# Working Papers in Trade and Development

## Long-term effects of Agent Orange on health capital in Vietnam

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October 2020

Working Paper No. 2020/20

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# Long-term effects of Agent Orange on health capital in Vietnam

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*Abstract*: This paper examines the long-term health effects of Agent Orange—the military herbicide containing the hazardous chemical compound dioxin—which was widely disseminated in South Vietnam during the Vietnam War (1959–1975). Based on data from the 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 over 30 years since the end of the war. Critically, the health burden of severe mobility disability has been mostly born by women of ethnic minorities in the affected areas.

*JEL Classification:* I14, I15, J15

*Keywords:* Vietnam War, Agent Orange, health effects of war, public health.

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# Long-term effects of Agent Orange on health capital in Vietnam*

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## 1. Introduction

Despite the formidable human losses attributable to wars,[1] evidence has suggested that the economy itself remains remarkably resilient to wartime destruction, returning relatively quickly to its long-term growth trajectory (Davis & Weinsten, 2002; Miguel & Roland, 2011). However, it is increasingly recognised that, even long after they have ended, wars continue to pose major threats to public health—not only for war veterans (Gade & Wenger, 2011; Johnston, Shields & Siminski, 2016) but also for civilians and their families (Do & Lyer, 2012; Ghobarah, Huth & Russett, 2003). 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, Bhalotra, Leone & Osili, 2018; Tsujimoto & Kijima, 2020).

This paper contributes to the line of research identifying the long-term effects of war legacy on public health. We focus on one specific aspect of the long-term public health consequences of the military herbicides used in the deforestation attempts by the US military 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 Vietnamese people. We identify 'treatment' based on spatial variations of intensity of sprayed Agent Orange from US military archive data, the US Military Assistance Command Data Management Agency's Herbicide Report System (HERBS) (Do, 2009; Stellman, Stellman, Christian, Weber & Tomasallo, 2003).

* 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 per cent of its population during the Second World War, 10 per cent of the Korean population was wiped out in the Korean war and 13 per cent of the Vietnamese population died in the Vietnam War (Garfield & Neugut, 1997).

[2] The name 'Agent Orange' originates in the colour-coded labels on the steel storage units 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 per cent of the herbicides applied (Stellman et al., 2003).

One major methodological challenge is partitioning the long-term effects of Agent Orange on disabilities from other confounding wartime factors, when the same individuals may also 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 were born and live through the wartime period. However, although sprayed only temporarily, Agent Orange (dioxin) is known to linger in the ecosystem due to its unique chemical structure.[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 the drainage canal, where it attaches to organic matter and ascends food chains, extending to fish and wild animal species (Banout, Urban, Musil, Szakova & Balik, 2014; Olson & Morton, 2019). Ultimately, the compound is absorbed by human bodies.[4]

The health problems attributable to military herbicides extends to not only those directly exposed but also the wider public, due to a gradual process in which people are unknowingly exposed to the threat.[5] Several medical studies of war veterans have established that dioxin is linked with adverse health outcomes including cancers, diabetes and birth defects such as spina bifida, cerebral palsy, cognitive impairment and missing or deformed limbs that diminish mobility (Stone, 2017). Anecdotal evidence has also indicated 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 who 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. Our strategy identifies an 'intention-to-treat' (ITT) effect, under the assumption that the probability of reported disabilities would have been similar in areas with varying degrees of Agent Orange application if it were absence.

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. While its economic magnitude is very small, it should be noted that the sample we examined is relatively young, with an average age of 18. Our analysis also

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[3] Agent Orange is hydrophobic. In soil, the lifespan of dioxin may reach 100 years if deposited 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, Olsen, Thao & Anh, 2008).

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

[6] 50,000 children with disabilities are believed to have been born (Palmer, 2005).

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

restricted the sample to ethnic minorities who are believed to have reduced opportunities to migrate from their areas of residence and, hence, longer exposure to military herbicides. Even in this further restricted sample, we found that females remained more likely to report a serious disability in mobility, accounting for approximately 3.4 per cent 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 post-war reconstruction policies in affected areas.

This paper 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 have been identified as exogenous shocks to the health status of those directly exposed, such as veterans (Gade & Wenger, 2011) and families and their children (Akresh, Bhalotra, Leone & Osili, 2012; Akresh, Lucchetti & Thirumurthy, 2012; Palmer, Nguyen, Mitra, Mont, & Groce, 2019; Singhal, 2019), in addition to human capital formation in the affected cohorts (Akbulut-Yuksel, 2017; Pivovarova & Swee, 2015; Swee, 2015). 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 Vietnam public.

