.97	0.06	21.26	40.94	0.02
College (%)	3.77	19.24	1.57	12.43	0.26	13.14	33.80	0.04
Observations	53		383			997		

Note: This table presents the descriptive baseline statistics for the labor characteristics of individual appearing in the individual-level panel regressions by using data from the Labor Force Survey 2016. Information on total income, income from main job, workload and whether having a second job is from the pre-Formosa period. "Control industries" refers to manufacturing, construction and retailling industries. "Formosa provinces" refers to observations belonging to the four Formosa-affected provinces (Ha Tinh, Quang Binh, Quang Tri, and Hue). "Control provinces" refers to observations belonging to all provinces south of Phu Yen, i.e., distant from the Formosa-affected region. 1 USD ≈22,550 VND (Vietnam Dong) as of December 31st, 2015.

Table A1(b)
Saltwater Fishery Industry – Statistics and Means Difference Test (LFS 2016).

		Observations	Pre-disaster		Post-disaster		Means
		Mean	S.D.	Mean	S.D.	Difference	
Formosa-affected fishers	Income (main job)	362	6387	5308	4311	2787	-2076^{***}
	Total income	362	6449	5291	4358	2778	-2091^{***}
Southern (unaffected) fishers	Income (main job)	2115	5892	6287	6946	21,458	1055
	Total income	2115	5942	6292	6987	21,460	1045
Unaffected workers (other industries)	Income (main job)	7629	4741	3605	4694	3524	46
	Total income	7629	4875	3633	4810	3516	64

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table presents the pre- and post-disaster descriptive statistics for fishery income (monthly; '000 VND), separately for the treatment group (i.e., fishery workers in the four Formosa-affected provinces), the "geographic control group" (i.e fishery workers living in unaffected Southern provinces), and the "industry control group" (i.e., workers in unaffected industries living the the four affected provinces). "Income (main job)" is the monthly earning from saltwater fishery. "Total income" includes monthly income from all sources, including secondary jobs. Statistical results from the means-difference tests are shown in the last column.

Table A2
Impacts on Fishing Activity in the Fishing-restricted Zone: Robustness to Alternative Control Groups.

	Boat-detection Intensity (modified log)			**Boat-detection Probability (%)**		
	(1)	(2)	(3)	(4)	(5)	(6)
[Panel A] Alternative control group: Lower-Southern provinces (Ba Ria-Vung Tau to Ca Mau)						
treat X post	−0.0700***	−0.229***	−0.190***	−0.0220***	−0.0671***	−0.0601***
	(0.0181)	(0.0164)	(0.0166)	(0.00827)	(0.00766)	(0.00811)
Observations	100,272	100,272	98,183	100,272	100,272	98,183
R-squared	0.516	0.622	0.625	0.447	0.520	0.521
[Panel B] Alternative control group: Upper-Northern provinces (Quang Ninh to Nam Dinh)						
treat X post	−0.567***	−0.494***	−0.504***	−0.231***	−0.171***	−0.181***
	(0.0202)	(0.0196)	(0.0201)	(0.00941)	(0.00912)	(0.00971)
Observations	65,568	65,568	64,202	65,568	65,568	64,202
R-squared	0.438	0.521	0.523	0.390	0.455	0.457
[Panel C] Alternative control group: All else except the four affected provinces						
treat X post	−0.239***	−0.270***	−0.245***	−0.0871***	−0.0768***	−0.0712***
	(0.0161)	(0.0156)	(0.0157)	(0.00731)	(0.00698)	(0.00740)
Observations	219,984	219,984	215,401	219,984	219,984	215,401
R-squared	0.505	0.602	0.603	0.424	0.500	0.500
Grid-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Coast-ID X Month Fixed Effects	No	Yes	Yes	No	Yes	Yes
Climate Covariates	No	No	Yes	No	No	Yes

