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ISSN: 2365-9793

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ABSTRACT

The Long-Term Health Impact of Agent Orange: Evidence from the Vietnam War*

This paper examines the long-term health impact of Agent Orange, a toxic military herbicide containing dioxin that was used extensively during the U.S.-Vietnam war in the 1960-70s. Using a nationally representative health survey and an instrumental variable approach that addresses the potential endogeneity in the location and the intensity of U.S. defoliant missions, we report several findings. First, relative to the average prevalence rate of the sample population, we find that Vietnamese civilians located in a commune one-standard-deviation more exposed to herbicide during the war were 19.75 percent more likely to suffer from a health disease medically linked to Agent Orange three decades later. Second, disaggregating by disease types, we observe significant effects on blood pressure disease and mobility disability. Third, across cohorts, we find significant detrimental impact on those born before herbicide missions ended, especially among wartime children, infants, and those in-utero during the 1962-1971 period.

JEL Classification: N45, I10, Q53

Keywords: Agent Orange, herbicide, health, conflicts, Vietnam war

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* We would like to thank Ritam Chaurey, Benjamin Fordham, Ivan Korolev, Tung Duc Phung, David Slichter, Susan Wolcott, and the Labor Group Meeting participants at SUNY Binghamton University for helpful comments and suggestions. All remaining errors are our own. The findings, interpretations, and conclusions are entirely those of the authors. They do not necessarily represent the views of the World Bank Group.

1 Introduction

Among many aspects of the U.S.-Vietnam War during the 1960-70s, the use of herbicides was perhaps one of the most damaging and controversial. Between 1962 and 1971, under the U.S. Air Force's *Operation Ranch Hand*, approximately 19 million gallons of defoliants were sprayed across the Republic of Vietnam.[1] Many defoliants, with *Agent Orange* being the most extensively used, contained a high concentration of dioxin—an extremely toxic substance for human health.[2] Over five decades after the war ended, the footprint of Agent Orange (AO) is still visible today across the South of Vietnam (Banout et al., 2014; Tuyet-Hanh et al., 2010; Schecter et al., 2001). Despite robust medical evidence regarding its negative health consequences, the population-wide causal effects of herbicide exposure, especially AO, have remained a controversial subject. There have been numerous class-action lawsuits both by American and Vietnamese nationals against the chemical manufacturers, all leading to incongruous resolutions (Graybow, 2008; Blumenthal, 1984).

In this paper, we revisit existing empirical evidence and provide new causal estimates on the impact of AO exposure on Vietnamese civilians' health outcomes. We utilize a granular variation in herbicide exposure across South Vietnam at the commune level, which we derive from an extensive dataset on herbicides dispersal during Vietnam War by Stellman et al. (2003a,b) and Stellman and Stellman (2004). Adopting a unique historical war-related instrumental variable (IV) to address the potential endogeneity with the spatial exposure to herbicide, we estimate the impacts of herbicide on key available health indicators that are medically linked to AO exposure. Our individual-level health outcomes are obtained from the 2001-2002 Vietnam National Health Survey, the latest nationally representative survey on health conducted by the Vietnamese General Statistical Office with technical assistance from the World Bank.

Our results show that an increased exposure to herbicide spraying during the war caused a greater probability of individual respondent reporting Agent Orange-related diseases and disabilities, specifically blood pressure disease and mobility disability.[3] On average, civilians located in

[1] Now is the southern part of the Socialist Republic of Vietnam.

[2] *Agent Orange*is the non-scientific name derived from the marking color of the herbicide's storage containers. As discussed subsequently, Agent Orange is the herbicide mixture which, by far, contains the greatest concentration of dioxin which makes it the most widely known among defoliant chemicals. We therefore use the terms *herbicide exposure* and *Agent Orange exposure* interchangeably in this paper.

[3] We discuss detailed classification of diseases based on their medical association with AO in chapter 2. Specifically, the AO-related diseases among available health indicators include blood pressure disease, cancer, and mobility disability. Cancer are directly associated with AO exposure, while blood pressure disease is strongly correlated with hypertension, stroke, and ischemic heart disease, and mobility disability is strongly correlated with various other ailments resulting from AO exposure such as leukemia, multiple myeloma, lymphoma, Parkinson, and peripheral nephropathy.

a commune that was one-standard-deviation more exposed to herbicide during the war were 1.28 percentage point more likely to report health issues related to Agent Orange, a magnitude 19.75 percent greater than the sample population's mean prevalence rate. Disaggregating by the types of disease, we observe significant effects on blood pressure disease and mobility disability. Across cohorts, we find that the impact is predominantly attributed to civilians who were directly exposed to herbicide spraying missions, i.e., those born before 1971, especially among the wartime children, infants, and those in-utero during the 1962-1971 period.

When estimating the impacts of wars and conflicts on individuals' outcomes, a major endogeneity concern arises as conflict sites, in this case herbicide spraying destinations, are not likely to be randomly distributed. To address this concern, our identification strategy makes use of the military purpose of the U.S. herbicide missions during the Vietnam War. The herbicides were sprayed mainly to defoliate inland forests, coastal mangrove forests, and cultivation land around suspected North Vietnamese army (NVA) areas to improve visibility and destroy the enemy food crop supply (Institute of Medicine, 1994). This historical fact, coupled with the NVA infiltrators' principal "guerrilla warfare", a tactic pivoted on their locations being highly unpredictable, allows us to construct a spatial IV. Specifically, we instrument for the intensity of herbicide exposure in south Vietnamese communes by the communes' proximity to NVA's bases identified by the U.S. Intelligence during the war.

The first-stage result exhibits a strong spatial correlation between herbicides-spraying intensity and the proximity to NVA military bases. We further empirically test for and find no significant evidence of endogenous sortings of individual, household, commune, or district level characteristics with respect to the distance to a historical NVA base. Our analysis also accounts for a spatial treatment of bombing intensity—a proxy for other war-related physical exposures of which health impacts have been studied in the literature—by constructing a commune-level bombing measure, defined as the total amount of bombs, missiles, and rockets dropped during the war in the commune (Singhal, 2019; Palmer et al., 2019).

Our approach that exploits the geographic distance to major war locales as an approximation for conflict intensity is in the same vein as existing studies that utilize a similar technique to address potential endogenous conflict exposure. For instance, Guo (2020) uses distance from the two main targeted bombing areas, the Plain of Jars and Ho Chi Minh Trail, as an instrument (IV) for the intensity of unexploded ordnance to estimate the long-term impact of war on educational attainment in Laos. Merrouche (2011) instruments for the level of land-mine contamination in Cambodia by using distance from the Thailand border. In Africa, Akresh and De Walque (2008) exploit the distance from the Uganda border as a source of variation in the intensity of Rwanda genocide, while Arcand et al. (2015) and Voors et al. (2012) use the distance from the rebel headquarters and formal capital as the instrument for conflict intensity in Angola and Burundi, respectively. In the setting of Vietnam, Miguel and Roland (2011) and Singhal (2019) employ proximity to the historical North-South Vietnamese border (i.e., the 17th Parallel line) to instrument for U.S. bombing intensity during the Vietnam War.

Our analysis contributes directly to the understanding of the causal impacts of Agent Orange on health. Current research, mostly from the medical and public-health literature, have found that exposure to herbicide are detrimental to several health outcomes such as cancer (Bertazzi et al., 2001), skin diseases (Institute of Medicine, 2002), cardiovascular disease mortality (Humblet et al., 2008), hypertension (Kang et al., 2006), and genetic disturbance, which potentially results in birth defects and other inter-generational health consequences (Ugalde et al., 1999). However, most of the existing research efforts have been limited to small (and more than often, non-representative) samples of U.S. war veterans or chemical workers. Due to data limitations, very few studies have paid attention to Vietnamese civilians, the group arguably bearing the brunt of AO contamination.

By employing a representative health survey that covers over 66,000 individuals across the south of Vietnam, this paper is one of the few existing analyses that evaluate the impact of AO on the prevalence of diseases among the Vietnamese civilian population. To our knowledge, there are two existing empirical studies. Do (2009) employs a logistic model to estimate the impact of herbicide exposure on cancer prevalence. Godpodinov and Nguyen (2015) exploit the differences in cancer and hypertension prevalence across cohorts in South Vietnam (i.e., the AO-affected location) relative to North Vietnam (i.e., the unaffected area) in a double-differences framework. Our methodology complements the former in our attempt to estimate causal health impacts of AO by introducing an IV that specifically addresses potential endogenous locations targeted by the herbicide spraying missions.[4] In addition, we are able to utilize the spatial variation in herbicide exposure in South Vietnam's communes to capture adverse health consequences.[5] While our finding of significant detrimental effect on blood pressure disease is in line with that found in Godpodinov and Nguyen

[4] Do (2009) explores the spatial variation in herbicide exposure but does not specifically tackle the potential endogeneity related to this variation.

[5] Godpodinov and Nguyen (2015) do not explore the spatial variation in treatment exposure in the difference-in-difference analysis.

(2015), the weak statistical effect found on cancer prevalence is similar to the result in Do (2009). A new and significant health impact that our IV model estimates is mobility impairment—a disability that has been medically linked to AO exposure through its strong association with various diseases resulting directly from dioxin contamination, such as leukemia, lymphoma, Parkinson disease, and peripheral nephropathy (Department of Veterans Affairs, 2016). Our heterogeneity analysis also detects significant detrimental impact on the wartime children, infants, and those in-utero during the war.

More broadly, our paper also adds to a larger body of literature on the health impacts of wars and conflicts. Ghobarah et al. (2003), Akresh et al. (2011, 2012), Bundervoet et al. (2009), Alderman et al. (2006) provide separate evidence on the negative impacts of civil wars on long-term health around the world, in Rwanda, Nigeria, Burundi, Zimbabwe. Directly related to the health consequences of the U.S.-Vietnam war, Singhal (2019) and Palmer et al. (2019) study the long-term health effects of exposure to U.S. Air-force bombing, and find significant negative impacts on mental distress and prevalence of disability among Vietnamese civilians.

