Policy Research Working Paper 8827

Labor Market Impacts and Responses

The Economic Consequences of a Marine Environmental Disaster

Trung Hoang
Duong Trung Le
Ha Nguyen
Nguyen Dinh Tuan Vuong

WORLD BANK GROUP
Middle East and North Africa Region
Office of the Chief Economist
April 2019

Policy Research Working Paper 8827

Abstract

This paper examines the labor market impacts of a large-scale marine environmental crisis caused by toxic chemical contamination in Vietnam's central coast in 2016. Combining labor force surveys with satellite data on fishing-boat detection, the analysis finds negative and heterogeneous impacts on fishery incomes and employment and uncovers interesting coping patterns. Satellite data suggest that upstream fishers traveled to safe fishing grounds, and thus bore lower income damage. Downstream fishers, instead, endured severe impact and were more likely to substitute fishery hours for working secondary jobs. The paper also finds evidence on an impact recovery to fishing intensity and fishery income, and a positive labor market spillover to freshwater fishery.

This paper is a product of the Office of the Chief Economist, Middle East and North Africa Region. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The authors may be contacted at hanguyen@worldbank.org.

Labor Market Impacts and Responses: The Economic Consequences of a Marine Environmental Disaster*

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

Keywords: environmental disaster, coping mechanisms, satellite detection, fisheries

JEL Classification: J30, O13, Q52

*We would like to thank Rabah Arezki, Ritam Chaurey, Ian Coxhead, Ousmane Dione, David Flath, Seema Jayachandran, Solomon Polachek, Anh Pham, David Slichter, Susan Wolcott, participants at the NEUDC 2018 (Cornell University) and the Development Workshop at the University of Wisconsin-Madison for helpful comments. All remaining errors are our own.

†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 have started gaining academic attention. One of the burgeoning topics is how increasingly frequent and severe industrial disasters have taken place around the world. Since the 1990s, the number of documented large-scale industrial disasters has increased by nearly fivefold (EM-DAT, 2017). According to the International Disaster Database from the Centre for Research on the Epidemiology of Disasters (CRED), the types of industrial disasters that nations experience include gas leaks, oil spills, nuclear explosions, and chemical contamination. These incidents often lead to disastrous environmental consequences with impacts felt for years. Developing countries, with laxer environmental standards and a strong desire to promote industries and attract foreign investment, are most likely to bear the brunt of these industrial disasters. Ironically, these countries usually lack the capacity to fully evaluate the causes and effects of disasters, hold perpetrators accountable, and provide timely assistance to the affected population. Existing studies on the effects of man-made environmental disasters in developing countries, due to capacity and budget constraints, and sometimes political sensitivities, are rare.

In this paper, we examine the labor-market impacts of *Formosa*,[1] an industrial marine pollution crisis breaking out in Vietnam that devastated the ecosystem and disrupted fishery activities in the country's central coast in 2016. Our empirical analysis leverages a novel source of high-resolution satellite data on night-time boat detection in Vietnam's marine exclusive economic zone (EEZ), and relates it to employment data from Vietnamese labor force surveys. Exploiting both the industry-specific and location-specific natures of the *Formosa* shock, our identification strategy compares fishery workers that lived in the affected region to both non-fishery workers in the same area and other fishery workers outside the affected zone.

We estimate the impact of *Formosa* by employing a series of difference-in-differences estimations (DiD) using individual-worker data, and show that the disaster sharply reduced average fishery income by as much as 42 percent in the rest of 2016. Utilizing high-resolution satellite's boat-detection data at the monthly interval, we additionally estimate a direct impact of *Formosa* on fishing activities, showing an average decline in fishing intensity of as much as 36 percent in the immediate period following the pollution breakout. Interestingly, we find that the negative impact of the disaster did not distribute evenly across locations; the

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

fishery communities located downstream in contaminated zone were affected more heavily, compared to those located upstream and thus closer to safe waters. This, in consequence, seems to have induced different coping responses. Satellite data suggests a strong northward movement in fishing pattern of the affected upstream fishers. Being able to travel to safer fishing locations allowed these workers to maintain the number of work hours; however, their average monthly income still declined by as much as 45 percent in 2016. In contrast, fishers located downstream were more likely "trapped" inside the contaminated zone; their average income was cut by more than half. This adverse circumstance led to a significant reduction in fishery work hours and an increase in the likelihood of working secondary jobs.

Next, we study aspects of disaster recovery, examining the impacts of *Formosa* on both fishing intensity and fishery income over time. We find a gradual reduction in disaster damage to both outcomes. We also show that, by the last quarter of 2016, while fishing activity in the affected region had largely recovered, the average monthly earnings of affected fishers were still only two-third of the base level in the first quarter (i.e. the pre-disaster period). Finally, we study potential spillover effects of *Formosa* to other related industries in the affected provinces. Among the industries deemed eligible for *Formosa* compensation by the government, we show that fishers in freshwater fisheries, especially those located downstream, actually benefited from the incident in terms of earnings.

We focus on examining the immediate impacts of *Formosa* on fishery workers, and how the affected fishers adapted to this extreme environmental shock, for at least two important reasons. First, fishery 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). Fishery-related activities also make up a considerable share of the economics in the central coastal of Vietnam. At the four-digit Vietnam Standard Industrial Classification (VSIC) level, the single sub-industry of saltwater fishery accounts for 3.8 and 7.3 percents of total employment and income in coastal districts[2] of Ha Tinh, Quang Binh, Quang Tri, and Hue in 2015 (General Statistics Office, 2016a). Second, it is worth noting that most of the Vietnamese fishery sector is small and medium scale, where fishers predominantly operate nonpower or outboard-engine (i.e. low-powered) boats. This puts a considerable restriction on the length and types of the fishing voyage, and often makes fishery earnings highly vulnerable to the uncertainty in fishing conditions, such as unfavorable climates or extreme, albeit rare, incidents like *Formosa*. Because we are interested in examining the immediate impact of the crisis, we confine the scope of the analysis to the period before any

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

formal source of compensation was distributed.[3] The time frame of our analysis allows us to evaluate fishery economic damages and adaptation activities during the most urgent time, thereby providing insights related to the timing and effectiveness of assistance policies.

This paper directly contributes to the emerging literature on the economic impacts of environmental disasters. Most of this literature has dealt with 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. Dell et al. (2014) provide a detailed overview of the literature.[4] Directly related to the fishery industry, Chaijaroen (2019) shows that coral breaching – a climate change phenomenon caused by abnormally high sea surface temperature – has a negative impact on marine resources, and subsequently, fishery households' income and protein consumption in Indonesia. Chaijaroen (2019) also finds evidence of long-run adaptation mechanisms, in terms of workers' adjustments in labor supply and industry switching. Our paper differs in studying the impulsive, short-run impacts on, and subsequent labor market responses of, local fishery communities to a breakout of a marine environmental crisis.

Compared 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; in many cases, they are one-off events without any precedents. The difficult task of anticipating the occurence of such events often leads to serious challenges with the design of emergency responses and adaptation mechanisms. 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 in-

[3] 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.

[4] At the macro level, Strobl (2012) and Noy (2009) find that natural disasters typically cause a drop in output in developing countries. Natural disasters may also affect the behavior of individuals. For instance, Page et al. (2014) show that victims of the flood become more risk-seeking after a loss in Australia. In contrast, Cameron and Shah (2015) show that individuals living in villages that recently suffered a natural disaster such as a flood or earthquake exhibit more risk-aversion than individuals in other villages. In terms of the labor market's implications, Gray and Mueller (2012) and Groger and Zylberberg (2016) find that natural disasters cause labor migrating to better off areas. In the U.S., Belasen and Polachek (2009) find that workers' earnings increase up to 4 percent in hurricane-stricken counties while wages in nearby counties decrease. Also, workers in hurricane-hit counties migrate into neighboring areas.

fant and childhood leukaemia (Petridou et al., 1996). The environmental damages of oil-spill disasters to local marine ecosystems, which directly affect the fishery and tourism industries, have been documented for the *Exxon Valdez* on south-central Alaska (Cohen, 1995), the *Prestige* in Galicia (northwest Spain) (Garza-Gil et al., 2006), or the *Penglai* in the Bohai sea (northeast China) (Pan et al., 2015), along with associated studies on risk assessment analysis (Al-Majed et al., 2012; Wirtz et al., 2007; Liu et al., 2015).

We contribute to the literature by evaluating the economic impacts of *Formosa*, a marine pollution crisis in coastal Vietnam, on the labor-market outcomes of the local fishery workers. Our analysis also emphasizes investigating the victims' responses to this extreme environmental shock. The fact that our empirical evidence shows a large distributional impact of *Formosa* on different local fishery communities provides an important implication of assistance polices that aim to support the victimized population.

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

2 The *Formosa* Disaster

In early April 2016, tonnes of fish and other marine creatures were suddenly found dead and floated ashore along the coast of four provinces in central Vietnam: Ha Tinh, Quang Binh, Quang Tri, and Hue. Shortly after, the main perpetrator was identified to be Formosa Ha Tinh Steel Corporation, whose malfunctioned underwater drainage system discharged heavy industrial waste containing phenol, cyanide and iron hydroxides – all are toxic chemical substances – into the ocean. After initially denying responsibility, the company admitted guilt on June 30, 2016, and agreed to settle for an immediate remedial compensation package worth US$500 million. It was 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 it officially went into law (Prime Minister of

Vietnam, 2017).[5]

The Formosa incident wreaked havoc on the livelihoods of local coastal communities residing in the four affected provinces, which happen to rely heavily on saltwater fishery. In May 2016, for the first time in history, the Vietnamese government announced a double-ban on both fishing activity and the processing and selling of seafood caught within 20 nautical miles of central Vietnam provinces, worrying that contaminated seafood in the region might not meet safety standards (VOA, 2016b). The ban would eventually last six months and was lifted in September 2016. However, all near-shore (within 20 nautical miles) deepwater fishing activity continued to be restricted, and would only eventually be lifted in May 2018, after series of inspections from the Health Ministry concluding that seafood caught in the area had met safety standards, and that marine resources had recovered (Vnexpress, 2018).

Figure 1 shows the map of Vietnam (divided into provinces) with a focus on the study area. The shaded provinces in central Vietnam are those directly affected by *Formosa*: Ha Tinh, Quang Binh, Quang Tri, and Hue (from north to south). The location of Formosa steel plant is geo-coded and shown as the green asterisk on the southern tip of Ha Tinh province. The thick dashed line (in red) indicates the near-shore fishing-restricted zone demarcated by the government that was in effect for six months, between April and September 2016.[6] The thin dash line (in blue) indicates the Maritime Exclusive Economic Zone (EEZ) of Vietnam.

3 Data and Empirical Methodology

3.1 Data and summary statistics

We analyze the impact of *Formosa* on fishery workers in central Vietnam using two main data sources. We collect labor-market information of fishery workers from the Labor Force Surveys of Vietnam ("LFS") in 2015 and 2016. The second set of data comes from the Visible Infrared Imaging Radiometer Suite ("VIIRS"), which is a remote-sensing data source storing satellite-imaged night-light luminosity and administered by the National Oceanic and Atmospheric Administration ("NOAA"). We specifically utilize VIIRS' Boat Detection Module ("VBD"), which processes worldwide night-time light emitted from fishing boats to attract catch. Importantly, VBD also implements an automatic boat detection identification system

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

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

that converts high-resolution marine-light intensity to actual boat counts. This algorithm enables us to obtain a monthly gridded panel dataset of fishing intensity (i.e. boat counts) for the entire Vietnam's maritime Exclusive Economic Zone (EEZ) between 2013 and 2016.