HAC-robust standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table illustrates the robustness of *Formosa* impacts on fishing activity to different control-group specifications (alternative to the main specification). *Treat* area includes all 10-mile-square grids located within the fishing-restricted region (i.e., within 20 nautical miles of the coasts of Ha Tinh, Quang Binh, Quang Tri, and Hue). The sample includes all monthly observations between 2013 and 2016. *Post* indicates May-2016 or after. The reported outcome variables include log-transformed monthly aggregate boat counts in each grid (column 1–3) and the probability that the grid was detected with at least a boat in that month (column 4–6). Panels A to C report estimates from the specifications that employ the control groups (coastal provinces) from Vung Tau to Ca Mau (Panel A), from Quang Ninh to Thai Binh (Panel B) and from all other provinces except for the four affected (Panel C). All standard errors are robust-adjusted to heteroskedasticity and autocorrelation (up to six lags) (i.e., HAC-robust).

Table A3
Falsification Tests – Hypothetical Impacts on 1) Fishery in Predetermined Period (2015) and 2) Unaffected Industries in 2016.

	Income (main job)	Total income	Income (main job)	Total income
	Repeated cross-section		Individual-level panel	
	(1)	(2)	(3)	(4)
[Panel A] Fishery Impact from Hypothetical Event (April 2015)				
treat × post April 2015	−0.062	−0.058	−0.035	−0.040
	(0.126)	(0.122)	(0.140)	(0.138)
Observations	2445	2445	1014	1014
R-squared	0.339	0.331	0.116	0.114
[Panel B] Validity of the “Industry Control Group”				
treat × post	0.001	−0.006	0.020	0.016
	(0.019)	(0.017)	(0.023)	(0.022)
Observations	145,311	145,311	55,984	55,984
R-squared	0.277	0.270	0.002	0.003
Month Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	No	No	Yes	Yes

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table presents estimates from two Falsification Tests. Panel A (Test 1) reports results from the difference-in-differences regressions using saltwater fishery income data from the Labor Force Survey 2015, and imposing a fictional event in April 2015. Treated fishers are those located in Ha Tinh, Quang Binh, Quang Tri and Hue. Panel B (Test 2) reports estimates of *Formosa* impact using LFS-2016 workers in (arguably) unaffected industries (i.e., the industries included in the “Industry control group”). Thus, “treat” refers to workers in manufacturing, construction and retail who live in Ha Tinh, Quang Binh, Quang Tri and Hue; and “control” are workers in these sectors living in other provinces. Errors are clustered at the district level.

Table A4
Placebo Impacts on Fishing Activity: Using Pre-event Fictional Outcomes (April-2014).

	Boat detection density (modified log)				Boat detection probability (%)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat X Post	0.00478	−0.00219	−0.0257	−0.0271	0.0150^{**}	0.0126^{*}	0.000377	0.00163
	(0.0170)	(0.0171)	(0.0174)	(0.0176)	(0.00720)	(0.00725)	(0.00751)	(0.00757)
Precipitation (mm)		-0.00016^{***}		−0.00002		-0.00005^{***}		0.00003^{**}
		(0.00002)		(0.00003)		(0.00001)		(0.00001)
Sea-surface Temperature (Celsius)		-0.0095^{***}		−0.00336		−0.00101		−0.00138
		(0.0019)		(0.00230)		(0.00102)		(0.00124)
Observations	98,240	98,240	66,848	66,848	98,240	98,240	66,848	66,848
R-squared	0.612	0.612	0.616	0.616	0.515	0.515	0.517	0.517
Grid-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coast-ID X Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control Groups	Main Specification		Lower-Southern		Main Specification		Lower-Southern	

HAC-robust standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table reports estimates of the *placebo* impact of *Formosa* on fishing activity within the fishing-restricted zone (i.e., within 20 nautical miles of the coasts of Ha Tinh, Quang Binh, Quang Tri, and Hue). Each observation is a 10-mile-square grid-month georeferenced from VIIRS's boat-detection data set. The sample includes all monthly observations between 2012 and 2014. The fictional *Post* dummy refers to all months starting from May 2014. The reported outcome variables include log-transformed monthly aggregate boat counts in each grid (columns 1–3) and the probability that the grid was detected with at least a boat in that month (columns 4–6). The alternative control groups include all grid-month observations located within 20 nautical miles of the southern coastal provinces between Phu Yen and Ca Mau (i.e., "Main Specification") and between Ba Ria-Vung Tau and Ca Mau (i.e., "Lower-Southern"). All standard errors are robust-adjusted to heteroskedasticity and autocorrelation (up to six lags) (i.e., HAC-robust).

