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Long-Term Effects of Vietnam War: Agent Orange and the Health of Vietnamese People After 30 Years

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This article examines the long-term health effects of Agent Orange, a military herbicide containing the hazardous chemical compound dioxin that was widely disseminated in South Vietnam during the Vietnam War (1959–1975). Based on data from US military archives on the herbicide operations, we estimate the prevalence of disabilities among Vietnamese people using the 2009 Population Census. The results demonstrate that the legacy of Agent Orange continues, with ongoing adverse (although small) effects on health even more than 30 years since the end of the war. Critically, the health burden of severe mobility disability has been mostly borne by ethnic minority women in the affected areas.

Keywords: Agent Orange, disabilities, long-term effects of war, public health, Population Census, Vietnam War.

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I. Introduction

Despite the formidable human losses attributable to wars,[1] evidence suggests that the economy itself remains remarkably resilient to wartime destruction, returning relatively quickly to its long-term growth trajectory (Miguel and

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We owe special thanks to Dr Quy-Toan Do of the World Bank for generously sharing with us the US Military Assistance Command Data Management Agency's Herbicide Report System (HERBS) datafiles. Further, we have received many useful comments from Yutaka Arimoto, Chandra Athukorala, Paul Burke, Chiaki Moriguchi and seminar attendees at Australian National University, International University of Japan, Keio, Hitotsubashi and the Asia and Australian Society of Labour Economics Conference.

[1] Russia lost 10 percent of its population during World War II, 10 percent of the Korean population was wiped out in the Korean War, and 13 percent of the Vietnamese population died in the Vietnam War (Garfield and Neugut, 1997).

Roland, 2011). However, it is increasingly recognized that, even long after they have ended, wars continue to pose major threats to public health, not only for war veterans (Gade and Wenger, 2011; Johnston *et al.*, 2016) but also for civilians, their families, and offspring (Ghobarah *et al.*, 2003; Do and Lyer, 2012). Such additional deaths and adverse health effects are overwhelmingly concentrated in women and children; these populations are more vulnerable due to limited strategies to mitigate such effects (Akbulut-Yuksel, 2017; Akresh *et al.*, 2018).

This article contributes to the research that identifies long-term effects of war on public health. We focus on one specific aspect of the long-term public health consequences of the military herbicides used in the US military's deforestation attempts during the Vietnam War. One of the chemicals used in this deforestation campaign was Agent Orange, which contains the highly toxic chemical compound dioxin.[2] Using the 2009 Population Census, we estimate the likelihood of disability as a key barometer of health capital among the Vietnamese. We identify 'treatment' based on spatial variations of intensity of sprayed Agent Orange, which we obtained from US military archive data, specifically the US Military Assistance Command Data Management Agency's Herbicide Report System (HERBS) (Stellman *et al.*, 2003; Do, 2009).

One major methodological challenge is partitioning the long-term effects of Agent Orange in regard to disabilities from other confounding wartime factors when the same individuals also may have been exposed to either bombing or direct combat. Consequently, disabilities observed in 2009 may not be attributed solely to military herbicide exposure if we focus on cohorts that were born and lived through the wartime period. However, although sprayed only temporarily, due to its unique chemical structure, Agent Orange (dioxin) is known to linger in the ecosystem.[3] Even long after the end of the war, scientific tests still detect hazardous levels of dioxin contamination in soils and sediments at the bottom of drainage canals, where it attaches to organic matter and ascends food chains, extending to fish and wild animal species (Banout *et al.*, 2014; Olson and Morton, 2019). Ultimately, the compound is absorbed by human bodies.[4]

The health problems attributable to military herbicides hence can occur not only in those directly exposed, but also in the wider public due to a gradual process in which people are unknowingly exposed to Agent Orange.[5] Several

[2] The name 'Agent Orange' originates in the color-coded labels on the steel storage units that were used to distinguish different types of chemicals employed for the operation. The chemical name of dioxin is 2,3,7,8-tetrachloro-dibenzo-para-dioxin. Other chemicals used include 'Agent White' and 'Agent Pink'. Agent Orange accounted for approximately 65 percent of the herbicides applied (Stellman *et al.*, 2003).

[3] Agent Orange is hydrophobic. In soil, the lifespan of dioxin can be as long as 100 years underground. Dioxin ultimately enters the human body via ingestion, migrating through fatty tissue, the liver, and breast milk.

[4] A majority of Vietnamese in rural communities are reported to consume above-average quantities of fish per day (Tuu *et al.*, 2008).

[5] There was very little public awareness in Vietnam regarding exposure to military herbicides even some years after the end of the war.

medical studies of war veterans have established that dioxin is linked to adverse health outcomes, including cancer and diabetes, and to birth defects such as spina bifida, cerebral palsy, cognitive impairment, and missing or deformed limbs (Stone, 2017). Anecdotal evidence indicates that these disabilities (to varying degrees) are observed in the generations who were born after the war in the Agent Orange–affected areas of Vietnam.[6] Based on these findings, our analysis focuses on the cohorts that were born and residing in rural areas[7] of South Vietnam after the war ended in 1975, comparing the public health status of those residing in the higher intensity military herbicide spray zones with those in the lower intensity zones. In short, our strategy identifies an 'intention-to-treat' (ITT) effect, under the assumption that the probability of reported disabilities would have been similar in areas in the absence of Agent Orange application.

This study found that the legacy of wartime Agent Orange application continues to this day, with ongoing adverse effects on the current lives of Vietnamese people more than 30 years after the end of the war. Our estimates suggest that such adverse effects are experienced mostly by females: a female living in an area that was subject to high-intensity Agent Orange application is more likely to report a serious disability in hearing, mobility, or memory than her counterpart living in an area without Agent Orange exposure. Although the economic magnitude of our finding is very small, note that the sample we examined is relatively young, having an average age of 18. Our analysis also restricted the sample to ethnic minorities, who are believed to have reduced opportunities for migrating from their areas of residence and, hence, longer exposure to military herbicides. Even in this further restricted sample, we found that females continued to be more likely to report a serious disability in mobility, accounting for approximately 3.4 percent of the sample average of disabilities for females of ethnic minorities. In sum, our study highlights the hidden war legacy affecting public health using the unique episode of military herbicide operations in the Vietnam War. It also makes informative contributions to the design of postwar reconstruction policies.