3.1.1 Vietnam labor force surveys

The Labor Force Survey is conducted annually by the General Statistics Office of Vietnam. The surveys in 2015 and 2016 include 689,747 and 814,611 individuals, respectively. LFS provides primary labor-market information including employment status, income and workload of workers at a quarterly basis. 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. In addition, there is a representative sub-group of households randomly selected to be surveyed twice a year, with the first survey visit taking place in the first or second quarters, and the subsequent revisit taking place in the third or fourth quarters.[7] For the purpose of analysis, we restrict our sample to only working-age individuals between 18 and 70 years old.

We focus on the labor outcomes specifically in saltwater fishery industry, and examine the changes in these outcomes before and after the *Formosa* incident. Our main sample includes all individuals who worked in the saltwater fishery industry before the disaster in 2016 (i.e. in Q1-2016). Thus, the fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue – the four *Formosa*-affected provinces – serve as the treatment group. As we will elaborate further, we exploit both the location-specific and industry-specific characteristics of *Formosa* to obtain the two separate groups of counterfactuals. First, because *Formosa* took place strictly in the central provinces, we form a "geographic" control group consisting of non-affected fishers located in other coastal provinces. To avoid the concerns related to contaminated counterfactuals, we restrict to only fishery workers living in the southern provinces distant from Formosa, specifically between Phu Yen to Ca Mau (see Figure 1). Second, the fact that *Formosa* mainly affected the fishery industry allows us to form an "industry" control group consisting of individuals living in the affected zone, who worked in non-affected industries such as manufacturing, construction, and retail.[8]

The first Panel (Panel I) in Table 1 presents descriptive statistics for the primary labor-market and observable characteristics of the saltwater fishery industry, using LFS 2015. The

[7] This survey design allows us to additionally control for the individual-level unobservables with the inclusion of individual-specific fixed effects in one of our empirical specifications.

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

mean and standard deviation for each outcome variable are shown separately for *Formosa*-affected (i.e. treatment) and control provinces. The control group consists of all fishery workers located in Vietnam' southern coastal provinces, from Phu Yen to Ca Mau. At the baseline, it is evident that fishery is a considerably more influential income-generating activity for individuals living in central Vietnam. On average, a central Vietnam fisher works over 62 hours a week and earns 7.4 million VND in total monthly income (approx. 335 USD), compared to the respective figures of 55 hours and 6.2 million VND of a southern (i.e. control) fisher. Saltwater fishery average monthly income is significantly higher than that of other industries in the central provinces, which is the result of a longer workload and the compensating wage differential from much harsher working environment.[9] Because of the arduous and labor-intensive condition, well over 90% of the fishers are male. More than a quarter of them did not have any formal educational training and only less than 3% obtained high-school or college level education; most fishers are born and raised in families that have been attached to fishery for generations.

Table A1 provides preliminary evidence indicating the negative impact of *Formosa* on fishery earnings in central Vietnam. The table compares pre-disaster (i.e. Q1-2016) and post-disaster (i.e. the rest of 2016) average monthly incomes, separately for 3 groups: (1) the treament group, i.e. the fishery workers living in the *Formosa*-affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue; (2) the unaffected fishery workers living in southern provinces distant from Formosa, which we refer to as the "geographic" control group; and (3) the non-fishery workers living in the *Formosa*-affected provinces that work in other unaffected industries, referred to as the "industry" control group. The means difference test (last column) indicates drastic and statistically significant declines in average fishery incomes of the *Formosa*-affected individuals. In contrast, we do not observe any statistically meaningful changes in incomes of the "control" fishers.[10]

A crucial aspect of the DiD method employed in this paper is the validity of the parallel pre-trend assumption. Figure 3 visually addresses this element; the figure plots raw average monthly income profiles for the treatment (thick line) and control groups (thin-dash line), using both LFS 2015 and LFS 2016. While the line plots exhibit strong parallel pre-trend between the two groups, they suggest an abnormal downward deviation from trend by the treatment group, right after *Formosa* took place (in April 2016). It is also evident that

[9] An average non-fishery worker living in Ha Tinh, Quang Binh, Quang Tri, and Hue works 41 hours per week and earns 3.9 million VND per month.

[10] In fact, there is an expected (insignificant) increase in the average fishery earnings of the unaffected southern fishers after the first quarter of 2016. This is because the fishing season usually takes place between May and November each year, as visually seen in Figure 4.

there was a gradual trend-conversion in the monthly earnings of the affected fishes; by the end of 2016, the average monthly income of these individuals seemed to have recovered to the lower-bound level of their pre-*Formosa* earnings. Also consistent with the descriptive statistics from Table A1, we observe a rather flat earning profile for the control group (i.e. the unaffected fishers) across the entire analysis period.

3.1.2 Satellite data on boat detection

To measure the impact of *Formosa* on fishing activity, we use the Visible Infrared Imaging Radiometer Suite ("VIIRS"), which documents high-resolution night-time light luminosity at the globe's surface. VIIRS is administered by the National Oceanic and Atmospheric Administration (NOAA). Specifically, we utilize a special Boat Detection Module of VIIRS ("VBD"), which detects the ocean's night-time light source emitted from fishing boats.[11] VBD is jointly sponsored by the U.S. Agency for International Development, NOAA, and the World Bank. The project collects and processes remote-sensing images from the Suomi National Polar-orbiting Partnership (Sunomi-NPP) satellite. Joint Polar Satellite System (JPSS) is the new generation polar-orbiting operational environmental satellite system in the U.S. The VIIRS itself is the primary imager on Sunomi-NPP.[12]

The use of night-time light brightness as a measure of economic activity has become increasingly popular in economic research. Especially in developing countries where subnational accounting data are often missing or unreliable, luminosity at night has been shown to provide an unbiased proxy for growth outcomes. It is noted that the majority of existing studies adopting night-light measure have relied on the Meteorological Satellite Program-Operational Line Scan package (DMSP-OLS). DMSP-OLS final output provides composite annual light density measures at a coarse footprint of 5km $\times$ 5km pixel resolution (see Donaldson and Storeygard (2016) for a comparative analysis on this literature). Compared to the imaging sensors suite in DMSP-OLS, VIIRS provides higher quality remote sensing imagery in terms of spatial resolution, coverage interval, and the ability to detect weak light sources, which makes it ideal for our analysis. The VIIRS Day/Night Band sensor unit has a 742m $\times$ 742m footprint, and thus can detect boat activities within as fine an area as 0.2 mile squares. Couple 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

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

[12] 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].

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 ionosphere.

For the purpose of this analysis, we use the monthly-aggregate VBD products published by NOAA for the period between 2013 and 2016.[13] We then aggregate the number of monthly boats detected into 10-mile-square geo-grid cells that, together, spans Vietnam's entire Maritime Exclusive Economic Zone.[14] The chosen resolution of 10-mile-square grid allows us to better capture the effect for different fishing grounds across the entire country's coastal area. It covers a marine space granular enough to detect micro changes in fishing activity's patterns (e.g. within-province fishing grounds' migration). Nevertheless, this footprint level still spans a sufficiently large sea segment, which allows us to be less concerned with issues about spatial autocorrelation or spurious boat detection.

The second panel (Panel II) in Table 1 presents fundamental statistics of two dependent variables related to fishing intensity that are made possible by VIIRS: (1) *fishing prevalence*, i.e. boat detection likelihood, which is the probability that at least a boat was detected inside a particular grid in a given month and, thus, provides information regarding the *extensive* margin of the disaster's impact; and (2) *fishing density*, i.e. the number of boats detected in each grid, which captures the *intensive* margin. The three-year baseline grid-month statistics from VIIRS 2013-2015 suggests that fishery actions are considerably more intense in the central coast. Near-shore ($\leq$ 20 nautical mile) fishery activity has a 59 percent average monthly coverage, while off-shore fishing covers over two-third of the marine pixels.[15] The respective boat-detection likelihoods in the control provinces are 40 (near-shore) and 55 (off-shore) percent. On average, there are approximately 5 boats detected per month in each of the 10-mile-square pixel in the treatment provinces, similar across both near-shore and off-shore fishing grounds. It is also noted that these statistics on fishing intensity are consistent with the LFS labor-market information; recall in Panel I of the table that saltwater fishers in the central (*Formosa*-affected) provinces have a greater baseline average workload relative to those in the control provinces.

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

[14] According to Elvidge et al. (2018), the monthly temporal aggregation addresses each of the three criteria that could be potential concerns for higher-frequency intervals: lunar cycle effect, seasonal variation, and cloud cover. The monthly aggregation VBD mitigates 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).

[15] We cap the off-shore marine space to be the pixels located between 20nm and 80 nm from the shoreline.

Figure 2 visually illustrates the use of boat-light detection data. This figure presents a side-by-side comparison between two raw satellite snapshots from VIIRS' VBD images. In each of the two panels, we process the original raster-formatted data published by the NOAA for the two months of May 2016 (right; i.e. the month immediately after the *Formosa* breakout) and May 2015, resampling the light maps into 10-mile-square grids covering the entire marine space within the maritime EEZ of Vietnam.[16] The brighter pixels in these figures represent fishing grounds with higher boat density. One could visually notice the impact of *Formosa* on fishing intensity by contrasting the two snapshots. First, while near-shore fishing boats were densely detected along the coast of all central coastal provinces in May 2015, this region experienced a marked decrease in boat density the first month *Formosa* took place (May 2016), especially in the near-shore region from Ha Tinh to Hue – the directly affected area. *Formosa* seemed to also affect major offshore fishing grounds (further out from the 20nm fishing ban zone) of Quang Binh, Quang Tri and Hue, where the brightest cluster of densely-fished area became significantly dimmer. Interestingly, the coastal area north of Ha Tinh seems to experience a significant *increase* in brightness after the incident, suggesting a level of fishing concentration in this area after *Formosa* took place. As we will discuss empirically in the next section, this observation on the transition of fishing grounds from within to outside the contaminated zone (to the northern sites) offers a direct explanation to the large geographic distribution of the disaster's impact.

Figure 4 provides further evidence supporting the parallel pre-trend assumption in near-shore fishing intensity (i.e. boat counts) between the treatment (left) and control zones (right). In this figure, we plot the aggregate monthly boat counts for all the months between 2014 and 2017, separately for the two groups.[17] Even under the apparent existence of fishing seasonality, it is clearly visible that 2016 was an anomalous period with low monthly boat counts in the affected region (left panel). The number of boats captured in the peak month of July 2016 was just above 4,000, compared to that of greater than 6,000 in other years. While this sharp downward deviation is noticeable in the treatment zone, it is not the case for the control region; the 2016 near-shore average monthly boat counts in the southern provinces seemed to closely follow its yearly pattern.

[16] Note that each of these pixel stores a composite monthly-aggregate boat count value made feasible by the VIIRS's automatic boat detection identification capability.

