Is Tomorrow Another Day?
Coping with an Environmental Disaster: Evidence from Vietnam[*]

Trung Hoang[†]
Duong Trung Le[‡]
Ha Nguyen[§]
Nguyen Dinh Tuan Vuong[¶]

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Abstract

We examine the coping mechanisms of fishermen to a large-scale environmental disaster in 2016, when toxic industrial waste contaminated the marine ecosystem of Vietnam's central coast. Combining labor force surveys with a novel satellite data of boat detection, we find significant negative effects on fishing activities and fishermen's income. The labor-market effects and subsequent fishermen's responses are heterogeneous by locations. Upstream fishermen could travel to safer fishing grounds. Downstream fishermen, instead, endured severe impact and were more likely to quit fishing or have secondary jobs. Saltwater fishermen in the neighboring unaffected provinces and freshwater fishermen benefited from the incident.

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[†] Email: hoangxuantrung3012@gmail.com. Vietnam Academy of Social Sciences.

[‡] Email: dle1@binghamton.edu. Binghamton University - SUNY.

[§] Email: hanguyen@worldbank.org. Office of the Chief Economist for the Middle East and North Africa. The World Bank.

[¶] Email: nguyen.vuong@wisc.edu. University of Wisconsin - Madison.

1 Introduction

It was not until recently that the downsides of intensified industrialization has 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 1970s, the number of documented large-scale technological disasters have increased by nearly tenfold (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. Systematic 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's chemical contamination disaster which devastated both sea lives and human activities in Vietnam's coastal region in 2016. We leverage 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 individual-level data from the labor force surveys. By doing so, our study makes two contributions to the literature. First, we rigorously quantify the impact of the industrial disaster on a local population of fishing community. Our result supplies new evidence on how disasters affect local economic activities, emphasizing on a developing country's context. Second, we pay particular attention to the heterogeneous coping mechanisms of the victims. We empirically show that affected fishermen responded to the incident in ways which helped mitigating their losses.

The Formosa disaster was a marine pollution crisis breaking out in Vietnam in April 2016. Tonnes of fishes and other marine creatures were found dead in the seas of four provinces in central Vietnam: Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue (see Figure 1). The main perpetrator was identified as Formosa Ha Tinh Steel Corporation, which discharged toxic industrial waste into the ocean through their underwater drainage pipes. The employments of hundred thousands were affected, including many in the saltwater fishing industry. In early May 2016, the Vietnamese government issued a double-ban against fishing and processing seafood caught within 20 nautical miles off the coast of the four affected provinces. The ban was subsequently lifted in September 2016. However, the government continued to restrict near-shore deepwater fishing until May 2018, in order to safeguard the quality of food consumption and the recovery of marine resources in the damaged area.

We focus on examining the immediate and medium-run impacts of Formosa on fisheries, and how fishermen cope with the disaster, for at least two important reasons. First, fishing is a major industry in Vietnam, accounting for 19.97 percent of the country's total agricultural GDP in 2016, according to the Statistical Yearbook (General Statistics Office, 2016b). Fishing activities also make up a considerable share of the economics in central coastal Vietnam. At the four-digit Vietnam Standard Industrial Classification (VSIC) level, the single sub-industry of saltwater fishing accounts for 3.8 and 7.3 percents of total employment and income in coastal districts[1] of Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue in 2015 (General Statistics Office, 2016a). Second, we confine the scope of the analysis in the period before any formal source of compensation was distributed.[2] This allows us to evaluate the economic damage and coping activities during the most urgent time, thereby providing certain insights towards the timing and effectiveness of the government's assistance policies.

We employ a two-way fixed-effect difference-in-differences model at the individual-worker level and find that the Formosa disaster sharply reduced income of fishermen by as much as 45 percent for the rest of 2016. Utilizing high-resolution boat detection at the monthly interval, we additionally show that fishing activities significantly declined in the affected region by as much as 23 percent after the disaster took place. The negative impact of the disaster, however, does not distribute evenly across locations; we find that fishing communities located downstream within the contaminated zone were affected more heavily, compared to those located upstream and thus closer to safe waters. This, in consequence, likely induced different coping mechanisms. Satellite data shows a clear fishing migration pattern of the affected upstream fishermen from the contaminated waters to safer fishing grounds. Being able to travel to alternative fishing locations allowed these workers to maintain the number of work hours; however, their monthly income still reduced by as much as 44 percent. In contrast, both workload and income of "persistent" fishermen located downstream and far from safe waters were cut by more than a half. This adverse circumstance resulted in 14 and 25 percentage-point increases in the likelihoods that fishermen reported working extra jobs or giving up fishing for a new occupation.

In a collaborating subsection, we address the underlying cause triggering fishermen's responses. We exploit the discontinuous variation in fishing eligibility around the official

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

[2] As we will discuss in greater detail, the government's official directives on compensating and subsidizing the victims, as well as subsequent revisions of the original directives, were not passed to law and formally implemented until almost a full year after the incident was first discovered.

fishing ban's "cutoff", and find, under a spatial regression discontinuity design, no "cutoff" effect to fishing activity just outside of the ban zone. This evidence suggests that the negative effects on fishing activity that we discovered were likely driven by the contamination itself, rather than the legal reinforcements under the fishing ban policy. Next, we conduct a spillover analysis. We show that fishermen in freshwater fishing industry, especially those located downstream, benefited from the incident in terms of both income and employment. We also find a positive spillover to income of saltwater fishermen in the nearby unaffected provinces, even though this effect was transient. Finally, we study fishing recovery, and show that by the last quarter of 2017, fishing activity in the affected coastal areas had returned to the base level.

The existing disaster-economics literature has extensively concerned about natural disasters. One common characteristic of natural disasters is seasonality – hurricanes, floods, droughts, or earthquakes usually repeat in certain locations, and tend to take place during specific periods. Natural disasters are generally found to cause significant economic losses. At the macro level, Strobl (2012) show that the average hurricane strike decreases output by at least 0.83 percent in the Central American and Caribbean regions. Noy (2009) finds that natural disasters typically cause a drop in output of 9 percentage points 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 droughts lead to larger men's labor migration in rural Ethiopia. In the U.S., Belasen and Polachek (2009) investigate the effect of hurricanes on the local labor market in Florida, and find that worker's earnings increase up to 4 percent in hurricane-stricken counties while wages in nearby counties decrease. They show evidence that workers in hurricane-hit counties migrate into neighboring area.

Compare with the extended body of literature on the economic consequences of natural disasters, the evidence on impacts caused by man-made, industrial disasters is scant. Unlike natural disasters, industrial disasters are consequences of human errors and mechanical malfunctions, and thus, often have a large uncertainty aspect: in many cases, they are one-off events without any precedents. This greater level of unpredictability often poses serious challenges to the emergency responses and coping activities of the affected population. 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), and increase infant and childhood leukaemia (Petridou et al., 1996). In terms of oil-spill disasters, the environmental damages to local marine ecosystems which affect fisheries and tourism industries have been documented for the *Exxon Valdez* on southcentral 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). We extend the literature by evaluating the economic damages of *Formosa*, a toxic chemical contamination incident in coastal Vietnam, to local fishing community at the micro level. To the best of our knowledge, this paper is the first to analyze an industrial disaster's consequences to labor market outcomes of the victimized population. By focusing not only on the overall impact to fishermen's employment and income, but also on their coping activities, we add new evidence to the cumulative understanding of the intricate disaster-economics relationship.

The rest of this article 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 shows our main empirical results for the overall impacts of the disaster on fishing activities and affected fishermen's labor market outcomes, along with a series of robustness and falsification exercises. Section 5 extends to the equally-important discussions on fishermen's coping mechanisms, underlying cause, spillover effects, and fishing recovery. Finally, Section 6 concludes.

2 Formosa Disaster

Massive amount of fish carcasses were reported to have washed up on the beaches of Ha Tinh province, a central coastal province in Vietnam, from as early as April 6, 2016. Later, an unprecedentedly large number of dead sea lives continued to be washed ashore on the coast of Ha Tinh and three other nearby provinces including Quang Binh, Quang Tri and Thua Thien-Hue. By early May 2016, official reports documented that the amount of collected fish carcasses had surpassed 100 tonnes. It was shortly later uncovered that Formosa Ha Tinh Steel Corporation (hereafter "Formosa"), a steel plant located in the south of Ha Tinh and operated as a subsidiary of Taiwanese conglomerate Formosa Plastics Group, was responsible for this incident. Formosa illegally discharged toxic industrial wastewater contained phenol, cyanide and iron hydroxides – all are harmful chemical substances to sea lives – into the ocean through drainage pipes. After initially denying responsibility, the company admitted guilt on June 30, 2016, and agreed to settle for an immediate remedial compensation package worth $500 million USD. It was exactly three months after, on September 29 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 officially went into law (Prime Minister of Vietnam, 2017).[3]

The Formosa incident wreaked havoc on the livelihood of local coastal communities residing in the four affected provinces, which happen to rely heavily on saltwater fishing activities for the living. Official estimates from the Resource and Environment Ministry indicate that more than 200,000 people were directly affected; and that marine life in the affected region could take decades to completely recover. In July 2016, official reports documented that a total loss of over 322 tonnes of both wild and caged sea lives across the coast of the four affected provinces (RFA, 2016b). For the first time in the Vietnamese history, on May 4 2016, the 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 (VOA, 2016b). The double ban was lifted in September 2016. However, all near-shore (within 20 nautical miles) deepwater fishing activity remained restricted. In May 2017, the Prime Minister of Vietnam continued to order the ban to be upheld (Phys.org, 2017), and only finally lifted it in May 2018, after series of inspections from the Health Ministry concluding that seafood from the area had met safety standards, and that marine resources had recovered (Vnexpress, 2018).

Figure 1 shows the map of Vietnam with a focus on the Formosa study area. The shaded provinces in Central Vietnam are those directly affected by the environmental disaster: Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-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 red dashed line indicates the near-shore fishing ban zone demarcated by the government, where all fishing activity was not allowed between May and September 2016.[4] The thin blue dash line indicates the Maritime Exclusive Economic Zone (EEZ) of Vietnam. Since we also address potential spillover effects of Formosa, we label all coastal provinces in the figure.

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[3] See time-line of the Formosa environmental disaster in Appendix B.

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

3 Data and Empirical Methodology

3.1 Data and summary statistics

We measure the impact of the Formosa disaster on fishing communities in central Vietnam using two main data sources. We collect the first set of information on workers' workload and income from the Labor Force Surveys of Vietnam ("LFS") in 2015 and 2016. The second set of information comes from the Visible Infrared Imaging Radiometer Suite ("VIIRS"), a novel remote-sensing data source of satellite-imaged night-light luminosity which is administered by the National Oceanic and Atmospheric Administration ("NOAA"). We specifically utilize VIIRS' Boat Detection Module ("VBD"), which processes worldwide lights sources detected from boating activities present at the earth's ocean surface. Importantly, VBD also implements an automatic boat detection identification system which converts high-resolution ocean-light intensity to actual boat counts. This algorithm enables us to obtain a monthly balanced panel dataset of boat counts captured for the entire Vietnam's maritime Exclusive Economic Zone (EEZ) between April 2012 and May 2018.

3.1.1 Vietnam labor force surveys

The Labor Force Surveys 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 information related to the labor market including employment status, income, workload, unemployment, migration as well as demographic information on a quarterly basis. Particularly, each household in the sample is visited by interviewers in the first or the second quarters. Then, these households would be revisited in the third or the fourth quarters, respectively. This method of surveying enables us to control for individual unobservables with the inclusion of individual-specific fixed effects in our empirical model. Household members are selected from a stratified random sampling method, which ensures representativeness by province and industry. The sample includes all family members of interviewed households, but we only analyze labor outcomes for working-age individuals between 18 and 70 years old.

We focus on the labor outcomes specifically in saltwater fisheries and study the changes in these outcomes before and after Formosa incident. We obtain an LFS's representative sample consisting of 657 saltwater fishermen who worked in the industry before the disaster in 2016, in which 563 remained fishing after the incident took place. Table 1 provides the summary statistics of important labor outcomes, separately for the samples of all fishermen (Panel A) and "persistent" fishermen (Panel B). Descriptive statistics show that, after April 2016, the monthly income from fishing and total income of an average saltwater fisherman in unaffected provinces (i.e. the control group) increased slightly by 5.2 and 4.9 percent. In contrast, post-Formosa monthly income from saltwater fishing and total income of a treated fisherman declined significantly by over 36 percent. The average weekly working hours in saltwater fisheries in the affected provinces also dropped by 6.8 percent after; meanwhile, this figure was only 0.2 percent for fisheries in the rest of the country. This pattern is broadly consistent between the two panels, except that the average decline in workload was smaller for the affected "persistent" fishermen, whereas the drop in income was more dramatic. It is also worth noting that income from extra job only accounts for less than 1.2 percent on average. In the last two columns of the table, we report results from our tests on statistical differences between pre- and post-Formosa outcomes, separately for the treated and control groups. The reductions in magnitudes of both income and workload of treated fishermen after Formosa are statistically significant, while that of the control group are small and statistically indistinguishable from zero.

3.1.2 Satellite data on boat detection

To measure the impact of the Formosa disaster to fishing activity, we use a novel dataset of satellite-captured images called Visible Infrared Imaging Radiometer Suite ("VIIRS"), which 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 source emitted from fishing boats.[5] VBD project is jointly sponsored by the U.S. Agency for International Development, NOAA, and the World Bank, collecting and processing 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.[6]

The use of night light brightness as a measure for economic activity has become increasingly popular in economics research. Especially in developing countries where (sub-)national accounting data are often missing or unreliable, luminosity at night has been shown to provide an unbiased proxy for growth outcomes. However, it is noted that almost all existing studies adopting night-light have relied on the NOAA's Meteorological Satellite Program Operational Line Scan (DMSP-OLS). DMSP-OLS final output provides composite annual light density measures at a coarse footprint of 5km X 5km pixel resolution. See Donaldson and Storeygard (2016) for a comparative analysis on this literature. Compared to the imaging

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

[6] We collect the raw-, raster-formatted VBD's light intensity and boat detection data at https://ngdc.noaa.gov/eog/viirs/download_boat.html [Accessed July 26, 2018].

sensors suite in DMSP-OLS, VIIRS provides higher quality remote sensing imagery in terms of spatial resolution and ability to detect weak light sources. The VIIRS Day/Night Band sensor unit has a 742m X 742m footprint, thus could detect boat activities within as fine as 0.2 mile-square area. Being introduced for the first time in April 2012, VIIRS Boat Detection Module (VBD) supplies daily remote sensing images of light outputs at the global scale. Coupling with the implementation of an automatic boat detection identification system that converts light intensity to actual boat counts, VBD has greatly advanced the usefulness of satellite images for fishery management. In short, the VBD algorithm detects spikes in the illumination from offshore areas, at the same time controls for background noise radiance due to moonlight, and filters out lighting, and energetic particles in the upper atmosphere (ionosphere). Moreover, using the spectral characteristics of a spike, gas flares such as those from the offshore drilling stations are separately captured and labeled (Elvidge et al., 2015).