The most similar to our work, in terms of methodology and setting, is a study by Do (2009) that examined the effects of Agent Orange dispersion on the prevalence of cancers among Vietnamese people. Our work further extends Do (2009) by focusing on disabilities in those generations who were 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 the US military herbicide operations than those covered by the Vietnam Health Survey (VHS) used by Do (2009).[8] Whereas Do (2009) utilised the hit counts of the herbicide operations, we measure the intensity of the application of military herbicides in terms of the quantity in gallons. Despite differences in empirical approach, both our study and that of Do (2009) have reached similar findings regarding the long-term legacy of wartime Agent Orange application—both have demonstrated the lingering effects of Agent Orange on the current health of Vietnamese people.

Second, this paper aims to increase understanding of the public health consequences of Agent Orange—this is important in its own right due to its controversial nature surrounding the health effects of Agent Orange. A sizeable number of medical and epidemiological studies have now linked causes of prostate cancer, diabetes, skin disease, cardiovascular disease mortality and hypertension to direct exposure to dioxin for US war veterans. However, to date, relatively little compelling evidence has linked Agent Orange to long-term health effects on the Vietnamese public. This has led to the dismissal of the class

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

action lawsuit against US companies which manufactured and supplied Agent Orange to the US military during the war (Stone, 2007). Existing war-related studies on the Vietnamese are only based on direct exposure to bombing or direct combat in relation to long-term mental health (Korinek & Teerawichitchainan, 2014; Singhal, 2019; Teerawichitchainan & Korinek, 2012).

The rest of this paper is structured as follows. Section 2 presents background to and a brief discussion of the Vietnam War. Section 3 presents the estimation strategy, followed by the data in Section 4. Section 5 discusses the results and Section 6 concludes the paper.

## 2. The Vietnam War and Agent Orange[9]

### Background

During a particular period of the Vietnam War (1961–1971),[10] the US military disseminated approximately 20 million gallons (75 million litres)[11] of herbicides 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 has been reported that these herbicide operations covered approximately 24 per cent 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, codenamed Operation Ranch Hand, was performed with little knowledge about the hazardous health effects of military herbicides, particularly the chemical compound Agent Orange—a dioxin.

The chemical lifespan of dioxin is known to be persistent. Its lifespan depends on the deposit location, such as under the surface of farmlands and deep in the sediments of rivers and ponds in the sprayed areas, but even today, residual contamination of dioxin in Vietnamese soils has been detected (Olson & Morton, 2019). Once absorbed into the ecosystem, this chemical compound can remain for a long time because it is hydrophobic, meaning that it does not easily dissolve in water. This longevity is further

[9] This section has drawn upon several articles on the legacy of Agent Orange (e.g., Black, 2019; Stone, 2017), 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
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 papers, 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) have stated that 'more firepower was unleashed during the Vietnam War than during any other conflict in human history'.

[11] 1 US gallon is 4.5 litres.

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

influenced by multilayer factors such as spray frequency and distribution, partitioning, bioavailability, recycling in the ecosystem and decomposition rate. Following dioxin deposit in the ecosystem, there are several pathways by which people may be exposed to the compound. Transfer to human bodies may have been assisted by the consumption of animal foods such as fish, beef and poultry, which were contaminated as long as dioxin remained undecomposed under the ground, in canals and ponds. Once absorbed in the human body, dioxin can remain for up to 20 years (World Health Organization [WHO], 2016). Since the mid-2000s, joint clean-up operations of contaminated lands and soils have been conducted by 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) reported that the concentration of Agent Orange contamination is as high as 37.5 pg per gram of fat in sampled fish from Phong My commune (village) of Thua Thien-Hue province, situated 40 km north-west of the Hue city in central Vietnam.[13] According to the World Health Organisation, a tolerable monthly intake of dioxin for human bodies is 70 pg/kg (WHO, 2016).

Following the Vietnam War, war veterans from the US, Australia and New Zealand who were directly exposed to Agent Orange have been reported to suffer adverse health issues (Donovan, MacLennon & Adena, 1983). Based on this medical evidence, the US veteran office now lists the following diseases—cancer (prostate, respiratory and chronic B-cell leukaemia) 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 (United States Department of Veterans Affairs, 2020).