This article makes contributions to the following two strands of literature. First, it adds to the literature on the consequences of war-related shocks for public health. Wars, combat, and bombing are identified as exogenous shocks to the health status of those directly exposed, such as veterans (Gade and Wenger, 2011) and families and their children (Akresh *et al.*, 2012; Palmer *et al.*, 2019; Singhal, 2019), in addition to being a barrier to human capital formation in the affected cohorts (Pivovarova and Swee, 2015; Akbulut-Yuksel, 2017). Our work is distinguished from these studies because it relates the legacy of the wartime military herbicide operation to long-term health implications for the Vietnamese people.

Most similar to our work in terms of methodology and setting is a study by Do (2009) that examines the effects of Agent Orange dispersion on the prevalence of cancers among the Vietnamese. Our work extends Do (2009) by

[6] Fifty-thousand children are believed to have been born with disabilities (Palmer, 2005).

[7] The military herbicide operations were concentrated in jungle and coastal mangrove areas, away from urban areas.

focusing on disabilities in those generations born after the war. The strength of our analysis lies in its use of the Population Census, which covers the much wider geographical areas affected by US military herbicide operations than those covered by the Vietnam Health Survey (VHS) used by Do (2009).[8] Whereas Do (2009) utilized the hit counts of the herbicide operations, we measure intensity of application of military herbicides in terms of gallons. Despite differences in empirical approach, both our study and that of Do (2009) reach similar findings regarding the long-term legacy of wartime Agent Orange application—both studies demonstrate the lingering effects of Agent Orange on the current health of the Vietnamese people.

Second, this article aims to increase understanding of the public health consequences of Agent Orange. A sizeable number of medical and epidemiological studies now link prostate cancer, diabetes, skin disease, cardiovascular disease mortality, and hypertension in US war veterans to direct exposure to dioxin. However, to date, relatively little compelling evidence links Agent Orange to long-term health effects on the Vietnamese public. This lacuna led to dismissal of the class action lawsuit against US companies that manufactured and supplied Agent Orange to the US military during the war (Stone, 2007). Existing war-related studies on the Vietnamese are based only on direct exposure to bombing or direct combat in relation to long-term mental health (Teerawichitchainan and Korinek, 2012; Korinek and Teerawichitchainan, 2014; Singhal, 2019).

The rest of the article is structured as follows. Section II presents the background to and a brief discussion of the Vietnam War. Section III presents the estimation strategy, followed by the data in Section IV. Section V discusses the results and Section VI concludes.

II. The Vietnam War and Agent Orange[9]

II.1 Background

During a particular period of the Vietnam War (1961–1971),[10] the US military disseminated approximately 20 million gallons (75 million liters)[11] of herbicides

[8] The VHS covered 18 provinces, whereas the 2009 Population Census surveyed over 63 provinces.

[9] This section has drawn on several articles on the legacy of Agent Orange (e.g., Stone, 2017; Black, 2019), in addition to the following websites:https://www.aspeninstitute.org/programs/agent-orange-in-vietnam-program/; https://www.history.com/topics/vietnam-war/agent-orange-1; and https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health.

[10] The Vietnam War lasted from 1959 to 1975. The destructive nature of the Vietnam War has been described by many, including Miguel and Roland (2011, p. 2): the 'Vietnam War bombing thus represented at least three time as much (by weight) at both European and World War II bombing combined, and about fifteen times total tonnage in the Korean war'. Dell and Querubin (2017) state that 'more firepower was unleashed during the Vietnam War than during any other conflict in human history'.

[11] 1 US gallon is 4.5 liters.

from the ground and air[12] with the aim of clearing dense forests in which guerrilla forces were hiding and destroying crops and causing disruption to food supplies for the enemy forces. It is reported that these herbicide operations covered approximately 24 percent of land in South Vietnam, destroying 5 million acres of farmland, upland, and mangrove forests and approximately 500,000 acres of crops (Stellman *et al*., 2003). This US military operation, code named Operation Ranch Hand, was undertaken with little knowledge about the hazardous health effects of military herbicides, particularly the chemical compound in Agent Orange, dioxin.

The chemical lifespan of dioxin is persistent and depends on the deposit location, such as under the surface of farmlands or deep in the sediments of rivers and ponds in the sprayed areas, but even today, residual dioxin contamination of Vietnamese soils has been detected (Olson and Morton, 2019). Once absorbed into the ecosystem, this chemical compound can remain there for a long time because it is hydrophobic, meaning that it does not easily dissolve in water. This longevity is further influenced by multilayer factors such as spray frequency and distribution, partitioning, bioavailability, recycling in the ecosystem, and decomposition rate. Following deposit of dioxin in the ecosystem, there are several pathways by which people may be exposed to the compound. Transfer to human bodies may be assisted by the consumption of animal foods such as fish, beef, and poultry, which will be contaminated as long as dioxin remained undecomposed under ground, in canals, and/or in ponds. Once absorbed in the human body, dioxin can remain for up to 20 years. Since the mid-2000s, joint clean-up operations of contaminated lands and soils have been conducted by the Vietnamese and US governments (Congressional Research Service, 2019). However, exposure through food chains is still being detected. For instance, a recent environmental study conducted by Banout *et al*. (2014) reports that the concentration of Agent Orange contamination is as high as 37.5 pg per gram of fat in fish sampled from the Phong My commune (village) of Thua Thien-Hue province, situated 40 km northwest of Hue City in central Vietnam.[13] According to the World Health Organization, a tolerable monthly intake of dioxin for human bodies is 70 pg/kg (WHO, 2016).