For the purpose of this analysis, we use the monthly-aggregate VBD products published by NOAA from April 2012 to May 2018, obtaining a total of 74-month worth of boat detection data. We then aggregate the number of monthly boats detected in VIIRS into each 10-mile-square geo-grid cells which, together, spans the entire Vietnam's Maritime Exclusive Economic Zone. The final dataset that we utilize is a 74-month balanced panel of 26,324 grid cells per month (1,947,976 observations in total). According to Elvidge et al. (2018), the monthly temporal aggregation addresses each of the three criteria that could be a concern for higher-frequency interval: lunar cycle effect, seasonal variation, and cloud cover. The monthly aggregation VBD mitigates for lunar cycle effects and improve the cloud-free boat-detection capability. It should also be noted that monthly temporal aggregation 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). In addition, the chosen observation scale of 10-mile-square grid area allows us to better capture the effect for different fishing grounds across the entire country's coastal area. It covers an oceanic space granular enough to detect micro changes in fishing activity's patterns (e.g. within-province fishing grounds' migration), and still spans a sufficiently large sea segment, which allows us to be less concerned with issues about spatial autocorrelation or spurious boat detection.

To illustrate the use of boat-light detection data in this paper, we make a comparison of snapshots of raw-data ocean light from fishing activities collected from VIIRS's remote sensing images. In Panels A1 and A2 of Figure 2, we process the original raster data published by the NOAA for two separate months – May 2015 and May 2016 – into a product of light maps with each pixel re-sampled to a square footprint covering a 10-mile-square sea space for the entire maritime EEZ of Vietnam. Each of these pixel also stores a composite monthly-aggregate boat count value made feasible by the VIIRS's automatic boat detection identification capability. The brighter pixels in these figures represent fishing grounds with higher boat density. One could visually observe the effect of Formosa by comparing the raw-data light snapshots. First, while near-shore fishing boats were densely detected along the coast of all central coastal provinces in May 2015 (a year before the Formosa took place), this region experienced a marked decrease in boat density the first month Formosa happened (May 2016), especially for the four affected provinces. The toxic wastewater also demolished major fishing grounds offshore (further out from the 20nm fishing ban zone) of Quang Binh, Quang Tri and Hue, where the brightest cluster of densely-fished area became significantly dimmer. However, this cluster of fishing boats seems to migrate north, brightening almost the entire region, both near- and off-shore, of the northern-most coastal provinces.

We further examine the effect of Formosa on fishing activity within the contaminated zone across time by aggregating the 20nm near-shore total boat counts separately for the banned region (Panel B1) and for the near-shore area of other coastal provinces (Panel B2), from 2014 to 2017. Even under the appearance of fishing seasonality, it is still clearly visible that 2016 was an anomalously unproductive period for the affected provinces. The peak monthly boats detected was just above 4,000 (in July 2016), compared with statistics greater than 6,000 in other years. While this sharp drop is noticeable in Panel B1, it is not the case for Panel B2; the 2016 near-shore boat counts in other regions, on average, seems to closely follow its yearly pattern. Besides, it is arguable that the observations from VBD images might only reflect the lower bound of near-shore fishing activity during Formosa duration; more marine patrol boats were expected to be deployed during this sensitive time spell.

3.2 Econometric specification

To causally quantify Formosa's effect, we employ two different datasets. The Labor Force Surveys provide information on fishermen's income and workload, and the VIIRS Boat Detection Module provides satellite-captured data on boats detected at night offshore of coastal Vietnam. For estimations using Labor Force Surveys, we perform a set of Difference-in-Differences (DiD) regression analysis of the form:

$$y_{im} = \beta_0 + \beta_1(treat_i \times post_m) + \sigma_i + \theta_m + \varepsilon_{im} \tag{1}$$

where the subscripts refer to an individual i surveyed in month m of 2016.[7] y_{im} is the dependent variable at the individual level. We investigate the effect of Formosa incident on three main labor outcomes: fishermen's monthly income generated from saltwater fishing, their total income, and weekly workload (i.e. working hours per week). The standard

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[7] We also report result for placebo test using data from the 2015 Labor Force Survey.

difference-in-differences indicator terms are

$$treat_i = \begin{cases} 1, & \text{if the individual resides in a Formosa-affected province (i.e. treated group)} \\ 0, & \text{otherwise (i.e. control group),} \end{cases}$$

and

$$post_m = \begin{cases} 1, & \text{if the month is between May and December} \\ 0, & \text{otherwise.} \end{cases}$$

σ_i represents the individual-specific fixed effects which capture time-invariant unobserved characteristics (e.g. innate ability). θ_m represents the month-specific fixed effects, which absorb unobserved monthly variations affecting country-wide fishing activities. ε_{im} represents idiosyncratic standard errors clustered at the district-level.

For estimations using the VIIRS Boat Detection data, we run DiD regressions of the primary form:

$$y_{cpmy} = \delta_1(treat_c \times post_{my}) + \gamma_c + \lambda_{my} + \pi_{pm} + \epsilon_{cpmy} \tag{2}$$

where the subscripts refer to a 10-mile-square grid cell observation c that belongs to the maritime EEZ of province p, and stores the monthly-aggregate average number of boats detected in month m in year y. Thus, the outcome variable y_{cpmy} provides a measure for fishing activity at each 10-mile-square fishing grounds, spanning the entire Vietnam's EEZ.[8] The standard DiD indicator terms are

$$treat_c = \begin{cases} 1, & \text{if the cell belongs to a Formosa-affected province (i.e. treated group)} \\ 0, & \text{otherwise (i.e. control group),} \end{cases}$$

and

$$post_{my} = \begin{cases} 1, & \text{if the month is} \geq \text{May 2016} \\ 0, & \text{otherwise.} \end{cases}$$

γ_c represents the grid-specific fixed effects which capture time-invariant unobserved characteristics within each 10-mile-square fishing ground. λ_{my} represents the month-by-year fixed effects, which subsume the single month-specific and year-specific fixed effect terms, and essentially absorb any monthly unobserved variations affecting country-wide fishing activities. π_{pm} represents the province-by-month fixed effects, which capture the existence of seasonality individually embedded to each of the 24 coastal provinces (e.g. Springs are often the

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[8] Note that in this paper we do not consider the effect to boat detection outside of Vietnam's maritime EEZ. Even though illegal fishing outside of Vietnamese boundary is a possibility, we consider such action rare and of second order in magnitude.

off-season for fishery business in the central provinces, but are instead the busy months for near-shore Southern provinces' fishing activity.) ϵ_{cpmy} represents idiosyncratic standard errors clustered at the province-level. Note that we remove all observations in April 2016 in the main regressions, since it was not anecdotally clear when the Formosa disaster took place exactly within this particular month. Our estimates remain highly consistent when we include April 2016 as a post-treatment period.[9]

The estimated coefficients of interest in equations (1) and (2) in our difference-in-differences regressions are β_1 and δ_1, which measure the differential changes in fishermen's income and workload (equation (1)) and the number of fishing boat detected (equation (2)), for the four affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue after Formosa happened, relative to other unaffected provinces.

In the last section of the paper, we investigate the underlying cause of the overall impact to fishing activity in the affected region. Specifically, we aim to shed light on whether the negative impact to fishing – measured using boat detection data – was driven directly by the damage caused by Formosa disaster itself, or simply by the fishing ban that the government imposed in 2016. To answer this question, we rely on a set of Regression Discontinuity (RD) estimations, utilizing the 20nm fishing-ban cutoff (i.e. the red-dotted line shown in Figure 1) as the source of discontinuous spatial variation. We run the following RD regression separately for each month in our sample:

$$y_{cp} = \alpha_0 + \alpha_1 \times outsideBanZone_c + f(z_c, outsideBanZone_c) + \eta_p + \varepsilon_{cpy} \tag{3}$$

where $outsideBanZone_c$ is an indicator equals one if cell c locates outside of the fishing ban zone (i.e. more than 20nm 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 normalized grid-specific distance to the 20nm 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 20nm fishing ban zone, and positive outside the ban zone.[10] $f(z_c, outsideBanZone_c)$ 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 $outsideBanZone_c$

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[9] Results available upon request.

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

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.[11]

Last but not the least, we accompany our first set of RD result by exploiting a series of estimators that compare the difference in the discontinuities at the 20nm fishing ban cutoff across months, which is often referred to as Difference-in-Discontinuities estimators (Shenoy, 2018):

$$\begin{aligned} y_{cm} = \sum_{m=i}^{j}\{\alpha_0\} \times [MonthDummy_m] + \sum_{m=i}^{j}\{\alpha_1\} \times [MonthDummy_m] \times outsideBanZone_c \\ + \sum_{m=i}^{j}\{\alpha_2\} \times [MonthDummy_m] \times z_c + \gamma_c + \varepsilon_{cm} \end{aligned} \quad (4)$$

where all elements remain the same as in equation (3), except for the month dummies summation terms, and the inclusion of cell-specific fixed effects γ_c, which subsumes the individual terms $outsideBanZone_c$ and z_c. Indeed, equation (4) differs in which it allows for the comparison of the discontinuities in monthly fishing activity at the 20nm threshold, for all months from i to j that are subsequent to the baseline month of January 2015.[12]

4 Overall Impact of the Formosa Disaster

In this section, we systematically test for the causal impact of the Formosa environmental disaster to fishing communities in four affected central provinces. We separately investigate the disaster's effects to labor outcomes and fishing activities of saltwater fishermen, utilizing the inter-related information obtained from the labor force surveys and satellite images. Using the LFS, we estimate a massive and significant reduction to monthly incomes of the victims after Formosa took place. However, empirical result suggests that their workload was not affected. We then examine the changes in fishing pattern, focusing on the 20-nautical-mile near-shore fishing-ban zone along the coast from Ha Tinh to Thua Thien-Hue. We continue to

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

[12] In the main regressions, we report the difference-in-discontinuities estimates for all months between Febuary 2015 and December 2017, using the RD estimate in January 2015 as the baseline. This period coincides with the period used in out earlier DiD regressions.

find sharp reductions to both fishing prevalence and intensity in this contaminated sea waters. In the last sub-section, we probe our findings with a battery of validity and falsification tests, from which we observe no "hypothetical" effect of Formosa before the accident actually took place, or to other unaffected provinces and industries.

4.1 Impact on labor outcomes in saltwater fisheries

Table 2 shows result from our DiD estimations of Formosa' impact on monthly wages from the main job, weekly hours worked on the main job, and total monthly income of Formosa-affected saltwater fishermen. The treatment group consists of pre-event fishermen in the four affected provinces and the control group consists of pre-event fishermen in all other coastal provinces. Columns (1) to (3) present our empirical results for pre-event fishermen who either stayed with saltwater fishing or changed to other jobs after the disaster. There were a total of 657 fishermen who met these criteria and were representatively surveyed in the entire country in 2016. In columns (4) to (6), we document the same regression outcomes, but limiting our sample to only "persistent" fishermen: those who did not (or could not) switch jobs in 2016 after the disaster took place. In total, there were 563 fishermen in this restricted sample.

Because the Formosa disaster affected a specific industry (saltwater fishing) in a specific region (central coastal Vietnam), we are able to quantify the magnitude of its damage with two separate DiD exercises. In Panel A, we compare the before-after changes in fishermen's labor outcomes in saltwater fisheries between the affected region (treatment group) to other region (control group) in the country. In Panel B, we instead focus only within the four Formosa-affected provinces – Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue – and compare labor outcomes of workers working in saltwater fisheries (treatment group) to workers working in the non-fishing, Formosa-unconnected industries (control group) namely manufacturing, construction, and retails. In both exercises, the magnitude of the estimated coefficient $\hat{\beta}_1$ would convey the impact of Formosa on affected fishermen's employment and income after the disaster occurred in April 2016.

Overall, after controlling for both the month-specific and individual-specific fixed effects and clustering the errors terms at the district-level, our estimation results robustly indicate a massive and statistically significant drop to fishermen's monthly earning and total income by between 43 to 45 percent (columns (1) and (3)). The negative impact seems to be of even larger magnitude for the individuals who strictly stayed with saltwater fishing; their incomes dropped by an additional 3 to 5 percent. The fact that fishermen who were unfortunate to locate within the contaminated waters saw their income cut in half speaks directly to how destructive this environmental disaster was to both the supply and demand sides of saltwater fishing industry. From the supply-side perspective, safe fish and sea products, suddenly, became much more rare and costly to catch. As will be discussed in detail later, we show that affected fishermen, depending on their location within the affected region, had basically two options to select between; they either coped with the shock by going to safer fishing grounds with an inevitable cost, or switched to a new, obviously less specialized, job. From the demand side, seafood consumers, in lights of Formosa-related news and the subsequent ban on poisoned seafood processing, were reluctant to purchase.

What is interesting from the empirical result in Table 2 is that fishermen's worked hours, regardless of the lengthy fishing ban and the obvious dip in seafood prices following the disaster, did not seem to decline. Even though Formosa's impact on the weekly length of employment is negatively estimated, it is not statistically meaningful at conventional levels across different specifications and/or empirical exercises. In section 5, we provide corroborating evidence. We show that fishermen, on average, did find ways to continue working to support themselves and their dependents, even when their labor were being compensated much less than before.

4.2 Impact on satellite-detected fishing activities

Having shown a significant decline to affected fishermen's welfare, we next immediately concern with Formosa's impact to fishing activities in the damaged region. To build upon our visual inspection in Figure 2 and rigorously analyze the causal relationship, we rely on the DiD exercises. In Table 3, we report the estimated coefficient $\hat{\delta_1}$, using a balance panel of monthly boat-detection grid cells for the three most-relevant years from 2015 to 2017. Our two key outcomes include fishing intensity – changes in total number of boats detected (measured with the logarithm of the number of boats in a cell), and fishing prevalence (measured with the 0/1 probability that a cell detected at least one boat). The nature of this novel dataset allows us to check for the robustness of the results by varying the level of fixed-effects control, as well as the choice of comparison groups. Because there is no official definition/threshold for what is considered near- or off-shore, in this and subsequent exercises, we rely on the government's fishing ban zone's cutoff. Consequently, we define any grid cells located less than 20nm from the shoreline as near-shore; those locating further than 20nm, but less than 80nm, away from shore would be considered off-shore. The 80nm is enforced to ensure that we do not spuriously count moving ships/freights which often travel far away from coast as fishing boats, since it is possible that light from these ships are also detected by VIIRS' satellites.[13]

Consistent to what we observe in Figure 2, it is evident that near-shore fishing within

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[13] Computational-wise, restricting the geographic upper bound also enables us to employ large sets of grid cell, province, and month fixed effects in our regressions.

the ban zone was negatively affected. All DiD estimates were statistically significant at the 99% confidence level. The result suggests a lower bound in the negative differential growth of between 15 and 19 percent in boat detection within the fishing ban zone, relative to near-shore fishing in control regions. Overall, after the disaster, there was also a differentially greater percentage of empty fishing grounds in the contaminated zone – the DiD coefficients with boat detection probability outcome is documented to be between -6 and -9 percentage points. Note that the effect estimated in Table 3 is at the intensive margin due to the inclusion of grid cell's fixed effects, which essentially captures changes to grid cells that were detected with boats both before and after Formosa disaster. It should be mentioned that due to the nature of fisheries business, vast majority of fishing boats often choose to populate around fishing grounds, where it is known to have provided high catch rates. These fishing grounds are illustrated in Figure 2 by clusters of bright pixels. In contrast, there is usually little to no fishing action outside of the fishing grounds. Indeed, approximately half of the cell pixel are continuously unlit, indicating "empty" sea segments with no boat detected. In our regressions, we accommodate for this particular characteristic by modifying the log-transformed boat-detection outcome variable, adding a constant of ones to boat counts before the transformation. We refer to this specification in the result tables as "modified log" value. We additionally report in the Online Appendix's Table OA1 the DiD results adopting two other indicative outcomes of boat detection, including measures of boat count in level, as well as in unmodified logarithm version. Our result remains robust in both the estimates' direction and magnitude.