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

3.2 Econometric specification

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

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

where the subscripts refer to an individual i surveyed in month m in 2016.[18] y_{im} is the dependent variable at the individual level. We investigate the effect of *Formosa* on several primary fishery earnings and employment, including monthly fishery and total incomes, weekly work hours, and the probability of working secondary jobs. The standard DiD indicator terms are

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

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

1. Geographic control group: all individuals who worked in saltwater fishery before May 2016 and lived in the non-affected region. We purposefully narrow the geographic location of our control group to only the southern provinces distant from the Formosa's location in order to mitigate any possibility that part of the control group could be contaminated due to potential spillovers of *Formosa*. Specifically, we include all fishery workers living in the provinces South of Phu Yen, with Phu Yen being approximately 600 km away from Hue – the southern-most *Formosa*-affected province.[19]

2. Industry control group: all individuals who worked in *Formosa*-unaffected industries before May 2016 and lived in the affected region. To identify unaffected industries, we cross-check on different government's official sources regarding *Formosa* compensations to the affected industries. In the main analysis, we adopt three major industries that

[18] We also report results for a placebo test using data from the LFS 2015.

[19] We also experimented with including all provinces south of Hue, as well as including an additional province of Quang Nam in the control group and obtained robust estimates. Results available upon request.

are arguably the most *unaffected*, including manufacturing, construction, and retail.[20]

$$post_m = \begin{cases} 1, & \text{if the month is between May and December in 2016} \\ 0, & \text{otherwise.} \end{cases}$$

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 any unobserved monthly variations affecting the country-wide fishery industry. 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:

$$y_{cpmy} = \beta_1(treat_c \times post_{my}) + \gamma_c + \lambda_{my} + \pi_{pm} + \epsilon_{cpmy} \tag{2}$$

where the subscripts refer to a 10-mile-square grid cell c located within the marine zone of province p, and stores the monthly-aggregate boat-detection value in month m in year y. Thus, the outcome variable y_{cpmy} provides a measure for fishing intensity at each 10-mile-square fishing grounds, spanning the entire Vietnam EEZ.[21] We focus on two measures of fishing intensity: (1) boat detection likelihood (extensive margin); and (2) aggregate boat counts (intensive margin). The standard DiD indicator terms are

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

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 the time-invariant unobserved characteristics within each 10-mile-square fishing ground. λ_{my} represents the month-by-year fixed effects, which absorb the month-specific and year-specific single fixed effect terms, and essentially control for any monthly unobserved variations affecting country-wide fishing activities. π_{pm} represents the province-by-month fixed effects, which captures the existence

[20] Our estimates remain highly robust when we adopt workers in each of the 3 industries as the "control group".

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

of seasonality specific to each of the 24 coastal provinces. ϵ_{cpmy} represents idiosyncratic standard errors clustered at the province-level.[22]

The estimated coefficients of interest in Equations (1) and (2) are α_1 and β_1, which measure the differential changes in fishery earning (Equation (1)) and fishing intensity (Equation (2)) after *Formosa*, in the central coastal provinces (i.e. the treatment zone) relative to the unaffected provinces.

4 Overall Impacts of *Formosa*

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

4.1 Impact on labor outcomes in saltwater fisheries

Table 2 presents the DiD estimates for our primary indicator of economic well-being – fishery monthly incomes. We consider two earning measures: (1) monthly income from the primary occupation (columns 1 and 3) and (2) total monthly income from all sources (columns 2 and 4). In all regressions, the treatment group consists of pre-event saltwater fishers located in the affected provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue. As mentioned, we employ simultaneously two control groups in all subsequent regressions. In Panel A, the counterfactuals are pre-event fishers located in the unaffected coastal provinces. To avoid concerns related to potential spillover effects of *Formosa* to nearby regions, we restrict the sample to only the southern provinces distant from Formosa, i.e. from Phu Yen to Ca Mau (see Figure 1). In Panel B, the counterfactuals are workers located within the *Formosa*-affected region who were employed in non-affected industries. We purposefully

[22] In a robustness exercise, we remove all observations in April 2016 in the regressions, since the actual start of *Formosa* in April remains unclear. Our estimates are robust to the exclusion of April 2016 as a post-treatment month. Results are available upon request.

select industries that are arguably the most *unrelated* to the marine pollution crisis, namely manufacturing, construction, and retail.

The fundamental "parallel trend" assumption of a DiD model implies that the average monthly earnings of the treatment and control individuals follow similar pre-trends, and that the average earning's movement of the counterfactual group is "smooth" across the *Formosa* incident timeline. Recall that we discuss several empirical supports for the validity of this assumption in Figure 3 and Table A1. Therefore, we are able to quantify the Average Treatment Effects (ATE) of *Formosa* by measuring (1) the changes in fishery earnings in the treated location relative to the control region (Panel A), or (2) the changes in fishery earnings relative to the average earnings in unaffected industries in the *Formosa* zone (Panel B). In both exercises, the average impact of *Formosa* for the rest of 2016 (i.e. after the incident took place) is estimated by $\hat{\alpha}_1$.

Overall, using LFS 2016 data and controlling for the month-specific and individual-specific fixed effects as well as clustering the standard errors at the district-level, our estimation robustly indicates a massive and statistically significant decline in fishery monthly incomes caused by *Formosa*, with the magnitude ranges from 30 percent in the "pooled" regressions (columns 1-2) to approx. 45 percent under the individual fixed-effect specification (columns 3-4). The fact that fishery income reduced by almost half after the crisis indicates how destructive the disaster was. From the supply-side perspective, safe seafoods became much more costly to catch. In the subsequent section of the paper, we show that affected fishers, depending on their location within the contaminated zone, either coped with the shock by traveling longer distance to safe fishing grounds with an inevitable cost, or had to substitute fishery hours with working secondary jobs.

4.2 Impact on satellite-detected fishing activities

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

Table 3 reports the estimated DiD coefficient $\hat{\beta}_1$, which illustrates the ATE of *Formosa* on fishing prevalence and density in the demarcated 20nm near-shore fishing-restricted zone until the end of 2016. We further test for the robustness of our estimation under various specifications controlling for different sets of fixed-effects, as well as under two separate comparison groups. In each set of regressions, the "All Other Provinces" refers to the control group consisting of near-shore ($\leq 20nm$) marine grids in all other coastal provinces except for Ha Tinh, Quang Binh, Quang Tri, and Hue. Given the potential geographical spillover effect of *Formosa*, we also consider a "Restricted" control group, referring to the near-shore grids in coastal provinces located south of Phu Yen (i.e. distant from the *Formosa*-affected region).[23]

Consistent to what we initially observe in Figures 2 and 4, it is evident that near-shore fishing within the *Formosa*-affected zone declined significantly in intensity. All DiD estimates were statistically significant at the 99% confidence level. The empirical result suggests a robust reduction in average boat detection density (i.e. the intensive margin) of up to 27 percent, and a reduction in boat detection likelihood (i.e. the extensive margin) of close to 9 percentage points. Note that we accommodate for the portion of "unlit" grids (i.e. those detected with no boats) in the log specification of boat density measure by adding a constant of ones to boat counts before the transformation. We refer to this specification in the main result tables as "modified log" value. In Table OA1 (Online Appendix), we report the additional DiD results adopting two other indicative outcomes of boat density, including boat counts in level and unmodified logarithm.

4.3 Validity and falsification tests

In this subsection, we supply evidence from several empirical exercises to validate our DiD approach, and to ensure that the treatment effects estimated above are robust and statistically meaningful.

[23] As yet another robustness exercise reported in Appendix Table A2, we further restrict the control provinces to only southern coastal provinces, from Vung Tau to Ca Mau, and obtain highly robust and consistent estimates.

4.3.1 Validity of the parallel-trend assumption

Recall that a crucial assumption underlying the difference-in-differences approach is that units of the treatment and control groups 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. We have discussed descriptive evidence from Figures 3 and 4, and Table A1. Specifically, we show that both measures of fishery income (Figure 2) and boat density (Figure 4) in the treatment and control groups seem to follow a common monthly pre-trend. Additionally, in Table A1, while we detect a significant reduction in means between the pre- and post-treatment earning averages for *Formosa*-affected fishery workers in 2016, we find no such statistical differences for the control groups. In this sub-section, we conduct additional empirical exercises to further support the validity of the parallel-trend assumption.

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

We repeat an identical falsification exercise for fishing activity's outcomes (i.e. boat detection likelihood and density) in Table A4, using an antecedent sample of grid observations for the months between 2013 and 2015, in which a fictional event is imposed hypothetically in May 2014. Everything else remains similar to the regressions in Table 3. As can be seen, all of the estimated DiD coefficients are small and statistically insignificant, with only one exception in column 6. In this column, $\hat{\beta}_1$ was actually *positively* estimated; however, the estimate is small in magnitude (3 percent) and barely significant at the conventional 10% level.

In Panel B of Table A3, we provide a direct test for the validity of the "industry control group" in the main DiD analysis. Recall from Table 2 that individuals who lived in the *Formosa*-affected provinces and worked in manufacturing, construction and retail serve as the counterfactuals for fishery workers, the average monthly earnings of these individuals should not be affected by *Formosa*. We test for this hypothesis by comparing these individuals' before-after earning differentials to that of workers living in provinces unaffected by *Formosa* who also work in the same industries.[24] The estimation result suggests that *Formosa*, indeed, did not seem to affect earnings in these industries in any statistically meaningful way.

4.3.2 Falsification tests with permutation inferences

Given that we obtain a strong and highly significant set of impact estimates in Tables 2 and 3, it is hard to believe that these are spurious outcomes. However, we are still interested in empirically testing for this potential. From an econometric perspective, is there a possibility that the effects shown are simply outcomes of "the luck of the draw" that is entirely unrelated to *Formosa*? We show that such "lucky draw" is highly unlikely to materialize. We take randomly three to five provinces within the unaffected coastal region. We then assign a "treatment" status to these randomly-picked unaffected provinces and a "control" status to the rest. We then replicate the DiD regressions similar to equations (1) and (2) with fishery incomes and boat density using these falsified treatment and control groups. We perform this permutation inference test with 1,000 iterations, and plot the distributions of the estimated coefficients and their respective t-statistics in Figure 5. For both fishery income and fishing density, the distributions of these falsified estimates exhibit strong normality centered at 0. The large majority of these coefficients are also imprecisely estimated, as indicated by the small magnitudes (in absolute term) of the majority of the t-values.[25] As indicated by the red vertical lines in each of the panels, the estimated values obtained from the earlier regressions using the four *actually* affected provinces as the treatment group are complete left-tail outliers. This suggests that the causal impacts captured in Tables 2 and 3 are not likely to be randomly regenerated.

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

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

5 Coping Mechanisms, Fishing Recovery and Industry Spillover Effects

In this section, we turn to focus on the different coping mechanisms of the victimized fishery workers. We corroborate evidence from both the satellite and labor force data. First, we discover a large distributional impact to fishery incomes by location. We also show that, dependent upon where fishers were located, these individuals likely responded differently to the shock. Those who could feasibly travel to safe grounds likely did so to sustain fishing activities. In contrast, fishers who were likely "trapped" inside the contaminated zone chose to substitute fishery work-hours with having secondary jobs. Next, we look at disaster recovery, examining the *Formosa* impacts on both fishing intensity and fishery income by quarters. We find a gradual reduction in disaster damage to both outcomes, even though the impact on earnings still remained sizable in the last quarter of 2016. Lastly, we study potential spillover effects of *Formosa* on related industries, and find evidence suggesting an increase in freshwater fishery earnings.