Table A5
Heterogeneous LFS Impacts by Income Distribution.

	Monthly income ('000 VND)								
	$\tau = 10\%$	20%	30%	40%	50%	60%	70%	80%	90%
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Geographic control group									
treat × post	-0.705^{***}	-0.503^{***}	-0.285^{**}	$-0.182^{\S}$	$-0.196^{\S}$	-0.270^{**}	-0.275^{**}	-0.377^{**}	$-0.397^{\S}$
	(0.231)	(0.139)	(0.119)	(0.121)	(0.121)	(0.125)	(0.138)	(0.170)	(0.304)
Observations	872	872	872	872	872	872	872	872	872
R-squared	0.072	0.079	0.031	0.012	0.017	0.025	0.027	0.031	0.023
Individual Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Post-event dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: Industry control group									
treat × post	-0.634^{**}	-0.443^{***}	-0.513^{***}	-0.271^{**}	-0.203^{*}	-0.201^{*}	-0.228^{*}	-0.405^{**}	-0.510^{*}
	(0.297)	(0.137)	(0.129)	(0.107)	(0.113)	(0.114)	(0.136)	(0.185)	(0.268)
Observations	2090	2090	2090	2090	2090	2090	2090	2090	2090
R-squared	0.012	0.029	0.048	0.020	0.011	0.011	0.013	0.022	0.019
Individual Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Post-event dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$, $^{\S}p < 0.2$.

Note: This table shows results from the unconditional quantile regression (UQR) proposed by Firpo et al. (2009). We use STATA command `xtrifreg` by Borgen (2016) and include individual fixed effects in the UQR model. "Treat" indicates saltwater fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e., distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e., manufacturing, construction, and retail) living in the four Formosa-affected provinces. The sample is restricted to only individuals who were surveyed twice—before and after May-2016.

B. *Timeline of the Formosa incident*

- April 6, 2016: Over two tons of farm-raised saltwater groupers and red snappers died Ky Anh district, Ha Tinh. Wild fish carcasses also reported to had been washed ashore in mass in Vung Ang sea, Ha Tinh.

- April 10–15, 2016: fish carcasses started to be found along the seaside of southern provinces: Quang Binh and Quang Tri, and Thua Thien-Hue.

- April 26, 2016: the Thua Thien-Hue Department of Natural Resources and Environment examined the water sample in Lang Co lagoon and Lang Co seaport and confirmed that the seawater was heavily polluted, which was the cause of mass fish death.

- May 4, 2016: the Vietnamese government announced a double-ban on both fishing activity and the processing and selling of seafood caught within 20 nautical miles of central Vietnam provinces, worrying that contaminated seafood in the region might not meet safety standards.

- June 30, 2016: the Minister of Natural Resources and Environment announced that phenol and cyanide were the main and direct cause of mass fish deaths. These toxic substances were discharged illegally to the ocean by Formosa Ha Tinh Steel Co., Ltd. The government held a press conference on the same day and stated that Formosa was the perpetrator of mass death of fish along the seaside of four provinces: Ha Tinh, Quang Binh, Quang Tri and Thua Thien Hue. Formosa agreed to settle for an immediate remedial compensation package worth $500 million USD.

- July 2016: official reports documented that the total loss had amounted to over 322 tonnes of both wild and caged sea lives across the coast of the four affected provinces.

- August 2016: the Ministry of Agricultural and Rural Development demarcated a no-fishing zone, banning all deepwater fishing activity within the 20 nautical miles near the shorelines of the four affected provinces.