4.3 Validity and falsification tests

In this subsection, we supply evidence from a series of empirical exercises to validate our DiD approach, and to ensure that the main effects found in Tables 2 and 3 are sensibly and reliably identified.

4.3.1 Validity of the parallel-trend assumption

An important assumption underlying the difference-in-differences approach is that units of the treatment and control groups were following a "parallel trend", so that outcomes of the control would reasonably serve as counterfactuals for the treated units after the Formosa disaster took place. In this section, we address the validity of this parallel trend assumption by replicating the identical regression exercises in Tables 2 and 3 on predetermined labor and fishing activity outcomes.

In the first placebo test, we use the 2015 labor force data and generate a fictional event in April 2015. Because this entire time frame predates the actual Formosa disaster, we do not expect any effect. Table A1's Panel A in the Appendix section documents the DiD result. Indeed, relative to the control group, the differential change in income and worked hours of affected fishermen before and after April 2015 are shown to be insignificant; the effect is imprecisely estimated around zero, especially for the income measures. We repeat this falsification exercise for fishing activity in Table A2, utilizing an antecedent sample of months between 2013 and 2015, in which a fictional event is hypothetically created in May 2014. The majority of the estimates are small and indistinguishable from zero, except for the coefficients in columns (3), (7), and (8). In these columns, $\hat{\delta_1}$ was actually *positively* estimated, suggesting that *more* fishing activities were detected within the contaminated zone relative to others, before Formosa happened.

Another valid concern would be whether it was actually the Formosa disaster *causing* massive reduction to economic welfare and activity of saltwater fishermen. Our estimates would represent an upward bias to Formosa's true effect if there happened to be another unfavorable shock taking place in central Vietnam during the exact same period. We address this concern in Table A1's Panel B. In this panel, we select industries that are either highly-unconnected (columns (1) to (3); manufacturing, construction, and retail), or loosely-unconnected (columns (4) to (6); farming) to the Formosa disaster.[14] We then replicate the DiD estimation on workers who strictly stayed in these professions throughout the two 2016 survey visits. If there were a region-wide shock which affected economic performance in central Vietnam around the same period as Formosa did, the shock would likely also affect other industries such as manufacturing, construction, or retail.[15] Coupling with anecdotal evidence, we empirically show that there was likely no such shock; both income and workload for industrial-waged workers in the four Formosa-affected provinces did not differential change in 2016, relative to other places in the country. This result further speaks to the validity of our DiD setting in Table 2 (Panel B), in which we measured Formosa impact to fishermen's labor outcomes by holding the performance of waged workers in other industries as the comparison group.

Yet another concern could emerge: what if there was a shock affecting central provinces around April 2016, which did not negatively influence all economic activities in the region, but only narrowly affected a subset of Formosa's more-connected industries, such as agriculture or farming? For instance, a high-category hurricane strike would likely dampen both fishing and farming activities, but leave industrial workers undamaged. Even though hurricane seasons in central Vietnam do not often start until the beginning of Fall (i.e. around the

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[14] Arguably, the incident only damaged coastal fishing industries, and, to a lesser extent, tourism.

[15] These specific industries were employed as control group in our earlier DiD estimation reported in Panel B of Table 2.

end of September), we still perform another placebo test using a sample of farming workers before and after Formosa incident in April 2016. In Panel B's columns (4) to (6), the estimates for these individuals continue to be small in magnitude and statistically insignificant, further indicating that Formosa itself was the cause to the devastation endured by fisheries communities in central Vietnam.

4.3.2 Falsification tests with randomization inferences

From an econometric perspective, is there a possibility that the effects shown in Tables 2 and 3 are spurious, that is, they are simply outcomes of "the luck of the draw" and not at all because of Formosa incident? We show that such "lucky draw" is highly unlikely to materialize. We take randomly three to five provinces among the unaffected coastal provinces. We assigned these randomly-picked unaffected provinces as the treatment group and rerun the DiD regressions for saltwater fishermen's log-transformed monthly income as well as the intensity of boat-detection between this falsified random treatment group and falsified random control group. We perform this randomization inference test for 1,000 iterations, and plot the distributions of these 1,000 estimated coefficients and their respective t-statistics in Figure 3. For both income and boat detection, the falsified estimated coefficients seem to be statistically distributed around zero (panels A1 and B1), so are the t-statistics (panels A2 and B2). 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.[16] Note that the estimated values obtained from regressions with the four affected provinces as the treatment group – those reported in Tables 2 and 3 – always lie at the left-tail of the distribution (the red vertical lines in the panels), indicating that the effects we captured are not likely to be regenerated using other provinces.

5 Coping Mechanisms, Spillover Effects, and Fishing Recovery

In this section, we study how Formosa's main victims – saltwater fishermen in Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue – responded to such negative disturbance affecting their livelihood. We show evidence that fishermen who could feasibly travel to fish in safe

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[16] We select randomly between three to five provinces in each iteration due to the fact that the coastal areas of provinces are not the same – some provinces have larger or smaller coast lengths than others. We also experimented with the random treatment selection of between one and five provinces and obtained highly identical results. Note that we remove Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue from the all iterative samples to prevent contaminated effect.

locations did likely resort to this option, even though at an associated cost in earnings. In contrast, fishermen who were restricted from moving to safe waters had to look for secondary jobs, or change their job entirely, to mitigate the income losses. In a collaborating subsection, we empirically address the underlying cause triggering fishermen's responses. Utilizing the fishing ban zone's 20-nautical-mile threshold as a source of discontinuous variation, we find, under a spatial regression discontinuity setting, no "cutoff" effect to fishing activity just outside of the 20nm cutoff. Coupling with the earlier coping mechanism result, this evidence suggests that it was not likely the fishing ban that fishermen responded to, but more likely the contaminated waters the underlying cause triggering coping activities. Next, we proceed with the examination on potential spillover effects of Formosa disaster to the neighboring fishing communities. There is evidence that the southern neighboring region absorbed a negative spill, mostly due to the fact that contaminated waters spread, or were perceived to had spread, southward (and not upward) because of the downstream ocean flow. Both labor outcomes and fishing activity in the northern neighboring communities, on the contrary, benefited from the situation. Finally, we study short- and medium-run fishing recovery after the incident. Our estimates suggest that fishing communities in the affected region recovered to the base level after approximately a year and a half.

5.1 How did the victims cope with the shock?

To motivate our discussion on fishermen's coping mechanisms to the environmental disaster, we first provide evidence that the disaster did not uniformly affect the four provinces. In Table 4, we split the affected provinces (i.e. treatment group) into two separate groups by their geographic locations: Ha Tinh and Quang Binh as the northern half, and Quang Tri and Thua Thien-Hue in the south. We immediately discover a distinct difference in how saltwater fishermen in these two groups were affected by Formosa. In terms of the impact on incomes, the damage to individuals located north of the poisonous ocean stream (i.e. in Ha Tinh and Quang Tri) is statistically significant, and ranges consistently between 44 to 49 percent reduction to fishermen who either stayed or switched jobs after the incident. In contrast, the estimated income damage to "persistent" fishermen who located south of the contaminated zone (i.e. in Quang Tri and Thua Thien-Hue) in columns (4) and (6) are almost doubled the figures in columns (1) and (3) (in which all fishermen were considered), and are also found to be 8 to 11 percent more severe than their counterpart's in Ha Tinh and Quang Binh. This evidence suggests a huge incentive for Quang Tri' and Hue's fishermen to give up fishing and change their jobs, which we indeed observe and will subsequently discuss in Table 5. Estimation outcomes for workload further showcases how disadvantaged fishermen in the southern half of Formosa-affected region were, compared to those in the northern half;

the average weekly worked hours for saltwater fishermen in Quang Tri and Thua Thien-Hue dropped significantly by 23 (column (2)) to 30 hours (column (5)), but did not drop for those located in Ha Tinh and Quang Binh.

In order to investigate the reason underlying such discrepancy in the geographic distribution of Formosa impact, we turn to our satellite's boat-detection data. To begin with, there was an immediate five-month ban to near-shore fishing activities within 20nm off the coastline of all four affected provinces. In addition, an ultimate demand-side shock to the saltwater industries was reinforced – the government put an unconditional ban in the processing and selling of seafood caught within 20 nautical miles of central Vietnam provinces shortly after Formosa incident was discovered, worrying that contaminated seafood in the region might not meet safety standards. For a lengthy period of time after the Formosa disaster, the general public was expressing their unwillingness to purchase and consume saltwater seafoods caught *anywhere* in the central coastal region south of Ha Tinh. This disinclination is rooted on reasonable grounds. In the first place, there was initial delay and confusion in the public communication between different ministries regarding the assessment on the magnitude and location of the disaster.[17] Secondly, the public was fearing that central waters' fishes and sea products caught outside of the four affected provinces were also contaminated, citing potential direct downstream spillovers of toxic wastewater to neighboring coasts south of the ban zone.[18] While we delay our detailed discussion on the spillover effects of Formosa to the next sub-section, we rely on these anecdotal evidences and show empirically that they were likely reinforcing a scenario in which fishermen in different affected regions had to cope with the disaster differently.

To closely examine how fishermen coped with the incident, we perform a province-by-province DiD exercise, separately estimating Formosa's impact to each individual provinces along the northern and central coast of Vietnam, for both near-shore and off-shore fishing activities. That is, each province is iteratively granted "treatment" status, and its associated average boat detection outcomes are then compared to those of the control groups. In this setting, our preferred control group is the Southern coasts, where fishing activity was arguably unaffected by the Formosa environmental disaster[19] (columns (2) and (4)). To

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[17] For instance, the National Resources and Environment Ministry initial rejected any linkage between Formosa discharge and the mass fish kill in central coastal waters in April 2016, but then reverted the claim later in May (Nguyen and Nguyen, 2016) The Minister later publicly apologized for such confusion (RFA, 2016a). Another confusion source came from the uncoordinated responses between different officials. For instance, the government's announcement on the ban of processing and selling seafood caught within 20 nautical miles of central Vietnam provinces in May 2016 came just one day after the Ministry of Natural Resources and Environment had claimed that the seafood in the region met safety standards (VOA, 2016b).

[18] Up to this point, there has been no concrete sources documenting this claim.

[19] Fishing migration, especially of small boats which often operate near-shore, between the central to southern coasts is highly cost-ineffective due to substantial traveling distance. Fishermen's limited knowledge

further advance the visualization of our finding, we present Figure 4, plotting the province-by-province DiD estimated coefficients and their 95% confidence intervals, separately for near-shore (Panel A) and off-shore activities (Panel B).[20]

Panel A illustrates the effect of Formosa incident to the northern and central coastal provinces, from Quang Ninh to Binh Thuan. It can be observed that Formosa incident did not just hit near-shore fishing communities located inside the fishing ban zone, but also negatively influenced activities south of the study area, including Da Nang, Quang Nam, Quang Ngai, and Binh Dinh.[21] The effect's magnitude does seem to decrease for regions further away south, and becomes small and statistically insignificant starting from Phu Yen. In Panel B, we consider the potential effect to offshore fishing. Unlike near-shore, the negative effect to offshore fishing is considerably less dramatic and geographically narrower – only activities in the region immediately surrounding the location of Formosa seems to be affected.

Figure 4 also exhibits another interesting pattern. Across Panels A and B, there was a significant increase in fishing activities to the northern-most coastal provinces following Formosa disaster. For near-shore, this positive effect stresses from Quang Ninh all the way to Nghe An, the neighboring province north of Ha Tinh. The effect is also highly positive and meaningful offshore of Quang Ninh, Hai Phong and Thai Binh. This finding, coupling with our result using the Labor Force Surveys that the affected fishermen's workload did not decrease after the incident, directly suggests that there was a coping mechanism in place: fishermen traveled to uncontaminated grounds to continue fishing.

An immediate question, then, occurs: where did the affected fishermen migrate to fish? The pattern in Figure 4 continues to provide potential evidences. Among the four affected provinces, those located in the northern part – Ha Tinh and Quang Binh – were likely to possess better adapting options. Recall the fact stated earlier that toxic substances discharged by Formosa plant in Ha Tinh were perceived to have flown downstream due to the ocean flows, leaving the waters in region north of Ha Tinh safe for fishing. Thus, fishermen in Ha Tinh and Quang Binh could move north and either catch fishes near- or offshore, explaining for the differential increase in fishing boats detected at the northern coast. In contrast, the options for fishermen in Quang Tri and Thua Thien-Hue were much more limited: transporting north, especially for those operating small boats and mainly fish near-shore, was much more

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of new fishing grounds is another important constraint. Of course, these limitations are of lesser concern to off-shore fishing boats, which are often equipped with more advanced gears compatible to longer-duration fishing.

[20] This plot corresponds to estimations reported in column (2) of Table OA3.

[21] It is noted that there is no official boundary for the maritime zones at the provincial-level. In this paper, we roughly define a province's water boundary by using the latitude of its provincial land-border's interception with the shoreline. We then consider any water space (i.e. grid cells) lies within this defined boundary to be the sea zone belonging to the province itself.

cost-ineffective due to the traveling distance they have to make. Besides the higher direct transportation cost in terms of diesel consumption, fishermen would also have to worry about the inflated expenses related to preservation of sea-products' freshness – a crucial factor of the selling price. Migrating south to fish near-shore was also not prospective when seafood consumers were also reluctant to purchase products caught in Da Nang, Quang Nam, and Quang Ngai, provinces immediately south of Hue. These fishermen, then, had to make the hard choices; to stay in saltwater fisheries, they had to travel distantly and cost-ineffectively offshore (either further down south to Binh Dinh or Phu Yen – areas experiencing positive effect in boat detection after Formosa, or up to the northern sea). Otherwise, the only other prospect is to obtain secondary jobs away from fishing, or change their jobs entirely. Indeed, the descriptive statistics on job-switching after Formosa disaster in Table A5 indicate that as much as 40 percent of fishermen in Quang Tri and Thua Thien-Hue stopped fishing, compared with just 8.3 percent in Ha Tinh and Quang Binh, or 14.1 percent for the rest of the country.

Table 5 further reflects our intuition. The table shows that fishermen in Quang Tri and Thua Thien-Hue are more likely to have secondary jobs or to switch jobs after Formosa disaster. A fisherman who stayed in saltwater fisheries was 9 to 14 percentage points more likely to obtain secondary jobs after the disaster relative to the control group (columns (1) and (2)). In addition, a pre-event fishermen in these two provinces were 26 percentage points more likely to drop out of fishing and moved into a different industry. This is not the case in Ha Tinh and Quang Binh; Formosa did not induce differential increase in job-switching or the likelihood of obtaining secondary jobs for saltwater fishermen in these provinces. This finding directly explains for the distinct patterns in the income impacts that we found earlier (in Table 4).

5.2 The underlying cause: the fishing ban or the contamination?

Up to this point, we have measured the overall impact of Formosa to fishing industry in the affected region, and presented empirical evidences indicating heterogeneous coping mechanisms of fishermen. In this subsection, we aim to identify the underlying cause triggering fishermen's responses. Recall that the Formosa disaster erupted in April 2016, followed by a five-month fishing ban for the entire 20nm near-shore water along the coast of Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue. The question, then, is whether the economic coping activities found earlier the consequence of fishermen responding to the contaminated waters, or to the legal reinforcement imposed by the fishing ban. Answering this question would allow us to elucidate the necessity of the ban, as well as to shed more light on understanding the magnitude of the disaster. To do so, we empirically rely on a setting of regression discontinuity design, exploiting the fishing ban zone's 20-nautical-mile threshold as a source of discontinuous variation in fishing eligibility.