Following the Vietnam War, war veterans from the USA, Australia, and New Zealand who were directly exposed to Agent Orange have been reported to suffer adverse health consequences (Donovan *et al*., 1983). Based on this medical evidence, the US Department of Veterans Affairs now lists the following diseases—cancer (prostate, respiratory, and chronic B-cell leukemia) and other serious diseases such as diabetes, Parkinson's disease, and peripheral neuropathy—as being related to direct exposure to military herbicide operations during the war (US Department of Veterans Affairs, 2020).

[12] Aerial application of Agent Orange was by cargo planes flying at low altitudes in a single continuous spray mission covering 14 km in 45 minutes (Stone, 2017).

[13] A picogram (pg) is equal to 10^{-12} gram.

The most crucial health effect of Agent Orange is that it can be transferred to later generations in the form of birth defects. Studies and anecdotal evidence report health problems extending to the second and third generations in Agent Orange–contaminated areas (Palmer, 2005; Vo, 2015). According to the US National Academy of Science, the most commonly observed birth defect among the offspring of war veterans is spina bifida, which affects the spines of developing fetuses and infants. Children with spina bifida may suffer nerve damage, paralysis, and psychological disabilities (National Institute of Neurological Disorders and Stroke, 2013; US Department of Veterans Affairs, 2020).

Medical studies suggest a link between exposure to Agent Orange (dioxin) and adverse health outcomes for those directly exposed to the compound. More crucially for our purposes, these effects on human health are observed long after the deposit of these toxic chemical compounds into Vietnamese soils. Human bodies' indirect exposure occurs through several pathways—via the ecosystem and food chains—in addition to effects that extend into following generations.

II. 2 Studies on Vietnam War–related health consequences

Most research in this area focuses on US war veterans, but several studies examine the health consequences of Agent Orange using a sample of Vietnamese civilians. This section reviews these studies to set a framework for our analysis and its findings.

Schecter *et al*. (1995) provide some of the earliest evidence of the persistent effects of Agent Orange on Vietnamese people. Using a sample of 1043 Vietnamese adults from 1984 to 1992, the authors find that dioxin levels among people living in the north were significantly lower than those found in people living in the central and south regions, which is where herbicides were sprayed. Further, northern soldiers who served in Agent Orange–sprayed areas in the south are found to have higher levels of dioxin compared to the average levels in the north sample. Focusing on the relationship between Agent Orange and birth defects, Ngo et al. (2006, 2010) provide a systematic review of the medical literature, finding that parental exposure to the herbicides is associated with a higher risk of birth defects. Based on 13 Vietnamese studies and nine non-Vietnamese studies, the researchers conclude that parental exposure to Agent Orange is linked to an increased risk of bearing children with birth defects such as spina bifida.

In the economics literature, there are many studies on the long-term effects of direct exposure to the Vietnam War (e.g., Gade and Wenger, 2011), but only a few investigate the health effects on Vietnamese people. One exception is the study by Do (2009), which provides the first empirical evidence of the effects of Agent Orange on the Vietnamese population using combined evidence from both health and household surveys. Do (2009) finds some association between the prevalence of cancers in the exposed communes and exposure to Agent Orange. However, data limitations, including self-reporting of cancer and migration issues, prevented the author from conducting additional robustness checks of the results. While unrelated to military herbicides during the Vietnam War, a study by Singhal (2019) examines the long-term effects of US bombing on the prevalence of mental illness among Vietnamese survivors in the affected areas. Palmer *et al*. (2019) use a similar strategy, as well as the 2009 Vietnam Population Census, to examine the prevalence of disability.

Our article is a contribution to the literature that uses a Vietnamese sample to examine the health consequences of Agent Orange application. More significantly, we focus on a large sample of cohorts born after the war to determine any long-term and/or intergenerational adverse health effects of Agent Orange 30 years after the end of the war.

III. Estimation Strategy

We estimate the probability of reporting disabilities by individuals who reside in those southern areas with higher intensity Agent Orange dispersal. The specification is as follows:

$$\text{Disability}(1/0)_{ijb} = \alpha 0 + \alpha 1 \log(AO)_j + \boldsymbol{X}_{ij}\phi + \mu_p + Y_b + \theta pt + \varepsilon_{ijb}, \qquad (1)$$

where $Disability(1/0)_{ijb}$ is a binary indicator variable of disabilities for individual i resident in district j born in cohort year b.

The key control variable AO denotes the intensity of military herbicides (per km^2) dispersed in district j during the Vietnam War. The estimated coefficient (α_1) indicates the probability of disability observed for person i in year 2009, given the intensity of Agent Orange in district j during wartime. A vector of $\boldsymbol{X}$ includes predetermined individual characteristics such as gender and racial status, in addition to district-level information such as log expenditure per capita, and location information such as a dummy for central district, distance from major cities, and characteristics of the district. The parameter μ_p corresponds to the province fixed effects and Y_b subsumes cohort fixed effects by birth year. The interaction term $\theta_p t$ between the province fixed effects and the linear time trend controls for post-war mitigating factors at the province level. We present results both with and without these province-specific time trends. We also performed a separate regression analysis for males and females due to strong evidence that boy preference operates in the intra-household resource allocation process, particularly in Asian countries. We estimate Equation (1) with a linear probability model with cluster standard errors at the district level.[14]

[14] This linear estimator is preferred and more feasible due to the large sample (i.e., nearly 2 million data points), making the alternative nonlinear methods computationally cumbersome.