- September 2016: the government lifted the double-ban in May 2016 on near-shore fishing activity and seafood processing. The ban on deepwater fishing, however, remained intact.

- September 29, 2016: the Prime Minister of Vietnam passed Directive 1880/QD-TTg on the compensation to the provinces of Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue, following the marine environmental incident.

- March 09, 2017: the Prime Minister of Vietnam passed Directive 309/QD-TTg on the revision of Directive 1880/QD-TTg on September 29, 2016, regarding the compensation for the provinces of Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue following the marine environmental incident.

- May 2018: the Health Ministry concluded that seafood from the ban zone had met safety standards and that marine resources had recovered. As a consequence, the near-shore deepwater fishing ban was lifted.

C. Impact of the Fishing-Ban Policy? Evidence from a Spatial Regression Discontinuity

Following Section 5.3, this Appendix presents empirical evidence on the impacts of the fishing ban policy. To do so, we first rely on a setting of a spatial regression discontinuity design (RD). Specifically, we exploit the fishing ban zone's 20-nautical-mile threshold (i.e., the red-dotted line shown in Fig. 1) as a source of discontinuous variation in fishing eligibility for the months the ban was in effect:

$$y_{cp} = \alpha_0 + \alpha_1 \times outsideBanZone_c + f(z_c, outsideBanZone_c) + \eta_p + \varepsilon_{cpy} \tag{4}$$

where $outsideBanZone_c$ is an indicator equals one if cell c locates outside of the fishing ban zone (i.e., more than 20 nm from shore). We measure a grid's distance to shore using its centroid's coordinates (longitude and latitude) information. z_c is the running variable in our RD setting, which is the re-centered grid-specific distance to the 20 nm cutoff line. This variable reflects the grid's exposure to the threshold, measuring how far the grid is to the cutoff. By construction, z_c takes negative values if the grid locates within the 20 nm fishing ban zone, and positive outside the ban zone.[44] $f(z_c, outsideBanZone_c)$ is a polynomial function of the running variable. To check for the robustness of our RD result, we allow for $f(.)$ to take both parametric and non-parametric forms. For parametric regressions, we report results for both the linear and quadratic specifications of z_c. As a standard RD approach, we further include the interactions of these terms with "treatment" indicator $outsideBanZone_c$ to allow for flexible fitted slopes around the threshold (Imbens and Lemieux, 2008). For non-parametric RD regressions, we report estimates of the local polynomial effect at the threshold by following Imbens and Kalyanaraman (2012) and Calonico et al. (2014) to obtain mean-square-error- (MSE-) optimal data-driven RD bandwidth. To further check for bandwidth sensitivity, we also report result using the approach of Calonico et al. (2018), which obtain optimal bandwidth from a coverage-error-rate- (CER-) optimal technique.[45]

The RD estimation essentially compares fishing activity just around this 20 nm threshold during the five-month ban period. Importantly, we hypothesize that if fishers' response was driven strongly by the ban policy, we would likely observe a rational migration of near-shore fishing boats to just right outside of the 20 nm cutoff. This movement would enable them to continue fishing legally (by abiding to the ban), and effectively (by not having had to travel too far offshore, which can inflate costs). In this case, we would observe a significant effect to boat detection just outside the 20 nm cutoff. On the other hand, if the ban was not strongly communicated and reinforced (and thus, the reduction in near-shore boat detection was mainly driven by the *Formosa* incident itself, no matter whether it was due to a pull or push factor), we would not observe any discontinuous changes in fishing activity around the 20 nm threshold.