5.1 How did the victims cope with the shock?

To motivate our discussion on the coping mechanisms of fishery workers following *Formosa*, we first provide evidence that the impact of the crisis is highly heterogeneous. In Table 4, we split the treatment provinces into two separate groups by geographic location: Ha Tinh and Quang Binh (i.e. the "upstream" group), and Quang Tri and Hue (i.e. the "downstream" group). Immediately, we discover a stark difference on how *Formosa* affected fisheries. In terms of the impact on incomes, the estimated ATE size (i.e. the size of average income reduction) for the downstream fishers is found to be between 10 and 15 percentage points larger than that for the upstream counterparts, suggesting a more severe impact of *Formosa* on the economic well-being of fishers living downstream.

In order to investigate the reason underlying such discrepancy in the geographic distribution of earning impacts, we turn to satellite information. Recall from the initial observation in Figure 2, there seems to be a transition in fishing grounds (i.e. the bright pixel clusters) from within the contaminated zone to the "safe" region located north of Ha Tinh. The anecdotal explanation for this altered fishing pattern pertains to the southward flow of the ocean; toxic substances discharged by *Formosa* in Ha Tinh were likely spread south along the current (hence affecting also Quang Binh, Quang Tri, and Hue), leaving the marine region north of Ha Tinh uncontaminated. Therefore, what is shown in Figure 2 nicely corresponds to a rational expectation in fishery response: we would expect fishers located near the safe water, i.e. the upstream individuals who lived in Ha Tinh and Quang Binh, to travel north to continue fishing. However, going north is perhaps not an equally convenient option for the downstream fishers, given how far away they are located. Traveling there to fish is certainly much more costly, if not impossible, provided that the majority of these individuals are small-scale fishers. This difference in relocation feasibility likely attributed directly to the large geographic distributional impact of *Formosa*. Furthermore, it might have also triggered different responses in the fishery labor market, as we discuss subsequently.

In oder to more formally examine how fishers coped with *Formosa*, we empirically estimate a province-by-province ATEs on fishing intensity along the coast of each of the northern and central provinces in Vietnam. To remain consistent with the regression exercises, we employ the same restricted control group consisting of fishery workers located in from Phu Yen to Ca Mau, where fishing activity was arguably unaffected by the disaster. Figure 6 plots the DiD estimated coefficients and their 95% confidence intervals for each provinces from Quang Ninh to Quang Ngai, using all 10-mile-square grid observations located within 80 nautical miles from shore. Panel A illustrates the impact on fishing density, measured by log-transformed monthly-aggregate boat counts. Panel B illustrates the impact on fishing prevalence, measured by the indicator for boat-detection likelihood in each grid. The detailed results corresponding to this figure are provided in Online Appendix Table OA3.

Both Panels A and B show that the directly-affected area between Ha Tinh and Hue suffered the most dramatic impacts. Consistent with the ATEs estimated in Table 3, we find reductions of over 20 percent in fishing density and close to 10 percentage points in fishing prevalence in this region. It can also be seen that the crisis did not just affect fishery communities located inside the fishing-restricted zone, but also negatively influenced activities in the nearby regions. The spillover effect is noticeable in the southern adjacent area including Da Nang and Quang Nam, where both fishing density and likelihood were negatively affected.[26] The impact does seem to dissipate for regions further away south, and becomes small and statistically insignificant starting from Quang Ngai.

Turning to the spillover effects in the northern provinces, Figure 6 exhibits an interesting pattern that corresponds to what is observed in Figure 2. The Panels illustrate a large and

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

significant *increase* in fishing intensity in the majority of coastal provinces north of Formosa. The positive effect stretches from Quang Ninh to Nam Dinh, the northern-most provinces in the country. While there is a negative spillover in fishing density lingered in the *Formosa*-adjacent provinces of Nghe An and Thanh Hoa, this effect is negligible and insignificant in terms of fishing prevalence. Taken together, the findings in Figure 6 provide certain suggestive evidence reinforcing our hypothesis for a coping mechanism in fishery pattern: the fishers capable of traveling to uncontaminated fishing zones did likely resort to this option in order to sustain fishing as an income-generating activity.

There are two immediate follow-up questions: (1) among the affected fishers, who were more likely to travel to safe fishing grounds to continue fishing? and (2) from the labor-market standpoint, do fishers respond differently, depending on the possibility of relocation? The pattern in Figure 6 continues to provide empirical evidence. As we already discussed, among the four affected provinces, those located upstream – in Ha Tinh and Quang Binh – were likely to possess better adapting options due to their proximity to the uncontaminated fishing grounds north of Ha Tinh. In contrast, the options for the downstream fishers in Quang Tri and Hue were much more limited: transporting north, especially for those operating small boats and mainly fish near-shore, was much more cost-ineffective due to the distance.[27] Going south to fish near-shore was also not prospective when seafood consumers were also reluctant to purchase products caught in this region, citing the concern with potential southward spillover of the contaminated water. These downstream fishers, then, had to make the hard choices; to stay in fishing, they had to travel more distantly and cost-ineffectively, no matter north- or south-ward.[28] Otherwise, the only other prospect is to obtain secondary jobs away from fishing activities. Indeed, that latter is what we empirically observe in Table 5.

Table 5 presents the ATE estimates for two dependent variables directly related to the labor-market responses: (1) fishery weekly work hours and (2) the probability of having secondary jobs (in the surveyed month). To get at the heterogeneous responses, we continue to split the *Formosa*-affected sample into upstream (Ha Tinh & Quang Binh) and downstream provinces (Quang Tri & Hue). The empirical results obtained in Table 5 strongly corroborate the overall hypothesis after looking at satellite data. Consistently estimated across the choices of control groups, the downstream fishers in Quang Tri and Hue – those who were likely "trapped" inside the contaminated zone – responded to *Formosa* by reducing their weekly fishing workload by approximately 29 hours. This massive and significantly es-

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

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

timated reduction in workload amounts to almost a half of total baseline weekly work hours (62 hours; see Table 1) and reflects how disastrous the disaster was to fishery employment in this region. In stark contrast, and consistent with the hypothesis that upstream fishers could transition to the northern safe waters, we find a slight increase in the fishery workload of these individuals after *Formosa*. Albeit mostly imprecisely estimated, this increase of approximately 1.5 hours is consistent with the potentially longer travel duration that these fishers have to make, if they indeed resort to the option of traveling to safe fishing locations. It might have been the case that this extra travel cost and, perhaps, the unfamiliarity with new fishing grounds directly factor into a reduction in earnings that we saw in Table 2. Finally, because upstream fishers were likely to find a way to continue fishing, we do not observe any significant changes in the likelihood that these individuals look for secondary jobs. However, the sizable reduction in downstream fishery workload seems to trigger another channel of employment response that these individuals resorted to. In column 2, we find a 14-percentage-point increase in the likelihood that fishers located in Quang Tri and Hue had secondary jobs outside fishery. While we do not observe in the data the type of secondary jobs these workers performed, it is likely that the jobs are menial in characteristics, given the low average educational background of most fishers.[29]

5.2 Impact recovery and spillover effects

Having presented the dramatic impact of *Formosa* on fishery earnings, employment choices, and fishing intensity, we now turn to the discussions on (1) damage recovery and (2) potential spillover effects on other industries.

Table 6 presents empirical evidence for the recovery on fishing density (columns 1 and 2) and prevalence (columns 3 and 4) after *Formosa*. The empirical setting is identical to what shown in Table 3, with the only exception being the ATEs estimated separately for each quarters after April 2016. Relative to the pre-treatment period, we find pronounced reductions in fishing density by between 33 and 36 percent, and in fishing prevalence by approximately 9 percent. The substantial negative impact lingered to the third quarter, before swiftly dissipated in the last three months of the year – most likely due to the lift in the official fishing-restriction order imposed by the government.

Correspondingly, Table 7 presents the impact recovery on fishery incomes. Again, we follow the same empirical setting similar to that in main regressions in Table 2, except for

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

the quarterly ATEs estimation. The empirical result also suggests a clear declining trend in negative average treatment effects; while *Formosa* is estimated to have caused as much as a 65 percent reduction in fishery income in the second quarter of 2016, the effects decreased to approximately a half in the last quarter, and are statistically indistinguishable from 0 in the "pooled" specifications. While it is encouraging to observe a rapid recovery, the fact that fishery earnings still declined by over 30 percent half-a-year after *Formosa* took place, and especially when fishing activities have almost resumed to the normal rate (recall from Table 6), shows how devastating the disaster was.

Last but not least, we study the potential spillover effects of *Formosa* on other industries. Recall that we have shown in Table A3 (Panel B) that *Formosa* did not seem to have any effect on the highly-unrelated industries such as manufacturing, construction and retail, which facilitates our adoption of workers in these industries as counterfactuals to saltwater fishery workers. We now pay attention to the potential spillovers to individuals employed in other industries that have a higher level of linkages to fishery (Table 8). We examine four industries, including freshwater fishery, husbandry, restaurants and lodging. On the one hand, freshwater fishery and husbandry are industries that produce direct substitute products to saltwater seafoods; hence it is reasonable to expect certain spillover effects of *Formosa*, most likely through a supply-determinant channel such as substitute-product pricing. On the other hand, restaurant and lodging are selected because of the potential damage to the coastal tourism industry. In fact, together with saltwater fishery, restaurant and lodging are among the sub-industries eligible for several *Formosa* compensation schemes, as documented in the government's official reports (VOA, 2016a).[30]

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

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

6 Conclusion

This paper examines the economic impacts of a large-scale marine pollution disaster on the employment and earnings of a local fishery community. The *Formosa* incident, in which toxic wastewater was discharged into the ocean and damaged an entire ecosystem in the central coast of Vietnam in 2016, presented a special case study for how the affected communities – saltwater fishers – coped with the negative shock. We combine a novel satellite data capturing night-time light detected from fishing boats with the fishery earnings and labor-market information provided by the labor force surveys. We show that the disaster reduced incomes by as much as 46 percent for the immediate period after the *Formosa* breakout. We further provide evidence indicating potential coping mechanisms. Upstream fishers who live closer to safe fishing grounds were likely to travel there and continue fishing, as shown by the intensified fishing activities in those regions after the incident took place. In contrast, downstream fishers, who live far away from safe waters, experienced more dramatic impact on average earnings. In terms of the labor-market responses, we find that these individuals substitute work hours in fishery with working secondary, non-fishery jobs. Both coping mechanisms are shown to help mitigate the income losses, even though far from entirely. We also find that the income damage to fishery diminished over time, even though it remained sizable and statistically significant at the end of 2016. Finally, we discover a positive spillover income effect on the freshwater fishery industry, which produces seafood's substitute products.

Examining the impact of *Formosa* on the affected population, and how these victims cope with the extreme shock, is relevant to the design of different assistance policies. We show that, even on average, the impact of *Formosa* was not uniformly distributed among the victims. It is also evident that *Formosa* did not just affect saltwater fishery in the four provinces located within the contaminated zone, but also the nearby regions and other industries as well. These findings should be factored into any top-down incentives to compensate and subsidize Formosa-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.

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

Chaijaroen, Pasita, "Long-lasting income shocks and adaptations: Evidence from coral bleaching in Indonesia," *Journal of Development Economics*, 2019, *136*, 119–136.