III. 1 Identification issues

In our framework, there are two issues involved in identifying the effects of Agent Orange on the likelihood of disabilities being reported by the current Vietnamese population. First, Agent Orange deposit points were not random. Second, bombing sites are closely related to Agent Orange because one purpose of Agent Orange was to improve the visibility for and consequent accuracy of bombing strikes (Stellman *et al.*, 2003). Therefore, those Vietnamese who were directly exposed to Agent Orange, that is, those both born and continuing alive during the war period (1965–1975), are not suitable for our purposes. The same cohorts might also have been exposed to direct combat and bombing, rendering it impossible to distinguist the adverse health effects of Agent Orange from other war-related health effects.[15]

We addressed these issues by focusing on those Vietnamese cohorts born after the end of the war (1975). In this way, we were able to focus solely on the health effects of Agent Orange in isolation from other confounding wartime factors. Our empirical approach is supported by evidence that Agent Orange persists in the ecosystem and food chains, causing exposure for Vietnamese living in the affected areas even now (as reviewed in Section II). Moreover, use of the post-war sample moderates the identification threat stemming from the non-randomness of Agent Orange deposit points. We believe that our approach is superior to the instrumental method employed by Singhal (2019) and Palmer *et al*. (2019). Inspired by Miguel and Roland (2011), these two studies employ geographical distance from the 17th Parallel demilitarized zone as an instrument in addressing the non-randomness of US bombing to estimate the long-term effects of US bombing on the mental health of the Vietnamese. However, using this instrument in our context would be insufficient as it would face the same issues outlined above.[16]

However, an empirical challenge remains because migration away from the affected areas in the post-war period attenuates any adverse health effects of Agent Orange.[17] We approached this in the following ways. First, we excluded the sample with a history of migration, defined as those located in their current residence for only the last five years. In our data, the migration rate is relatively low (approximately 6.7 percent). Previous studies attempt to address the migration issue, finding that a selective migration bias is minimal (e.g., Singhal, 2019). This evidence supports our use of the post-war cohort as the most suitable cohort when analyzing any health effects of wartime herbicides.

[15] This is particularly the case because the 2009 Population Census did not report the underlying reasons for disabilities.

[16] Practically, employing a single instrument still causes a problem of under-identification with two endogenous variables—locations of US bombings and Agent Orange—without resorting to another instrument.

[17] We also acknowledge the selection bias due to the culling effects of military herbicides.

Second, we use the subsample group of ethnic minorities, which accounts for approximately 18 percent of the full sample (see Table 1). Ethnic minorities such as the hill tribe people, who constitute an isolated population, may be more immune to the possible attenuation resulting from migration (Dwernychuk *et al*., 2002; Palmer, 2005). Ethnic minorities in Vietnam tend to be poor, to have less access to health-care services, and to live in an agrarian society. The lower rates of literacy and resulting language barriers of ethnic minorities significantly diminish their opportunities to migrate in search

Table 1 Descriptive statistics

	Mean	SD	*Min.*	*Max.*
Panel A: Individuals, full sample (*N* = 1,949,684)				
Gender (1 = female; 0 = male)	0.48	0.50	0.00	1.00
Age	18.39	8.23	5.00	33.00
Year of birth	1990.61	8.23	1976.00	2004.00
Minorities (1 = ethnic minorities; 0 = Kinh)	0.18	0.39	0.00	1.00
Household size	4.88	1.71	1.00	26.00
Full sample				
Any disability	0.64	7.95	0.00	100.00
Vision disability	0.13	3.56	0.00	100.00
Hearing disability	0.20	4.41	0.00	100.00
Mobility disability	0.24	4.94	0.00	100.00
Memory disability	0.41	6.41	0.00	100.00
Female sample (*N* = 937,435)				
Any disability	0.57	7.53	0.00	100.00
Vision disability	0.12	3.42	0.00	100.00
Hearing disability	0.18	4.23	0.00	100.00
Mobility disability	0.21	4.60	0.00	100.00
Memory disability	0.38	6.16	0.00	100.00
Male sample (*N* = 1,012,249)				
Any disability	0.70	8.32	0.00	100.00
Vision disability	0.14	3.69	0.00	100.00
Hearing disability	0.21	4.57	0.00	100.00
Mobility disability	0.27	5.24	0.00	100.00
Memory disability	0.44	6.63	0.00	100.00
Panel B: District-level data (*N* = 270)				
Log per capital expenditure	9.55	0.34	8.37	10.57
Distance to nearby cities (km)	136.66	90.54	0.00	358.72
Agent Orange (million liters per km^2)	0.15	0.29	0.00	2.75
Other herbicides (million liters per km^2)	0.10	0.25	0.00	3.24
Total bombs, missiles, and rockets (per km^2)	42.01	78.40	0.00	561.49
Number of provinces	34.00			
Number of districts	270.00			

Notes: The sample comprises individuals who were born between 1976 and 2004 and resident in the rural areas of South Vietnam during the survey year (2009). We excluded individuals with a history of migration.

of labor opportunities elsewhere (Phan, 2012; Amare and Hohfeld, 2016). Thus, ethnic minorities tend to be of low endowment, with a lower likelihood of migrating away from their regions of birth (Pivovarova and Swee, 2015). Further, ethnic minorities often suffer discrimination in terms of accessing health-care services due to their weak ability to attract the required resources in the areas where they live(Deaton, 2002; Ghobarah *et al*., 2004). These arguments support the use of ethnic minorities in our study to increase the statistical power of ITT in this context.

Finally, one related issue is survivor bias—healthier children are more likely to survive than are less healthy children. However, more in-depth demographic studies show that mortality in post-war cohorts does not exhibit an upward trend. For instance, according to Savitz *et al*. (1993), secular trends toward reduced infant mortality (neonatal, post-neonatal, infant, and childhood mortality) were most apparent only during wartime, with little sign of an increasing trend in the post-war period. The study used the 1988 Vietnam Demographic and Health Survey, the first national survey of reproductive health and behavior.[18] Even if we accept this bias, any effects should be minor.