The RD estimation essentially compares fishing activity just around this 20nm threshold during the five-month ban period. Importantly, we hypothesize that if fishermen's response was driven mainly by the ban policy, and not by the toxic near-shore water, we would likely observe a rational migration of near-shore fishing boats to just right outside of the 20nm cutoff. This movement would enable fishermen to continue fishing legally (by abiding to the ban), and effectively (by not having had to travel too far offshore which inflates costs). In this case, we would observe a significant and discontinuous effect to boat detection just outside the 20nm cutoff. However, if it was not the government's policy that fishermen responded to, but instead the contaminated near-shore fishing grounds, we would not observe any effect around the 20nm threshold. Because, unlike the fishing ban, the degree to which the ocean ecosystem was poisoned does not change discontinuously at the 20nm, or at any other distance cutoff, for that matter.

We present the main result from our RD analysis in Figure 5. In Panel A, we provide plots of the discontinuity in boat detection at the 20nm threshold, separately for fifteen consecutive months, in groups of 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 20nm 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). These plots correspond to the RD estimation of equation (3), which we report in detail in Appendix's Table A4. The result from Table A4 indicates that, across all parametric and non-parametric RD estimators, and irrespective of the polynomial orders or the choice of bandwidth intervals, we find no significant effect in fishing activity just outside of the 20nm zone, for any month before, during, and after the effective period of the fishing ban. This robust insignificant "cutoff" effect is visually illustrated in Panel A of Figure 5, where we detect no meaningful discontinuity at the threshold in any of the fifteen monthly plots. Figure 5's Panel B further corroborates the result. The figure shows monthly estimates of the difference-in-discontinuities effect between January 2015 and December 2017[22], comparing the estimated discontinuities at the 20nm threshold for all subsequent months to the baseline in January 2015 (i.e. the first month in the sample). For all the months between February 2015 and December 2017, the discontinuities are estimated to be indistinguishable from the level in January 2015, suggesting that there were likely nothing "special" in fishing activity around the 20nm threshold during the fishing ban period in 2016. This finding suggests that the underlying cause to the vast decline in fishing activity was not likely the fishing ban imposed by the government. Instead, the

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[22] This is the period used in our main DiD regressions reported earlier.

reduction in boat detection was more likely a direct consequence of Formosa's damage itself.

5.3 Spillover effects of Formosa

The dramatic impact of Formosa put a heavy toll on the welfare of those working in saltwater fishing industry. We have also shown earlier (in Table A1) that this incident did not affect unconnected industrial industries such as manufacturing, construction, retail, or farming. We now pay attention to potential spillovers to more-connected industries in the four affected provinces. Four industries we examine are freshwater fishing, husbandry, restaurants and lodging. Freshwater fishing and husbandry are chosen because there might have been food substitutions from saltwater fish to freshwater fish or poultry. Restaurants and lodging are chosen because of potential spillovers on tourism that was anecdotally reported (VOA, 2016a). As Table 6 indicates, there seems to be a positive spillover to income and workload in freshwater fishing in provinces where Formosa had the highest impact (Quang Tri and Thua Thien-Hue). The estimated increases are 19 to 24 percent for monthly incomes, and 8 to 10 working hours. This effect is likely due to the positive demand shock for freshwater fishes after Formosa took place – prices of the saltwater-substituted fishes soared when demand for them elevated. Unlike the case of the freshwater fisheries, we find no evidence for spillovers in labor outcomes to husbandry, restaurant, or lodging industries.

In Table 7, we examine a different kind of spillover effect. We look at the impact of Formosa to saltwater fishing industry in the neighboring regions immediately north and south of the fishing ban zone. We do so by running a pooled fixed-effect DiD regression, partialling out the sample into different groups including the affected provinces (i.e. Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue – Panel A), provinces immediately north (Nghe An and Thanh Hoa – Panel B), and south (Da Nang, Quang Nam, and Quang Ngai – Panel C). We then further partial out the post-treatment period into subsequent quarters, and interact these quarter indicators with each of the newly defined groups of provinces. Overall, table 7 shows that there was no Formosa spillover impact on the workload of neighboring saltwater fishermen. Coupling with the earlier result in Figure 4 which shows intensified boating activities detected at safe fishing grounds up north (especially for near-shore zones), the fact that workload did not increase for the fishermen located there further supports our hypothesis; it suggests that there were deferentially more boats migrated north from the Formosa-affected provinces, most likely from Ha Tinh and Quang Binh. Interestingly, income from saltwater fishing for the adjacent provinces – both north and south of the fishing ban zone – increased, most significantly in July, August and September (columns (2) and (4)). This, combined with largely unchanged working hours, indicates that the increase in income must has come from increasing in the prices of safe saltwater seafood.

5.4 Fishing recovery

In this last subsection, we study the recovery of fishing communities after Formosa incident. We address this by analyzing Formosa's effect over time. The result in Panel A of Table 7 indicates a clear declining trend on the negative impact of Formosa to affected fishermen's monthly income; the effect's magnitude decreases from as much as 58 percent in the second quarter (i.e. April to June – right after the incident took place) to 35 percent at the end of 2016.[23] Workload, instead, was never affected, which is consistent with our early results. While it is encouraging to observe the rapid recovery to income of affected fishermen, the fact that their monthly earnings were still cut by more than a third months after the Formosa took place shows how devastating and long-lasting the disaster was.

Because our monthly boat-detection data were collected up to May 2018, we are able to capture a longer recovery timeline for fishing activity in the affected area. Table 8 reports this result for the recovery of fishing prevalence and intensity within the ban zone, 20nm near-shore of coastal Ha Tinh, Quang Binh, Quang Tri, and Thua Thien-Hue. Across different estimating specifications, and for both outcome measures, the negative impact of Formosa seems to have dissipated as time goes by. If the number of detected boat in the affected area was reducing some 40 percent more than in other regions, this magnitude diminished to on between 17 to 26 percent around 15 months later (during Q3-2017). The effect also started fading out at the end of 2017 – even though remaining negative, the DiD coefficients are no longer significantly estimated in 2018. Fishing prevalence, as measured by the probability of boat detection, broadly exhibits the same pattern – the statistically significant effect seems to disappear at the end of 2017. Our estimates for the recovery of near-shore fishing activity in the contaminated zone is consistent with official reports at different snapshots along the timeline. For instance, in June 2017, the Ministry of Agriculture & Rural Development in Ha Tinh reported that near-shore fishing has reached a magnitude equaling to 75 percent of pre-Formosa period (VOV, 2017). By May 2018, reports claimed that both near-shore and off-shore fishings in affected region had returned to the base level (Vnexpress, 2018).

6 Conclusions

This paper examines the economic impact of a large-scale industrial disaster to the employment outcomes of a local population. The Formosa's chemical contamination incident, in which toxic wastewater was discharged into the ocean and damaged an entire ecosystem in

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[23] For completeness, we also report results from a "conventional" DiD regression with binary treatment indicator (instead of categorical, as in Table 7). As shown in Appendix's Table A6, the estimates are consistent to that found in Table 7.

the central coastal provinces of Vietnam in 2016, presented a special case study for how the affected communities – workers in saltwater fisheries – coped with the negative shock. We combine a novel satellite-captured boat-light detection dataset with the labor force surveys and show that the disaster reduced incomes by as much as 46 percent. We further provide evidence indicating potential coping mechanisms. Fishermen located closer to uncontaminated fishing grounds were likely to travel there and continue fishing, as shown by the intensified boating activities in those regions after the incident took place. In contrast, fishermen who located far away from safe waters suffered more in terms of the damage to income and working hours. They are more likely to obtain secondary jobs, or change jobs. Both coping mechanisms are shown to help mitigate the income losses, even though far from entirely. We find that the negative labor market effects, and subsequent coping activities, were likely driven by the contamination itself, and not by the near-shore fishing ban that the government put in place. We also find a positive spillover effect to the incomes of saltwater fishermen in neighboring provinces, and of freshwater fishermen in the affected region. Finally, we show that the affected saltwater fishing communities recovered over time; fishing activities returned to base level after one year and a half.

Examining the impact of the Formosa disaster on the affected population and how they cope with the shock is relevant for the design of assistance policies when environmental disasters take place. We show that, even on average, the impact of Formosa is not uniformly distributed among the victims. It is also evident that Formosa did not just affect the four provinces located within the contaminated zone, but nearby regions as well. These elements should be factored into any top-down incentives to compensate and subsidize the affected individuals and households.

References

Al-Majed, Abdul Aziz, Abdulrauf Rasheed Adebayo, and M. Enamul Hossain, “A sustainable approach to controlling oil spills,” *Journal of Environmental Management*, 2012, *113*, 213 – 227.

Belasen, Ariel R. and Solomon W. Polachek, “How Disasters Affect Local Labor Markets: The Effects of Hurricanes in Florida,” *Journal of Human Resources*, 2009, *44* (1).

Burkhauser, Richard V., Kenneth A. Couch, and David C. Wittenburg, “Who Minimum Wage Increases Bite: An Analysis Using Monthly Data from the SIPP and the CPS,” *Southern Economic Journal*, 2000, *67* (1), 16–40.

Calonico, Sebastian, Matias D. Cattaneo, and Max H. Farrell, “On the Effect of Bias Estimation on Coverage Accuracy in Nonparametric Inference,” *Journal of the American Statistical Association*, 2018, *0* (0), 1–13.

__ , __ , and Rocio Titiunik, “Robust Nonparametric Confidence Intervals for Regression-Discontinuity Designs,” *Econometrica*, 2014, *82*, 2295–2326.

Cameron, Lisa and Manisha Shah, “Risk-Taking Behavior in the Wake of Natural Disasters,” *Journal of Human Resources*, 2015, *50* (2), 484–515.

Chaurey, Ritam and Duong Le, “Infrastructure Grants and the Performance of Microenterprises,” *IZA Discussion Paper No. 11749*, 2018.

Christodouleas, John P., Robert D. Forrest, Christopher G. Ainsley, Zelig Tochner, Stephen M. Hahn, and Eli Glatstein, “Short-Term and Long-Term Health Risks of Nuclear-Power-Plant Accidents,” *The New England Journal of Medicine*, 2011, *364*, 2334–41.

Cohen, Maurie J., “Technological Disasters and Natural Resource Damage Assessment: An Evaluation of the Exxon Valdez Oil Spill,” *Land Economics*, 1995, *71* (1), 65–82.

Donaldson, Dave and Adam Storeygard, “The View from Above: Applications of Satellite Data in Economics,” *Journal of Economic Perspectives*, November 2016, *30* (4), 171–98.

Elvidge, Christopher D., Mikhail Zhizhin, Kimberly Baugh, and Feng-Chi Hsu, “Automatic Boat Identification System for VIIRS Low Light Imaging Data,” *Remote Sensing*, 2015, *7* (3), 3020–3036.

__ , Tilottama Ghosh, Kimberly Baugh, Mikhail Zhizhin, Feng-Chi Hsu, Nilo Selim Katada, Wilmon Penalosa, and Bui Quang Hung, “Rating the Effectiveness of Fishery Closures With Visible Infrared Imaging Radiometer Suite Boat Detection Data,” *Frontiers in Marine Science*, 2018, *5*, 132.

EM-DAT, “EM-DAT: The Emergency Events Database - Universit catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium,” www.emdat.be 2017.

Garza-Gil, M. Dolores, Albino Prada-Blanco, and M. Xos Vzquez-Rodrguez, “Estimating the short-term economic damages from the Prestige oil spill in the Galician fisheries and tourism,” *Ecological Economics*, 2006, *58* (4), 842 – 849.

General Statistics Office, “Labor Force Survey 2016,” Technical Report, Government of Vietnam 2016.

__ , “Statistical Yearbook of Vietnam, 2016,” Technical Report, General Statistics Office of Vietnam 2016.

Gray, Clark and Valerie Mueller, “Drought and Population Mobility in Rural Ethiopia,” *World Development*, 2012, *40* (1), 134–145.

Imbens, Guido and Karthik Kalyanaraman, “Optimal Bandwidth Choice for the Regression Discontinuity Estimator,” *Review of Economic Studies*, 2012, *79* (3), 933–959.

Imbens, Guido W. and Thomas Lemieux, “Regression discontinuity designs: A guide to practice,” *Journal of Econometrics*, 2008, *142* (2), 615 – 635. The regression discontinuity design: Theory and applications.

Liu, Xin, Ruolin Meng, Qianguo Xing, Mingjing Lou, Hui Chao, and Lei Bing, “Assessing oil spill risk in the Chinese Bohai Sea: A case study for both ship and platform related oil spills,” *Ocean & Coastal Management*, 2015, *108*, 140 – 146. Estuaries and Coastal Areas in Times of Intense Change.

Neidell, Matthew J., “Air pollution, health, and socio-economic status: the effect of outdoor air quality on childhood asthma,” *Journal of Health Economics*, 2004, *23* (6), 1209 – 1236.

Nguyen, Ho Binh and Mai Nguyen, “Vietnam says no proof Formosa steel plant linked to mass fish deaths,” https://www.reuters.com/article/us-vietnam-formosa-plastics-environment-idUSKCN0XO18L 04 2016. Accessed July 29, 2018.

Noy, Ilan, “The macroeconomic consequences of disasters,” *Journal of Development Economics*, March 2009, *88* (2), 221–231.

Page, Lionel, David A. Savage, and Benno Torgler, “Variation in risk seeking behaviour following large losses: A natural experiment,” *European Economic Review*, 2014, *71* (C), 121–131.

Pan, Guangchen, Shengyao Qiu, Xin Liu, and Xiaoke Hu, "Estimating the economic damages from the Penglai 19-3 oil spill to the Yantai fisheries in the Bohai Sea of northeast China," *Marine Policy*, 2015, *62*, 18 – 24.

Petridou, E., D. Trichopoulos, N. Dessypris, V. Flytzani, S. Haidas, M. Kalmanti, D. Koliouskas, H. Kosmidis, F. Piperopoulou, and F. Tzortzatou, "Infant leukaemia after in utero exposure to radiation from Chernobyl," *Nature*, 1996.

Phys.org, "Vietnam Maintains Ban on Deep-water Fishing in Polluted area," https://phys.org/news/2017-05-vietnam-deep-water-fishing-polluted-area.html 05 2017. Accessed July 29, 2018.

Prime Minister of Vietnam, "Decision 1880/Q-TTg on the compensation to the provinces of Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue following the marine environmental incident.," September 2016.

__ , "Decision 309/Q-TTg on the revision of Decision 1880/Q-TTg on September 29 2016 regarding the compensastion for the provinces of Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue following the marine environmental incident.," March 2017.

RFA, "Vietnam Minister Apologizes For 'Confused' And 'Slow' Response to Fish Crisis," https://www.rfa.org/english/news/vietnam/vietnam-fish-04292016170303.html 04 2016. Accessed July 29, 2018.

__ , "Vietnam says Taiwan firm's pollution affected 200,000 people," https://www.rfa.org/vietnamese/news/vietnamnews/vn-says-taiwan-firm-s-pollution-affected-200000-people-07292016090943.html 07 2016. Accessed July 29, 2018.

Shenoy, Ajay, "Regional Development through Place-Based Policies: Evidence from a Spatial Discontinuity," *Journal of Development Economics*, 2018, *130*, 173–189.

Strobl, Eric, "The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions," *Journal of Development Economics*, 2012, *97* (1), 130–141.

Vnexpress, "Vietnam Health Ministry Declared Fishes in Central Provinces are Safe for Consumption," https://vnexpress.net/tin-tuc/thoi-su/bo-y-te-cong-bo-hai-san-bon-tinh-mien-trung-bao-dam-an-toan-3750773.html 05 2018. Accessed July 29, 2018.