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 have reported 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 foetuses and infants. Children with spina bifida may suffer nerve damage, paralysis and psychological disabilities (National Institute of Neurological Disorders and Stroke, 2013; United States Department of Veterans Affairs, 2020).[14]

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

[14] Spina bifida is a condition in which the neural tube of a foetus develops abnormally into a brain, spinal cord and enveloping tissues. This causes incomplete development of the spine, which is why the condition can be so severe. The worst form of spina bifida occurs when the spinal defect is uncovered, exposing the spinal fluid and spinal cord tissues. This can result in nerve damage, loss of muscle function and muscle sensation and partial or complete paralysis of the parts of the body below the spinal opening. Further, spina bifida can cause the abnormal build-up of cerebrospinal fluid in the brain (a condition called hydrocephalus). If the excess fluid is not drained, the resulting pressure on the brain and spinal cord can damage the brain and affect mental development. In 1996, the US Veterans Administration began offering compensation to veterans whose children were born with severe forms of the condition.

Medical studies have suggested 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 intergenerational effects, which extend into following generations.

**Studies on Vietnam War–related health consequences**

While most research has focused on US war veterans, several studies have examined the health consequences of Agent Orange using the sample of Vietnamese civilians. This section will review these to frame our analysis and its findings in the literature.

Schecter et al. (1995) provided some of the earliest evidence of the persistent effects of Agent Orange on Vietnamese people. Using a sample of 1,043 Vietnamese adults from 1984 to 1992, the authors found that levels of dioxin among people living in the north is significantly lower than those living in the central and south regions—where herbicides were sprayed. Further, northern soldiers who served in Agent Orange–sprayed areas in the south were found to have higher levels of dioxin compared to the average levels of the north sample.

Focusing on the relationship between Agent Orange and birth defects, Ngo, Taylor and Roberts (2006, 2010) provided a systematic review of the literature, finding that parental exposure to the herbicides is associated with a higher risk of birth defects. The key contribution of these papers lies in the fact that they represent the first attempts to incorporate studies using previously unpublished studies from Vietnam - most previous research primarily relied on English studies. Based on 13 Vietnamese studies and nine non-Vietnamese studies, the researchers concluded that parental exposure to Agent Orange was linked to an increased risk of bearing children with birth defects. The second literature review focused specifically on spina bifida and its relation to paternal Agent Orange exposure—it demonstrated that paternal exposure to Agent Orange was associated with an increased risk of spina bifida in offspring.

In the economics literature, while many studies have been conducted on the long-term effects of direct exposure to the Vietnam War (e.g., Gade & Wenger, 2011), only a few studies have investigated the health effects on Vietnamese people. One exception is the study conducted by Do (2009), which provided 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) found some association between the prevalence of cancers in the exposed communes and exposure to Agent Orange. However, data limitations such as the self-reporting of cancer and migration prevented the author from conducting additional robustness checks on the results. While unrelated to military herbicides during the Vietnam

War, the study conducted by Singhal (2019) examined the long-term effects of US bombing on the prevalence of mental illness among Vietnamese survivors in the affected areas. Palmer et al. (2019) used a similar strategy to examine the prevalence of disability using the 2009 Vietnam Population Census.

Our paper adds to the limited number of studies that use 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 intergenerational adverse health effects of Agent Orange, 30 years after the end of the war.

## 3. Estimation strategy

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

$$\text{Disability}(1/0)_{ijb} = \alpha_0 + \alpha_1 \log(AO)_j + \boldsymbol{X}_{ij}\phi + \mu_p + Y_b + \theta_p t + \varepsilon_{ijb} \quad (1)$$

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

The key control variable *AO* denotes the intensity of military herbicides (per $km^2$) dispersed in the district *j* during the Vietnam War. The estimated coefficient ($\alpha_1$) indicates the probability of disability observed for a person *i* in the year 2009, given the intensity of Agent Orange in a district *j* during the 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 dummy for central district, distance from major cities and characteristics of the district. The parameters $\mu_p$ correspond to the province fixed effects and $Y_b$ subsumes cohort fixed effects by the 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 ran a separate regression for males and females. This was driven by 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 area at the level of districts.[15]