IV. Data

IV. 1 Agent Orange

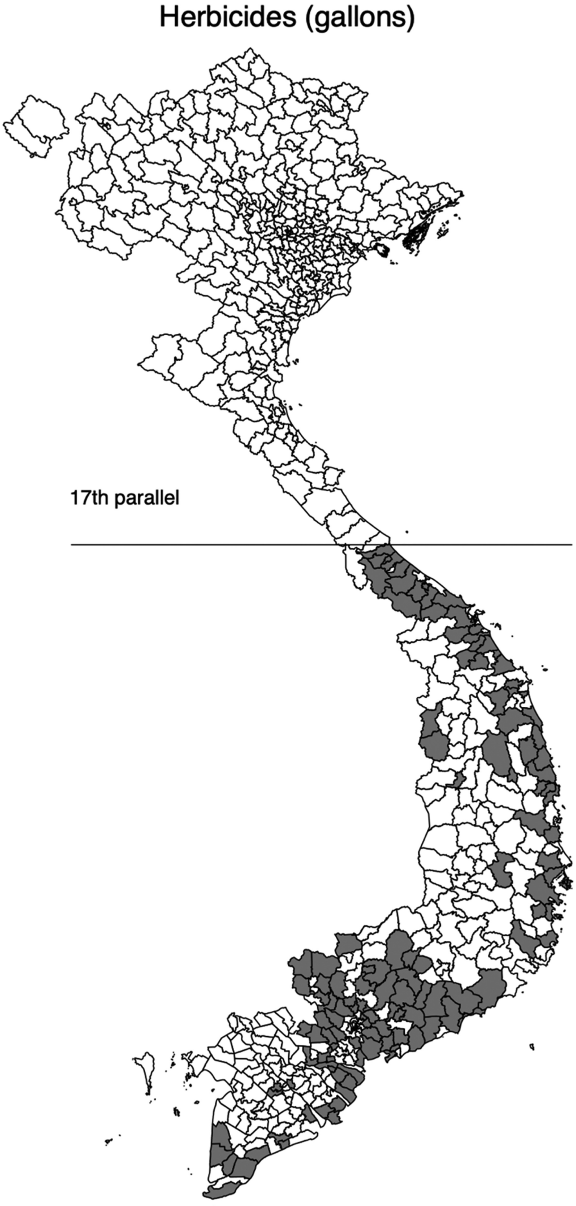
Data on military herbicide exposure, known as the US Military Assistance Command Data Management Agency's HERBS file, were first published by the US Department of Defense (Data Management Agency, 1970). The HERBS database records that nearly 19.5 million gallons of herbicides were sprayed during the Vietnam War, using both flight-path coordinates of spraying and ground military operations conducted under Operation Ranch Hand. Stellman *et al*. (2003) transform the raw herbicide data by the number of gallons and the instances of herbicide spray applications in each grid cell by attaching the geographic information system (GIS). Following Do (2009), we used the administrative map of Vietnam to calculate herbicide data from the attached GIS database. The herbicide data are categorized into two types: Agent Orange (dioxin) and other forms of herbicides. Figure 1 shows the intensity of the total quantity of the military herbicides sprayed for each district.

For each type of herbicide application, we computed the quantity in terms of gallons per square kilometer in each district. We aggregated the commune-level information used by Do (2009) for the district because the district-level data allow for wider margins of exposure. The exact deposit location of military herbicides becomes less critical in our context because

[18] Hirschman *et al*. (1995) provide an estimate of wartime infant mortality in Vietnam.

indirect exposure is believed to extend through the food and water chains in the affected areas.

Figure 1 Drop points of Agent Orange during the Vietnam War



Notes: The shaded areas (districts) represent those areas where the quantity of applied herbicides was higher than 10 million gallons

IV. 2 Disability and the Census

We constructed the main data from the individual record data of the 2009 Population Census,[19] obtained from the Integrated Public Use Microdata Series International (IPUMS-I).[20] The 2009 Population Census is the fourth census to be conducted in Vietnam. While IPUMS-I also stores the 1989 and 1999 census, the coverage of the 2009 Population Census is expansive: 15 percent of the population, covering 3,692,042 households, 14,177,590 individuals, and 58 provinces (out of approximately 684 districts). From the original 2009 Population Census, we derived a sample of those born between 1976 and 2004 (aged 5–33 at the time they were recorded by the 2009 Population Census) and whose residential districts are in South Vietnam. We followed the former wartime division of North and South Vietnam, following the 17 degrees parallel line established by the Geneva Accord in 1954. The 2009 Population Census also includes basic demographic information such as gender and ethnicity.

More crucially for our purposes, the 2009 Population Census contains information about the disability status of individuals aged five and above. The census respondents were asked to scale the severity of each disability in the following four domains: (i) vision/seeing; (ii) hearing; (iii) mobility/walking; and (iv) memory/cognitive impairment. These were scaled according to four exclusive responses: (1) no difficulty; (2) some difficulty; (3) a lot of difficulties; and (4) cannot do at all.

We constructed a dummy variable to represent the disability status for individuals when he or she rated either a 3 or a 4 for at least one of the disability domains. This is consistent with the standard criteria for identifying disability suggested by the UN Statistical Commission's Washington Group on Disability Statistics.

Unfortunately, such disability information does not include the cause. Therefore, at best, this health indicator is only suggestive regarding the adverse health effects of dioxin. For instance, as discussed in Section II, spina bifida may be linked to reduced mobility and scientific inquiries support a link between memory or cognitive disabilities and dioxin exposure. Nonetheless, the 2009 Population Census is superior to the Household Health Survey used by Do (2009) because it provides information on individuals living in all parts of South Vietnam, not for just a handful of surveyed districts or provinces. This allowed us to focus the analysis on residents in South Vietnam while retaining a sufficient sample size in each birth cohort and affected versus non-affected districts. We also retained, from the census, the sample of those households identified as current residents in rural areas because the long-term health effects of war are likely to have reduced effects on those in urban areas due to their easier access to healthcare and services.