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.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken, "What Do We Learn from the Weather? The New ClimateEconomy Literature," *Journal of Economic Literature*, 2014, *52* (3), 740–798.

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., 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.

Groger, Andr and Yanos Zylberberg, "Internal Labor Migration as a Shock Coping Strategy: Evidence from a Typhoon," *American Economic Journal: Applied Economics*, April 2016, *8* (2), 123–153.

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.

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.

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.

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.

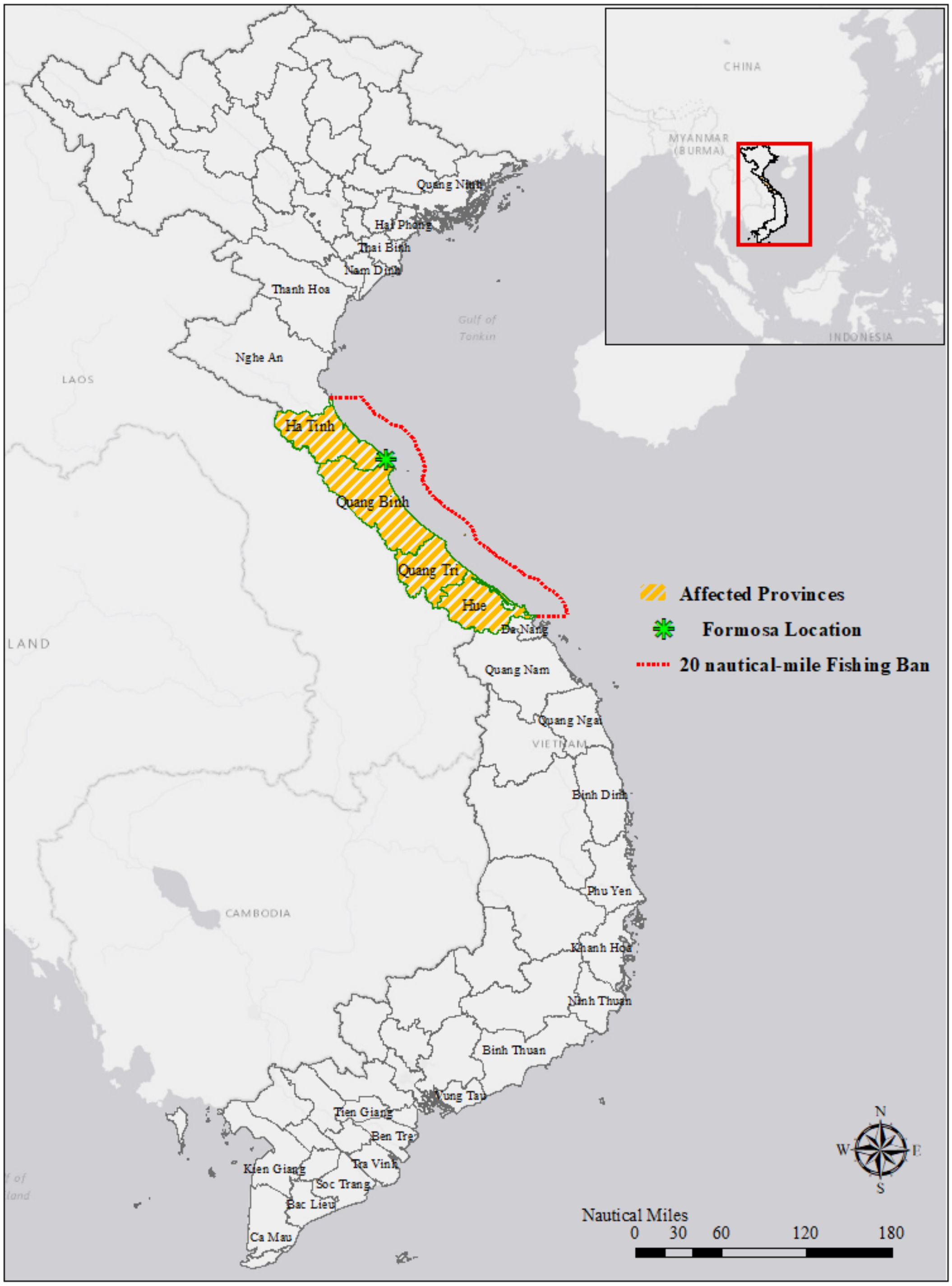
Vnexpress, "Vietnam Health Ministry Declared Fishes in Central Provinces are Safe for Consumption," https://vnexpress.net/tin-tuc/thoi-su/bo-y-te-cong-bo-hai-san-bon-tinh-mien-trung-bao-dam-an-toan-3750773.html 05 2018. Accessed July 29, 2018.

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.

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 the Formosa Study Area

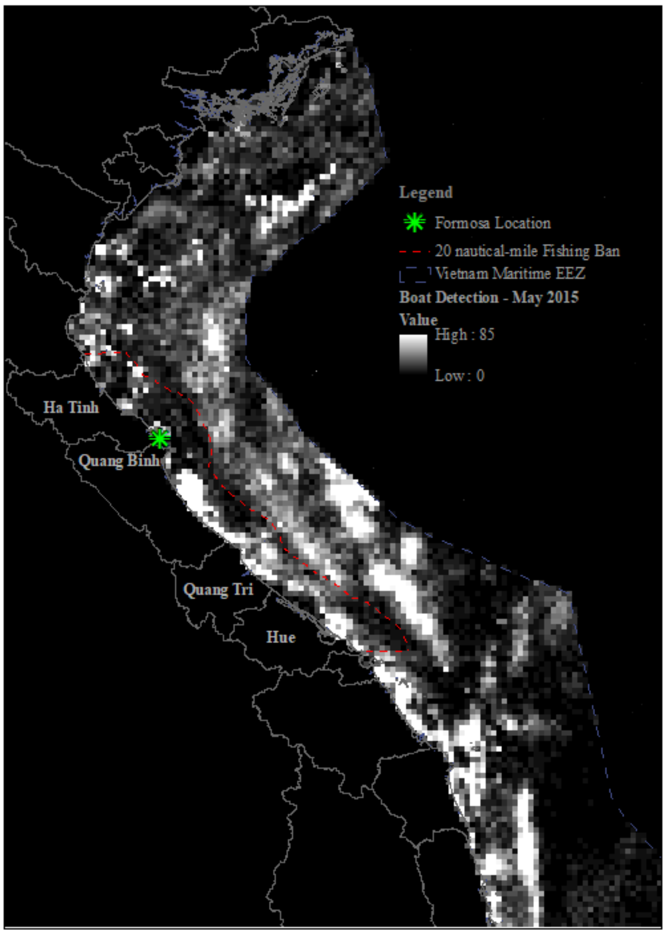


Note: the figure shows the map of Vietnam, divided into 63 provinces (first-tier administrative units). The treated group (i.e. the Formosa-affected provinces) is shaded in orange and includes the provinces of Ha Tinh, Quang Binh, Quang Tri, and Hue. The red dash line illustrates the 20 nautical-mile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

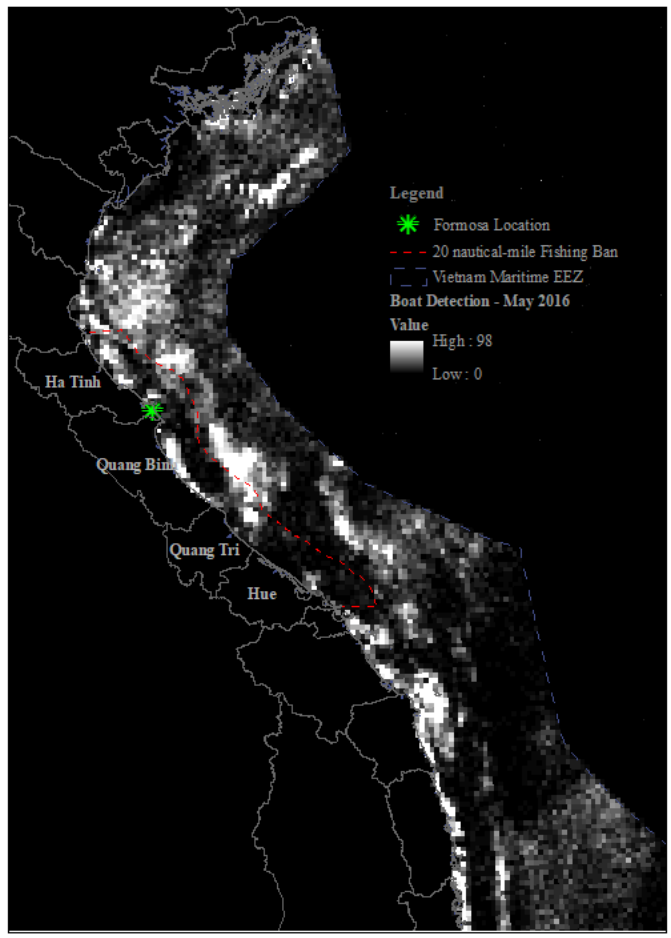
Disclaimer: The boundaries, colors, denominations and other information shown on any map in this work do not imply any judgement on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

Figure 2: Comparisons using VIIRS Night-light Boat Detection: Raw-data Plots

(a) VIIRS Boat Detection (May 2015)



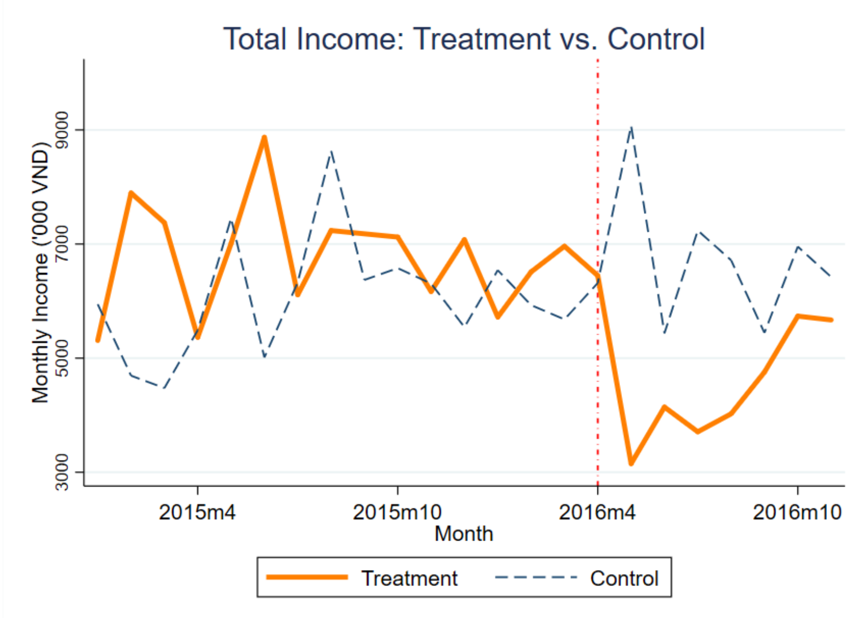
(b) VIIRS Boat Detection (May 2016)



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

Disclaimer: The boundaries, colors, denominations and other information shown on any map in this work do not imply any judgement on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