### Identification issues

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

We note the following two issues of identifying the effects of Agent Orange on the likelihood of disabilities reported by the current Vietnamese population in our framework. First, the Agent Orange deposit points were not random. Second, the bombing sites were closely related to Agent Orange because one purpose of Agent Orange was tactical support to aid the visibility of bombing strikes (Stellman et al., 2003). Therefore, those Vietnamese who were directly exposed to Agent Orange—both born and living in the war period (1965–1975)—are not suitable for our purposes. The same cohorts might have also been exposed to direct combat and bombing, rendering it impossible to partition the adverse health effects of Agent Orange from other war-related health effects.[16]

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 in the present time (as reviewed in Section 2). Moreover, the use of the post-war sample moderates the identification threat stemming from the non-randomness of the 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 studies employed the geographical distance from the 17th parallel demilitarised zone as an instrument to address 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 still be insufficient as it would face the same issues outlined above.[17]

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.[18] We approach this in the following ways. First, we exclude 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 per cent). Previous studies have also attempted to address the migration issue, finding that a selective migration bias is minimal (see e.g., Singhal, 2019). This evidence supports our use of the post-war cohort as the most suitable cohort to analyse any health effects of wartime herbicides.

Second, we use the sub-sample group of ethnic minorities, which accounts for approximately 18 per cent 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

[16] This is particularly the case because the 2009 Census did not report the underlying reasons for disabilities.
[17] 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.
[18] We also acknowledge the selection bias due to the culling effects of military herbicides.

(Dwernychuk et al., 2002; Palmer, 2005). Ethnic minorities in Vietnam tend to be poor, to have less access to healthcare services and to live in an agrarian society. Lower rates of literacy and increased language barriers significantly diminish opportunities for inhabitants to migrate away to seek labour opportunities elsewhere (Amare & Hohfeld, 2016; Phan, 2012). Thus, those of ethnic minorities tend to be low endowment, with a lower likelihood of migrating away from the regions (Pivovarova & Swee, 2015). Further, it is often the case that ethnic minorities suffer discrimination in terms of accessing healthcare services due to their weak ability to attract the required resources in such areas (Deaton, 2002; Ghobarah, Huth & Russett, 2004). These arguments support the use of ethnic minorities in our study to increase the power of ITT in this context.

Finally, one related issue is survivor bias—healthier children are more likely to survive than less healthy children. However, more in-depth demographic studies have shown that mortality in post-war cohorts exhibited no upward trend. For instance, according to Savitz, Thang, Swendon and Stone (1993), the secular trends towards reduced infant mortality (neonatal, post-neonatal, infant and childhood mortality) were most apparent during the wartime only, with little sign of an increasing trend in the post-war period. This study used the 1988 Vietnam Demographic and Health Survey, the first national survey of reproductive health and behaviour surveys.[19] Even if we accept this bias, any effects should be minor, going against finding any effects of Agent Orange on the disability status.

## 4. Data

### Agent Orange

Data on military herbicide exposure was first published by the US Department of Defence, known as the US Military Assistance Command Data Management Agency's HERBS file (Data Management Agency, 1970). The HERBS database recorded nearly 19.5 million gallons of herbicides sprayed during the Vietnam War, using both flight path coordinates of spraying from the air and the ground military operations conducted under Operation Ranch Hand. Stellman et al. (2003) have transformed 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 has been categorised into two types: Agent Orange (dioxin) and other forms of herbicides. Figure 1 presents the intensity of the total quantity of the military herbicides sprayed for each district.

[19] Hirschman, Preston and Loi (1995) provided the estimate of wartime infant mortality in Vietnam.

For each type of herbicide application, we computed the quantity in terms of gallons per square kilometre in each district. We aggregated the commune-level information used by Do (2009) for the district because the district-level data allows for wider margins of exposure. The exact deposit location of military herbicides becomes less critical in our context because indirect exposure is believed to extend through the food chains and the river extensions in the areas.

**Disability and the Census**

We constructed the main data from the individual record data of the 2009 Population Census,[20] obtained from Integrated Public Use Microdata Series International (IMPUS-I).[21] The 2009 Census is the fourth Census to be administrated in Vietnam. While the IMPUS also stores the 1989 and 1999 Census, the coverage of the 2009 Census is expansive: 15 per cent of the population, covering 3,692,042 households, 14,177,590 individuals and 58 provinces (approximately 684 districts) in Vietnam. From the original Census, we cultivated the sample of those who were born between 1976 and 2004 (aged 5–33 at the time they were recorded by the 2009 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 Census also includes basic demographic information such as gender and ethnicity.