19 The census was conducted by the Vietnam General Statistics Office with technical support from the UN Population Fund.

20 See https://international.ipums.org/international/.

IV. 3 District-level control variables

To control for other, potential confounding factors at the district level, we included information on the total number of bombs, missiles, and rockets per square kilometer of each district. These data are from the replication files compiled by Miguel and Roland (2011).[21] While we focused on the post-war cohorts, we note that the level of bombing intensity might be correlated with general public health status in the long term (Palmer *et al*., 2019).

IV. 4 Descriptive statistics

Table 1 provides descriptive statistics for the key variables used in our analysis. Approximately 0.6 percent of the sample were identified as individuals with serious disabilities in at least one of the following areas: vision, hearing, mobility, and/or memory. Among these four disabilities, on average, memory disability is the highest at 0.4 percent, followed by mobility disability at 0.2 percent. Indeed, the average percentage of individuals with any disabilities seemed low. In comparison, individuals with any disabilities account for approximately 5 percent in a sample of 650,000 (average age of 24) from the 1996 Population Census in South Africa (Dinkelman, 2017). Similarly, Almond and Mazumder (2011) report that 5 percent of 80,000 individuals between the ages of 20 and 80 from the 2002 Uganda Census reported a disability; the same is true for 1.5 percent of 250,000 individuals between the ages of 20 and 39 in the 1997 Iraq Census. However, our sample is comparatively large, with close to 2 million observations, and involves a considerably younger cohort (average age of 18).

The ensuing analysis also explores heterogeneity by gender and ethnicity. The 2009 Population Census is relatively balanced between males and females. Ethnic minorities comprise a small proportion (approximately 18 percent) of the sample. Panel B of Table 1 sets out information for 270 districts about the application intensity of Agent Orange (dioxin) and other herbicides.

V. Results

V. 1 Main results

Table 2 presents the key results of Equation (1), with the binary dependent variable indicating any form of disability. Individuals were marked as having disabilities when they reported ‘a lot of difficulties’ or ‘cannot do at all’ in at least one of the following functionality domains: vision, hearing, mobility, or memory. We present results using the full sample in Column (1) and in Column

[21] The raw data were derived from a database assembled by the US Defense Security Cooperation Agency, which provides a detailed and accurate record of all ordinance dropped from US and allied airplanes and helicopters at the district level throughout 1965–1975.

Table 2 Effects of long-term exposure of military herbicides on disability for the post-war cohorts in 2009

	(1)	*(2)*	*(3)*	*(4)*
	*Dependent variable = 100*disability (Yes = 1; No = 0)*			
	All	*All*	*Female*	*Male*
Log Agent Orange	0.0042	0.0042	0.0078**	0.0008
	(0.0028)	(0.0028)	(0.0030)	(0.0037)
Cohort FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Province time trend	No	Yes	Yes	Yes
Mean of dependent variable (%)	0.64	0.64	0.57	0.70
R^2	0.001	0.001	0.001	0.001
Number of districts	262	262	262	262
Obs.	1,904,751	1,904,751	915,848	988,903

Notes: The sample comprises individuals who belong to ethnic minorities and who were born between 1976 and 2004 and resident in South Vietnam during the survey year (2009). Robust standard errors, clustered by district level, are displayed. Each column presents a separate regression with the inclusion of the size of household, per capita expenditure (in log), and distance to nearest cities. *** denotes 1 percent significance; ** denotes 5 percent significance; * denotes 10 percent significance.

(2) with the inclusion of the time-varying province fixed effects. We transformed the binary outcome to provide an interpretation of change in percentage points due to low incidence. All regression estimates in this table also include birth-year cohort, the district fixed effects, and time-varying province-level effects. Robust standard errors clustered at the district level are in square brackets underneath the point estimates.

The estimate using the full sample shows that the long-term effects of Agent Orange are statistically indistinguishable from zero (0.0042) (Column (1) of Table 2). The inclusion of time-varying province-level fixed effects has little effect on this result (Column (2)). However, these overall effects mask some heterogeneities. For instance, it is reported that both the direct and indirect effects of war differ according to gender. Male wartime mortality is disproportionately higher than that of females (due to direct involvement in combat), whereas women and children are more affected indirectly and experience greater post-war issues (Buvinic *et al.*, 2013).[22] In the following discussion, we exploit heterogeneity in gender, disability type, and ethnicities.

In Columns (3) and (4) of Table 2, we split the sample by gender. The estimate of the long-term effects on the female sample also tend toward zero (0.008); however, the estimate is statistically significant at 5 percent (see

[22] Direct effects are defined as killing, wounding, and physical destruction, whereas indirect effects extend to health, human capital, and labor-market performance (Buvinic *et al.*, 2013).

Table 3 Effects of long-term exposure to military herbicides on the specific disabilities of post-war cohorts in 2009

	(1) 100*Vision disability (Yes = 1; No = 0)	(2)	(3)	(4) 100*Hearing disability (Yes =1; No = 0)	(5)	(6)	(7) 100*Mobility disability (Yes = 1; No = 0)	(8)	(9)	(10) 100*Memory disability (Yes = 1, No = 0)	(11)	(12)
	All	*Female*	*Male*	*All*	*Female*	*Male*	*All*	*Female*	*Male*	*All*	*Female*	*Male*
Log Agent Orange	–0.0007	0.0004	–0.0016	0.0015	0.0033*	–0.0001	0.0010	0.0037*	–0.0016	0.0033	0.0052**	0.0016
	(0.0012)	(0.0015)	(0.0020)	(0.0016)	(0.0018)	(0.0024)	(0.0020)	(0.0022)	(0.0024)	(0.0021)	(0.0024)	(0.0026)
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean of dependent variable (%)	0.13	0.12	0.14	0.20	0.18	0.21	0.24	0.21	0.27	0.41	0.38	0.44
Num of districts	262	262	262	262	262	262	262	262	262	262	262	262
Obs.	1,903,089	915,008	988,081	1,902,997	914,966	988,031	1,902,989	914,958	988,031	1,902,572	914,770	987,802

Notes: The sample comprises individuals who were born between 1976 and 2004 and resident in South Vietnam during the survey year (2009). Robust standard errors, clustered by district level, are displayed. Each column presents a separate regression with the inclusion of the size of household, per capita expenditure (in log), and distance to nearest cities.
*** denotes 1 percent significance; ** denotes 5 percent significance; * denotes 10 percent significance.