We present the main result from our RD analysis in Figure C1. The figure shows plots of the discontinuities in boat detection at the 20 nm threshold, separately for fifteen consecutive months including the five months before, during, and after the ban period. We use Calonico et al. (2014)'s technique to show local polynomial fits for each side of the 20 nm threshold, adopting evenly-spaced bin selection and triangular kernels. Ultimately, we plot the modified log-transformed boat detection value as a function of the RD running variable (i.e., the grid cell's normalized distance to the cutoff). According to the figure, there is little evidence of a discontinuity at the threshold in any of the fifteen monthly plots. While we do not detect meaningful RD effects in Figure C1 (most likely due to the separate monthly RD tests being substantially underpowered), the detailed RD regression results do provide evidence suggesting *some* policy-ban effects. Table C1 shows the comprehensive RD estimates across several parametric and non-parametric RD estimators with varying polynomial orders and choices of bandwidth intervals; several estimates, especially though under the specification that employs a larger bandwidth (i.e., 10 nm around the threshold), now indicate a statistically significant difference in fishing activity across the fishing ban.

To further confirm the RD results, we present another alternative empirical approach that estimates the potential effect of the fishing ban under a triple-difference analysis:

$$y_{cpmy} = \beta_1(treat_c \times post_{my}) + \beta_2(treat_c \times outside20nm_c) + \beta_3(outside20nm_c \times post_{my}) + \beta_4(treat_c \times post_{my} \times outside20nm_c) + \gamma_c + \lambda_{my} + \pi_{pm} + \epsilon_{cpmy} \tag{5}$$

where all the components are identical to those in Equation (2), except for the inclusion of an additional binary term $outside20nm_c$ that indicates whether the grid is less/greater than 20 nautical miles from shore. The estimation results from this exercise is presented in Table C2. The coefficient of interest is the triple-interaction term, which illustrates the differential *Formosa* impact on fishing activity outside the 20 nm zone along the coasts of the four affected provinces relative to inside. According to Table C2, there is no statistically significant policy-ban effects on the fishing intensity outcome (Panel A); which aligns with Figure C1. However, at the extensive margin, the table shows suggestive evidence indicating a positive differential effect on the fishing prevalence indicator outside of the ban zone (Panel B). Consistent with the results from Table C1, the significant estimates are only obtained under the larger-band specifications (columns 3 to 5).

Overall, the combined findings from our RD and triple-difference analyses provide empirical evidence to support our view that we discuss in Section 5.3: the fishing ban, while perhaps *not* being strictly enforced or a major factor influencing the decline in near-shore fishing activity within