More crucially for our purposes, the 2009 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: (a) vision/seeing, (b) hearing, (c) mobility/walking and (d) memory/cognitive impairment. These were scaled according to four multiple exclusive responses: (1) no difficulty, (2) some difficulty, (3) a lot of difficulties and (4) cannot do at all.

In our application, we constructed a dummy variable to represent the disability status for individuals if he or she rated either (3) or (4) for at least one of the four domains of disabilities. This is consistent with the standard criteria for identifying disability suggested by the United Nations Statistical Commission's Washington Group on Disability Statistics.

[20] The census was conducted by the Vietnam General Statistics Office with technical support from the United Nations Population Fund.
[21] https://international.ipums.org/international/

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 2, spina bifida may be linked to reduced mobility and scientific inquiries have supported a link between memory or cognitive disabilities and dioxin exposure. Nonetheless, this data source 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 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 the sample of those households identified as current residents in the rural areas in the Census because the long-term health effects of war are likely to have reduced effects on those in urban areas due to easier access to healthcare and services.

**District-level control variables**

To control for other potential cofounding factors at the district level, we included information on the total number of bombs, missiles and rockets per square kilometre of the districts. These data were drawn from the replication files compiled by Miguel and Roland (2011).[22] 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).

**Descriptive statistics**

Table 1 provides descriptive statistics of the key variables used in our analysis. Approximately 0.6 per cent of the sample were identified as individuals with serious disability in at least one of the following areas: vision, hearing, mobility and memory. Among these four disabilities, on average, memory disability is the highest at 0.4 per cent, followed by mobility disability at 0.2 per cent. It is worth highlighting that the average percentage of individuals with any disabilities seemed low. In comparison, individuals with any disabilities account for approximately five per cent of the sample size of 650,000, with an average age of 24 in the 1996 Population Census in South Africa (Dinkelman, 2017). Almond and Mazumder (2011) reported that five per cent of 80,000 individuals between the age of 20 and 80 from the 2002 Uganda Census reported a disability; the same was true for 1.5 per cent of 250,000 individuals between the age of 20 and 39 in the 1997 Iraq Census. However, our sample is comparatively

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

large, with close to two million observations, and a considerably younger cohort, with an average age of 18.

The ensuing analysis also explores heterogeneity by gender and ethnicity—the Census is relatively balanced between male and female. Ethnic minorities comprise a small proportion (approximately 18 per cent) of the sample. Panel B of Table 1 also displays information about 270 districts with the application intensity of Agent Orange (dioxin) and other herbicides.

## 5. Results

### Key results

Table 2 presents the key results of estimating the regression in equation (1), with the binary dependent variable that indicated a presence of any form of disability. Individuals are marked as having disabilities if they reported 'a lot of difficulties' or 'cannot do at all' in at least one of the following functionality domains: vision, hearing, mobility and memory. We present results using the full sample in column (1) and column (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 level of districts are displayed in square brackets underneath the point estimates.

The estimate using the full sample shows that the long-term effects of sprayed Agent Orange intensity 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 has been reported that both the direct and indirect effects of war differ according to gender. Male wartime mortality is disproportionately higher than for females (due to direct involvement in combat), whereas women and children are more affected indirectly and experience greater post-war issues (Buvinic, Das Gupta, Casabonne & Verwimp, 2013).[23] In the following discussion, we exploit heterogeneity in gender, disability type and ethnicities.

In column (3) and (4), we split the sample by gender. The estimate of the long-term effects on the female sample also tends towards zero (0.008); however, it is statistically significant at five

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

per cent (see column 3). Relative to the sample average disability rate for females, this accounts for approximately 1.4 per cent (0.008/0.57). The magnitude appears minuscule—however, it must be noted that our study sample is considerably younger (average age of 18 years), whereas other studies using disability statistics have used much older cohorts (Almond & 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). As previously stated, disability is identified if 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 towards zero; however, some estimates in the female sample emerged as statistically significant. In the hearing (column 5), 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 per cent. Unfortunately, our dataset does not contain the underlying cause of each disability. However, according to the medical studies reviewed in Section 2, 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 used the sample of US veterans’ children have highlighted 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 given in Tables 2 and 3 suggest that individuals (particularly females) who live in those areas sprayed with Agent Orange at higher intensities, but were 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, over 30 years since the war ended, is possibly due to the long-term and intergenerational effects of military herbicides. While medical studies have offered no clear indication of the gender-specific effects of Agent Orange on health, our findings echo economics studies that report that women and children are more vulnerable to the indirect effects of the war aftermath (Buvinic et al., 2013; Ghobarah et al., 2003).