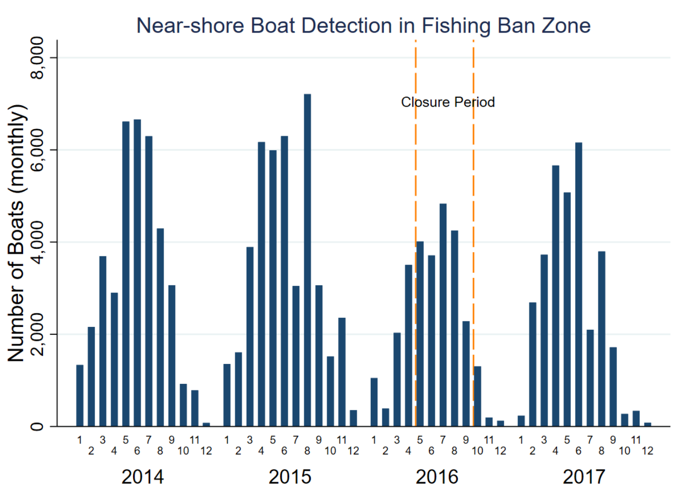
Figure 3: Comparison of Income Trends: using Labor Force Surveys 2015-16



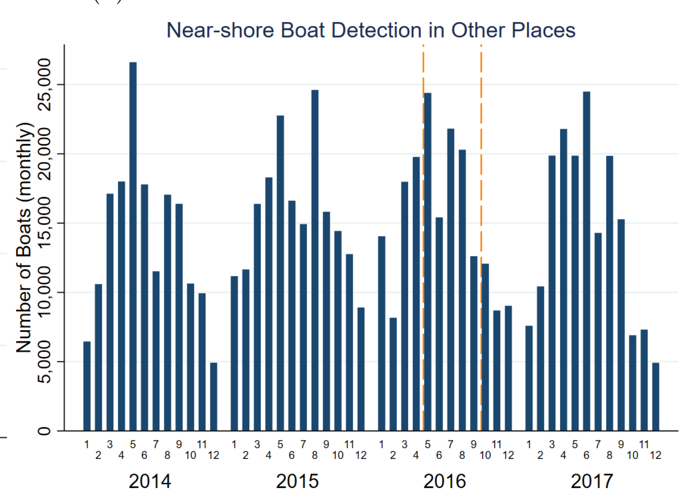
Note: this figure plots the pre-and post-Formosa movements of saltwater fishery monthly average incomes (in '000 VND), for each month between January 2015 and December 2016, separately for the treatment group (i.e. fishers in Ha Tinh, Quang Binh, Quang Tri, and Hue) and control group (i.e. fishers located in the Southern provinces distant from Formosa – Phu Yen to Ca Mau).

Figure 4: Comparison of Fishing Intensity: using VIIRS Boat Detection data

(a) Near-shore Boat Detection - Ban Zone



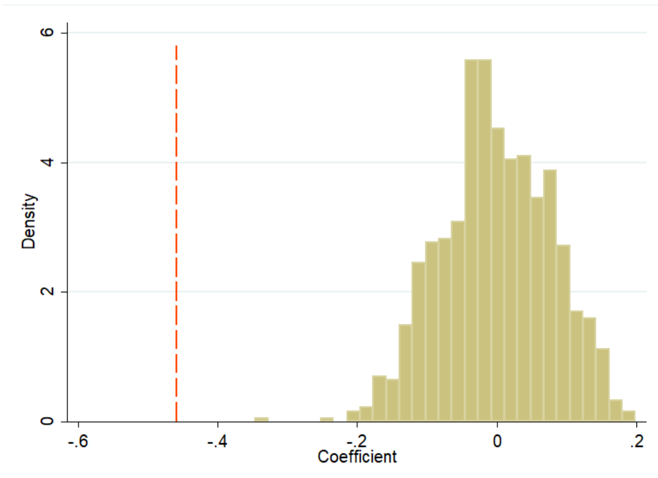
(b) Near-shore Boat Detection - Other Zone



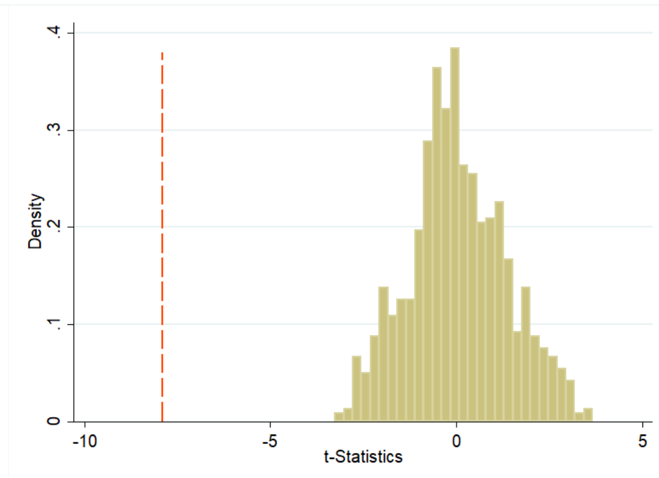
Note: this figure plots the pre-and post-Formosa movements of fishing intensity, measured by total monthly boats detected, for every months in 2014-2017. The left panel shows statistics for the treatment area, i.e. the 20 nautical-mile restricted fishing zone along the coast of the affected provinces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

Figure 5: Falsification Exercise: Permutation Tests

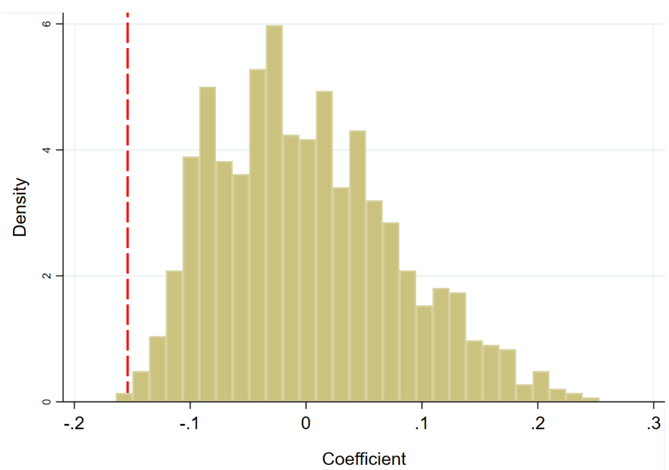
(a) **A1**: Coefficient values – Monthly Income



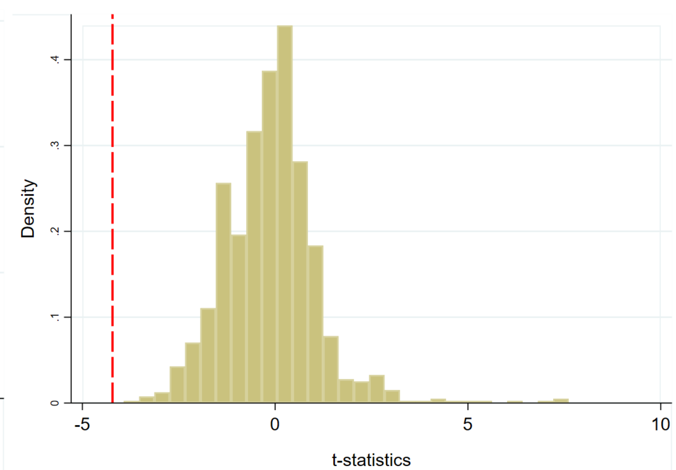
(b) **A2**: t-statistics – Monthly Income



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



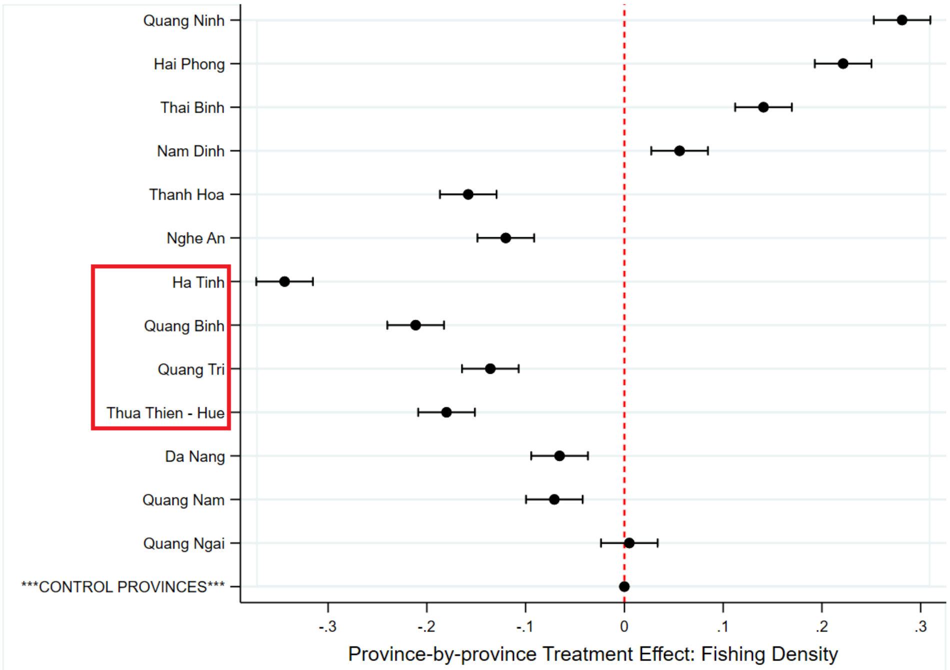
(d) **B2**: t-statistics –Boat Detection



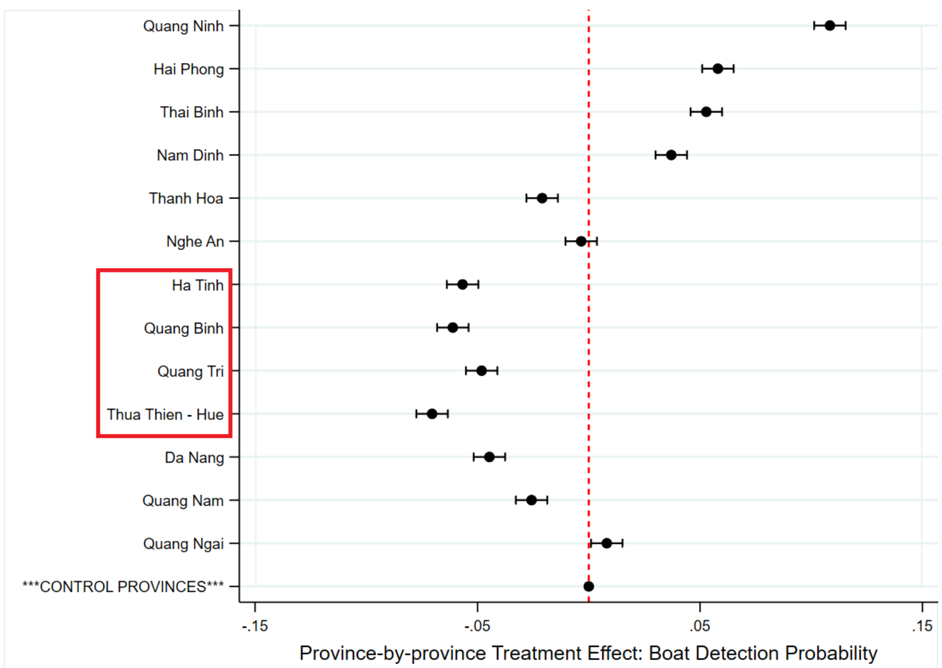
Note: this figure presents the results from a falsification exercise consisting of two permutation tests for (1) monthly fishery income (Panel As) and (2) fishing intensity (i.e. log of number of boats detected) (Panel Bs). Each iteration randomly assigns hypothetical treatment status to between 3 and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

Figure 6: Province-by-province Treatment Effects

(a) Panel A: Fishing Density



(b) Panel B: Fishing Prevalence



Note: this figure illustrates the province-by-province impact estimates on fishing density (Panel A; i.e. log-transformed monthly-aggregate boat counts) and fishing prevalence (Panel B; i.e. probability of boat detection) for all northern and central coastal provinces. The control group consists of all southern provinces (from Phu Yen to Ca Mau; i.e. distant from the *Formosa* zone). The sample includes all grid-month observations from 2013 to 2016. Whiskers indicate 95% statistical intervals.