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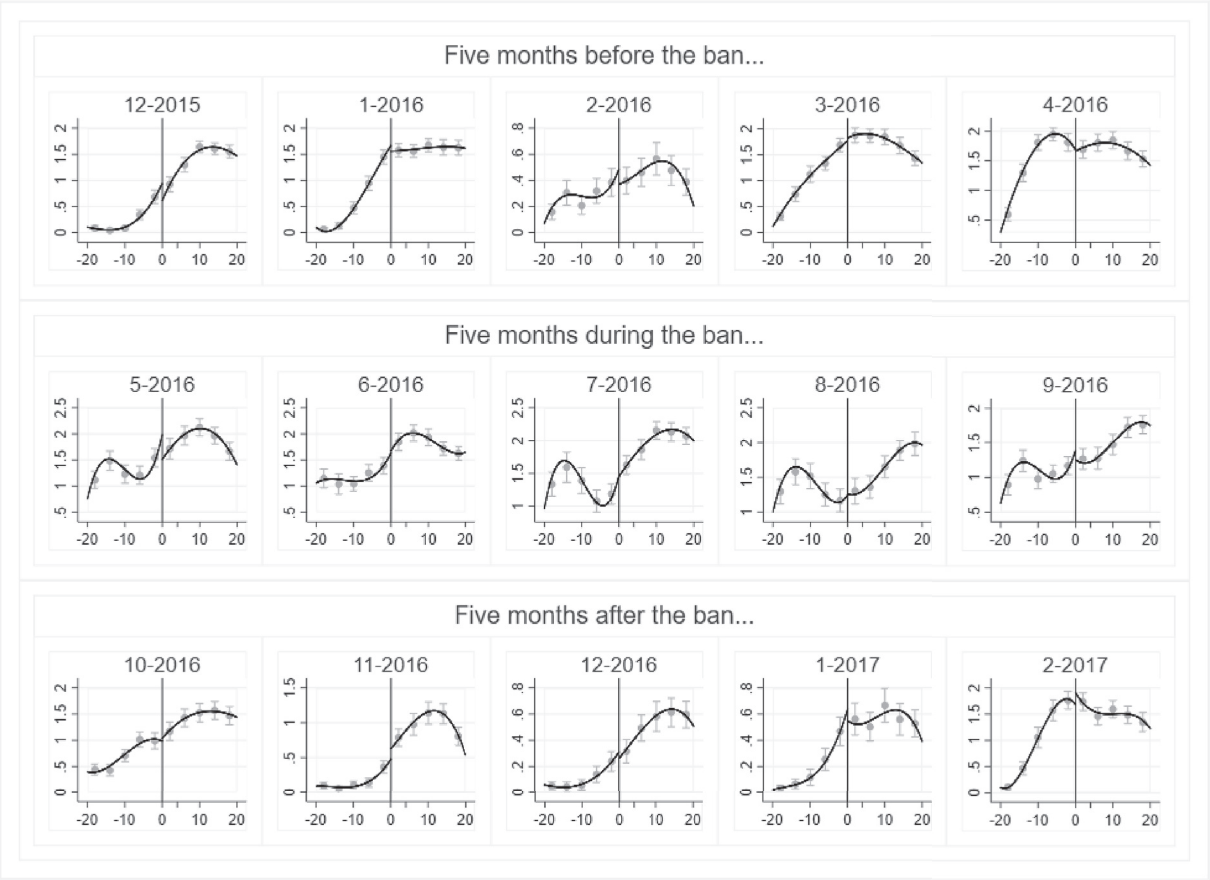
[44] For example, the grids locate 15 nm and 10 nm away from shore (i.e., within the fishing ban zone) would have $z_c = -5$ and $z_c = -10$, respectively. Similarly, the grids locate 25 nm and 30 nm away from shore (i.e., outside of the fishing ban zone) would have $z_c = 5$ and $z_c = 10$, respectively.

[45] See Chaurey and Le (2018) for an application of employing these data-driven optimal bandwidth selection techniques in RD practice.

the *Formosa*-affected region, still served an important role as a warning to fishers. In the absence of detailed knowledge about how toxic and widespread the chemical spill was to the ocean and the fish, the policy-ban announcement was needed as a guidance through which the government could broadly communicate the severity of the contamination to the public. This perspective is supported by the fact that the RD exercises did not find significant effects right at the 20 nm border of the ban (because the ban itself was likely not strictly enforced due to obvious capacity constraints), but did find some effects under the larger bands, and that the triple-difference results indicate the same pattern.



Note: This figure illustrates the monthly non-parametric local polynomial RD estimates for boat detection at the 20nm threshold for the months before, during, and after the fishing ban. The plots adopt Calonico et al. (2014)'s method with evenly-spaced bin selection and triangular kernels.

Fig. C1 Regression Discontinuity in Boat Detection at the 20 nm Fishing Ban Threshold.

Table C1

Regression Discontinuity in Monthly Boat Detection at the 20 nm Policy-ban Threshold.