VOA, "Formosa disaster destroyed toursim industry in central Vietnam," https://www.voatiengviet.com/a/formosa-giet-chet-du-lich-mien-trung/3606970.html November 2016. Accessed July 29, 2018.

__ , "Vietnam Bans Unsafe Seafood in Central Provinces," https://www.voanews.com/a/vietnam-bans-unsafe-seafood-in-central-provinces/3316289.html 05 2016. Accessed July 29, 2018.

VOV, "Fishing Activities rapidly Recover after the Formosa disaster," https://baomoi.com/sau-su-co-formosa-khai-thac-thuy-hai-san-hoi-phuc-nhanh/c/22637150.epi 06 2017. Accessed July 29, 2018.

Wirtz, Kai W., Nick Baumberger, Susanne Adam, and Xin Liu, "Oil spill impact minimization under uncertainty: Evaluating contingency simulations of the Prestige accident," *Ecological Economics*, 2007, *61* (2), 417 – 428.

Figure 1: Map of Vietnam with a focus on Formosa study area.

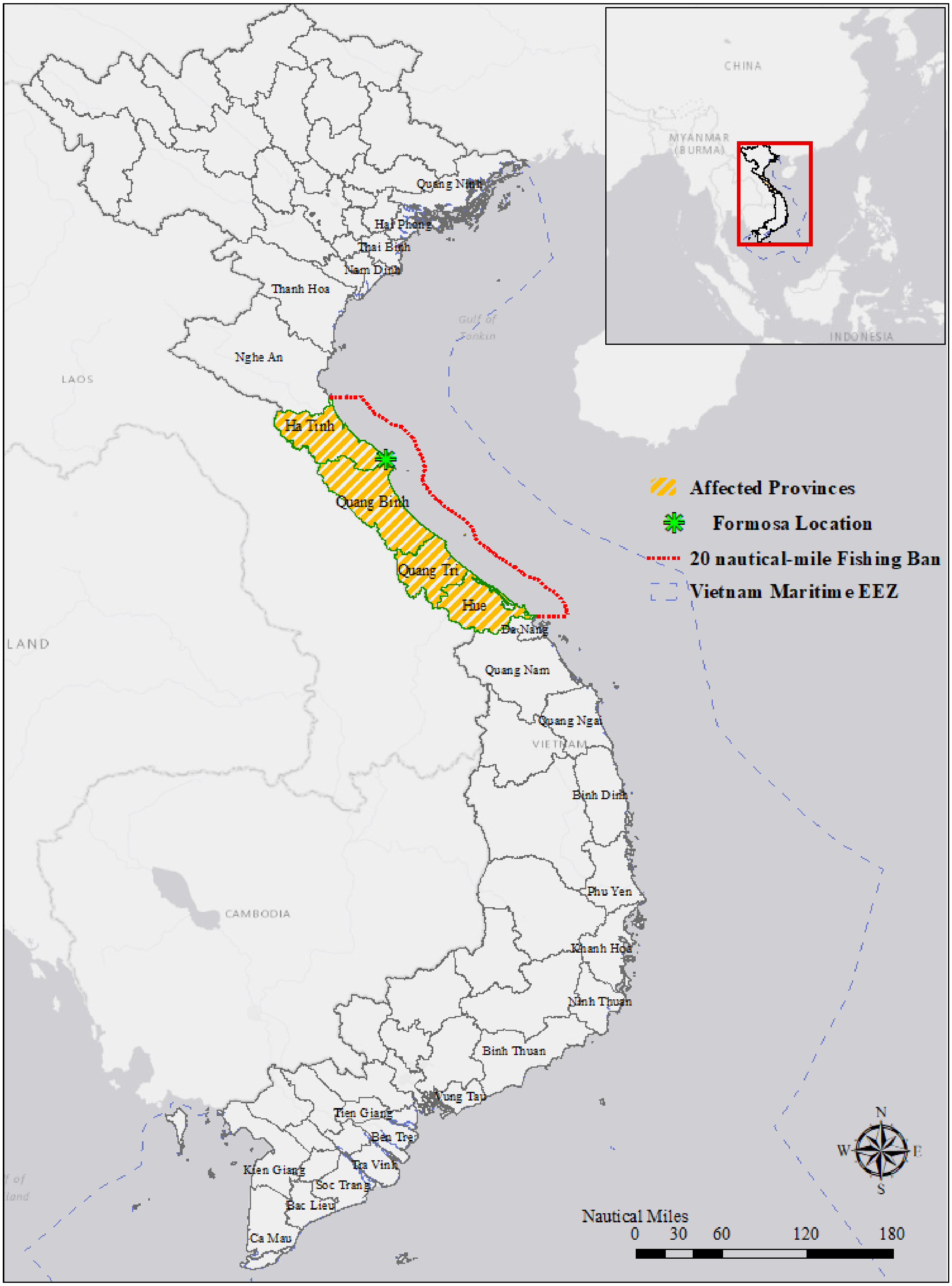
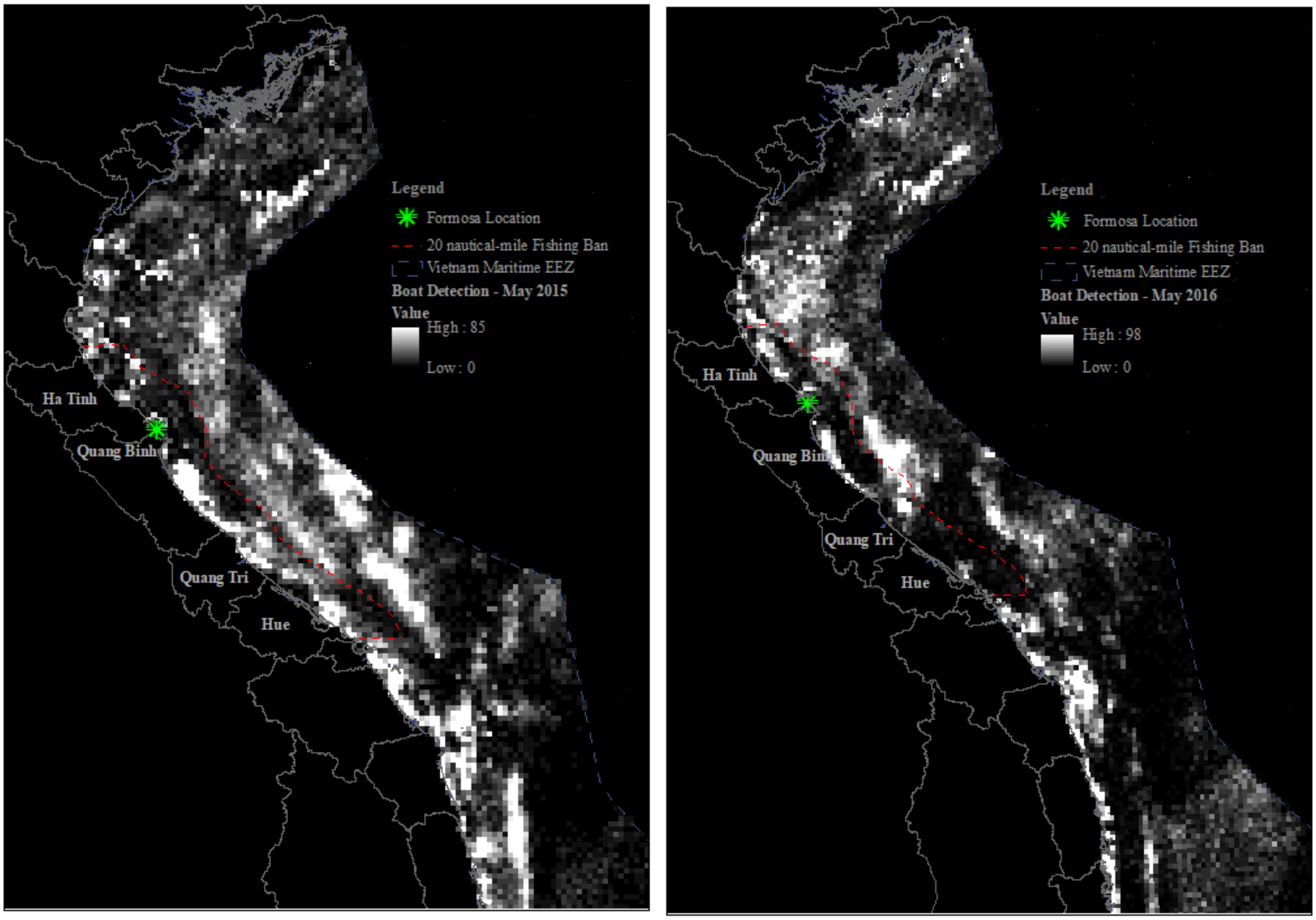
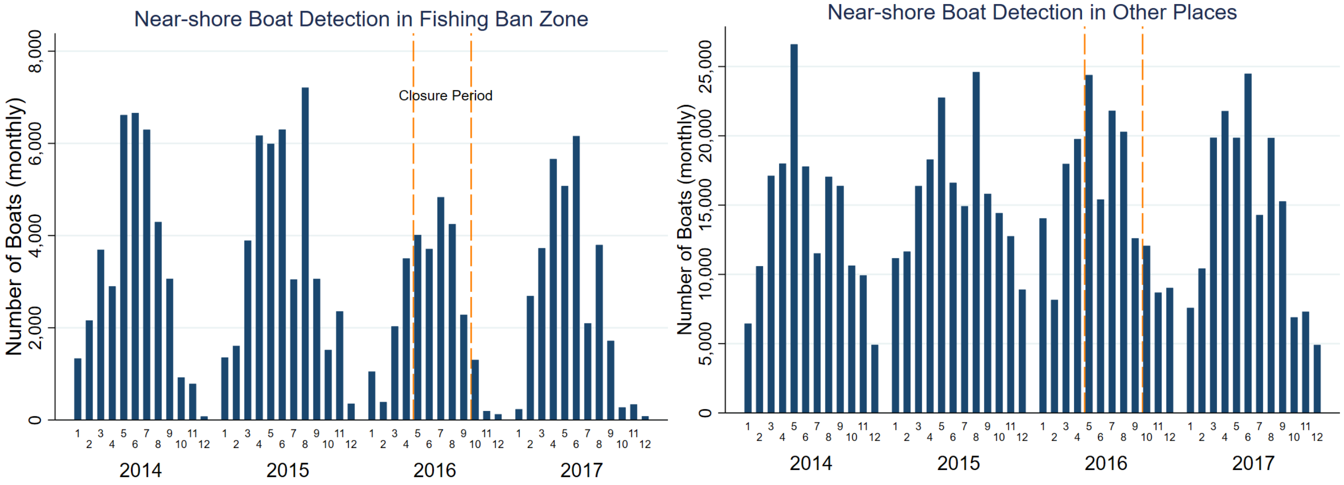


Figure 2: Comparisons using VIIRS Nightlight Boat Detection: raw-data plots



(a) **A1**: VIIRS Boat Detection (May-15)

(b) **A2**: VIIRS Boat Detection (May-16)



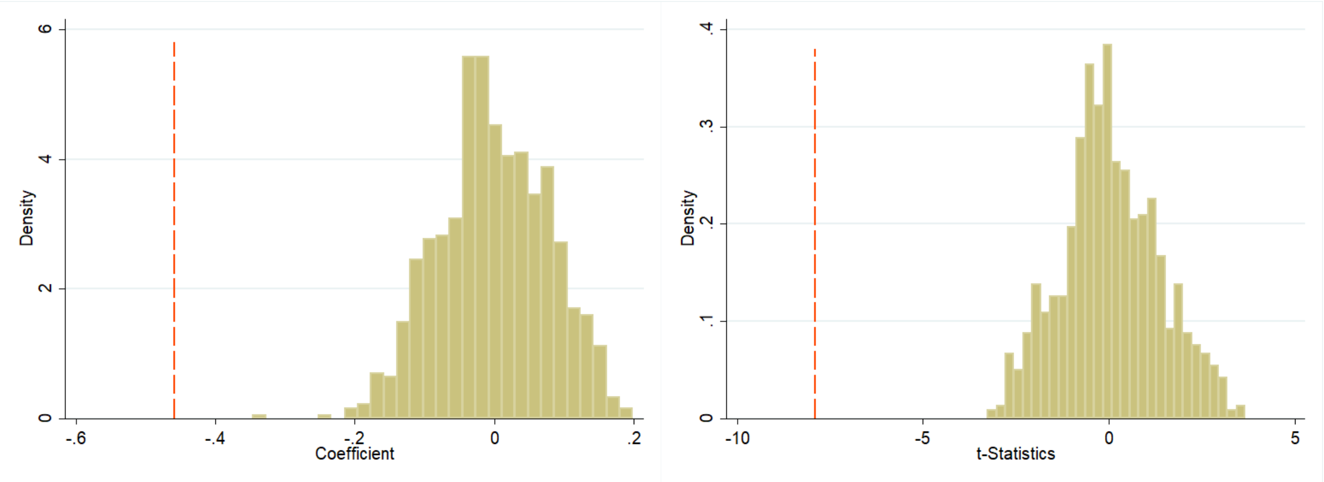
(c) **B1**: Near-shore Boat Detection - Ban Zone

(d) **B2**: Near-shore Boat Detection - Other Zone

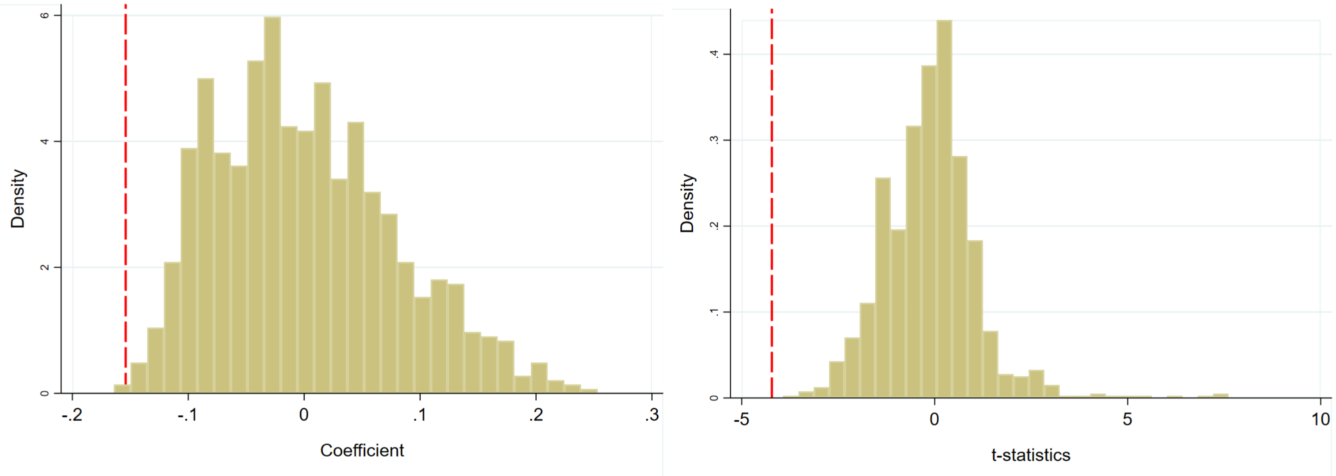
Note: VIIRS raw-data plots using VIIRS Nightlight Boat Detection (monthly aggregate) for total boats detected. Panel A1 and A2 compare light densities captured within Vietnam Maritime EEZ between May-2015 (A1) and May-2016 (A2). Grid cells are resampled to 10-mile-square each. Panel B1 and B2 plot the total monthly boats detected near-shore ($\leq 20nm$, i.e. within the 20 nautical-mile from shoreline) derived from VIIRS, separately for the four affected provinces (B1) and other provinces (B2).