The rest of the paper proceeds as follows. Section 2 provides background on the Vietnam war and some existing evidence on the association of AO exposure and health impacts presented in the medical literature. Section 3 describes different dataset employed in this study. Section 4 introduces our IV identification strategy and presents the estimation methodology. Section 5 discusses the main results on the causal impacts of AO exposure and explores different heterogeneities. We also present a battery of robustness checks and validity tests in this section. Finally, Section 6 concludes.

2 The Vietnam War, Agent Orange, and existing medical evidence

The Vietnam War was a long, destructive conflict that put the Democratic Republic of Vietnam (DRV-the North Vietnam) against the Republic of Vietnam (the South Vietnam) and its ally, the United States. The war followed the end of the first Indochina War, with the French defeat in the battle of Dien Bien Phu. The loss put an end to the France's almost a century long colonial rule over the Indochina region and led to the signing of the treaty at the Geneva conference on July 1954 that split Vietnam in half along the 17th North Parallel latitude line, with the DRV in the north and the U.S.-backed Republic of Vietnam in the south.

The North Vietnam, with the objective of reuniting the country, began military actions against the South, with the first known engagement in 1959 in the form of guerilla attacks. The United States started to provide military assistance to South Vietnam under the cause of stopping communism's "domino theory". Initially restricted to financial support and technical aid, the involvement of the U.S. escalated to a full-scale military intervention in 1965, following the Gulf of Tonkin incident, in which the two U.S. destroyers were attacked off the coast of Vietnam in August 1964. At the height of the war, there were more than 500,000 U.S. military personnel in Vietnam. The U.S. began its withdrawals and the conflict between the North Vietnam and the U.S. ended following the Paris peace accords in January 1973. The Vietnam War itself continued and officially ended on April 30th, 1975, after the surrender of the Republic of Vietnam (the South Vietnam) government.

During the war, the U.S. military engaged in an aggressive and controversial chemical warfare program with the code-name *Operation Ranch Hand*. With the purpose of destroying forest cover, cultivation land, and food crops supply to the North Vietnamese army, from 1962 to 1971, the U.S. military sprayed approximately 19 million gallons of herbicides across south Vietnam. Many herbicide defoliants, with Agent Orange was the most commonly used, contained a high concentration of dioxin–an extremely toxic substance for human health. It is estimated that up to 366 kilograms of pure dioxin were sprayed and as many as 4.8 million civilians were exposed Stellman et al. (2003a), while a tolerable daily dioxin intake is defined by the World Health Organization to be between 1 and 4 picograms (pg) per kilogram of body weight (1 pg = 10^{-15} kg).

Numerous biological and epidemiological studies have shown robust medical linkages between herbicide exposure and a range of health problems. The most comprehensive among them is the *Veterans and Agent Orange report* conducted and updated biennially by the National Academies of Sciences, Engineering, and Medicine following The Agent Orange Act of 1991 (National Academies, 2018). The report essentially classifies ailments into three categories for which there is *"sufficient evidence"*, *"limited suggestive evidence"*, or *"inadequate or insufficient evidence"* but where more research is needed to determine linkages to Agent Orange. Below is an excerpt from the latest update of the Veterans and Agent Orange report in 2018:

1. Epidemiological evidence is *sufficient* to conclude that there is a positive association between exposure to herbicides and the outcomes: Hypertension; Non-Hodgkin Lymphoma; Chronic Lymphocytic Leukemia; Hodgkin Lymphoma Chloracne; and Monoclonal Gammopathy of Undetermined Significance.
2. Epidemiological evidence *suggests* an association between exposure to herbicides and the outcomes: Parkinson diseases; Laryngeal cancer; Cancer of the lung, bronchus, or trachea; Prostate cancer; Cancer of the urinary bladder; Multiple Myeloma; AL Amyloidosis; Early-onset peripheral Neuropathy Porphyria Cutanea Tarda; Ischemic heart disease; Stroke; and

Hypothyroidism.

3. Epidemiological studies are of *insufficient* quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an association between exposure to herbicides and the outcomes: Bone conditions; Eye problems; Cancers of brain and nervous system (including eye); Hearing loss; Neurobehavioral disorders (cognitive and neuropsychiatric); Neurodegenerative diseases; etc.[6]

In addition, the Vietnamese Red Cross also associates the following with exposure to dioxin: lipid metabolism disorder; reproductive abnormalities and congenital deformities such as cleft lip, cleft palate, club foot, hydrocephalus, neural tube defects, fused digits, muscle malformations and paralysis; and some developmental disabilities (The Aspen Institute, 2013).

Several existing medical studies have found medical linkages between AO exposure and different types of cancer (Bertazzi et al., 2001), skin diseases (Institute of Medicine, 2002), cardiovascular disease mortality (Humblet et al., 2008), and hypertension (Kang et al., 2006). However, these studies often rely on small and/or non-representative samples of American veterans, chemical workers, pesticide manufacturers and applicators, which limit population-wide causal inferences (Godpodinov and Nguyen, 2015).

3 Data

Our main data source that captures the spatial variation in herbicide exposure is borrowed from the extensive series of work done by Stellman and Stellman (2004) and Stellman et al. (2003a,b). The U.S. Military Assistance Command Vietnam (MACV) recorded all military spraying operations (both aerial and ground) during the Vietnam War under MACV's Data Management Agency's Herbicide Report System (HERBS). Using this extensive dataset on the dispersal of herbicides, Stellman and Stellman (2004) and Stellman et al. (2003a,b) developed a geographical information system (GIS) framework that provides a quantitative exposure opportunity index (in log scale) for each civilian-inhabited hamlet in South Vietnam during the spray mission period.[7] This framework comprehensively accounts for the type and quantity of herbicide sprayed, distance from spray application and flight paths, and the time interval when exposure may have occurred. Furthermore, the framework also considers both direct spraying and indirect exposure to herbicide (or dioxin), using a conservative first-order model for environmental disappearance (Stellman and Stellman, 2004).

To construct an exposure score index for a commune, we first use coordinates of all underly-

[6] The full list is available on page 566 of National Academies (2018).
[7] A searchable list of all available hamlet-level exposure score indexes can be accessed here.

ing hamlets from the historical Hamlet Evaluation System (HES) database[8] and match them with current commune administrative boundaries. The database also contains hamlets' population information during the war time. We then derive the exposure score for each commune in the data by aggregating all respective hamlets' score indices weighted by the hamlets' population.

Our individual-level health outcomes are obtained from the 2001-2002 Vietnamese National Health Survey (VNHS). VNHS is a nationally representative survey administered by the Vietnamese General Statistics Office (GSO) with technical assistance from the World Bank. The VNHS records the respondents' living location (at the commune level) and socio-economic background information. More importantly, the survey collected information on individual morbidity status[9] with available binary indicators on a range of diseases such as blood pressure disease, cancer, epilepsy, mobility disability, deaf, speaking difficulty, slow mental development, mental illness, and eye disability. According to the latest Veterans and Agent Orange Update (National Academies, 2018), among the available morbidity indicators, blood pressure disease, cancer, and mobility disability are associated with diseases for which there is *"sufficient evidence"* or *"limited suggestive evidence"* linking them to Agent Orange exposure,[10] whereas other diseases such as: epilepsy, deafness, speaking difficulty, slow mental development, mental illness, and eye disability are either in the *"inadequate or insufficient evidence"* but more research is needed category or not mentioned at all in the reports. Therefore, our main health outcomes of interest are the prevalence of blood pressure disease, cancer, and mobility disability. Interestingly, as indicated in Table A.1, the prevalence of these AO-related diseases (top panel) is significantly higher in South Vietnam compared to North Vietnam, except for cancer (insignificantly higher in the south). Other impairments that have not been medically concluded to have an association with Agent Orange (Panel B) are either not statistically different across the two regions (e.g., eye disease, epilepsy, and speaking disability), or are significantly different but without a common direction (e.g., deaf, mental illness, and slow mental development). Incidentally, in addition to help motivate our analysis to measure the causal effects of herbicide exposure in South Vietnam, these anecdotes also lend support to the validity of our research design.

The Vietnam National Health Survey (VNHS) consists of approximately 160,000 individuals from 36,000 households. Because herbicide missions were strictly conducted in south Vietnam, we restrict the analysis sample to cover all respondents located in southern provinces, starting from Quang Binh province in central Vietnam. Further accounting for all changes in administrative boundaries from the 1970s to 2002 (the survey year), we obtain the final analysis sample consisting

[8] The database is housed at the U.S. National Archives (Record Group 330) for Vietnam War

[9] The sample questionnaires are provided in Figure A.1.

[10] Cancer is directly associated with AO exposure, blood pressure disease is strongly correlated with hypertension, stroke, and ischemic heart disease, and mobility disability is strongly correlated with various other diseases resulting from AO exposure such as Leukemia, Multiple Myeloma, Lymphoma, Parkinson, and Peripheral Nephropathy. The disease list is discussed in detail in Chapter 2.

of 66,006 individuals from 14,990 households in 483 communes.

It is noted that while VNHS does not provide an indicator of birthplace, it does provide information on household permanent residency status and an indicator for households who just moved to the residing commune in the last three years. In our analysis, we assume that the commune of permanent residence stated in the survey is the same as that of birth. To cross-check the validity of our assumption, we follow Singhal (2019) and rely on statistics from the 2016 Vietnam Access to Resources Household Survey (VARHS)—a representative survey that provides a birthplace indicator at the individual level. According to the 2016 VARHS, 77 percent of the sampled households had either the head or spouse born in the commune of current residence.

To help isolate the health consequences of herbicide exposure from bombing exposure, a potential channel though which exposure to the war could affect long-term health outcomes, we control for wartime bombing intensity in all estimation models. Given the granularity of our analysis, we construct a commune-level bombing intensity. Our bombing intensity measure is defined as the total quantity of bombs, missiles, and rockets per square-kilometer dropped on a commune. All bombing mission data is obtained from the Theater History of Operations Reports (THOR), a database published by the U.S. Department of Defense of all unclassified U.S. bombing operations and missions during the Vietnam War, as well as World War I, World War II, and the Korean War. We restrict the data to cover the available period relevant to the Vietnam War. We then geo-reference the bombing intensity coordinates to the Vietnamese commune level boundaries and derive the aggregate measure of bombing intensity for each commune. In a robustness check, we also use total tonnage weight of bombs, missiles, and rockets as an alternative bombing intensity measure.[11]

Lastly, in the fully specified model, we additionally control for a series of individual, household, commune, and district characteristics that we describe in detail in Chapter 4. Table 1 presents descriptive statistics of the main health outcome variables, socio-economic characteristics, and geographical covariates used in the analysis.