Column (3)). Relative to the sample average disability rate for females, this accounts for approximately 1.4 percent (0.008/0.57). The magnitude appears minuscule; however, note that our study sample is considerably younger (average age of 18 years) than that of other studies using disability statistics (Almond and Mazumder, 2011; Dinkelman, 2017).

Table 3 reports the results for each specific disability: sight/blind disability (Panel A), hearing disability (Panel B), mobility/walking disability (Panel C), and memory/non-cognition (Panel D). A disability was identified when individuals reported 'a lot of difficulties' or 'cannot do at all' in a given category. We also present the full, female, and male samples in a separate column.

Again, all estimated coefficients tend toward zero; however, some estimates in the female sample emerge as statistically significant. In the hearing (Column (5) of Table 3), mobility (Column (8)), and memory disability domains (Column (11)), we illustrate the statistically significant effects of Agent Orange on the current probability of having each disability. In the sample average for each domain, this accounts for between 1.4 and 1.8 percent. Unfortunately, our dataset does not contain the underlying cause of each disability. However, according to the medical studies reviewed in Section II, the most common congenital disability linked to Agent Orange is spina bifida—children born with spina bifida experience greater difficulties in mobility and walking. Medical studies that use a sample of US veterans' children highlight the possible contribution of herbicides to nervous system dysfunction and abnormalities in neurotoxicity ranging from mild to severe and long-standing (Institute of Medicine (United States) Committee to Review the Health Effects in Vietnam Veterans of Exposure to Herbicides, 1994).

Overall, the results in Tables 2 and 3 suggest that individuals (particularly females) who live in those areas sprayed with Agent Orange at higher intensities, but born in the post-war period, are more likely to report disabilities—most prevalently in hearing, mobility, and memory. The small but statistically significant effect on the probability of disability more than 30 years since the war ended is possibly due to the long-term and intergenerational effects of military herbicides. Although medical studies offer no clear indication of the gender-specific effects of Agent Orange on health, our findings echo economics studies reporting that women and children are more vulnerable to the indirect effects of war aftermath (Ghobarah *et al.*, 2003; Buvinic *et al.*, 2013).

V. 2 Other types of herbicides and bombing

We conducted a robustness check by changing the identification variable to the intensity of other types of wartime herbicides sprayed, in addition to the degree of the bombing (see Table 4). Using an empirical approach similar to that of the central analysis reveals that neither other types of herbicides nor bombing intensity are associated with the probability of having disabilities. As demonstrated by Miguel and Roland (2011), post-war reconstruction efforts are often

Table 4 Placebo test—effects of long-term exposure to bombs and other military herbicides on the disabilities of post-war cohorts in 2009

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	*Dependent variable = 100*disability (Yes = 1; No = 0)*							
	All	*All*	*Female*	*Male*	*All*	*All*	*Female*	*Male*
Log of other herbicides	0.004	0.004	0.004	0.004				
	(0.003)	(0.003)	(0.003)	(0.005)				
Log bombs					0.003	0.003	0.005	0.002
					(0.011)	(0.011)	(0.012)	(0.013)
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province time trend	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Mean of dependent variable (%)	0.64	0.64	0.57	0.70	0.64	0.64	0.57	0.70
R^2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Number of districts	262	262	262	262	262	262	262	262
Obs.	1,904,751	1,904,751	915,848	988,903	1,904,751	1,904,751	915,848	988,903

Notes: The sample comprises individuals of ethnic minorities who were born between 1976 and 2004 and resident in South Vietnam during the survey year (2009). Robust standard errors, clustered by district level, are displayed. Each column presents a separate regression with the inclusion of the size of household, per capita expenditure (in log), and distance to nearest cities.

*** denotes 1 percent significance; ** denotes 5 percent significance; * denotes 10 percent significance.

concentrated in areas and districts that experienced greater wartime capital destruction. Hence, it would be unsurprising if the long-term effects on public health of bombing are mediated by better access to medical and hospital services provided by post-war reconstruction.

We also note a study by Palmer *et al.* (2019) that reports on the adverse long-term effects of bombing on disability prevalence among Vietnamese using the same census data that we do. However, our findings are not directly comparable to their findings. Sample coverage and estimation technique differ from our study. Palmer *et al.* (2019) report that the highest incidence of disabilities is found in persons aged approximately 40 years (born during the Vietnam War). Our sample, the members of which were born in the post-war period, is much younger. Overall, the results of the Palmer *et al.* study reinforce our key findings on the adverse long-term effects on public health of Agent Orange.

V. 3 Ethnic minorities

Thus far, we have taken appropriate care (within the limitations of the data) to increase the power of our identification approach by using the post-war cohort sample of rural households from the 2009 Population Census. We now limit the sample to ethnic minorities in the post-war cohorts. Ethnic minorities are defined as those who are not 'Kinh', the most predominant ethnic group in Vietnam. Although limiting the sample in this way substantially reduces its size compared

Table 5 Effects of long-term exposure to military herbicides on the disability status of ethnic minorities of the post-war cohorts in 2009

	(1)	*(2)*	*(3)*	*(4)*
	*Dependent variable = 100*disability (Yes = 1; No = 0)*			
	All	*All*	*Female*	*Male*
Log Agent Orange	0.0013	0.0012	0.0058	–0.0029
	(0.0046)	(0.0046)	(0.0054)	(0.0064)
Cohort FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Province time trend	No	Yes	Yes	Yes
Mean of dependent variable (%)	0.64	0.64	0.56	0.71
R^2	0.001	0.001	0.002	0.002
Num of districts	222	222	218	214
Obs.	354,770	354,770	175,669	179,101

Notes: The sample comprises individuals who belong to ethnic minorities and who were born between 1976 and 2004 and resident in South Vietnam during the survey year (2009). Robust standard errors, clustered by district level, are displayed. Each column presents a separate regression with the inclusion of the size of household, per capita expenditure (in log), and distance to nearest cities.
*** denotes 1 percent significance; ** denotes 5 percent significance; * denotes 10 percent significance.