Figure 3: Falsification Tests – Randomization Inference

(a) **A1**: Coefficient values – Monthly Income (b) **A2**: t-statistics – Monthly Income



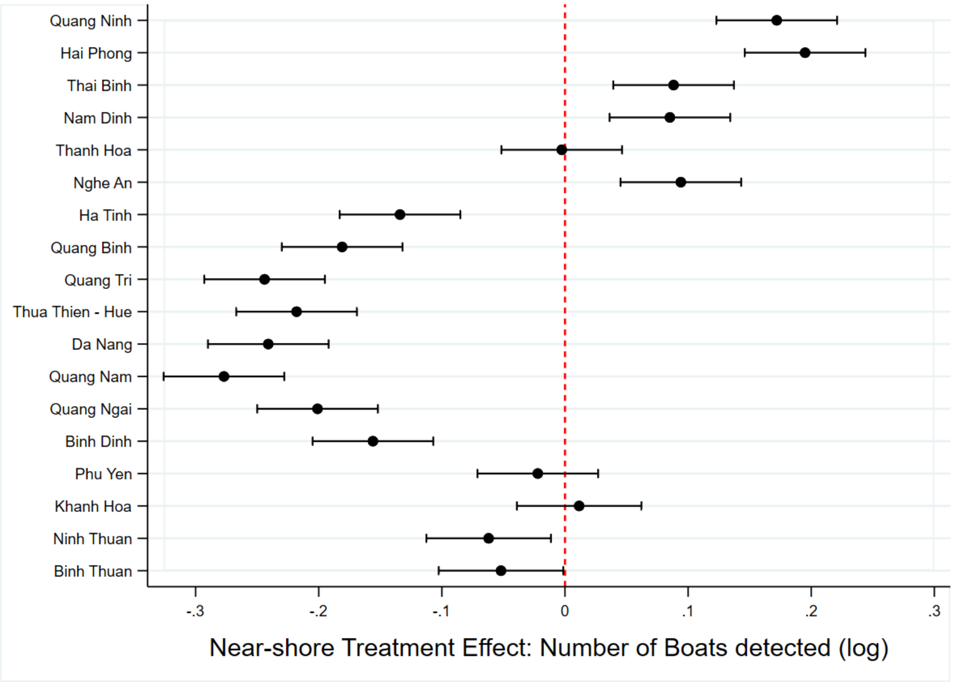
(c) **B1**: Coefficient values – Boat Detection (d) **B2**: t-statistics –Boat Detection



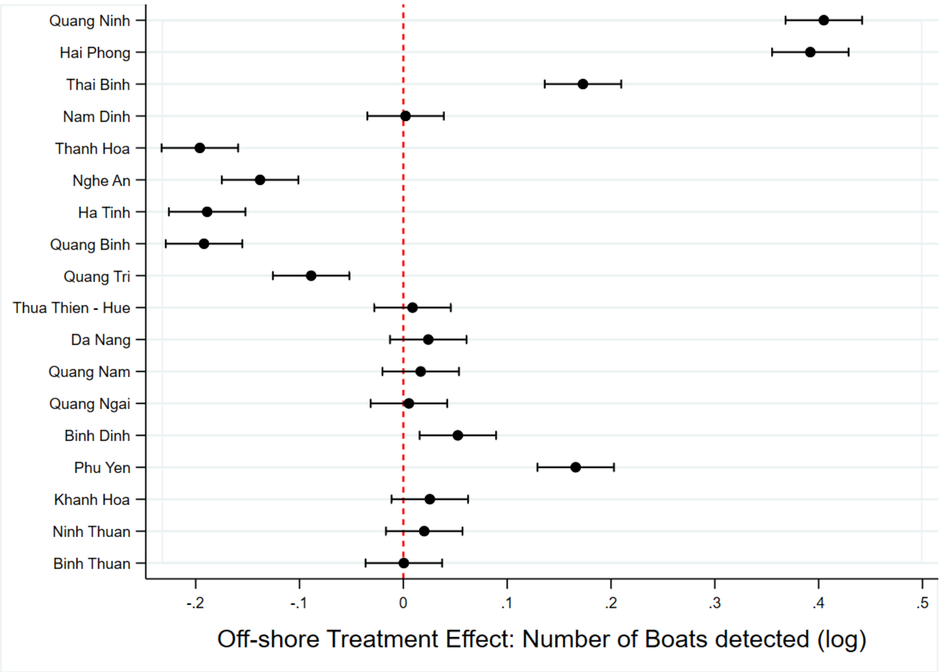
Note: randomization inference tests with 1,000 replication. The outcome variables are log of monthly income from the main job (Panel As) and log of number of boats detected (Panel Bs). Each iteration randomly assigns hypothetical treatment status to 3 to 5 unaffected provinces, and repeats the same regression analysis as in equation (1) and (2). Panel A1 and B1 plot the distributions of coefficient values from the 1,000 replications. Red lines indicate the coefficient values obtained from Table 2 (for Panel A1) and 3 (for Panel B1), with the treated group being the actual four affected provinces (Ha Tinh, Quang Binh, Quang Tri, Thua Thien-Hue). Panel A2 and B2 plot the distributions of the t-statistics.

Figure 4: Province-by-province Treatment Effects

(a) Panel A



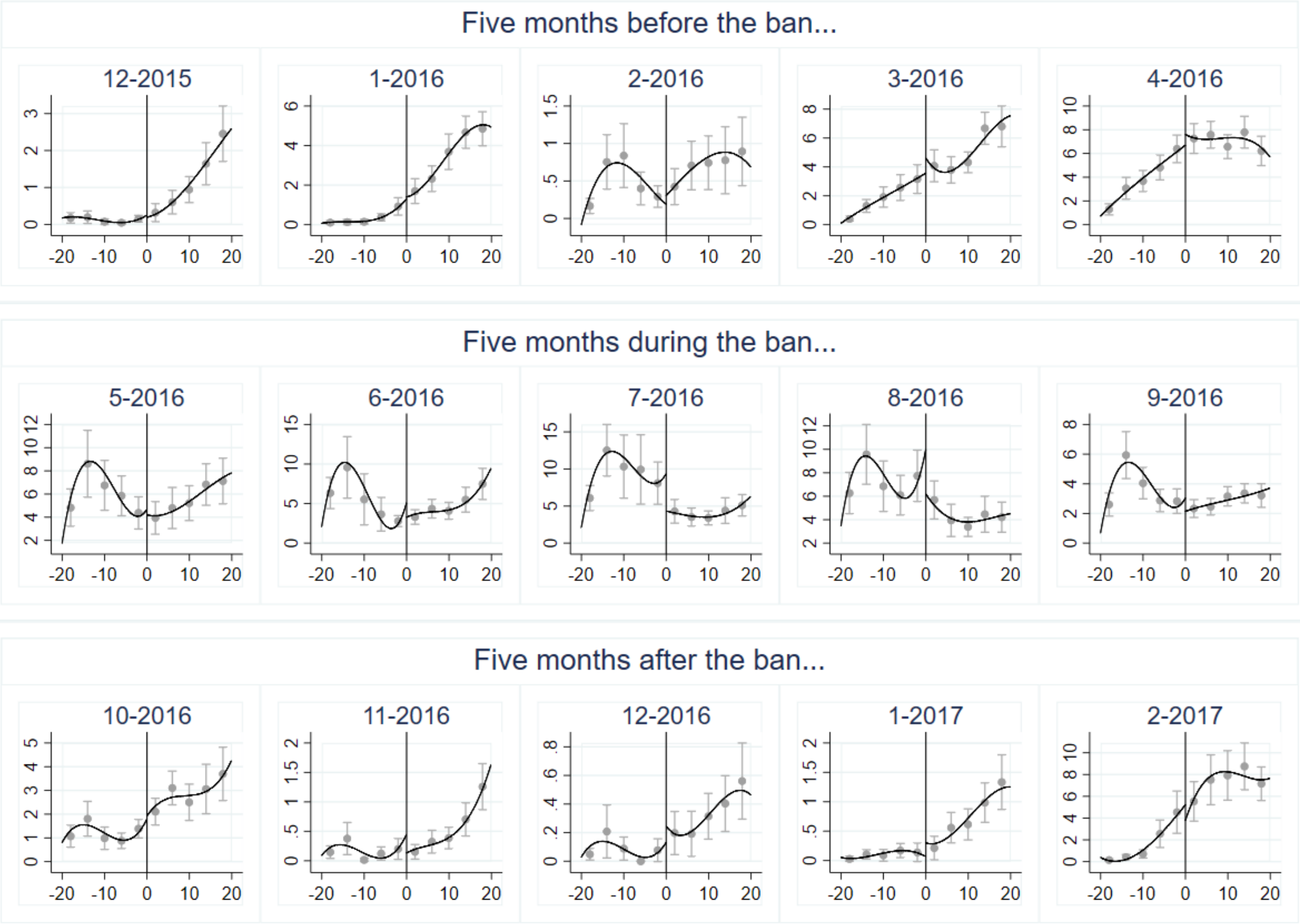
(b) Panel B



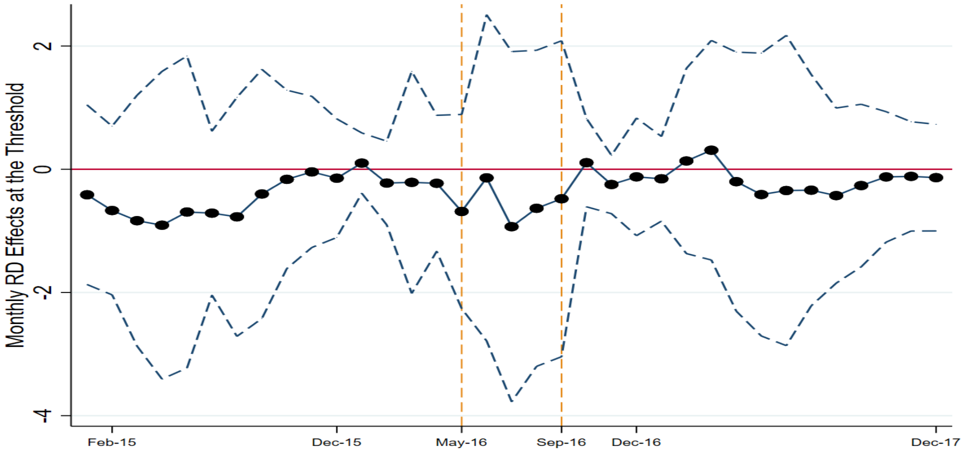
Note: This figure corresponds to the estimation result in column (3) of Table OA3, showing difference-in-differences estimates with each of the Northern and Central provinces as an individual treatment group. Control groups consist of all Southern provinces (south of Ba Ria-Vung Tau). The sample consists of monthly grid-level observations from 2015 to 2017. Panel A shows estimates for near-shore boat detection. Panel B shows estimates for off-shore boat detection. Whiskers indicate 95% statistical intervals.

Figure 5: Regression Discontinuity in Boat Detection at the 20nm Fishing Ban Threshold

(a) Panel A: Regression Discontinuity Estimates of Boat Detection (Local Polynomial)



(b) Panel B: Difference-in-Discontinuities Estimates – Monthly Effects



Note: Panel A shows monthly non-parametric local polynomial RD estimates for boat detection at the 20nm threshold for the months before, during, and after the fishing ban. Figures were made using Calonico et al. (2014)'s method, adopting evenly-spaced bin selection and triangular kernels. Panel B shows monthly RD effects from the difference-in-discontinuities estimates corresponding to equation (3).

Table 1: Summary Statistics for Labor Outcomes in Saltwater Fisheries

		Obs	Pre-disaster				Post-disaster				Mean Difference	$Pr[Diff = 0]$
			Mean	SD	Min	Max	Mean	SD	Min	Max		
Panel A	**All Saltwater Fishermen**											
Treatment group	Income (main job)	63	6,436	4,843	1,000	25,000	4,156	2373	450	10,000	-2,280***	0.001
	Workload (main job)	63	64.08	12.92	28	96	57.19	14.21	15	90	-6.89***	0.005
	Total income	63	6,504	4,814	1,000	25,000	4,206	2,354	450	10,000	-2,298***	0.001
Control group	Income (main job)	594	5,979	4,840	500	40,000	6,237	6,778	420	120,000	258	0.451
	Workload (main job)	594	55.88	1122	14	84	55.28	11.33	16	85	-0.60	0.358
	Total income	594	6,036	4,837	500	40,000	6,284	6,769	420	120,000	248	0.468
Panel B	**Persistent Saltwater Fishermen**											
Treatment group	Income (main job)	53	6,892	5,043	1,600	25,000	4,389	2,398	450	10,000	-2,502***	0.002
	Workload (main job)	53	65.09	12.55	28	96	60.66	10.77	35	90	-4.43*	0.054
	Total income	53	6,972	5,001	1,600	25,000	4,427	2,396	450	10,000	-2,546***	0.001
Control group	Income (main job)	510	6,113	4,956	500	40,000	6,430	7,121	420	120,000	317	0.409
	Workload (main job)	510	56.03	10.18	14	84	55.94	10.67	16	85	-0.09	0.888
	Total income	510	6,166	4,957	500	40,000	6,458	7,118	420	120,000	302	0.432

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: this table shows summary statistics for monthly income and weekly workload of workers in saltwater fisheries in both the treatment and control groups for pre-Formosa (December 2015 - March 2016) and post-Formosa (May 2016 - November 2016) periods. Note that the statistics are shown for fishermen who did not switch job after Formosa incident. The units of measurement for Income (main job) and Workload (main job) and Total income are thousand Vietnam Dong (thousand VND)/month, hours/week and thousand VND/month, respectively. Income (main job) is monthly income from the saltwater fishing industry, while total income includes income from extra job. Workload (main job) is the amount of weekly workload in the saltwater fishing industry. The last two columns show results from our mean-difference tests, reporting the differences in pre- and post- means of labor outcomes and the associated p-value of two-tail t-tests for statistical significance.