[11]Each mission is recorded with mission date, coordinates of target, weapon type, weapon quantity and other features. Of the 1.2 million kinetic mission records, approximately 15 percent do not contain information regarding the weapon type or quantity of weapon used in the missions. We exclude these records from our bombing intensity data.

4 Estimation Strategies

We estimate the health impact of herbicide exposure with an ordinary least squares (OLS) regression as follows:

$$y_{ihcd} = \beta_0 + \beta_1 ExposureScore_{ihcd} + X_i^{'}\Gamma + H_h^{'}\Theta + C_c^{'}\Psi + D_d^{'}\Delta + \epsilon_{ihcd} \quad (1)$$

where y_{ihcd} is the morbidity status for individual i of household h who lives in commune c that belongs to district d. The herbicide exposure index in commune c is represented by $ExposureScore_{ihcd}$, which is constructed as the population-weighted average of all hamlets' herbicide exposure indices taken from Stellman et al. (2003b) and Stellman and Stellman (2004). Vector X_i contains individual characteristics including age, gender, educational level, ethnicity, and smoking and drinking indicators as proxies that capture health-related habits. H_h is a vector of household-level covariates including household income, and importantly, household herbicide and pesticide usage for agricultural purposes, which account for potential confounders affecting individuals' health apart from the pure AO exposure during the war. Vector C_c contains information on commune characteristics such as poverty rate, commune area, population, and urban/rural status. C_c also includes a measure for the intensity of bombing that the commune was exposed to, given that bombing having been found to have long-term physical and mental health consequences in Vietnam (Singhal, 2019; Palmer et al., 2019). D_d represents district-level observable conditions, which includes an extensive list of geographic characteristics.[12] The standard errors in all regressions are clustered at the commune level to allow for potential correlation of the idiosyncratic individual error terms within each commune. Our coefficient of interest is β_1, which captures the health effects of AO exposure.

Herbicide spraying locations were most likely not random as the general purpose of U.S. spray missions was to defoliate forests to expose the North Vietnamese guerilla forces. Therefore, the majority of herbicide missions were likely targeted around locations where the U.S. Intelligence suspected to have the presence of infiltrators from the north. To address the potential endogeneity concern with spraying locations, we estimate a two-stage least square (2SLS) in the form of an IV approach. Our IV method uses the commune's proximity to a NVA's base identified by the U.S. Intelligence, measured by the distance between the commune's centroid to the nearest base,[13] as the instrument for the herbicide exposure intensity. The spatial distribution of herbicide exposure spraying missions and the locations of NVA's bases are shown in Figure 1. This figure visually illustrates the "first-stage" validity of the IV approach; areas in closer proximity to NVA bases were exposed to a greater degree of herbicide. Importantly, in all of our regressions, we control

[12] The list of variables in D is presented in Table 1.

[13] The locations of NVA's bases are documented in the 1967-1971 Enemy Base Area File (BASFA) under U.S. National Archives' Record Group 330 (declassified data).

for the commune's bombing intensity, which serves as the proxy for the degree of exposure to physical violence during the war and have been shown to also have medium- and long-term health consequences (Palmer et al., 2019; Singhal, 2019).[14]

Ultimately, the validity of our IV approach relies on the assumption that, conditional on bombing intensity, an increase in past herbicide exposure is the only channel through which proximity to NVA bases during the war can affect the health outcomes of Vietnamese civilians three decades later. This is arguably a reasonable assumption, given the fact that the North Vietnamese infiltrators principally followed a "guerrilla warfare" tactic that pivoted on their presence being highly unpredictable. Indeed, an average NVA's base in our data was only active for less than two years (median=21 months) before being either self-abandoned or destroyed. Regardless, we subsequently test for and find no significant evidence of systematic sorting of individual, household, commune, or district characteristics with respect to distance to NVA bases. In our fully specified model, we also control for a comprehensive set of observable characteristics to address any potential imbalances that could bias the 2SLS estimates.

As such, the corresponding IV first stage is:

$$ExposureScore_{ihcd} = \alpha_0 + \alpha_1 Dist\_Nearest\_Base_c + X_i^{'}\gamma + H_h^{'}\theta + C_c^{'}\psi + D_d^{'}\Delta + \mu_{ihcd} \quad (2)$$

The predicted commune $ExposureScore_{ihcd}$ for each individual from Eq.2 then enters Eq.1 in the second-stage analysis to estimate the herbicide exposure impact.

5 Results

5.1 First-stage result

Table 2 presents the formal first-stage result. The table reports the estimated coefficient $\hat{\alpha_1}$ from Eq. 2. Recall that our IV is the distance to the nearest North Vietnamese Army's base, measured in kilometers (km). The first-stage estimate is robust and statistically significant across different specifications. Our preferred model is the fully-specified formulation in which we control for extensive sets of district, commune, household, and individual characteristics as discussed in the previous section (column 3). For every km closer to an NVA base, the commune's herbicide exposure score increases by 0.05, or approximately 2.2 percent of the sample mean score (the commune-level average herbicide score in the sample is 2.198, according to Table 1. The relationship is illustrated graphically

[14] For instance, the presence of unexploded ordnance in locations intensely bombed in the past can be a factor causing injuries or disability long after the war ended.

in Figure 2 and Figure A.2. The significant and sizeable first-stage estimate lends support to the validity of the IV employed in this study.[15]

5.2 Health impacts of Agent Orange

5.2.1 Main regression results

Table 3 shows how exposure to Agent Orange affects civilians' health. Panel A starts off by presenting results from a pure OLS estimation in which the reported morbidity indicator of an individual is regressed on the degree of the herbicide exposure score calculated for his commune. Panel B then presents estimates from our 2SLS model, in which we instrument for the potentially non-random herbicide exposure intensity of a commune with its proximity to an NVA base—our IV of choice discussed in the previous section.[16] In both panels, column (1) presents estimates from a lean specification without adding any covariates. Column (2) controls for commune-level bombing intensity, which is defined as the total number of bombs, missiles, and rockets dropped per squared-kilometer. To further check for the sensitivity of our estimates to model specifications, we progressively add observable characteristics of the district and commune (column (3)). Column (4) presents the fully-specified model, in which we additionally include household and individual-specific controls.

We use the 2SLS coefficient of the fully-specified model in column (4) of Panel B to interpret the magnitude of the impact of AO exposure on health outcomes. Conditional on the level of bombing intensity and other observable characteristics discussed above, a standard deviation increase in the commune's herbicide exposure score leads to 1.284 percentage-point greater likelihood that an individual reported suffering from an AO-related diseases and disabilities, namely blood pressure disease, cancer, or mobility impairment. This magnitude equates to 19.75 percent of the population-average incidence rate of 6.5 percent.

It is also noted that the 2SLS estimates shown in Panel B are approximately four times larger than the pure OLS estimates in Panel A. This finding suggests an underestimation of the true effect of AO exposure when the endogeneity of AO sprayed locations are not accounted for. This potential downward bias might be a consequence of the fact that herbicide spraying missions happen to concentrate more on areas that have better socio-economic conditions today. Additionally, as bombing intensity and herbicide spraying are positively correlated, it might be that heavily sprayed

[15]We also present result of the reduced-form regressions in which we regress the main outcome variables on the IV (proximity to the nearest NVA base) in Table A.2. The results show that prevalence of AO-related ailments decreases with respect to distance from the NVA bases.

[16]The first-stage Kleinbergen-Paap F-statistics for the excluded instrument, shown in Table 3, is between 39 and 46, indicating a strong relationship between herbicide exposure intensity and the commune's proximity to the nearest NVA location.

areas were also heavily bombed during the war. According to (Miguel and Roland, 2011), after the war ended in Vietnam, these severely targeted places for bombing tended to receive more attention and aid, which resulted in a rapid economic recovery. Our IV approach therefore mitigates these confounding factors in estimating the health impact of AO exposure.

More importantly, as shown in Table A.3, our results on herbicide impacts are independent of bombing exposure. Column (1) indicates that a one standard deviation increase in a commune's herbicide exposure score yields a 1.7 percentage point increase in the prevalence of AO-related ailments. Adding commune level bombing intensity measure (column (2)) fails to significantly alter this coefficient. Furthermore, in column (4), the bombing coefficient is smaller than the herbicide exposure coefficient, suggesting that herbicide exposure has more effect on AO-related diseases than bombing exposure. We note, however, that considering bombing intensity endogenously could change the relative importance of herbicide exposure and bombing exposure. Nevertheless, our results imply that both herbicide exposure and bombing exposure have independent detrimental effects on AO-related diseases and disabilities.

5.2.2 Disease-specific results

Table 4 discusses the disease-specific effect of Agent Orange exposure. Of all the diseases that are linked to AO, the Vietnam National Health Survey (2001-2002) provides data on three indicators, including blood pressure disease (Panel A), mobility disability (Panel B), and cancer (Panel C). While blood pressure disease and cancers have been medically shown to be directly associated with AO exposure, mobility impairment can be considered an indirect effect since it is strongly correlated with various other diseases resulting from AO exposure such as leukemia, multiple myeloma, lymphoma, Parkinson disease, and peripheral nephropathy (Department of Veterans Affairs, 2016).

The results from Table 4 indicate robust and significant impacts of AO exposure on two main health indicators that we observe in the data: blood pressure disease and mobility impairment. According to estimates from the full specified model (column (4)), a standard deviation increase in the herbicide exposure score leads to an increase of approximately 1 percentage point in the prevalence of blood pressure disease in affected communes (corresponding to 18 percent of the population mean; Panel A), or 0.37 percentage point in the likelihood of having a disability related to mobility (corresponding to 30.8 percent of the population mean; Panel B).