**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 degree of bombing (see Table 4). Using a similar empirical approach to the central analysis has revealed that neither other types of herbicides nor the intensity of bombing is associated with the probability of having disabilities. As demonstrated by Miguel and Roland (2011), post-war reconstruction efforts are often concentrated in areas and districts that experienced greater wartime capital destruction. Hence, it would be unsurprising if the long-term effects of bombing on public health 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 reported on the adverse long-term effects of bombing on the disability prevalence among Vietnamese, using the same Census data. However, our findings are not directly comparable to their findings. The sample coverage and the estimation technique differ from our study. Palmer et al. (2019) reported that the highest incidence of disabilities occurred in persons aged approximately 40 years (born during the Vietnam War). Our sample, who 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 of Agent Orange on public health.

**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 Census. We now take one step further by limiting the sample to ethnic minorities in the post-war cohorts. Ethnic minorities, as we defined earlier, are those who are not 'Kinh'—the most predominant ethnic group in Vietnam. Although limiting the sample in this way has substantially reduced the size compared 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 healthcare services (Teerawichitchainan & Phillips, 2008). As developed in Section 3, our intention was to focus on the sample group with diminished possibilities of migration, which renders them more exposed to the adverse health effects of dioxin within their environments. Additionally, a focus on ethnic minorities is critical in the Vietnamese context because this group may be more vulnerable to the adverse health risks of wartime herbicides due to limited access to healthcare services (Teerawichitchainan & Phillips, 2008). Further, within this minorities group, cultural, social and economic characteristics significantly differ from those of the Kinh. 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 (Van de Walle & Gunewardena, 2001).

In the restricted sample, we do not observe any positive association between a disability measure and the intensity of Agent Orange application (columns 1 and 2, 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, Table 5), 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 disability in mobility is increased for the female sample in ethnic minorities in the high intensity Agent Orange areas (column 8, Table 6), but not for other disability categories. The estimated coefficient, with five per cent statistical significance, indicates that it accounts for approximately 3.4 per cent of the sample average of disability in mobility (0.007/0.22). While it is puzzling to observe a reduced probability of vision impairment in the male sample in column 3, non-detection of the adverse effects on the male sample may be associated with overall cultural attitudes and social stigma towards disabilities in the ethnic sample in addition to inadequate education and health services. Overall, we have highlighted the long-term adverse health effects of military herbicides on ethnic minorities in Vietnam. These health burdens are mostly born by females, who are undoubtedly more vulnerable to war-related problems.

## 6. Conclusion

An expanding literature has shown that wars have enduring adverse health effects on not only veterans but also the wider community in war-affected areas, even long after wars have ended. In this paper, we studied one unique episode: the US military herbicide operations that included a toxic chemical compound, known as Agent Orange (dioxin), which was sprayed 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 the post-war cohorts from 2009 Census data, we found that females in the highly sprayed areas exhibit a higher likelihood of reporting disabilities than their counterparts in less contaminated areas. This is primarily driven by the sample of females of ethnic minorities with a diminished possibility of migration and a mobility or walking disability. While the economic magnitude appears small (accounting for only 3.4 per cent of the sample average), the sample born in the post-war period is relatively young (on average, 18 years). Critically, these similar findings were unobservable for other types of applied herbicides and the degree of US bombing in the same areas.

In sum, our analysis has highlighted the often-overlooked adverse health consequences of the war, even long after it has ended. Even after 30 years have passed, although not directly involved in the war, relatively resource-poor young females who belong to ethnic minorities in areas that have been contaminated by Agent Orange still live under the legacy of the war, in a way that is often unrecognised. Our findings suggest that a post-war policy should be implemented that identifies those vulnerable groups and directs resources to them via long-term strategies. Crucially, any such process must first address any existing inequalities among the ethnic groups.