Table 2: Formosa's effect on Fishermen's Income and Workload

	All Saltwater Fishermen			Persistent Saltwater Fishermen		
	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: [Saltwater fishing] between regions						
treat X post	-0.455***	-6.616	-0.441***	-0.459***	-4.551	-0.467***
	(0.051)	(5.250)	(0.057)	(0.058)	(5.008)	(0.057)
Observations	1,314	1,314	1,314	1,126	1,126	1,126
R-squared	0.092	0.071	0.088	0.110	0.072	0.111
Panel B: [Saltwater fishing] versus other industries in affected region						
treat X post	-0.426***	-3.155	-0.435***	-0.460***	-3.524	-0.464***
	(0.066)	(4.997)	(0.069)	(0.056)	(5.062)	(0.058)
Observations	3,016	3,016	3,016	2,100	2,100	2,100
R-squared	0.047	0.040	0.049	0.067	0.038	0.078
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on fishermen's income and workload in 2016. Panel A show results from regressions using a sample of all saltwater fishermen in the country, with the treated group being those from Ha Tinh, Quang Binh, Quang Tri and Thua Thien-Hue. Panel B show results from regressions using a sample of all workers in the four affected provinces who work in saltwater fisheries and other non-fishing industries including manufacturing, construction, and retails. The first 3 columns show results from a sample that includes all individuals whose main jobs were fishermen or working in the manufacturing, construction and retail industries before Formosa incident. The last 3 columns show results for only individuals who never switched jobs. Income (monthly) from the main job (columns (1) and (4)) and Total Income (column (3) and (6)) are log-transformed. Workload (columns 2 and 5) are measured by the number of weekly working hours. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table 3: Formosa's effect on Fishing Activity (Boat Detection) in the Banned Zone

	Number of boats detected (modified log)				**Probability of boat detected (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	-0.154***	-0.146***	-0.0911***	-0.187***	-0.0755***	-0.0720***	-0.0562***	-0.0932***
	(0.0365)	(0.0381)	(0.0266)	(0.0331)	(0.0157)	(0.0166)	(0.0118)	(0.0175)
Observations	164,988	164,988	75,204	75,204	164,988	164,988	75,204	75,204
R-squared	0.522	0.624	0.531	0.643	0.435	0.512	0.447	0.527
Grid (10miSq) FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
provinceXmonth FE	No	Yes	No	Yes	No	Yes	No	Yes
Control Groups	All Other Provinces		Southern Provinces		All Other Provinces		Southern Provinces	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (2) for fishing activity in the fishing banned region (near-shore), using VIIRS' monthly-aggregate boat detection data from sample January 2015 to December 2017. Each observation is a grid-month. Each grid cell stores monthly aggregate number of boats detected in a 10-mile-square marine zone within Vietnam's marine EEZ. A grid is considered near-shore when it is located less than 20 nautical miles away from the coast line. The reported outcome variables include log-transformed boat counts in each grid, and 0/1 probability that the grid was detected with at least a boat that month. The control group "All Other Provinces" refers to all coastal provinces in the country except for the four Formosa-affected central provinces (Ha Tinh, Quang Binh, Quang Tri, Thua Thien-Hue). The control group "Southern Provinces" refers to all coastal provinces located south of Ba Ria-Vung Tau (i.e. those located far away from Formosa location, thus arguably completely unaffected.

Table 4: Formosa's effect on Income and Workload: Northern versus Southern Formosa provinces

	All Saltwater Fishermen			Persistent Saltwater Fishermen		
	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
(HaTinh & QuangBinh) X post	-0.491***	-1.662	-0.489***	-0.441***	0.480	-0.455***
	(0.045)	(2.088)	(0.048)	(0.063)	(1.831)	(0.064)
(QuangTri & Hue) X post	-0.292**	-23.103**	-0.281**	-0.556***	-30.469***	-0.533***
	(0.133)	(8.042)	(0.130)	(0.046)	(1.343)	(0.045)
Observations	1,314	1,314	1,314	1,126	1,126	1,126
R-squared	0.092	0.130	091	0.110	0.180	0.111
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on fishermen's income and workload in 2016, separately for the upper (Ha Tinh & Quang Binh) and lower (Quang Tri & Thua Thien-Hue) Formosa-affected regions. The sample consists of all saltwater fishermen in the country, with the treated group being (Ha Tinh & Quang Binh) and (Quang Tri & Thua Thien-Hue). The first 3 columns show results from a sample that includes all individuals whose main jobs were fishermen before Formosa incident. The last 3 columns show results from a sample that includes only individuals whose main jobs were fishermen both before and after Formosa incident (i.e. never switched jobs). Income (monthly) from the main job (columns (1) and (4)) and Total (monthly) Income (column (3) and (6)) are log-transformed. Workload (columns (2) and (5)) are measured by the number of weekly working hours. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table 5: Formosa's effect on the Probabilities of Having extra Jobs and Job-switching for affected Fishermen

	Having extra Jobs		**Switching Job**
	All Saltwater Fishermen	Persistent Saltwater Fishermen	
	(1)	(2)	(3)
(HaTinh & QuangBinh) X post	-0.054	-0.122	0.003
	(0.074)	(0.092)	(0.070)
(QuangTri & Hue) X post	0.092***	0.142***	0.255***
	(0.020)	(0.019)	(0.079)
Observations	1,314	1,126	657
R-squared	0.018	0.057	0.474
Month FE	Yes	Yes	Yes
Individual FE	Yes	Yes	N/A

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on fishermen's probabilities of working extra jobs or switching jobs, separately for the upper (Ha Tinh & Quang Binh) and lower (Quang Tri & Thua Thien-Hue) Formosa-affected region. The sample consists of all saltwater fishermen in the country, with the treated group being (Ha Tinh & Quang Binh) and (Quang Tri & Thua Thien-Hue). Columns (1) and (2) show results for the probability that affected fishermen reported to have an extra job after Formosa incident. Column (1) shows result from a sample that includes all individuals whose main jobs were fishermen before Formosa incident. Column (2) shows result from a sample that includes only individuals whose main jobs were fishermen both before and after Formosa incident (i.e. never switched jobs). Column (3) show results for the probability that affected fishermen switched jobs. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table 6: Spillover Effects to Labor Outcomes in Relevant Industries

	Working in the industry before the Formosa incident			Working in the industry persistently		
	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Freshwater fishing Industry						
(HaTinh & QuangBinh) X post	0.080	1.068	0.076	0.015	2.280	0.016
	(0.161)	(1.948)	(0.162)	(0.151)	(2.120)	(0.152)
(QuangTri & Hue) X post	0.186*	8.821***	0.176*	0.238**	10.523***	0.227**
	(0.099)	(2.189)	(0.092)	(0.107)	(1.968)	(0.088)
Observations	2,226	2,226	2,226	1,778	1,778	1,778
Panel B: Husbandry Industry						
(HaTinh & QuangBinh) X post	0.036	1.012	0.023	0.021	0.468	-0.003
	(0.074)	(0.788)	(0.059)	(0.060)	(0.724)	(0.049)
(QuangTri & Hue) X post	-0.116	-1.123	-0.140	-0.093	-0.894	-0.122
	(0.089)	(1.486)	(0.102)	(0.075)	(1.058)	(0.087)
Observations	7,844	7,844	7,844	5,350	5,350	5,350
Panel C: Restaurant Industry						
(HaTinh & QuangBinh) X post	-0.094	-3.581	-0.084	-0.142**	-3.881	-0.117
	(0.078)	(2.320)	(0.091)	(0.063)	(2.799)	(0.086)
(QuangTri & Hue) X post	-0.025	0.439	-0.014	-0.011	0.647	0.000
	(0.046)	(1.011)	(0.047)	(0.038)	(0.973)	(0.042)
Observations	3,500	3,500	3,500	2,838	2,838	2,838
Panel D: Lodging Industry						
(HaTinh & QuangBinh) X post	0.101	0.184	0.100	0.092	0.369	0.093
	(0.081)	(0.843)	(0.081)	(0.084)	(0.775)	(0.085)
(QuangTri & Hue) X post	0.069	-0.004	0.067	0.039	1.697	0.039
	(0.051)	(1.511)	(0.051)	(0.058)	(1.493)	(0.059)
Observations	736	736	736	586	586	586
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on wages of workers employed in other relevant industries, separately for the upper (Ha Tinh & Quang Binh) and lower (Quang Tri & Thua Thien-Hue) Formosa-affected regions. Panel A, B, C, and D report estimates using respective samples of workers in Freshwater fishing, Husbandry, Restaurant, and Lodging, with the treated individuals working in (Ha Tinh & Quang Binh) and (Quang Tri & Thua Thien-Hue). Columns (1), (2) and (3) show results for all individuals whose main jobs were in one of the above industries before Formosa incident. Columns (4), (5), and (6) show results for those who never switched jobs. Errors are clustered at the district level. Income (monthly) from the main job (columns (1) and (4)) and Total (monthly) Income (column (3) and (6)) are log-transformed. Workload (columns (2) and (5)) are measured by the number of weekly working hours. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table 7: Spillover Effects to Income and Workload of neighboring Fishermen: by Quarters

	All Saltwater Fishermen		Persistent Saltwater Fishermen	
	Hours (main job)	Income (main job)	Hours (main job)	Income (main job)
	(1)	(2)	(3)	(4)
Panel A: Formosa-affected region				
Treatment group X [Q2-2016]	-6.620	-0.559***	-3.194	-0.576***
	(6.614)	(0.109)	(6.108)	(0.126)
Treatment group X [Q3-2016]	-6.120	-0.408***	-4.709	-0.432***
	(7.632)	(0.087)	(7.384)	(0.084)
Treatment group X [Q4-2016]	-7.068*	-0.353***	-5.971	-0.355***
	(4.013)	(0.106)	(3.895)	(0.109)
Panel B: North of Formosa-affected region				
(ThanhHoa & NgheAn) X [Q2-2016]	2.597*	0.105	1.498	0.140**
	(1.488)	(0.065)	(1.700)	(0.066)
(ThanhHoa & NgheAn) X [Q3-2016]	-0.436	0.060	-1.425	0.151***
	(1.466)	(0.084)	(0.069)	(1.831)
(ThanhHoa & NgheAn) X [Q4-2016]	-3.076	0.006	-3.877	-0.067
	(2.315)	(0.055)	(2.662)	(0.0531)
Panel C: South of Formosa-affected region				
(DaNang to QuangNgai) X [Q2-2016]	2.659	0.066	0.489	-0.036
	(2.437)	(0.123)	(1.244)	(0.079)
(DaNang to QuangNgai) X [Q3-2016]	0.269	0.319**	-2.198	0.198**
	(2.850)	(0.133)	(2.118)	(0.096)
(DaNang to QuangNgai) X [Q4-2016]	-3.317	0.053	-2.797	0.160
	(2.461)	(0.101)	(2.233)	(0.119)
Observations	2,598	2,598	2,252	2,252
R-squared	0.054	0.060	0.052	0.069
Month FE	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on monthly income (log-transformed) and weekly work hours in saltwater fisheries for each subsequent quarters after the start of Formosa incident in April 2016, separately by regions. Panel A shows Formosa's effect over time for Ha Tinh, Quang Binh, Quang Tri, and Thue Thien-Hue. Panel B and C show spillover effects for the northern neighboring (Thanh Hoa and Nghe An), and southern neighboring provinces (Da Nang, Quang Nam and Quang Ngai). The sample consists of all saltwater fishermen in the country, with the treated group being those from the four affected provinces. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table 8: Formosa's effect on Fishing Activity (Boat Detection): Estimations by Quarters

	Number of boats detected (modified log)		**Probability of detecting boat (%)**	
	(1)	(2)	(3)	(4)
treat X [Q2-2016]	-0.406**	-0.471**	-0.0935**	-0.127***
	(0.150)	(0.153)	(0.0346)	(0.0349)
treat X [Q3-2016]	-0.244***	-0.205**	-0.0815***	-0.0724**
	(0.0811)	(0.0774)	(0.0277)	(0.0293)
treat X [Q4-2016]	-0.218***	-0.221***	-0.112***	-0.128***
	(0.0721)	(0.0553)	(0.0335)	(0.0279)
treat X [Q1-2017]	-0.369***	-0.446***	-0.0879***	-0.113***
	(0.0710)	(0.0567)	(0.0210)	(0.0225)
treat X [Q2-2017]	-0.194**	-0.369***	-0.143***	-0.239***
	(0.0788)	(0.0665)	(0.0344)	(0.0300)
treat X [Q3-2017]	-0.168**	-0.263***	-0.0780**	-0.114**
	(0.0643)	(0.0758)	(0.0319)	(0.0378)
treat X [Q4-2017]	0.0426	0.0182	-0.0441	-0.0360
	(0.0801)	(0.0937)	(0.0322)	(0.0410)
treat X [Q1-2018]	-0.0755	-0.106	-0.00904	-0.0429
	(0.124)	(0.138)	(0.0376)	(0.0382)
treat X [Q2-2018]	-0.167	-0.276	-0.00770	-0.0529
	(0.120)	(0.160)	(0.0292)	(0.0444)
Observations	187,903	85,649	187,903	85,649
R-squared	0.292	0.278	0.206	0.182
Grid (10miSq) FE	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes
coastXmonth FE	Yes	Yes	Yes	Yes
Control Groups	All	Southern	All	Southern

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result separately for each subsequent quarter after the start of Formosa incident in April 2016. Each observation is a grid-month. Each grid cell stores monthly aggregate number of boats detected in a 10-mile-square marine zone within Vietnam's marine EEZ. The reported outcome variables include log-transformed boat counts in each grid, and 0/1 probability that the grid was detected with at least a boat that month. The control group consists of all coastal provinces located south of Ba Ria-Vung Tau (i.e. those located far away from Formosa location thereby arguably unaffected.)

Appendix

A Supplementary Results

Figure A1: Fish washed ashore in Vietnam's central coast after Formosa incident.

(a) Source: Vnexpress.net

(b) Source: Vietnam Advisor

Table A1: Falsification Tests – Testing for hypothetical effect to Saltwater Fishing using Predetermined Outcomes in 2015, and to Unrelated Industries in 2016

	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Falsification Test with Hypothetical Event (April 2015) for Saltwater Fishing						
treat X post April 2015	0.0027	2.0115	-0.0013	-0.0004	2.1278	-0.0040
	(0.1424)	(2.9214)	(0.1409)	(0.1499)	(3.0567)	(0.1491)
Observations	1,326	1,326	1,326	1,178	1,178	1,178
R-squared	0.0860	0.0245	0.0835	0.1101	0.0206	0.1055
Sample	All Saltwater Fishermen			Persistent Saltwater Fishermen		
Panel B: Falsification Test for Effects to Formosa-disaster's Unrelated Industries						
treat X post	0.019	-0.571	0.011	0.016	0.141	0.024
	(0.020)	(0.469)	(0.018)	(0.056)	(0.591)	(0.052)
Observations	52,132	52,132	52,132	24,276	24,276	24,274
R-squared	0.007	0.001	0.007	0.015	0.003	0.017
Sample	Manufacturing, Construction and Retail			Farming		
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows two Falsification Tests of Formosa's effect estimating equation (1) for workers' monthly income and weekly work hours. Panel A (Test 1) reports results from difference-in-differences regressions using data in 2015 for all saltwater fishermen in the country, and imposing a fictional event in April 2015. Treated fishermen are those locating in Ha Tinh, Quang Binh, Quang Tri and Thue Thien-Hue. The first 3 columns show results from a sample including all individuals whose main jobs were fishermen before April 2015. The last 3 columns show results for fishermen who never switched jobs. Panel B (Test 2) shows estimates for Formosa's effect to industries unrelated to the disaster, using samples of all workers in the country who work in manufacturing, construction and retails industries (columns (1)-(3)), and farm sector (columns (4)-(6)) in 2016. In each panels, Income (monthly) from the main job (columns 1 and 4) and Total Income (column (3) and (6)) are log-transformed. Workload (columns (2) and (5)) are measured by the number of weekly working hours. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table A2: Placebo test – Formosa's effect on Fishing Activity (Boat Detection) in the Banned Zone

	Number of boats detected (modified log)				**Probability of boat detected (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	-0.00972	-0.00124	0.120**	0.0558	-0.00518	0.0324	0.0557***	0.0609**
	(0.0534)	(0.0394)	(0.0442)	(0.0601)	(0.0218)	(0.0287)	(0.0175)	(0.0236)
Observations	164,988	164,988	75,204	75,204	164,988	164,988	75,204	75,204
R-squared	0.507	0.610	0.530	0.639	0.431	0.511	0.467	0.542
Grid (10miSq) FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
provinceXmonth FE	No	Yes	No	Yes	No	Yes	No	Yes
Control Groups	All Other Provinces		Southern Provinces		All Other Provinces		Southern Provinces	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result for a placebo exercise testing for fictional effect of Formosa on fishing activity, using VIIRS' monthly-aggregate Boat Detection data between January 2013 and December 2015. The fictional event is generated for April 2014. Each observation is a grid-month. Each grid cell stores monthly aggregate number of boats detected in a 10-mile-square marine zone within Vietnam's marine EEZ. A grid is considered near-shore when it is located less than 20 nautical miles away from the coast line. The reported outcome variables include log-transformed boat counts in each grid, and 0/1 probability that the grid detected at least a boat that month. The control group "All Other Provinces" refers to all coastal provinces in the country except for the four Formosa-affected central provinces (Ha Tinh, Quang Binh, Quang Tri, Thua Thien-Hue). The control group "Southern Provinces" refers to all coastal provinces located south of Ba Ria-Vung Tau (i.e. those located far away from Formosa location, thus arguably completely unaffected.