The latter, sizable impact of AO exposure on mobility disability perhaps coincides with earlier finding by Palmer et al. (2019) regarding the impact of bombing on the prevalence of the disability status among Vietnamese. To examine whether the effect of bombing would interfere with the causal estimate of AO exposure on our outcomes, we present Table A.4. It contains coefficients for bombing intensity as well as an interaction term between herbicide exposure and bombing intensity. As before, the coefficients of bombing intensity are smaller than for herbicide exposure, indicating the importance of herbicide exposure relative to bombing. Furthermore, the insignificant interaction term suggests no marginal effect of bombing on herbicide exposure's impacts on disease outcomes.

To shed further light on the causal impact of AO exposure on diseases and disabilities, we follow Palmer et al. (2019) and explore data on the prevalence of disability from the 2009 Vietnamese Population and Housing Census (VPHC). Compared with the main health dataset (i.e., the 2002 National Health Survey), VPHC is a decennial survey administered by the Vietnamese General Statistics Office and collects data on population and housing from over 13 million Vietnamese representative at the district level. Detailed information about respondents' health and diseases are limited; however, each surveyed individual in the VPHC is asked about his or her general disability status. Tables A.5 and A.6 in the Appendix report results from our modified first-stage and 2SLS estimation model.[17] Despite some differences between two disability measures from the VNHS and VPHC, the IV result in Table A.6 indicate a significant and consistent detrimental impact of AO exposure on the prevalence of disability among the Vietnamese population.

In contrast to the significant results found for blood pressure disease and mobility disability, we find no statistically significant impacts of AO exposure on the prevalence of cancer. This result is in line with earlier evidence from Do (2009), which finds no significant difference in the prevalence of cancer between herbicide-exposed communes relative to those not exposed. However, we acknowledge several empirical limitations on this finding. First, the number of survey respondents reporting cancer in our dataset is low (about 0.1 percent of the sample). Secondly, the broad cancer indicator in the data cannot be specified into cancer types. In that sense, this outcome variable is fuzzy, as some of the most prevalence types of cancer in Vietnam[18] such as breast cancer, liver cancer, or stomach cancer are those still having insufficient medical evidence of an association with AO exposure (National Academies, 2018). Lastly, we acknowledge that our finding could reflect a downward attrition bias, as individuals who suffered from more serious health conditions related to herbicide

[17]Specifically, the regression to estimate the effect of herbicide exposure on the prevalence of disability in South Vietnam using the VPHC data can be estimated with:

$$y_{icd} = \beta_0 + \beta_1 ExposureScore_d + X_{ic}^{'}\Gamma + D_d^{'}\Delta + \sigma_c + \epsilon_{id} \tag{3}$$

where y_{icd} is the disability status for individual i of birth cohort c who lives in district d. The herbicide exposure index in district d is represented by $ExposureScore_d$. Vector X_{ic} contains individual characteristics including age, gender, education level, and ethnicity. D_d represents district-level observable conditions, which includes the district's bombing exposure during the war and an extensive list of geographic characteristics. The district level data are from Miguel and Roland (2011). Then, given the lack of commune identifiers in VPHC, we modify our IV for $ExposureScore_d$ as the district's proximity to a NVA's base-—measured by the distance between the district's centroid to the nearest base.

[18]Source: The Global Cancer Observatory 2020 report - International Research Agency for Cancer - World Health Organization.

exposure, such as cancer, might not have been alive at the time of the survey.

5.2.3 Heterogeneous effect across cohorts

We next examine the potential heterogeneous impacts of herbicide exposure across population cohorts, namely those directly exposed (i.e., individuals born during or before the herbicide missions) and indirectly so (i.e., individuals born after the spraying ended). The results are presented in Table 5. The estimated coefficients across columns (1) and (2) suggest that our finding of the significant adverse effect of herbicide exposure on AO-related diseases is driven by individuals born on or before 1971, i.e., those who were directly exposed to the herbicide spraying missions. All estimates in column (1), except for the coefficient on cancer, are statistically significant and of several degrees larger in magnitude than those in column (2), which are mainly insignificant at conventional levels.

However, of those alive at the time (those primarily represented in column (1)), the effects were varied. Our results in column (3), (4), and (5) of Table 5 suggest that children bare most of the brunt of the herbicide spraying missions. Specifically, those who were greater than 18 years old at the time herbicide missions started essentially endured little or no ill effect, as some of the coefficients in column (3) are statistically insignificant.[19] However, individuals who were children between the age of 5 and 18 when herbicide began (column (4)) and those in-utero or less than 5 (column (5)) suffered significantly, whereby one standard deviation increase in herbicide exposure score yielded a higher probability of having an AO-related disease by 30.1 percent (0.047/0.153) and 35.7 percent (0.02/0.056) for these two cohorts, respectively.

5.2.4 Effects on other diseases

Table 6 shows the estimation results for the other all other diseases indicators available in the survey, including epilepsy, deafness, speaking disability, slow mental development, mental illness, and eye disability. Among them, deafness, slow mental development, mental illness, and eye disability would be classified under Group 3 among the previously discussed categories in Chapter 2, i.e., illnesses with "inadequate or insufficient evidence" with respect to an association with AO exposure. In this group of diseases, we find a positive effect for eye disability at the 10% significant level. The last two available outcomes, epilepsy and speaking disability, do not feature in the *Veterans and Agent Orange* report's classification. We also do not find a significant effect of herbicide exposure on these diseases.

[19]However, we note that this cohort is the most likely to suffer from downward attrition bias, as many individuals in this age group might not been alive at the time of the survey.

5.3 Additional empirical checks for IV validity

In this subsection, we present results from different empirical tests that shed further light on the validity of the instrumental variable.

5.3.1 Sorting of individual, household, and commune characteristics

In Table 7, we check if there exists any major endogenous sorting of individuals, households, communes or districts relative to their distance to an NVA base. To do so, we separately regress each individual, household, commune, and district characteristics on our IV. We employ the same set of control as in the main regressions (Eqs.1 and 2). Overall, we find no clear evidence suggesting a systematic sorting based on the distance to NVA base. Specifically, the result suggests that households are similar across all observable characteristics employed in our covariate sets regardless of their proximity to an NVA base, except for the location to the provincial capital, and the intensity of bombing suffered during the war. To ensure that the above characteristics are not driving the results that we find, we control for them in all regressions (i.e., the fully specified models in each reported table).

5.3.2 Estimated effects based on resident status

In the analysis, we assume that the district of residence stated in the survey is the same as that of birth. We present several corroborating anecdotes in section 3. In an additional empirical exercise, we exploit an indicator related to permanent residency status (i.e., related to the household and residence registration system common in China and Vietnam that enable the governments to keep track of a citizen's birth, death, and migration) which is available in the data. Columns (1) and (2) in Table 8 examine the heterogeneous effect of herbicide exposure across respondents' residency status. The finding indicates significant impacts only among individuals who are more likely to have been born in the same location stated in the survey, i.e., those with permanent residency status in the residing commune (column (1)). The coefficients are statistically significant and consistent in magnitude with our main findings. On the other hand, we do not find statistically meaningful effects on respondents who had likely migrated to the current residing location, i.e., those without permanent residency status (column (2)), even though the average incidence rates of diseases are broadly similar across these two subgroups. This heterogeneous effect provides an additional corroborating evidence on the detrimental health impacts of AO among the directly exposed population.

5.4 Other robustness checks

In Table A.7, we perform a robustness test which estimates the impact of herbicide exposure on health outcomes with a probit model. All estimates across specifications are consistent with our main finding from the IV linear probability model. The IV-probit result continues to indicate a greater prevalence of blood pressure disease and mobility impairment among the population that lived in greater AO-exposed locations, in addition to a null effect on cancer prevalence.

Table A.8 examines the potential extent to which our 2SLS results are affected by extreme observations. In column (1), we exclude the top 5-percent most populated communes in our data. These urban centers tend to be the most rapidly developed over the recent decades and possess a high share of immigrants, which might confound (underestimate) the causal estimates of AO exposure. In column (2), we drop locations that are the closest in proximity to an NVA base (smaller than 5th percentile with respect to the distance to an NVA base). In columns (3) and (4), we exclude the most heavily sprayed communes from the herbicide missions as well as locales most severely bombed (above 95th percentile of herbicide and bombing intensity). The coefficients across all regressions are consistent with our main findings and their magnitudes are not statistically different from each other, suggesting that the main causal estimates are not sensitive to extreme outliers.

Table A.9 presents a battery of additional robustness checks. Panel (A) and Panel (B) present results from specifications with the standard errors clustered at the district and province levels. In Panel (C), we employ Conley standard errors to account for potential spatial correlation in the data. In Panel (D), we use an alternative measure of bombing intensity as a covariate, which is defined as total tonnage weight of bombs, missiles, and rockets per square-kilometer dropped on a commune. In Panel (E), we adopt a simple binary indicator for herbicide exposure, which equals one if there is at least one positively reported hamlet's herbicide score in a commune. This approach is similar to a majority of existing studies on U.S. veterans, in which AO exposure is usually defined if the veterans were presence in one of the four military combat tactical zones during the spraying period, despite the fact that spraying varied dramatically within each zone (Stellman and Stellman, 2018). The estimated results in all of the above robustness exercises are consistent with our main finding and provide corroborating evidence on the devastating impacts of AO on human health.

6 Conclusion

Exploring the spatial variation in the degree of herbicide usage during the U.S.-Vietnam War in the 1960-70s and different health indicators from a nationally representative health survey in Vietnam, this paper finds significant adverse effects of Agent Orange on the prevalence of several AO-related diseases among Vietnamese civilians, such as blood pressure disease and mobility disability. Our IV method, which exploits the proximity to North Vietnamese's military bases during the war as an instrument for the intensity of herbicide spraying, shows that civilians exposed to an additional standard deviation of the herbicide exposure score are, on average, 19.75 percent more likely to have a health issue related to Agent Orange relative to the population mean prevalence rate. We further find that the effect is predominantly attributed to the cohort that was directly exposed to herbicide spraying missions (i.e., those born before 1971), especially among children, infants, and those in-utero during the 1962-1971 wartime period.