	Boat detection density (modified log)						Boat detection likelihood (%)					
	Parametric				Local Polynomial		Parametric				Local Polynomial	
	Linear (1)	Quadratic (2)	Linear (3)	Quadratic (4)	MSE (5)	CER (6)	Linear (7)	Quadratic (8)	Linear (9)	Quadratic (10)	MSE (11)	CER (12)
May-2016	−0.0740	−0.329	−0.282	−0.362	−0.222	−0.234	−0.0481	−0.108	−0.0971	−0.172	−0.108	−0.135
	(0.144)	(0.219)	(0.196)	(0.312)	(0.259)	(0.319)	(0.0584)	(0.0889)	(0.0805)	(0.128)	(0.081)	(0.096)
Observations	613	613	308	308	344	235	613	613	308	308	369	263
June-2016	0.322**	0.240	0.206	0.410	0.290	0.391	0.104*	0.112	0.119	0.259**	0.157**	0.232
	(0.143)	(0.218)	(0.199)	(0.318)	(0.212)	(0.258)	(0.0547)	(0.0834)	(0.0780)	(0.124)	(0.064)	(0.075)
Observations	613	613	308	308	360	255	613	613	308	308	355	229
July-2016	0.346**	0.132	0.205	0.209	0.222	0.211	0.196***	0.0864	0.128	0.0978	0.104	0.079
	(0.140)	(0.212)	(0.193)	(0.308)	(0.175)	(0.208)	(0.0555)	(0.0836)	(0.0796)	(0.127)	(0.069)	(0.087)
Observations	613	613	308	308	369	262	613	613	308	308	318	221
August-2016	0.106	−0.0527	0.0399	−0.258	−0.233	−0.123	0.0285	−0.0683	−0.0155	−0.296**	−0.193	−0.352**
	(0.145)	(0.220)	(0.203)	(0.323)	(0.247)	(0.307)	(0.0647)	(0.0984)	(0.0955)	(0.150)	(0.136)	(0.169)
Observations	613	613	308	308	337	232	613	613	308	308	236	168
September-2016	−0.0408	0.0752	0.215	0.105	0.176	0.297	−0.0185	0.0631	0.0757	0.0560	0.586	0.103
	(0.115)	(0.176)	(0.154)	(0.242)	(0.237)	(0.302)	(0.0636)	(0.0969)	(0.0870)	(0.138)	(0.116)	(0.148)
Observations	613	613	308	308	236	168	613	613	308	308	293	203
Coast-ID Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flexible Slope	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes	N/A	N/A
RD Bandwidth Size	±10 nautical miles		±5 nautical miles		data-driven bandwidths		±10 nautical miles		±5 nautical miles		data-driven bandwidths	

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Note: This table reports estimates of the spatial regression discontinuity regressions for fishing activity at the 20 nm fishing-ban threshold (Equation (3)) during the ban period. Each of the parametric RD regressions controls for either linear (columns 1, 3, 7, 9) or quadratic (columns 2, 4, 8, 10) polynomials. The local polynomial (non-parametric) approach follows from Calonico et al. (2014) and Imbens and Kalyanaraman (2012), using Mean-Square-Error optimal bandwidth selection technique (columns 5 and 11), and Calonico et al. (2018) using Coverage-Error-Rate optimal bandwidth (columns 6 and 12).

Table C2
Effect of the Fishing Ban? A Triple-difference Analysis.

	(1)	(2)	(3)	(4)	(5)
[Panel A] Outcome Variable: Boat-detection Intensity (modified log)					
Treat X Post X OutsideBan	−0.0423	0.0251	0.0410	0.0570	0.0505
	(0.0934)	(0.0622)	(0.0516)	(0.0449)	(0.0400)
R-squared	0.620	0.602	0.602	0.603	0.598
[Panel B] Outcome Variable: Boat-detection Probability (%)					
Treat X Post X OutsideBan	0.0294	0.0436	0.0594**	0.0571**	0.0611***
	(0.0474)	(0.0315)	(0.0260)	(0.0230)	(0.0207)
R-squared	0.473	0.467	0.461	0.461	0.458
Observations	11,796	23,405	35,249	47,328	59,219
Grid-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-specific Fixed Effects	Yes	Yes	Yes	Yes	Yes
Coast-ID X Month Fixed Effects	Yes	Yes	Yes	Yes	Yes
Climate Covariates	Yes	Yes	Yes	Yes	Yes
Spatial Threshold Bandwidth	±1 nm	±2 nm	±3 nm	±4 nm	±5 nm

Note: This table reports the results from the triple-difference analysis presented in Equation (4). Due to space constraint, only the coefficient associated with the triple-interaction term in the model (i.e., β_4) is reported. Full regression result is available upon request. The spatial bandwidths vary from 1 to 5 nautical miles from the policy-ban's spatial threshold (i.e., 20 nautical miles from coastline). All regressions control for grid-specific, month-specific, and coast-ID X month Fixed Effects. HAC-robust standard errors reported in parentheses.