Table 1: Summary Statistics

	Formosa provinces		Control provinces	
	Mean	S.E.	Mean	S.E.
Panel I. Fishery Characteristics: Individual Level (Labor Force Survey 2015)				
Total Monthy Income ('000 VND)	7,475.4	8,294.5	6,232.0	12,073.8
Monthly Income from Fishery ('000 VND)	7,396.3	8,321.3	6,191.7	11,976.7
Work Hours (per week)	62.11	15.03	54.47	13.49
Age	39.52	12.73	37.46	11.01
Gender:				
Male (%)	98.53	12.04	92.28	26.69
Female (%)	1.47	12.04	7.72	26.69
Educational Attainment:				
No Training (%)	26.65	44.27	42.90	49.50
Primary School (%)	38.88	48.81	41.27	49.24
Secondary School (%)	31.54	46.52	12.79	33.40
High School (%)	2.93	16.90	2.12	14.40
College (%)	0.00	0.00	0.93	9.58
Observations	409		2,268	
Panel II. Fishing Intensity: Monthly Boat Detection (VIIRS 2013-2015)				
a. Near-shore ($\leq 20nm$):				
Boat Detection Likelihood (%)	59.13	49.16	39.78	48.94
Number of Boats Detected	4.62	8.20	3.33	7.84
Observations (grid-month)	25,560		84,960	
b. Off-shore:				
Boat Detection Likelihood (%)	72.84	44.48	54.62	49.79
Number of Boats Detected	5.09	7.10	3.00	5.38
Observations (grid-month)	51,624		207,324	

Note: this table presents the descriptive baseline statistics for the primary fishery characteristics – using data from the Labor Force Survey 2015 (Panel I), and fishing intensity – using monthly-interval satellite data from VIIRS Boat Detection module 2013-2015 (Panel II). "Formosa provinces" refers to observations belong to the four Formosa-affected provinces (Ha Tinh, Quang Binh, Quang Tri, and Hue). "Control provinces" refers to observations belong to all provinces south of Phu Yen, i.e. distant from the Formosa-affected region. 1 USD=22,550 VND (Vietnam Dong) as of December 31st, 2015. In Panel II, "Boat Detection Likelihood" refers to the probability that a marine pixel was "lit", i.e. was detected with at least one boat in a given month. "Number of Boats Detected" refers to the total number of boats detected in a pixel in a given month. A pixel's resolution is 10-mile-square. "Off-shore" region covers all marine pixels located between 20 and 80 nautical miles from the shoreline.

Table 2: Impact on Fishery Income

	Income (main job)	Total income	Income (main job)	Total income
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
treat × post	-0.297***	-0.298***	-0.433***	-0.441***
	(0.070)	(0.070)	(0.063)	(0.062)
Observations	2,477	2,477	872	872
R-squared	0.253	0.249	0.122	0.125
[Panel B] Industry control group				
treat × post	-0.301***	-0.299***	-0.461***	-0.465***
	(0.058)	(0.056)	(0.057)	(0.056)
Observations	7,991	7,991	2,090	2,090
R-squared	0.310	0.294	0.066	0.068
Month FE	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes

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

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

Table 3: Impact on Fishing Density and Prevalence: Using Satellite's Boat Detection

	Boat detection density (modified log)				**Boat detection probability (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	-0.239***	-0.270***	-0.134**	-0.223***	-0.0871***	-0.0768***	-0.0473**	-0.0594***
	(0.0578)	(0.0409)	(0.0477)	(0.0341)	(0.0225)	(0.0158)	(0.0178)	(0.0144)
Observations	219,984	219,984	147,360	147,360	219,984	219,984	147,360	147,360
R-squared	0.117	0.289	0.103	0.283	0.093	0.211	0.087	0.207
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		Restricted		All Other Provinces		Restricted	

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

Note: this table shows the impact of Formosa on fishing activity in the fishing-restricted region (i.e. 20nm near-shore of Formosa-affected provinces), using VIIRS' monthly-aggregate boat detection data. Each observation is a grid-month. Sample includes all monthly observations between 2013 and 2016. The grid size is 10-mile-square. 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 monthly-aggregate boat counts in each grid (columns 1-4), and 0/1 probability that the grid was detected with at least a boat in that month (columns 5-8). 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, and Hue). The control group "Restricted" refers to all coastal provinces located south of Phu Yen (i.e. distant from the Formosa-affected region).

Table 4: Heterogeneous Impacts on Fishery Incomes by Location

	Income (main job)	Total income	Income (main job)	Total income
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
(HaTinh & QuangBinh) × post	-0.251***	-0.259***	-0.413***	-0.427***
	(0.079)	(0.079)	(0.067)	(0.068)
(QuangTri & Hue) × post	-0.439***	-0.421***	-0.536***	-0.516***
	(0.136)	(0.135)	(0.056)	(0.056)
Observations	2,477	2,477	872	872
R-squared	0.254	0.250	0.123	0.126
[Panel B] Industry control group				
(HaTinh & QuangBinh)× post	-0.276***	-0.279***	-0.438***	-0.448***
	(0.060)	(0.058)	(0.063)	(0.067)
(QuangTri & Hue) × post	-0.429***	-0.400***	-0.574***	-0.546***
	(0.095)	(0.092)	(0.028)	(0.029)
Observations	7,991	7,991	2,090	2,090
R-squared	0.311	0.294	0.067	0.069
Month FE	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes

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

Note: this table shows the heterogeneous impact of Formosa on fishery income (monthly;'000 VND; log-transformed) in 2016, separately for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Thua Thien-Hue) Formosa-affected regions. "Post" indicates May-2016 or after. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e. distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e. manufacturing, construction, and retail) living in the four Formosa-affected provinces. Columns 1-2 report results using a sample consisting of all individuals identified as saltwater fishery workers (for Panel A) and workers in the control industries (for Panel B) before May-2016. Columns 3-4 report results using a sub-sample restricting to only individuals who were surveyed twice in the Labor Force Survey 2016 – before and after May-2016. Standard errors are clustered at the district level.

Table 5: Labor-Market Responses: Fishery Workload and Having Secondary Jobs

	Weekly workload (1)	Having extra Jobs (2)
[Panel A] Geographic control group		
(HaTinh & QuangBinh) × post	1.227	-0.122
	(1.917)	(0.093)
(QuangTri & Hue) × post	-28.825***	0.138***
	(1.085)	(0.020)
Observations	872	872
R-squared	0.240	0.066
[Panel B] Industry control group		
(HaTinh & QuangBinh) × post	1.720*	-0.114
	(1.015)	(0.091)
(QuangTri & Hue) × post	-29.562***	0.141***
	(0.674)	(0.017)
Observations	2,090	2,090
R-squared	0.119	0.015
Month FE	Yes	Yes
Individual FE	Yes	Yes

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

Note: the dependent variables are (1) fishery work hours per week (column 1), and (2) the probability that the affected fisher worked extra jobs (column 2). The heterogeneous labor-market responses are shown for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Thua Thien-Hue) Formosa-affected regions. "Post" indicates May-2016 or after. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e. distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e. manufacturing, construction, and retail) living in the four Formosa-affected provinces. All regressions include month and individual fixed effects. Standard errors are clustered at the district level.

Table 6: Impacts on Fishing Intensity and Prevalence by Quarters

	Boat detection density (log)		**Boat detection probability (%)**	
	(1)	(2)	(3)	(4)
treat X [Q2-2016]	-0.333***	-0.364***	-0.0931***	-0.0919***
	(0.0941)	(0.0928)	(0.0231)	(0.0238)
treat X [Q3-2016]	-0.310***	-0.226***	-0.0857***	-0.0640**
	(0.0654)	(0.0667)	(0.0205)	(0.0236)
treat X [Q4-2016]	-0.128**	-0.0532	-0.0481*	-0.0215
	(0.0480)	(0.0501)	(0.0257)	(0.0264)
Observations	219,984	147,360	219,984	147,360
R-squared	0.289	0.284	0.211	0.208
Light pixel FE	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes
provinceXmonth FE	Yes	Yes	Yes	Yes
Control Groups	All Other	Restricted	All Other	Restricted

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

Note: this table shows the quarterly impacts of Formosa for the rest of 2016, on fishing activity in the fishing-restricted region (i.e. 20nm near-shore of Formosa-affected provinces), using VIIRS' monthly-aggregate boat detection data. Each observation is a grid-month. Sample includes all monthly observations between 2013 and 2016. The grid size is 10-mile-square. 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 monthly-aggregate boat counts in each grid (columns 1-2), and 0/1 probability that the grid was detected with at least a boat in that month (columns 3-4). The control group "All Other" refers to all coastal provinces in the country except for the four Formosa-affected central provinces (Ha Tinh, Quang Binh, Quang Tri, and Hue). The control group "Restricted" refers to all coastal provinces located south of Phu Yen (i.e. distant from the Formosa-affected region).

Table 7: Impacts on Fishery Income by Quarters

	Income (main job)	Total income	Income (main job)	Total income
	(1)	(2)	(3)	(4)
[Panel A] Geographic control group				
treat × [Q2-2016]	-0.456***	-0.463***	-0.524***	-0.534***
	(0.144)	(0.145)	(0.111)	(0.114)
treat × [Q3-2016]	-0.252**	-0.252**	-0.383***	-0.382***
	(0.109)	(0.110)	(0.091)	(0.093)
treat × [Q4-2016]	-0.047	-0.063	-0.312***	-0.299***
	(0.101)	(0.097)	(0.109)	(0.105)
Observations	2,246	2,246	1,762	1,762
R-squared	0.356	0.355	0.064	0.064
[Panel B] Industry control group				
treat × [Q2-2016]	-0.631***	-0.628***	-0.630***	-0.653***
	(0.081)	(0.078)	(0.067)	(0.067)
treat × [Q3-2016]	-0.311***	-0.307***	-0.459***	-0.449***
	(0.069)	(0.066)	(0.064)	(0.063)
treat × [Q4-2016]	0.009	0.009	-0.319***	-0.316***
	(0.078)	(0.075)	(0.065)	(0.065)
Observations	7,991	7,991	4,486	4,486
R-squared	0.315	0.299	0.046	0.048
Month FE	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes

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

Note: this table shows the impact of Formosa on fishery income (monthly;'000 VND; log-transformed) for each subsequent quarters after the start of Formosa incident in April 2016. "Treat" indicates saltwater fishers living in Ha Tinh, Quang Binh, Quang Tri, and Hue. Geographic control group (Panel A) consists of all saltwater fishers living in provinces south of Phu Yen (i.e. distant from Formosa region). Industry control group (Panel B) consists of workers in unaffected industries (i.e. manufacturing, construction, and retail) living in the four Formosa-affected provinces. Columns 1-2 report results using a sample consisting of all individuals identified as saltwater fishery workers (for Panel A) and workers in the control industries (for Panel B) before May-2016. Columns 3-4 report results using a sub-sample restricting to only individuals who were surveyed twice – before and after May-2016. Standard errors are clustered at the district level.