Despite obtaining robust evidence, we acknowledge several caveats. First, our finding could reflect a downward attrition bias, as individuals who suffered from health conditions related to herbicide exposure or the war in general might not have been alive at the time of the survey. Second, the coarse measure of disease status from the survey does not permit us to elaborate on the precise types and causes of diseases (e.g., for mobility disability and cancer outcomes). Nevertheless, the paper adds important causal evidence on the devastating consequences of Agent Orange on individuals' well-being. Indeed, our finding that shows the significant, detrimental health impacts of Agent Orange exposure—particularly on the young cohort born during the war—could have important socioeconomic ramifications beyond the scope of this paper.

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Table 1: Summary Statistics

	Mean	SD	Min	Max
Panel A: Health Outcomes (N = 66,006)				
AO-related diseases and disabilities	0.065	0.246	0	1
Blood pressure disease	0.055	0.229	0	1
Cancer	0.001	0.032	0	1
Mobility disability	0.011	0.104	0	1
Deaf	0.007	0.083	0	1
Mental illness	0.003	0.059	0	1
Eye disability	0.009	0.093	0	1
Epilepsy	0.003	0.052	0	1
Slow mental development	0.005	0.067	0	1
Speaking disability	0.005	0.072	0	1
Panel B: Social-demographic characteristics (N = 66,006)				
Male	0.485	0.500	0	1
Age	28.785	20.034	0	101
Kinh Ethnic	0.831	0.375	0	1
Education (in level)	1.030	1.000	0	3
Ever moke	0.233	0.423	0	1
Smoke duration (years)	4.784	11.331	0	86
Ever drink	0.127	0.333	0	1
Drink duration (years)	2.078	6.930	0	72
Panel C: Household characteristics (N = 14,490)				
Herbicide and pesticide use	0.438	0.496	0	1
Herbicide and pesticide use (days/12months)	6.578	14.136	0	270
Household wealth (1. Rich- 5. Poverty)	2.821	0.806	0	5
Panel D: Commune characteristics (N = 483)				
Herbicide Exposure Score (in log)	2.198	2.267	0	6.78
Proximity to North Vietnamese army base (km)	19.164	11.770	0	83.99
Bombing intensity (total U.S. bombs, missiles, and rockets per km^2)	0.521	1.082	0	8.37
Area (km^2)	24.455	29.383	0.15	246.26
Poverty rate	0.124	0.111	0	0.82
Number of households	2891.172	1524.545	261	16499
Population	14032.465	7583.737	1371	83475
Urban	0.369	0.483	0	1
Panel E: District characteristics (N = 232)				
Distance to Ho Chi Minh or Ha Noi (km)	223.902	174.798	2.06	604.51
Elevation Mean (m)	111.968	216.758	1	1402.54
Proportion of land 0-250m	0.855	0.295	0	1
Proportion of land 250-500m	0.059	0.138	0	0.78
Proportion of land 500-1000m	0.070	0.193	0	1
Proportion of land >1000m	0.014	0.080	0	0.82
River length (km)	15.193	18.778	0	98.97
Average humidity (%)	82.109	1.152	80.40	85.23
Average sunshine (peak hours/month)	207.606	17.979	147.53	231.73
Distance to province capital	11.598	14.496	0.00	113.39

Note: Summary statistics of the main outcome and control variables. Individual observables include health outcomes (dependent variables; expressed as likelihoods of reporting a disease or disability), socio-economic, and household characteristics from the 2002 Vietnam National Health Survey (VNHS 2002; Panels A to C). An *Herbicide exposure score* for a commune is constructed as the population weighted average of the underlying hamlets' herbicide exposure indices, which are taken from (Stellman et al., 2003b). *Bombing intensity* is calculated using data from the U.S. Department of Defense Theater History of Operations Records (THOR). Distance to the nearest NVA base is calculated as the Euclidean distance between a commune' centroid (obtained from the Vietnamese general administrative directory) and the historic record of North Vietnamese Army base locations (documented in the 1967-1971 Enemy Base Area File under U.S. National Archives' Record Group 330). Other commune characteristics in Panel D are from VNHS 2002. District characteristics (Panel E) are from Miguel and Roland (2011).

Table 2: Instrumental Variable (2SLS First Stage)

Dependent variable: Herbicide Exposure Score				
	(1)	(2)	(3)	(4)
Proximity to NVA base (km)	-0.05212***	-0.05204***	-0.05112***	-0.05047***
	(0.00770)	(0.00782)	(0.00810)	(0.00805)
Observations	66,006	66,006	65,745	65,745
Commune Bombing Intensity	No	Yes	Yes	Yes
District & Commune Controls	No	No	Yes	Yes
Individual & Household Controls	No	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The estimated coefficients correspond to the first-stage regression (Eq.2). The dependent variable is the herbicide exposure score for commune c. The herbicide score for a commune is measured as the population weighted average of all underlying hamlets' herbicide indices, which are taken from (Stellman et al., 2003b). The instrument is the distance to the nearest North Vietnamese army's base, measured in kilometers. Standard errors are clustered at the commune level.

Table 3: Effect of herbicide exposure on AO-related diseases and disabilities

Dependent variable: Likelihood of an AO-related disease (Mean = 0.065)				
	(1)	(2)	(3)	(4)
Panel A: OLS regressions				
Herbicide Exposure Score	0.00357**	0.00348**	0.00312**	0.00352***
	(0.00141)	(0.00141)	(0.00129)	(0.00118)
Panel B: 2SLS regressions				
Herbicide Exposure Score	0.01735***	0.01656***	0.01810***	0.01284***
	(0.00541)	(0.00540)	(0.00528)	(0.00447)
Kleibergen-Paap F-statistics	45.79	44.25	39.81	39.32
Observations	66,006	66,006	65,745	65,745
Commune Bombing Intensity	No	Yes	Yes	Yes
District & Commune Controls	No	No	Yes	Yes
Individual & Household Controls	No	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table reports estimated effect of herbicide exposure on the prevalence of diseases related to Agent Orange using OLS (Panel A) and 2SLS (Panel B) estimations. A reported disease is categorized as AO-related if it is blood pressure disease, cancer, or mobility disability (see discussion on Chapter 2). Herbicide exposure score is expressed in standard deviations of the population mean (z-scores). All district, commune, household, and individual covariates are those discussed in Eq.1. The standard errors are clustered at the commune level.

Table 4: Effect of herbicide exposure on AO-related diseases and disabilities: by disease types

	(1)	(2)	(3)	(4)
Panel A: Blood pressure disease (mean = 0.055)				
Herbicide Exposure Score	0.01328***	0.01314**	0.01497***	0.00992**
	(0.00510)	(0.00511)	(0.00484)	(0.00406)
Panel B: Mobility disability (mean = 0.012)				
Herbicide Exposure Score	0.00528***	0.00449***	0.00412***	0.00377**
	(0.00158)	(0.00153)	(0.00158)	(0.00159)
Panel C: Cancer (mean = 0.001)				
Herbicide Exposure Score	0.00011	0.00022	0.00006	-0.00001
	(0.00037)	(0.00038)	(0.00041)	(0.00042)
Observations	66,006	66,006	65,745	65,745
Commune Bombing Intensity	No	Yes	Yes	Yes
District & Commune Controls	No	No	Yes	Yes
Individual & Household Controls	No	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table reports estimated effect of herbicide exposure on the prevalence of specific diseases related to Agent Orange exposure following the 2SLS regressions presented in Eqs. 1 and 2. The reported outcome variables are the prevalence of blood pressure disease (Panel A), mobility disability (Panel B), and cancer (Panel C). Herbicide exposure score is expressed in standard deviations of the population mean (z-scores). The 2SLS instrumental variable is proximity to the nearest North Vietnamese army base during the war (measured in kilometers). The standard errors are clustered at the commune level.

Table 5: Heterogeneities by birth cohorts

	Born on or before 1971	Born after 1971	Age $\geq$ 18 when herbicide started	Age 5 to 18 when herbicide started	Age <5 or in-utero during herbicide
	(1)	(2)	(3)	(4)	(5)
Panel A: Any AO-related diseases					
Herbicide Exposure Score	0.02435**	0.00186	0.02024	0.04676**	0.02008**
	(0.00957)	(0.00179)	(0.02417)	(0.02007)	(0.00797)
Sample mean	0.140	0.008	0.311	0.153	0.056
Panel B: Blood pressure disease					
Herbicide Exposure Score	0.01918**	0.00058	0.02392	0.04203**	0.01200*
	(0.00905)	(0.00131)	(0.02348)	(0.01935)	(0.00701)
Sample mean	0.124	0.004	0.287	0.132	0.047
Panel C: Mobility disability					
Herbicide Exposure Score	0.00664**	0.00170	0.00014	0.00827	0.00776***
	(0.00335)	(0.00134)	(0.01007)	(0.00651)	(0.00300)
Sample mean	0.019	0.005	0.038	0.022	0.009
Panel D: Cancer					
Herbicide Exposure Score	0.00025	-0.00032	-0.00109	0.00329	-0.00047
	(0.00090)	(0.00033)	(0.00247)	(0.00238)	(0.00073)
Sample mean	0.002	0.000	0.003	0.003	0.001
Observations	28,294	37,451	6,551	7,131	14,612
Commune Bombing Intensity	Yes	Yes	Yes	Yes	Yes
District & Commune Controls	Yes	Yes	Yes	Yes	Yes
Individual & Household Controls	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: This table reports the heterogeneous effect of herbicide exposure by cohorts. Column (1) presents estimate for the cohort directly affected by herbicide spray missions, i.e., those born on or before 1971. Column (2) presents estimates for the cohort born after 1971. Column (3) and (4) presents estimates for individuals who were at least 18 years of age and individuals who were 5-18 years of age when herbicide missions started, respectively. Column (5) presents estimate for individuals who were less than 5 in 1962 or born during the herbicide campaign. All estimations follow the 2SLS regressions presented in Eqs. 1 and 2. The outcome variables are the likelihood of having an AO-related disease (Panel A), blood pressure disease (Panel B), mobility disability (Panel C), and cancer (Panel D) (see discussion on Chapter 2). Herbicide exposure score is expressed in standard deviations of the population mean (z-scores). The 2SLS instrumental variable is proximity to the nearest North Vietnamese army base during the war (measured in kilometers). The regressions include all control variables defined in Eq. 1. The standard errors are clustered at the commune level.