D. Test for LFS Pre-event Parallel Trends

In this section, we provide a test for whether the pre-event trends between treatment and control groups are parallel. We consider monthly income as a function of time. Particularly, denote m the time variable in monthly unit. The income for individual i in group $j = \{\text{control}, \text{treatment}\}$ can then be expressed as $y_i = f_j(m) + \varepsilon_i$. Given this assumption, if the gap between $f_{\text{control}}(m)$ of the control group and $f_{\text{treatment}}(m)$ of treatment group is not a constant, then our DiD assumption of pre-event parallel trends would be violated.

Assume that the function $f(m)$ is a polynomial, we can run a regression with the specifications below:

$$y_{it} = \alpha + \beta x_{it} + \sum_{j=1}^{n} \gamma_j t_t^j + \delta.treat_i + \sum_{j=1}^{n} \tau_j t_t^j.treat_i + \varepsilon$$

In addition to the time variables, we control for demographic variables x_{it}, including age, age squared, marital status, education and gender. In this specification, the null hypothesis $\tau_1 = \cdots = \tau_5 = 0$ would be rejected if the functions $f(m)$ for the control and treatment groups have statistically different coefficients, which would imply a violation of the DiD parallel trend assumption.

By choice, we conduct a test for total monthly income up to $n = 5$, with additional results for alternative specifications available upon request. The results for the test is shown in Table D1. The F-test statistics in nine out of ten regressions indicate that we cannot reject the null hypothesis that $\tau_1 = \cdots = \tau_5 = 0$ (the F-test statistic for column 3 in Panel B is 1.69). Overall, the result from this test provides support to the validity of the DiD parallel trend assumption.

Table D1
Test for pre-event parallel trends.

	Monthly income ('000 VND)				
	(1)	(2)	(3)	(4)	(5)
Panel A: Geographic control group					
treat × t	−85.36	−2.76	−626.56	−1618.49	1052.53
	(93.16)	(706.02)	(1033.97)	(3002.32)	(4124.71)
treat × t^2		−5.45	83.16	322.18	−627.69
		(39.38)	(157.82)	(661.99)	(1325.80)
treat × t^3			−3.50	−24.73	115.49
			(6.92)	(52.57)	(203.04)
treat × t^4				0.62	−8.45
				(1.37)	(13.92)
treat × t^5					0.21
					(0.34)
Observations	3522	3522	3522	3522	3522
R-squared	0.12	0.12	0.12	0.12	0.12
District FE	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes
F-test statistics for $\tau_1 = \cdots = \tau_5 = 0$	**0.84**	**0.82**	**0.75**	**0.57**	**0.76**
Panel B: Industry control group					
fishery × t	−67.92	217.66	−959.75	−4623.06	−2340.63
	(78.25)	(612.22)	(958.79)	(3435.96)	(4266.26)
fishery × t^2		−16.98	149.33	1031.50	217.59
		(33.15)	(154.93)	(761.50)	(1208.36)
fishery × t^3			−6.53	−84.79	35.47
			(6.84)	(61.47)	(168.05)
fishery × t^4				2.30	−5.49
				(1.64)	(11.05)
fishery × t^5					0.18
					(0.27)
Observations	11,476	11,476	11,476	11,476	11,476
R-squared	0.17	0.17	0.17	0.17	0.17
District FE	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes
F-test statistics for $\tau_1 = \cdots = \tau_5 = 0$	**0.75**	**1.59**	**1.69**	**1.23**	**0.82**

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Note: This table presents the result from a formal parallel-trend test for LFS regressions. The standard errors are clustered at the district level. The control variables are age, age square, marital status, education and gender. The tests are conducted with the null hypothesis that the trends are parallel between the treatment and control groups before the *Formosa* event using all monthly income data from Jan 2015 to March 2016.

Appendix E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jdeveco.2020.102538.

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