Table 8: Spillover Effects to Labor Outcomes in Other (Relevant) Industries

	Geographic control group				Industry control group			
	Income (main job)	Total income	Income (main job)	Total income	Income (main job)	Total income	Income (main job)	Total income
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Freshwater Fishery Industry								
(HaTinh & QuangBinh) × post	-0.082	-0.130	0.047	0.050	-0.057	-0.058	-0.038	-0.035
	(0.132)	(0.093)	(0.158)	(0.158)	(0.079)	(0.076)	(0.137)	(0.142)
(QuangTri & Hue) × post	0.248***	0.205***	0.263**	0.256**	0.205***	0.195***	0.205**	0.194***
	(0.063)	(0.066)	(0.116)	(0.097)	(0.070)	(0.068)	(0.082)	(0.065)
Observations	4,408	4,408	1,422	1,422	7,941	7,941	2,082	2,082
Panel B: Husbandry Industry								
(HaTinh & QuangBinh) × post	-0.087	-0.076	0.036	0.010	-0.030	0.007	0.049	0.037
	(0.056)	(0.052)	(0.062)	(0.052)	(0.032)	(0.031)	(0.069)	(0.047)
(QuangTri & Hue) × post	0.051	0.034	-0.079	-0.109	0.180***	0.080**	-0.090	-0.128*
	(0.067)	(0.067)	(0.075)	(0.086)	(0.038)	(0.037)	(0.059)	(0.065)
Observations	8,980	8,980	2,558	2,558	9,769	9,769	2,404	2,404
Panel C: Restaurant Industry								
(HaTinh & QuangBinh) × post	-0.206	-0.200	-0.140**	-0.113	-0.050	-0.026	-0.158**	-0.127
	(0.138)	(0.142)	(0.068)	(0.090)	(0.062)	(0.060)	(0.073)	(0.090)
(QuangTri & Hue) × post	-0.040	-0.023	-0.006	0.006	-0.035	-0.016	-0.018	-0.004
	(0.040)	(0.042)	(0.039)	(0.042)	(0.045)	(0.043)	(0.045)	(0.047)
Observations	6,225	6,225	1,854	1,854	8,287	8,287	2,184	2,184
Panel D: Lodging Industry								
(HaTinh & QuangBinh) × post	-0.155	-0.151	0.093	0.092	-0.012	-0.026	0.040	0.047
	(0.238)	(0.237)	(0.084)	(0.087)	(0.124)	(0.120)	(0.062)	(0.060)
(QuangTri & Hue) × post	0.002	-0.005	0.038	0.036	-0.089	-0.082	-0.024	-0.017
	(0.062)	(0.061)	(0.060)	(0.061)	(0.096)	(0.093)	(0.054)	(0.053)
Observations	1,331	1,331	428	428	7,766	7,766	2,024	2,024
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes	No	No	Yes	Yes

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

Note: this table shows the distributional impact of Formosa on the labor income (monthly; '000 VND; log-transformed) of individuals working in other relevant industries (i.e. those deemed eligible by the government for official Formosa compensation), separately for the upstream (Ha Tinh & Quang Binh) and downstream (Quang Tri & Hue) Formosa-affected provinces. Panel A, B, C, and D report estimates using respective samples of workers in Freshwater Fishery, Husbandry, Restaurant, and Lodging, with the treated individuals working in (Ha Tinh & Quang Binh) and (Quang Tri & Hue). The control group consists of individuals working in the same industry who lived in unaffected provinces (south of Phu Yen). Standard errors are clustered at the district level.

Appendix

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

		Observations	Pre-disaster		Post-disaster		Means
			Mean	S.D.	Mean	S.D.	Difference
Formosa-affected fishers	Income (main job)	362	6,387	5,308	4,311	2787	-2,076***
	Total income	362	6,449	5,291	4,358	2,778	-2,091***
Southern (unaffected) fishers	Income (main job)	2,115	5,892	6,287	6,946	21,458	1,055
	Total income	2,115	5,942	6,292	6,987	21,460	1,045
Unaffected workers (other industries)	Income (main job)	7,629	4,741	3,605	4,694	3,524	46
	Total income	7,629	4,875	3,633	4,810	3,516	64

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

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

Table A2: Impacts on Fishing Activity in the Fishing-restricted Zone: Robustness to Additional Control Group

	Boat detection density (log)		**Boat detection probability (%)**	
	(1)	(2)	(3)	(4)
treat X post	-0.0700*	-0.229***	-0.0220*	-0.0671***
	(0.0349)	(0.0354)	(0.0106)	(0.0171)
Observations	100,272	100,272	100,272	100,272
R-squared	0.064	0.269	0.056	0.179
Grid (10miSq) FE	Yes	Yes	Yes	Yes
monthXyear FE	Yes	Yes	Yes	Yes
provinceXmonth FE	No	Yes	No	Yes
Control Groups	Southern Provinces			

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

Note: This table shows the impact of Formosa on fishing activity in the fishing-restricted region (near-shore), using VIIRS' monthly-aggregate boat detection data, and employing a "Southern Provinces" control group, which consists of southern coastal provinces (i.e. from Vung Tau to Ca Mau). Each observation is a grid-month. Sample includes all monthly observations between 2013 and 2016. The grid size is 10-mile-square. 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 (columns 1-2), and 0/1 probability that the grid was detected with at least a boat that month (columns 3-4).

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

	Income (main job)	Total income	Income (main job)	Total income
	(1)	(2)	(3)	(4)
[Panel A] Fishery Impact from Hypothetical Event (April 2015)				
treat × post April 2015	-0.062	-0.058	-0.035	-0.040
	(0.126)	(0.122)	(0.140)	(0.138)
Observations	2,445	2,445	1,014	1,014
R-squared	0.339	0.331	0.116	0.114
[Panel B] Validity of the "Industry Control Group"				
treat × post	0.001	-0.006	0.020	0.016
	(0.019)	(0.017)	(0.023)	(0.022)
Observations	145,311	145,311	55,984	55,984
R-squared	0.277	0.270	0.002	0.003
Month FE	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes

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

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

Table A4: Placebo Test – Impacts on Fishing Activity: Using Pre-event Outcomes (2013-2015)

	Boat detection density (modified log)				**Boat detection probability (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	0.00199	-0.00124	0.0615	0.000237	0.00553	0.0324*	0.0331	0.0376
	(0.0520)	(0.0389)	(0.0669)	(0.0501)	(0.0236)	(0.0185)	(0.0295)	(0.0215)
Observations	164,988	164,988	110,520	110,520	164,988	164,988	110,520	110,520
R-squared	0.121	0.299	0.102	0.300	0.094	0.211	0.082	0.211
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		Restricted		All Other Provinces		Restricted	

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

Note: this table presents a placebo test for the impact of Formosa on fishing activity in the fishing-restricted region (near-shore), using VIIRS' monthly-aggregate boat detection data between January-2013 and December-2015 and imposing a fictional event in April 2014. Each observation is a grid-month. The grid size is 10-mile-square. 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 (columns 1-4), and 0/1 probability that the grid was detected with at least a boat that month (columns 5-8). 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, and Hue). The control group "Restricted" refers to all coastal provinces located south of Phu Yen (i.e. distant from the Formosa-affected region).

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

Online Appendix – Not For Publication

Table OA1: Formosa Effect on Fishing Activity (Boat Detection) in the Fishing-restricted Zone: Robustness to Additional 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 tests for the robustness of the Formosa impact on fishing activity (similar to Table 3) by (1) employing additional measures of boat detection density (Panel A), and (2) using a winsorized sample (Panel B). The dependent variables in Panel A1 and A2 are boat counts in level and unmodified log-transformed (i.e. without adding a constant), respectively. The winsorized sample removes all continuously unlit cells before estimation. All else remains the same as in Table 3.

Table OA2: Impacts on Fishing Activity in the Fishing-restricted Zone: Using Satellite's Boat Detection data for an Extended Sample (April 2012 to May 2018)

	Boat detection density (modified log)				**Boat detection probability (%)**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat X post	-0.167***	-0.170***	-0.135**	-0.142**	-0.0591***	-0.0601***	-0.0471*	-0.0494*
	(0.0442)	(0.0457)	(0.0590)	(0.0614)	(0.0184)	(0.0190)	(0.0234)	(0.0244)
Observations	339,142	339,142	227,180	227,180	339,142	339,142	227,180	227,180
R-squared	0.120	0.275	0.107	0.271	0.093	0.199	0.085	0.198
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		Restricted		All Other Provinces		Restricted	

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

Note: this table shows the impact of Formosa on fishing activity in the fishing-restricted region (near-shore), using VIIRS' monthly-aggregate boat detection data. Sample includes all months from April 2012 (the first month VIIRS data is available) to May 2018. Each observation is a grid-month. The grid size is 10-mile-square. 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 (columns 1-4), and 0/1 probability that the grid was detected with at least a boat that month (columns 5-8). 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, and Hue). The control group "Restricted" refers to all coastal provinces located south of Phu Yen (i.e. distant from the Formosa-affected region).

Table OA3: Province-by-province impacts on fishing density and prevalence (corresponding to Figure 6)

	(1)	(2)
	Fishing Density	Fishing Prevalence
Quang Ninh X post	0.281***	0.108***
	(0.0171)	(0.00421)
Hai Phong X post	0.221***	0.0580***
	(0.0171)	(0.00421)
Thai Binh X post	0.141***	0.0528***
	(0.0171)	(0.00421)
Nam Dinh X post	0.0559***	0.0371***
	(0.0171)	(0.00421)
Thanh Hoa X post	-0.158***	-0.0209***
	(0.0171)	(0.00421)
Nghe An X post	-0.120***	-0.00340
	(0.0171)	(0.00421)
Ha Tinh X post	-0.344***	-0.0567***
	(0.0171)	(0.00421)
Quanh Binh X post	-0.211***	-0.0611***
	(0.0171)	(0.00421)
Quang Tri X post	-0.136***	-0.0481***
	(0.0171)	(0.00421)
Thua Thien-Hue X post	-0.180***	-0.0704***
	(0.0171)	(0.00421)
Da Nang X post	-0.0656***	-0.0447***
	(0.0171)	(0.00421)
Quang Nam X post	-0.0709***	-0.0257***
	(0.0171)	(0.00421)
Quang Ngai X post	0.00502	0.0081
	(0.0171)	(0.00421)
Observations	571,920	571,920
R-squared	0.197	0.150
Light pixel FE	Yes	Yes
monthXyear FE	Yes	Yes
coastXmonth FE	Yes	Yes
Control Group	Restricted	Restricted

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

Note: this table shows the province-by-province impacts of *Formosa* on fishing density and prevalence. Sample includes all months from 2013 to 2016. Each observation is a grid-month. The grid size is 10-mile-square. The control group consists of all southern coastal provinces from Phu Yen to Ca Mau (i.e. distant from the *Formosa*-affected zone).