Table 6: Effect of herbicide exposure on other diseases and disabilities (with insufficient medical evidence to confirm an association with AO)

	Epilepsy	Deaf	Speaking Disability	Slow Mental Development	Mental Illness	Eye Disability
	(1)	(2)	(3)	(4)	(5)	(6)
Herbicide Exposure Score	0.00118	0.00067	0.00160	0.00102	0.00124	0.00270*
	(0.00094)	(0.00130)	(0.00120)	(0.00111)	(0.00102)	(0.00146)
Sample Mean	0.003	0.007	0.005	0.005	0.003	0.009
Observations	65,745	65,745	65,745	65,745	65,745	65,745
Commune Bombing Intensity	Yes	Yes	Yes	Yes	Yes	Yes
District & Commune Controls	Yes	Yes	Yes	Yes	Yes	Yes
Individual & Household Controls	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The coefficients represent 2SLS estimated effects of herbicide exposure on the likelihood of reporting other diseases and disabilities that are available in the dataset. Among these, eye disability, deaf, and mental-related illnesses are ailments belong to the group of diseases being evaluated for probable medical associations with Agent Orange exposure (see discussion in Chapter 2). Herbicide exposure score is expressed in standard deviations of the population mean (z-scores). The instrument variable for the exposure score is the distance to the nearest North Vietnamese army base during the war. The standard errors are clustered at the commune level.

Table 7: Sorting of individual, household, commune, and district characteristics with respect to proximity to NVA bases

Variable	Coefficient	S.E.
Individual (N = 66,006)		
Male	-0.000	(0.000)
Age	0.004	(0.006)
Kinh Ethnic	-0.001	(0.001)
Education (in level)	0.000	(0.002)
Ever moke	0.000	(0.000)
Smoke duration (years)	0.000	(0.000)
Ever drink	-0.001	(0.002)
Drink duration (years)	-0.000	(0.000)
	0.001	(0.002)
Household (N = 14,490)		
Herbicide and pesticide use	-0.002*	(0.001)
Herbicide and pesticide use (days/12months)	0.042	(0.031)
Household wealth (1. Rich- 5. Poverty)	-0.000	(0.001)
Commune (N = 483)		
Bombing intensity (Total U.S. bombs, missiles, and rockets per Km2)	-0.013***	(0.003)
Area (Km2)	0.200	(0.125)
Poverty rate	-0.000	(0.000)
Number of households	-0.557	(1.310)
Population	6.010	(6.783)
Urban	0.001	(0.002)
District (N = 232)		
Distance to Ho Chi Minh or Ha Noi (km)	0.283	(0.372)
Elevation Mean (m)	-0.113	(0.138)
Proportion of land 0-250m	0.001	(0.000)
Proportion of land 250-500m	-0.001	(0.000)
Proportion of land 500-1000m	-0.000	(0.000)
Proportion of land >1000m	0.000	(0.000)
River length (km)	0.009	(0.073)
Average humidity (%)	0.001	(0.002)
Average sunshine (peak hours/month)	0.018	(0.040)
Distance to province capital	-0.249***	(0.052)

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

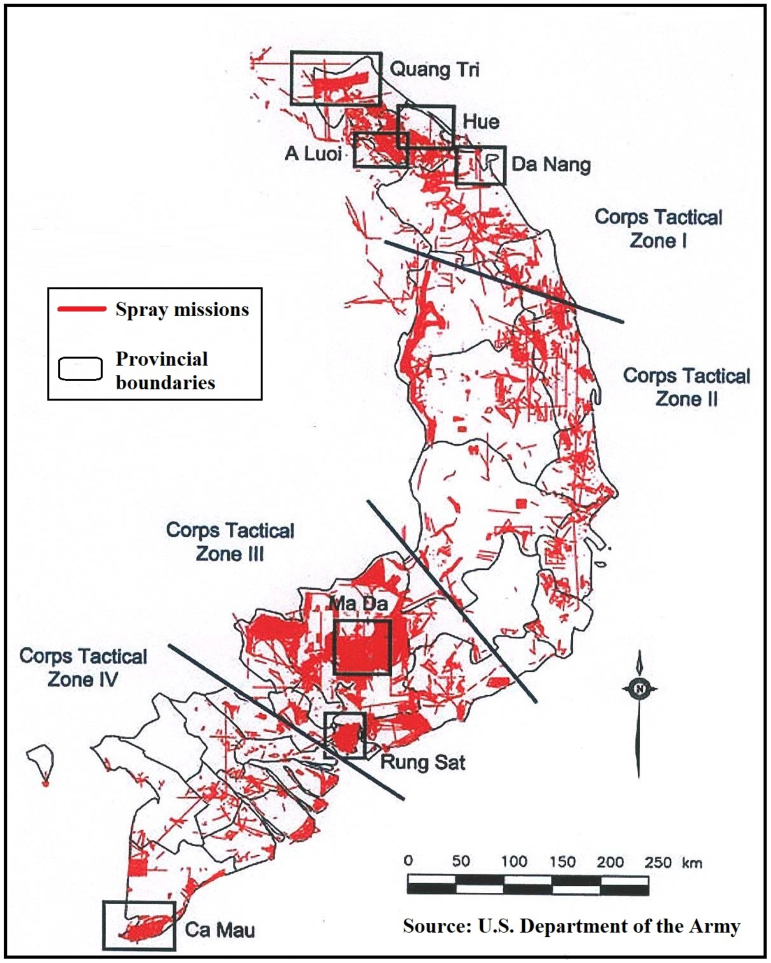
Note: This table reports the estimated coefficients from separate regressions in which each individual, household, commune or district characteristics is regressed on the distance to the nearest NVA base (measured in kilometers). All covariates discussed in Eq.1 are included. Standard errors are clustered at the commune level.

Table 8: Robustness check by residency status

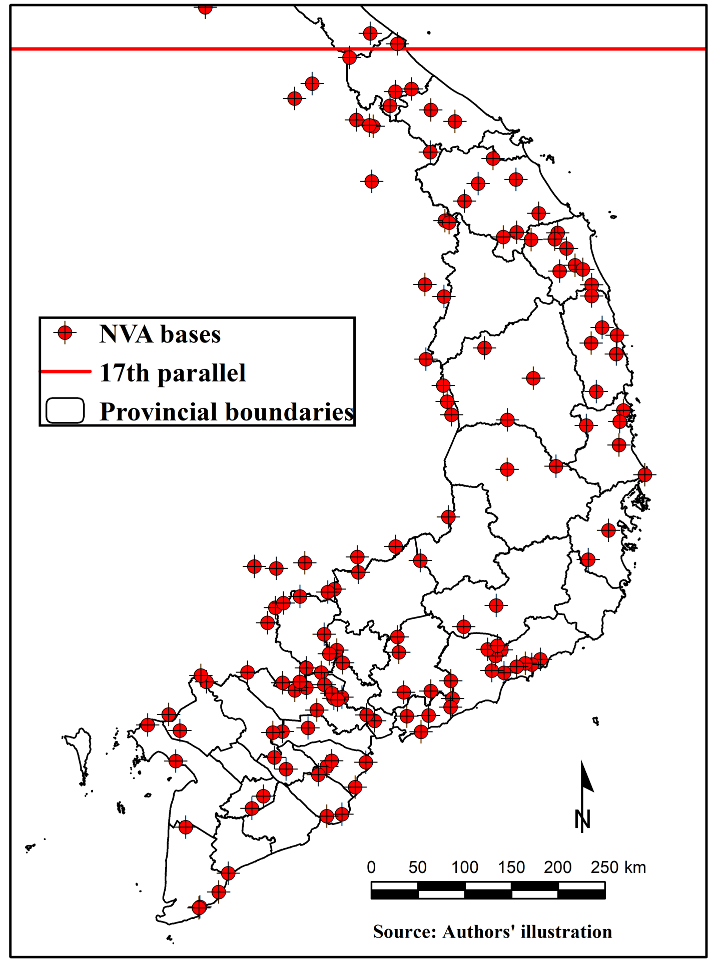
Sample:	Permanent Resident	Non-permanent Resident
	(1)	(2)
Panel A: Any AO-related diseases or disability		
Herbicide Exposure Score	0.01409***	-0.00247
	(0.00488)	(0.01295)
Sample mean	0.065	0.065
Panel B: Blood pressure disease		
Herbicide Exposure Score	0.01091**	0.00185
	(0.00441)	(0.01180)
Sample mean	0.056	0.052
Panel C: Mobility disability		
Herbicide Exposure Score	0.00396**	-0.00144
	(0.00173)	(0.00598)
Sample mean	0.012	0.014
Panel D: Cancer		
Herbicide Exposure Score	0.00010	-0.00027
	(0.00043)	(0.00238)
Sample mean	0.001	0.001
Observations	61,134	4,412
District & Commune Controls	Yes	Yes
Individual & Household Controls	Yes	Yes

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: This table reports the heterogeneous effects of herbicide exposure by residency status. Column (1) presents estimates for the individuals who are permanent residents of their residing commune. Column (2) presents estimates for non-permanent residents and individuals who migrated to the residing commune within the last 3 years of the survey time. All estimations follow the 2SLS regressions presented in Eqs. 1 and 2. The reported outcome variables are the prevalence of an AO-related disease (Panel A), blood pressure disease (Panel B), mobility disability (Panel C), and cancer (Panel D) (see discussion on Chapter 2). Herbicide exposure score is expressed in standard deviations of the population mean (z-scores). The 2SLS instrumental variable is proximity to the nearest North Vietnamese army base during the war (measured in kilometers). The regressions include all control variables defined in Eq. 1. The standard errors are clustered at the commune level.