Table 6 Effects of long-term exposure to military herbicides on specific disabilities of the post-war ethnic minority cohort in 2009

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*
	*100*Vision disability (Yes = 1; No = 0)*			*100*Hearing disability (Yes = 1; No = 0)*			*100*Mobility disability (Yes = 1; No = 0)*			*100*Memory disability (Yes = 1; No = 0)*		
	All	*Female*	*Male*	*All*	*Female*	*Male*	*All*	*Female*	*Male*	*All*	*Female*	*Male*
Log Agent Orange	–0.0021	0.0034	–0.0073**	0.0030	0.0033	0.0028	0.0013	0.0074**	–0.0045	–0.0014	0.0027	–0.0050
	(0.0018)	(0.0023)	(0.0028)	(0.0033)	(0.0043)	(0.0038)	(0.0024)	(0.0033)	(0.0031)	(0.0037)	(0.0041)	(0.0053)
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean of dependent variable (%)	0.14	0.12	0.17	0.21	0.18	0.25	0.25	0.22	0.29	0.36	0.32	0.39
Province time trend	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Number of districts	222	218	214	222	218	214	222	218	214	222	218	214
Obs.	354,534	175,539	178,995	354,526	175,536	178,990	354,522	175,534	178,988	354,441	175,492	178,949

Notes: The sample comprises individuals who belong to ethnic minorities and who were born between 1976 and 2004 and resident in South Vietnam during the survey year (2009). Robust standard errors, clustered by district level, are displayed. Each column presents a separate regression with the inclusion of the size of household, per capita expenditure (in log), distance to nearest cities, and a dummy for rural areas.
*** denotes 1 percent significance; ** denotes 5 percent significance; * denotes 10 percent significance.

to the previous analysis, we argue that one clear benefit of using this sample is that it is less subject to the bias arising from the possibility of migration away from the affected areas. This sample also captures those individuals most vulnerable to health problems due to the unavailability of or lack of access to health-care services (Teerawichitchainan and Phillips, 2008).

There is no positive association between a disability measure and the intensity of Agent Orange application in the restricted sample (Columns (1) and (2) of Table 5). Even in the sample that is split according to gender, the female sample does not exhibit any statistically significant effects of Agent Orange on health (Columns (3) and (4)), unlike the case of the full sample (see Table 2). However, once we examine a specific disability, the results reveal that the likelihood of having a mobility disability is increased for the female sample of ethnic minorities in the high-intensity Agent Orange areas (Column (8) of Table 6), but not for other disabilities. The estimated coefficient, with 5 percent statistical significance, indicates that it accounts for approximately 3.4 percent of the sample average of mobility disability (0.007/0.22). Although the reduced probability of vision impairment in the male sample in Column (3) is puzzling, nondetection of adverse effects in the male sample may be associated with overall cultural attitudes and a social stigma against disability in the ethnic sample, in addition to inadequate education and health services.

In sum, we have highlighted the long-term adverse health effects of military herbicides on ethnic minorities in Vietnam. These health burdens are mostly borne by females, who are undoubtedly more vulnerable to war-related problems. These findings may be structurally related to the gender bias against females in terms of health investment, including that involving access to medical care and medical facilities (Jayachandran, 2015). This gender bias is compounded by the relatively weaker position of ethnic minorities in Vietnamese society. Crucially, a majority of ethnic minorities still experience poverty, whereas the Kinh have enjoyed a significant reduction in poverty rates in the post-war period (Nguyen *et al*., 2017). This situation has naturally led to minority groups' limited access to health-care services (Teerawichitchainan and Phillips, 2008).

VI. Conclusion

A growing body of literature shows that wars have enduring adverse health effects on not only veterans but also on the wider community in war-affected areas, even long after wars have ended. In this article, we study US military herbicide operations, which included use of a toxic chemical compound known as Agent Orange (dioxin), conducted in South Vietnam during the Vietnam War (1959–1975). Examining geographical variation in the intensity of Agent Orange application, combined with information on disabilities of post-war cohorts from 2009 Population Census data, we find that females in the more intensely sprayed areas exhibit a higher likelihood of reporting disabilities than do their counterparts in less contaminated areas. This result is primarily driven by the sample of ethnic minority females, who generally have a diminished possibility of migration. While the economic magnitude appears small (accounting for only 3.4 percent of the sample average), the sample born in the post-war period is relatively young (on average, 18 years). Critically, there were no similar findings for other types of applied herbicides or the degree of US bombing in the same areas.

In sum, our analysis highlights the oft-overlooked adverse health consequences of a war (in this case, the Vietnam War), even long after it has ended. Even 30 years later, relatively resource-poor young females who belong to ethnic minorities in areas that have been contaminated by Agent Orange still live with the legacy of the war in a way that is often unrecognized. Our findings suggest the implementation of post-war policies that identify vulnerable groups and direct resources to them via long-term strategies. Crucially, any such process must first address any existing inequalities among the ethnic groups, as well as gender inequalities.

We focused on the public health impact of Agent Orange operations during the Vietnam War, but there is much scope for future research on this and related topics. One possible direction is to explore how the identified health disparities are related to the educational disparities between males and females and between ethnic majorities and minorities. The education system in Vietnam has improved along with the economy during the rapid growth phases since the war (Dang *et al*., 2021; Phan and Coxhead, forthcoming). However, educational disparities (e.g., access to schools) are still observed in other dimensions, such as gender and ethnicity. Future research can take up this issue by focusing on such progress in Agent Orange–affected regions versus less-affected or non-affected areas.

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