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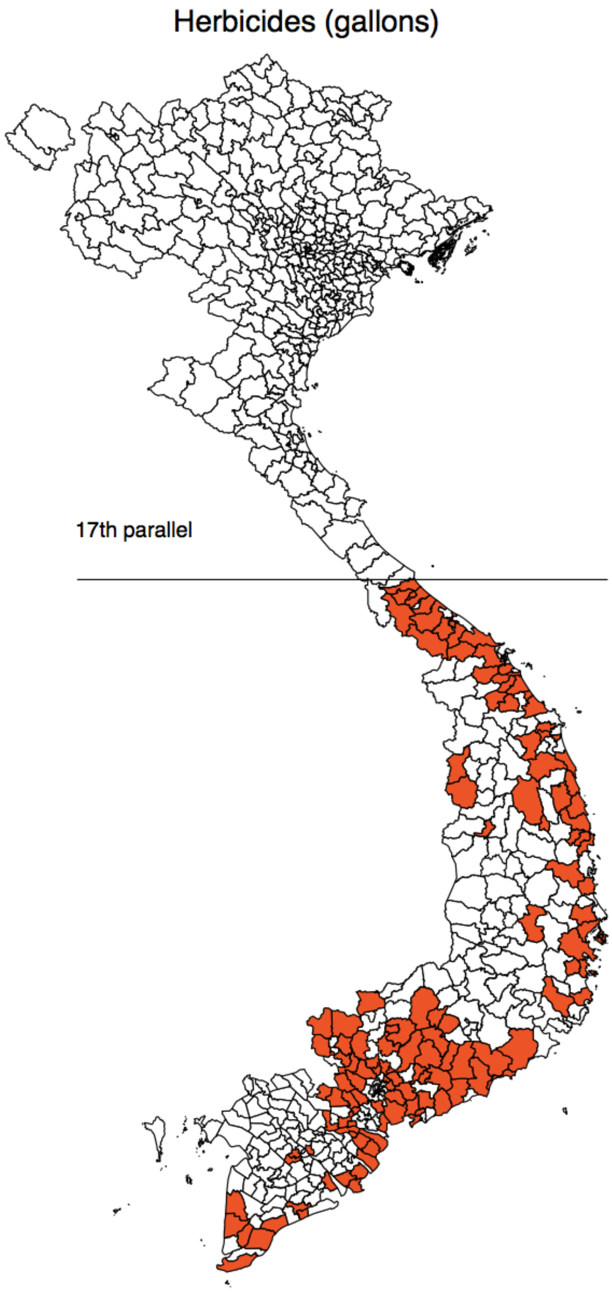
**Figure 1: Drop points of Agent Orange during the Vietnam War**




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

**Table 1**: Descriptive statistics

| | Mean | Standard Deviation | 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 litres per $km^2$) | 0.15 | 0.29 | 0.00 | 2.75 |
| Other herbicides (million litres 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.

**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 = 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-squared | 0.001 | 0.001 | 0.001 | 0.001 |
| Number of districts | 262 | 262 | 262 | 262 |
| Obs. | 1904751 | 1904751 | 915848 | 988903 |

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% significance
** denotes 5% significance
* denotes 10% significance

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

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vision disability (Yes = 1; No = 0) | | | Hearing disability (Yes =1; No = 0) | | | Mobility disability (Yes = 1; No = 0) | | | Memory disability (Yes=1, No=0) | | |
| | 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. | 1903089 | 915008 | 988081 | 1902997 | 914966 | 988031 | 1902989 | 914958 | 988031 | 1902572 | 914770 | 987802 |

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), distance to nearest cities and a dummy for rural areas.
*** denotes 1% significance
** denotes 5% significance
* denotes 10% significance

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

| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** |
|---|---|---|---|---|---|---|---|---|
| | Dependent variable = 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-squared | 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. | 1904751 | 1904751 | 915848 | 988903 | 1904751 | 1904751 | 915848 | 988903 |

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), distance to nearest cities and a dummy for rural areas.
*** denotes 1% significance
** denotes 5% significance
* denotes 10% significance

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

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Dependent variable = 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-squared | 0.001 | 0.001 | 0.002 | 0.002 |
| Num of districts | 222 | 222 | 218 | 214 |
| Obs. | 354770 | 354770 | 175669 | 179101 |

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% significance
** denotes 5% significance
* denotes 10% significance

**Table 6**: Effects of long-term exposure of 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vision disability (Yes = 1; No = 0) | | | Hearing disability (Yes = 1; No = 0) | | | Mobility disability (Yes = 1; No = 0) | | | 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. | 354534 | 175539 | 178995 | 354526 | 175536 | 178990 | 354522 | 175534 | 178988 | 354441 | 175492 | 178949 |

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% significance

** denotes 5% significance

* denotes 10% significance