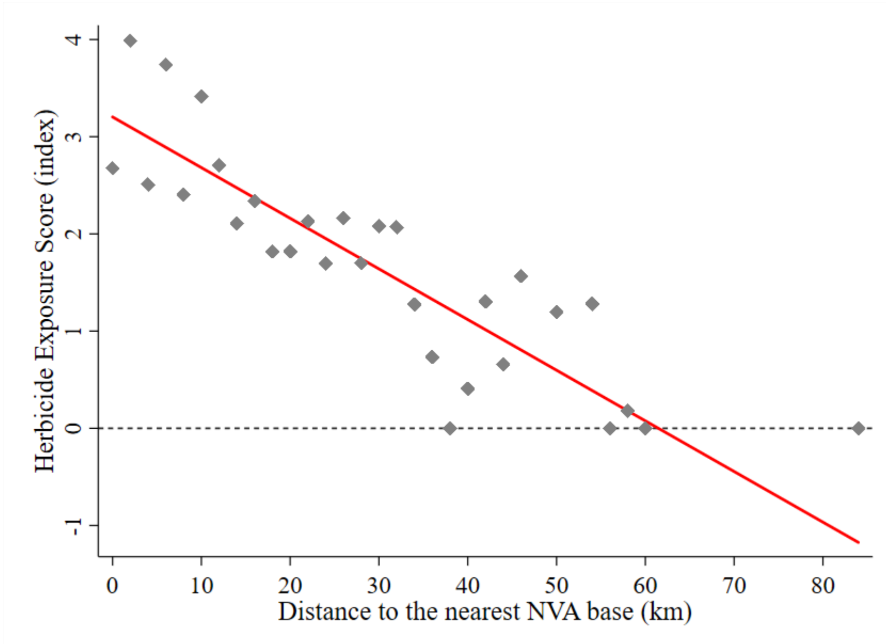
(a) Distribution of herbicide spraying



(b) Location of NVA bases (IV)

Note: Left figure shows the geographical distribution of herbicide spray missions in South Vietnam from 1965-1971 (source: U.S. Department of Army). Right figure plots the distribution of North Vietnamese Army Base (identified by U.S. Intelligence during the wartime).

Figure 1: Distribution of herbicide spraying & location of North Vietnamese Army (NVA) bases



Note: Correlation of communes' herbicide exposure scores and proximity to the nearest North Vietnamese Army's military base. Herbicide exposure scores are bin-averaged at each 2 kilometers distance and represented by diamond points.

Figure 2: First-stage – Herbicide exposure and proximity to North Vietnamese Army base

A Appendix

Table A.1: Prevalence rates of diseases and disabilities between north and south Vietnam

	South	North	Means difference (South-North)	S.E.	t-test value
Panel A: AO-related diseases and disabilities					
AO-related diseases & disabilities	0.062	0.053	0.010	0.001	8.383
Blood pressure disease	0.053	0.044	0.009	0.001	7.852
Cancer	0.001	0.001	0.000	0.000	0.730
Mobility disability	0.010	0.008	0.002	0.000	3.898
Panel B: other diseases and disabilities					
Deaf	0.007	0.007	-0.001	0.000	-2.166
Mental illness	0.003	0.003	0.000	0.000	1.812
Eye disability	0.009	0.008	0.001	0.000	1.651
Epilepsy	0.003	0.003	0.000	0.000	0.733
Slow mental development	0.005	0.006	-0.001	0.000	-3.521
Speaking disability	0.005	0.005	0.001	0.000	1.590
Observations	87,802	69,206			

Note: the table presents the mean prevalence rate by diseases and by North-South samples. The statistics are authors' calculations using the Vietnamese National Health Survey (2001-2002). Locations belong to the South sample if they are in Quang Binh province or to the south of Quang Binh province. Accordingly, North sample includes individuals locate to the north of Quang Binh province. The statistics are rounded to the third decimal point.

Table A.2: Reduced-form regressions—prevalence of AO-related diseases with respect to proximity to NVA bases (IV)

	(1) Any AO-related diseases	(2) Blood pressure disease	(3) Cancer	(4) Mobility disability
Proximity to NVA base (km)	-0.00029***	-0.00022**	0.00000	-0.00008**
	(0.00009)	(0.00009)	(0.00001)	(0.00003)
Observations	65,745	65,745	65,745	65,745
Commune Bombing Intensity	Yes	Yes	Yes	Yes
District Controls & Commune Controls	Yes	Yes	Yes	Yes
Household Controls & Individual Controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table shows results from the reduced-form regressions of the prevalence of AO-related diseases on distance to the nearest NVA base (IV). The standard errors are clustered at the commune level.

Table A.3: Effect of herbicide exposure on the prevalence of AO-related diseases and disabilities—displaying the coefficients of bombing intensity

Dependent Variable: Likelihood of any AO-related diseases (Mean = 0.065)				
	(1)	(2)	(3)	(4)
Herbicide Exposure Score	0.01735***	0.01656***	0.01810***	0.01284***
	(0.00541)	(0.00540)	(0.00528)	(0.00447)
Bombing Intensity		0.00122	0.00380**	0.00347***
		(0.00170)	(0.00169)	(0.00134)
IV-F Statistics	45.79	44.25	39.81	39.32
Observations	66,006	66,006	65,745	65,745
Commune Bombing Intensity	No	Yes	Yes	Yes
District & Commune Controls	No	No	Yes	Yes
Individual & Household Controls	No	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table reports estimated effect of herbicide exposure on the prevalence of diseases related to Agent Orange using a 2SLS estimation. A reported disease is categorized as AO-related if it is blood pressure disease, cancer, or mobility disability (see discussion on Chapter 2). Herbicide exposure score and bombing intensity are expressed in standard deviations of population mean (z-scores). All district, commune, household, and individual covariates are those discussed in Eq. 1. The standard errors are clustered at the commune level.

Table A.4: Effect of herbicide exposure on the prevalence of specific AO-related diseases and disabilities—interacting herbicide exposure score with bombing intensity

	Any AO-related diseases	Blood pressure disease	Cancer	Mobility disability
	(1)	(2)	(3)	(4)
Herbicide Exposure Score	0.01267***	0.00974**	-0.00003	0.00380**
	(0.00448)	(0.00409)	(0.00042)	(0.00160)
Bombing Intensity	0.00329**	0.00249	-0.00010	0.00101*
	(0.00148)	(0.00151)	(0.00010)	(0.00053)
Herbicide Exposure Score X Bombing Intensity	-0.00203	-0.00212	-0.00023	0.00037
	(0.00433)	(0.00454)	(0.00025)	(0.00164)
Observations	65,745	65,745	65,745	65,745
Commune Bombing Intensity	Yes	Yes	Yes	Yes
District Controls & Commune Controls	Yes	Yes	Yes	Yes
Household Controls & Individual Controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table reports estimated effect of herbicide exposure on the prevalence of specific diseases related to Agent Orange exposure following the 2SLS regressions presented in Eqs. 1 and 2. Herbicide exposure score and bombing intensity are expressed in standard deviations of population mean (z-scores). Interaction term between herbicide exposure and bombing intensity is added. The 2SLS instrumental variable is proximity to the nearest North Vietnamese army base during the war (measured in kilometers). The standard errors are clustered at the commune level.

Table A.5: Using 2009 Population and Housing Census Data—First-stage IV result

	Dependent variable: herbicide exposure score		
	(1)	(2)	(3)
Distance to the nearest NVA base (km)	-0.00939***	-0.00527***	-0.00549***
	(0.00143)	(0.00156)	(0.00156)
Observations	6,916,477	6,916,477	6,916,477
Sample	South Vietnam	South Vietnam	South Vietnam
District Controls	No	Yes	Yes
Individual Controls	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: The table reports estimated coefficients from the first-stage 2SLS regressions using outcomes from the Vietnamese 2009 Population and Housing census. The dependent variable is herbicide exposure score for district d. Herbicide exposure index for a district is measured as the population weighted average of all underlying hamlets' exposure scores, which are taken from (Stellman et al., 2003b). The instrument is the distance from the district centroid to the nearest North Vietnamese army's base, measured in km. District controls are presented in Table 1. Individual controls include age, gender, education, and ethnicity. Standard errors clustered at the district level. All standard errors are clustered at the district level.

Table A.6: Using 2009 Population and Housing Census Data—herbicide exposure on disability likelihood

	Dependent Variable: disability likelihood		
	(1)	(2)	(3)
Panel A: OLS regressions			
Herbicide Exposure Score	0.00137	0.00183**	0.00219***
	(0.000992)	(0.000868)	(0.000678)
Panel B: IV regressions			
Herbicide Exposure Score	0.00806***	0.0158**	0.0104**
	(0.00293)	(0.00638)	(0.00451)
Sample	South Vietnam	South Vietnam	South Vietnam
Observations	6,299,701	6,299,701	6,299,701
District Controls	No	Yes	Yes
Individual Controls	No	No	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: This table reports estimates on the impact of herbicide exposure on the prevalence of disability, estimated with OLS (Panel A) and 2SLS (Panel B) using the Vietnamese 2009 Population and Housing census. The dependent variable is the disability status for an individual i living in district d. Herbicide exposure index for a district is measured as the population weighted average of all underlying hamlets' exposure scores, which are taken from (Stellman et al., 2003b). The instrument is the distance from the district centroid to the nearest North Vietnamese army's base, measured in km. District controls are presented in Table 1. Individual controls include age, gender, education, and ethnicity. Standard errors clustered at the district level. The standard errors are clustered at the district level.

Table A.7: IV Estimations with Probit Model

	AO-related diseases	Blood pressure disease	Cancer	Mobility disability
	(1)	(2)	(3)	(4)
Herbicide Exposure Score	0.11477**	0.10002**	-0.04764	0.13027**
	(0.04563)	(0.05013)	(0.13703)	(0.06225)
Observations	65,745	65,745	65,745	65,745
Commune Bombing Intensity	Yes	Yes	Yes	Yes
District Controls & Commune Controls	Yes	Yes	Yes	Yes
Household Controls & Individual Controls	Yes	Yes	Yes	Yes

Notes: Marginal effects of herbicide exposure on the likelihood of having an AO related disease, estimated using IV-Probit model. Herbicide exposure score is expressed in standard deviations of population mean (z-scores). The instrument variable for the exposure score is the distance to the nearest North Vietnamese army base during the war. All district, commune, household, and individual covariate sets are those discussed in Eq. 1. Standard errors are clustered at the commune level.