Table A3: Estimations of Income and Workload: Fishermen in the Southern provinces as Control Group

	All Saltwater Fishermen			Persistent Salwater Fishermen		
	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A						
treat X post	-0.431***	-5.491	-0.428***	-0.435***	-3.603	-0.445***
	(0.059)	(4.241)	(0.060)	(0.062)	(4.254)	(0.060)
Observations	490	490	490	384	384	384
R-squared	0.178	0.129	0.191	0.205	0.142	0.218
Panel B						
(HaTinh & QuangBinh) X post	-0.458***	-1.502	-0.457***	-0.405***	0.536	-0.420***
	(0.058)	(2.196)	(0.057)	(0.059)	(2.036)	(0.060)
(QuangTri & Hue) X post	-0.325**	-21.212**	-0.313**	-0.617***	-28.734***	-0.599***
	(0.157)	(8.100)	(0.153)	(0.051)	(1.403)	(0.050)
Observations	490	490	490	384	384	384
R-squared	0.180	0.224	0.194	0.210	0.359	0.221
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on fishermen's monthly income and weekly workload in 2016 by using fishermen living from Ba Ria-Vung Tau to the South as control group. Panel A show results from regressions that the treated group are fishermen from Ha Tinh, Quang Binh, Quang Tri and Thua Thien-Hue. In Panel B, the treated group is separated into the upper (Ha Tinh and Quang Binh) and lower (Quang Tri and Thua Thien-Hue) Formosa-affected regions. The first 3 columns show results from a sample that includes all individuals whose main jobs were fishermen before Formosa incident. The last 3 columns show results from a sample that includes only individuals whose main jobs were fishermen both before and after Formosa incident (i.e. never switched jobs). Income (monthly) from the main job (columns (1) and (4)) and Total (monthly) Income (column (3) and (6)) are log-transformed. Workload (columns (2) and (5)) are measured by the number of weekly working hours. Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

Table A4: RD Estimates for the Discontinuity in Fishing Activity at the 20nm Ban-Zone Threshold

	Parametric						Local Polynomial	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	MSE bandwidth	CER bandwidth
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
May-2016	-0.514	0.0151	-0.260	0.162	0.0286	-0.112	0.0276	0.0496
	(0.245)	(0.195)	(0.160)	(0.275)	(0.361)	(0.545)	(0.458)	(0.481)
Observations	756	756	343	343	164	164	231	214
June-2016	0.00943	0.393*	0.0689	-0.0185	0.0410	0.0819	-0.0091	-0.0164
	(0.360)	(0.139)	(0.197)	(0.171)	(0.130)	(0.204)	(0.472)	(0..470)
Observations	756	756	343	343	164	164	263	239
July-2016	-0.736	-0.0440	-0.353	-0.440	-0.383	-0.820	-0.652	-0.720
	(0.358)	(0.237)	(0.270)	(0.230)	(0.171)	(0.477)	(0.478)	(0.489)
Observations	756	756	343	343	164	164	215	186
August-2016	-0.396	-0.0375	-0.281	-0.125	-0.151	-0.292	-0.259	-0.271
	(0.310)	(0.171)	(0.202)	(0.0588)	(0.107)	(0.179)	(0 .444)	(0.446)
Observations	756	756	343	343	164	164	262	239
September-2016	-0.287	0.212	-0.0232	0.0817	0.0479	0.122	0.0068	-0.0032
	(0.333)	(0.157)	(0.240)	(0.136)	(0.170)	(0.163)	(0.316)	(0.305)
Observations	756	756	343	343	164	164	282	253
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flexible Slope	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Bandwidth Size	±20 nautical mile		±10 nautical mile		±5 nautical mile		data-driven optimal bandwidths	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows results from the regression-discontinuity estimations for the effect to fishing activity at the 20nm fishing-ban threshold (equation (3)), for the five months during the ban period. Parametric RD results are presented in the first columns, non-parametric (local polynomial) in the last two columns. Each of the parametric RD regression controls for either linear (columns (1), (3), (5)) or quadratic (columns (2), (4), (6)) polynomials. The local polynomial (non-parametric) approach follows from Calonico et al. (2014) and Imbens and Kalyanaraman (2012) for the Mean-Square-Error optimal bandwidth selection technique (column (7)), and Calonico et al. (2018) for the Coverage-Error-Rate optimal bandwidth (column (8)).

Table A5: Number of Fishermen switching Job after the Disaster

	Total number of fishermen (1)	Number of fishermen switching job (2)	Percentage of switching job (3)
HaTinh & QuangBinh	48	4	8.33%
QuangTri & ThuaThien-Hue	15	6	40.00%
The rest of the country	594	84	14.14%

Note: This table shows the number of fishermen who worked in other sector after the Formosa incident in the sample. Column (1) is the number of individuals working in the saltwater fishing industry before the Formosa incident. Column (2) is the number of individuals who worked in the saltwater fishing industry before Formosa incident but change his job later. Column (3) is the percentage of fishermen that switched job after Formosa incident.

Table A6: Formosa's effect on Income and Workload: by Quarters

	All Saltwater Fishermen			Persistent Saltwater Fishermen		
	Income (main job)	Hours (main job)	Total income	Income (main job)	Hours (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)
treat X [Q2-2016]	-0.569***	-6.885	-0.581***	-0.580***	-3.299	-0.606***
	(0.107)	(6.625)	(0.109)	(0.124)	(6.099)	(0.118)
treat X [Q3-2016]	-0.431***	-6.022	-0.432***	-0.451***	-4.416	-0.444***
	(0.084)	(7.648)	(0.086)	(0.081)	(7.369)	(0.080)
treat X [Q4-2016]	-0.358***	-6.719*	-0.340***	-0.364***	-5.600	-0.366***
	(0.104)	(3.958)	(0.101)	(0.107)	(3.826)	(0.103)
Observations	2,598	2,598	2,598	2,252	2,252	2,252
R-squared	0.053	0.049	0.051	0.061	0.046	0.062
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating equation (1) for Formosa's effect on monthly income (log-transformed) in saltwater fisheries for each subsequent quarters after the start of Formosa incident in April 2016. The sample consists of all saltwater fishermen in the country, with the treated group being those from the four affected provinces. The first column shows result from a sample that includes all individuals whose main jobs were fishermen before Formosa incident. The last column shows result from a sample that includes only individuals whose main jobs were fishermen both before and after Formosa incident (i.e. never switched jobs). Observations in April 2016 are removed in all regressions. Errors are clustered at the district level.

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.

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

- 09 March 2017: the Prime Minister of Vietnam passed Directive 309/Q-TTg on the revision of Directive 1880/Q-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 2017: the Prime Minister of Vietnam continued to order the deepwater fishing ban to be upheld, citing that the quality deepwater seafood had still not returned to the acceptable standard.

- May 2018: the Health Ministry, after series of inspections, 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.

Online Appendix – Not For Publication

Table OA1: Formosa's effect on Fishing Activity (Boat Detection) in the Fishing Banned Zone: Robustness to other measures

	(1)	(2)	(3)	(4)
Panel A: Other Measures for Number of Boats detected				
[A1] Number of Boats detected (in level)				
treat X post	-1.183***	-1.224***	-1.193**	-1.305**
S.E.	(0.247)	(0.258)	(0.425)	(0.439)
R-squared	0.398	0.469	0.397	0.470
Observations	339,142	339,142	154,586	154,586
[A2] Number of Boats detected (in unmodified log)				
treat X post	-0.175***	-0.189***	-0.118	-0.2201
S.E.	(0.0523)	.05655	(0.0750)	0.0832
R-squared	0.378	0.415	0.418	0.104
Observations	159,447	159,447	61,881	61,881
Panel B: Winsorized sample (removing unlit grids)				
[B1] Number of boats detected (modified log)				
treat X post	-0.185***	-0.187***	-0.214**	-0.230**
S.E.	(0.0512)	(0.0530)	(0.0918)	(0.0943)
R-squared	0.002	0.276	0.004	0.265
Observations	290,302	290,302	121,804	121,804
[B2] Probability of detecting boats (%)				
treat X post	-0.0656***	-0.0662***	-0.0769*	-0.0825*
S.E.	(0.0213)	(0.0220)	(0.0396)	(0.0406)
R-squared	0.001	0.204	0.002	0.182
Observations	290,302	290,302	121,804	121,804
Grid (10miSq) FE	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes
provinceXmonth FE	No	Yes	No	Yes
Control Groups	All Other Provinces		Southern Provinces	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table replicate results shown in Table 1 to other measures of Boat Detections (Panel A), and by using a winsorized sample (Panel B) The other measures include boat detection in level, and log-transformation (without adding a constant). The winsorized sample removed all continuously unlit cells. All else remains the same as in Table 1.

Table OA2: Formosa's effect on Fishing Activity (Boat Detection) in the Fishing Banned Zone: Using extended sample (April 2012 to May 2018)

	Number of boats detected (log)				**Probability of boat detected (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	-0.167***	-0.170***	-0.179**	-0.194**	-0.0591***	-0.0601***	-0.0649*	-0.0700*
	(0.0445)	(0.0460)	(0.0734)	(0.0755)	(0.0185)	(0.0191)	(0.0310)	(0.0317)
Observations	339,142	339,142	154,586	154,586	339,142	339,142	154,586	154,586
R-squared	0.488	0.584	0.502	0.607	0.411	0.484	0.430	0.504
Grid (10miSq) FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
provinceXmonth FE	No	Yes	No	Yes	No	Yes	No	Yes
Control Groups	All Other Provinces		Southern Provinces		All Other Provinces		Southern Provinces	

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows result from estimating equation 2 for near-shore fishing activity in the affected region. Each observation is an grid-month. Each grid cell stores monthly aggregate number of boats detected in a 10-mile-square marine zone within Vietnam's marine EEZ. A grid is considered near-shore when it is located less than 20 nautical miles away from the coast line. The reported outcome variables include log-transformed boat counts in each grid, and 0/1 probability that the grid detected at least a boat that month. The control group ”All Other Provinces” refers to all coastal provinces in the country except for the four Formosa-affected central provinces (Ha Tinh, Quang Binh, Quang Tri, Thua Thien-Hue). The control group ”Southern Provinces” refers to all coastal provinces located south of Ba Ria-Vung Tau (i.e. those located far away from Formosa location, thus arguably completely unaffected.)

Table OA3: Formosa's effect – province-by-province estimations (corresponding to Figure 4)

	Number of boats detected (modified log)			
	Near-shore Fishing		**Off-shore Fishing**	
	(1)	(2)	(3)	(4)
Quang Ninh X post	0.227***	0.172***	0.398***	0.405***
	(0.0308)	(0.0250)	(0.0167)	(0.0188)
	139,428	57,744	294,696	139,608
Hai Phong X post	0.248***	0.195***	0.387***	0.392***
	(0.0309)	(0.0250)	(0.0167)	(0.0188)
	139,428	56,484	294,696	141,444
Thai Binh X post	0.135***	0.0882***	0.169***	0.173***
	(0.0324)	(0.0250)	(0.0168)	(0.0188)
	139,428	54,972	294,696	145,152
Nam Dinh X post	0.130***	0.0852**	-0.00558	0.00213
	(0.0321)	(0.0250)	(0.0169)	(0.0188)
	139,428	52,992	294,696	144,756
Thanh Hoa X post	0.0404	-0.00265	-0.214***	-0.196***
	(0.0329)	(0.0250)	(0.0131)	(0.0188)
	139,428	56,088	294,696	152,928
Nghe An X post	0.140***	0.0941***	-0.150***	-0.138***
	(0.0322)	(0.0250)	(0.0160)	(0.0188)
	139,428	53,964	294,696	148,788
Ha Tinh X post	-0.0923***	-0.134***	-0.197***	-0.189***
	(0.0314)	(0.0250)	(0.0166)	(0.0188)
	147,060	57,276	294,696	150,840
Quanh Binh X post	-0.140***	-0.181***	-0.199***	-0.192***
	(0.0314)	(0.0250)	(0.0166)	(0.0188)
	146,232	56,448	294,696	154,764
Quang Tri X post	-0.202***	-0.244***	-0.0964***	-0.0888***
	(0.0314)	(0.0250)	(0.0166)	(0.0188)
	143,856	54,072	294,696	151,668
ThuaThien-Hue X post	-0.176***	-0.218***	0.00128	0.00888
	(0.0314)	(0.0250)	(0.0166)	(0.0188)
	146,124	56,340	294,696	150,192

Da Nang X post	-0.203***	-0.241***	0.0168	0.0240
	(0.0316)	(0.0250)	(0.0170)	(0.0188)
	139,428	52,128	294,696	145,296
Quang Nam X post	-0.244***	-0.277***	0.00945	0.0167
	(0.0310)	(0.0250)	(0.0173)	(0.0188)
	139,428	54,720	294,696	149,904
Quang Ngai X post	-0.167***	-0.201***	-0.00237	0.00535
	(0.0317)	(0.0250)	(0.0174)	(0.0188)
	139,428	55,512	294,696	153,360
Binh Dinh X post	-0.120***	-0.156***	0.0476**	0.0525**
	(0.0322)	(0.0250)	(0.0176)	(0.0188)
	139,428	56,304	294,696	155,736
Phu Yen X post	0.0200	-0.0221	0.167***	0.166***
	(0.0329)	(0.0250)	(0.0159)	(0.0188)
	139,428	56,052	294,696	153,864
Khanh Hoa X post	-0.0552	0.0115	0.0190	0.0255
	(0.0380)	(0.0258)	(0.0177)	(0.0188)
	139,428	59,076	294,696	157,104
Ninh Thuan X post	-0.080**	-0.062**	0.0129	0.0201
	(0.0363)	(0.0258)	(0.0171)	(0.0188)
	139,428	53,316	294,696	147,384
Binh Thuan X post	-0.078**	-0.052**	-0.00761	0.000464
	(0.0364)	(0.0258)	(0.0176)	(0.0188)
	139,428	59,760	294,696	157,176
Grid (10miSq) FE	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes
provinceXmonth FE	Yes	Yes	Yes	Yes
Control Groups	All	Southern	All	Southern

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table shows difference-in-differences result from estimating Formosa's province-by-province effect on fishing activities both near-shore (columns (1) and (2)) and off-shore (columns (3) and (4)), using VIIRS' monthly-aggregate boat detection data between January 2015 and December 2017. Each of the Northern and Central provinces is consequentially assigned "treatment" status, corresponding to a result block in the table. Each observation is a grid-month. Each grid cell stores monthly aggregate number of boats detected in a 10-mile-square marine zone within Vietnam's marine EEZ. A grid is considered near-shore when it is located less than 20 nautical miles away from the coast line. The reported outcome variables include log-transformed boat counts in each grid. The control group "All" refers to all coastal provinces in the country except for the province being assigned "treatment" status. The control group "Southern Provinces" refers to all coastal provinces located south of Ba Ria-Vung Tau (i.e. those located far away from Formosa location, thus arguably completely unaffected.