Table A.8: Robustness check with winsorized samples

	Likelihood of any AO-related diseases			
	(1)	(2)	(3)	(4)
Herbicide Exposure Score	0.01305***	0.01388***	0.01445***	0.01070**
	(0.00448)	(0.00475)	(0.00513)	(0.00475)
Sample	Exclude commune population >95th percentile	Exclude distance to nearest NVA base <5th percentile	Exclude herbicide exposure score >95th percentile	Exclude bombing intensity >95th percentile
Observations	62,483	62,639	62,496	62,455
Commune Bombing Intensity	Yes	Yes	Yes	Yes
District & Commune Controls	Yes	Yes	Yes	Yes
Individual & Household Controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

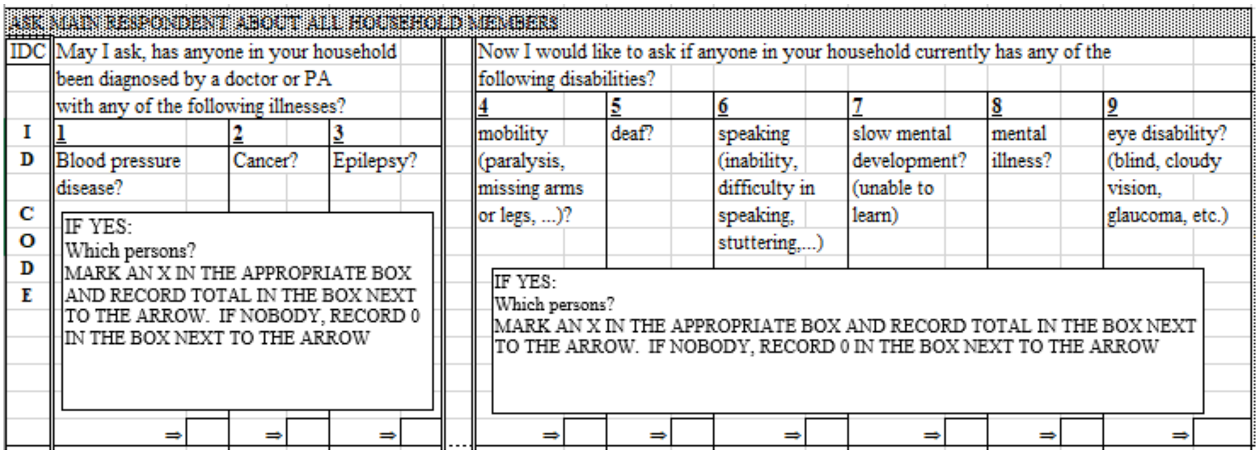
Notes: Robustness checks with winsorized samples (excluding of extreme observations). All estimates are from 2SLS model. Herbicide exposure score is expressed in standard deviations of population mean (z-scores). The instrument variable for the exposure score is the distance to the nearest North Vietnamese army base during the war. The standard errors are clustered at the commune level.

Table A.9: Robustness checks with different standard error clustering and alternative measures of herbicide exposure and bombing intensity

	AO-related diseases	Blood pressure disease	Cancer	Mobility disability
	(1)	(2)	(3)	(4)
Panel A: Standard errors clustered at the district level				
Herbicide Exposure Score	0.01284***	0.00992**	-0.00001	0.00377**
	(0.00493)	(0.00430)	(0.00043)	(0.00176)
Panel B: Standard errors clustered at the provincial level				
Herbicide Exposure Score	0.01284***	0.00992**	-0.00001	0.00377*
	(0.00478)	(0.00406)	(0.00044)	(0.00205)
Panel C: Conley standard errors (accounting for spatial correlation)				
Herbicide Exposure Score	0.01351***	0.01047**	-0.00002	0.00391**
	(0.00480)	(0.00408)	(0.00045)	(0.00174)
Panel D: Alternative measure for bombing intensity—total bombing weight per km^2 ***(in tonnages)***				
Herbicide Exposure Score	0.01350***	0.01052***	-0.00001	0.00385**
	(0.00445)	(0.00404)	(0.00041)	(0.00156)
Panel E: Alternative measure for herbicide exposure score—Binary indicator				
Herbicide Exposure Score	0.02885***	0.02230**	-0.00002	0.00847**
	(0.01016)	(0.00922)	(0.00094)	(0.00361)
Observations	65,745	65,745	65,745	65,745
Commune Bombing Intensity	Yes	Yes	Yes	Yes
District Controls & Commune Controls	Yes	Yes	Yes	Yes
Household Controls & Individual Controls	Yes	Yes	Yes	Yes

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: Robustness checks with clustering levels of standard errors and alternative measurement forms of the herbicide and bombing exposures. Panel A and B respectively report the results with district-level and provincial level clustering of standard errors. Panel C reports results from the estimations using Conley-corrected standard errors. Panels D and E employ density of total bombing weights and a binary measure for herbicide exposure, respectively. All estimates are from the 2SLS model. Herbicide exposure score is expressed in standard deviations of population mean (z-scores). Standard errors in Panels D and E are clustered at the commune level.



ASK MAIN RESPONDENT ABOUT ALL HOUSEHOLD MEMBERS

IDC | May I ask, has anyone in your household been diagnosed by a doctor or PA with any of the following illnesses?

I D C O D E

1 Blood pressure disease? | 2 Cancer? | 3 Epilepsy?

IF YES:
Which persons?
MARK AN X IN THE APPROPRIATE BOX AND RECORD TOTAL IN THE BOX NEXT TO THE ARROW. IF NOBODY, RECORD 0 IN THE BOX NEXT TO THE ARROW

⇒ ⇒ ⇒

Now I would like to ask if anyone in your household currently has any of the following disabilities?

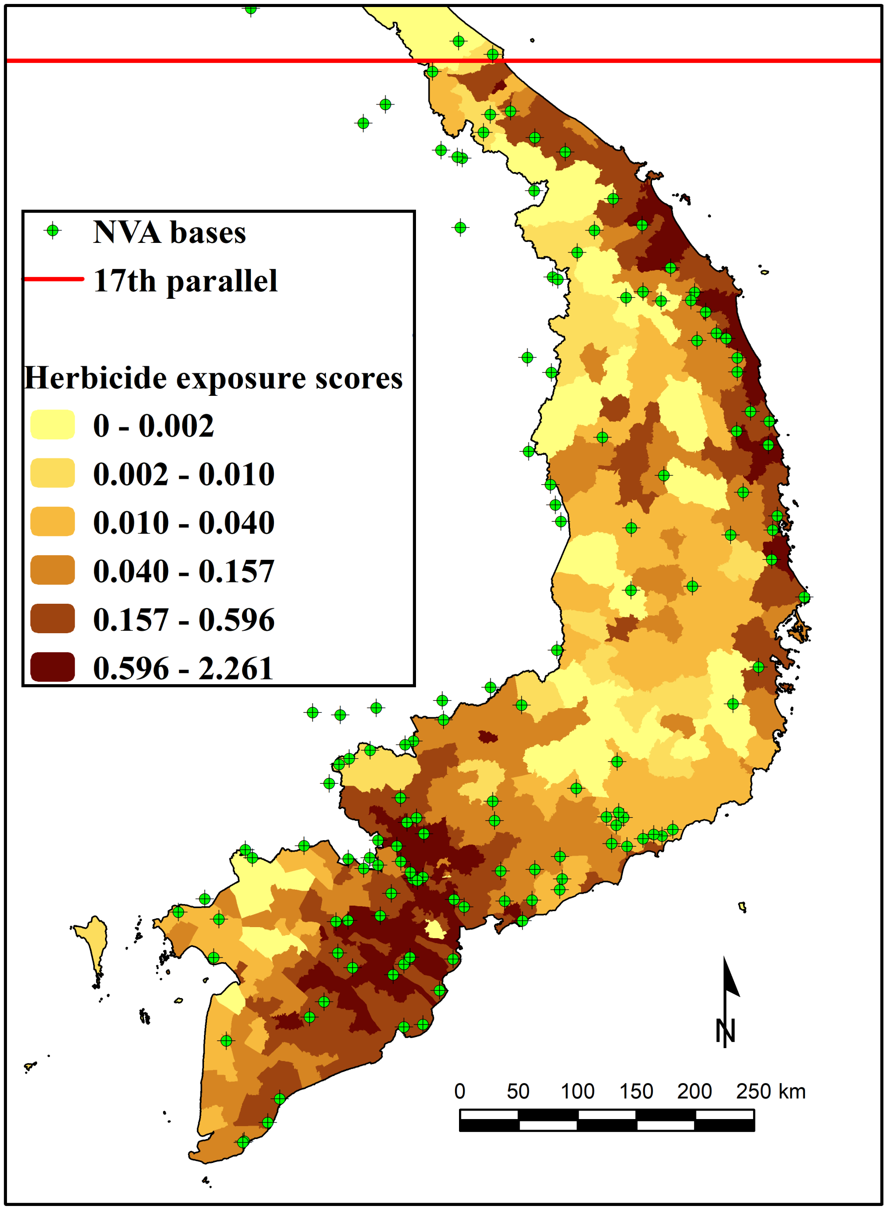
4 mobility (paralysis, missing arms or legs, ...)? | 5 deaf? | 6 speaking (inability, difficulty in speaking, stuttering,...) | 7 slow mental development? (unable to learn) | 8 mental illness? | 9 eye disability? (blind, cloudy vision, glaucoma, etc.)

IF YES:
Which persons?
MARK AN X IN THE APPROPRIATE BOX AND RECORD TOTAL IN THE BOX NEXT TO THE ARROW. IF NOBODY, RECORD 0 IN THE BOX NEXT TO THE ARROW

⇒ ⇒ ⇒ ⇒ ⇒ ⇒

Note: Extract from the Vietnam National Health Survey 2001-2002's questionnaire instrument with the main health outcomes studied in the analysis.

Figure A.1: Extract from the Vietnam National Health Survey 2001-2002's questionnaire instrument



Note: The figure shows the distribution of herbicide exposure scores and locations of NVA bases. The colorgram represents herbicide exposure intensity, averaged at the district level for ease of visualization, and weighted by hamlets' population.

Figure A.2: Distribution of herbicide exposure scores and location of NVA bases