How War Changes Land

The long-term economic impact of US bombing in Cambodia

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Abstract

What is the legacy of US bombing on the contemporary economic development of rural Cambodia? Relying on a dataset of 114,000 sites targeted by the US Air Force during the secret bombing of Cambodia and the 2012 agricultural output of 3,617 geo-referenced household rice paddies, this article provides evidence of a long-term ecological effect – that a bomb's trigger fuse is more likely to fail when it hits soft, fertile ground. This increases the likelihood of running into unexploded ordnance in the soil, which makes farming a dangerous and potentially life-threatening activity. I find that in high fertility soil bombing results in a contemporary decline in rice production and an increased rate of subsistence farming.

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They have got to go in there and I mean really go in.... I want everything that can fly to go in there and crack the hell out of them. There is no limitation on mileage and no limitation on budget. Is that clear?

Nixon to Kissinger, December 9, 1970
Regarding the covert escalation of air attacks, aimed at destroying the mobile headquarters of the Viet Cong and North Vietnamese Army in Cambodia.

1 Introduction

The literature associated with political geography (Diamond 1999; Herbst 2000; Acemoglu, Johnson, and Robinson 2001; Sachs 2001; Sachs 2003; Miguel, Satyanath, and Sergenti 2004; Ross 2006) is closely attuned to the impact of natural resources, weather, and land topography on political outcomes. A major empirical advantage to geographic characteristics is that they are plausibly exogenous to political outcomes of interest, like economic development and civil war. Whether we focus on elevation or proximity to the ocean, rainfall patterns or fluctuations in temperature, we assume that the political actors involved cannot directly change the fundamental attributes of land.

Unlike the predominant accounts which use geographic variables as a "random" shock to human behavior, I modify these theories by showing that the relationship between land characteristics and development can be dynamic and can depend on past geo-strategic decisions during war. Specifically, this paper shows how political actors, through war, can change natural endowments. This finding, in turn, should change how we as social scientists view environmental factors – not as exogenous or quasi-random, but as mutable, human-affected variables.

In this article, I aim to understand the long-run effects of war on land. I do so by theorizing the link between the variation in failure rates of aerial weapons and contemporary farmer behavior. I test the relationship using historical data of US Air Force sorties flown over Cambodia during the Vietnam War and the 2012 agricultural output of 3,600 geo-referenced household rice paddies. This paper examines the ecological consequences of the US bombing of Cambodia while answering a very basic question in comparative politics: what is the historical legacy of violence on development?

To answer the question, I examine the role of soil fertility and bombing intensity on present-day agricultural output and planting decisions. It is widely known within the weapons literature that fertile ground provides more of a cushion for the bomb upon impact; thus, the trigger fuse is less likely to detonate. I examine the long-term impact of this mechanical failure on land production. I find that as the level of historic bombing intensity increases across fertile land, today's farmers are more likely to subsistence farm and produce less rice due to the risk of encountering unexploded ordnance. This mechanism does not apply to less fertile land: since it tends to be harder and drier, bombs were much more likely to explode upon impact.

I test this theory using highly spatially disaggregated measures that overcome some of the limitations of district-level data used in prior studies. Specifically, I use a unique historical dataset of 114,000 sites targeted in 231,000 US Air Force sorties flown over Cambodia from 1965 to 1973. I identify the location and types of ordnance, and compare them to the 2012 agricultural output of 3,617 geo-referenced household plots. After matching household plots according to pre-war economic and geographic conditions, I run a multi-level OLS model with an interacted term for a household plot's exposure to bombs and land fertility. The findings support the hypothesis about the differential relationship between land fertility and the legacy of bombing. In highly fertile land, bomb intensity is significantly related to a decline in rice production and the amount of rice sold to market while in less fertile land, the relationship is negligible. The results demonstrate empirical limits of macro-economic measures in the post-conflict reconstruction literature, and emphasize the impact that local ecological changes have on long-term development.

Besides answering the empirical question, this project contributes to the social science literature in three distinct ways. First, studies on the effects of war on social cohesion (Fearon, Humphreys, and Weinstein 2009; Paluck and Green 2009; Humphreys, De La Sierra, and Van Der Windt 2012; Beath, Christia, and Enikolopov 2013), economic development (Collier et al. 2003; Sachs 2006), and future conflict (Collier et al. 2003) have invigorated a debate on the deep legacies of war. Yet the lion's share of this research has focused on the ten years following war, what Collier has coined the "post-conflict decade" (Collier 2006; Collier, Hoeffler, and Söderbom 2008). By showing how unexploded weapons dropped in the 1960s and 1970s still impact farmer behavior today, I show how the legacies of war on land can extend several decades after the initial peace settlement. Second, scholars have recently begun to explore the best ways to reconstruct post-war economies, from **capital**-intensive strategies like building social cohesion (Fearon, Humphreys, and Weinstein 2009; Gilligan, Pasquale, and Samii 2014; Cilliers, Dube, and Siddiqi 2015) and encouraging capital investment (Collier 1999; Collier et al. 2003) to **labor**-specific strategies, such as repopulating the labor supply (Davis and Weinstein 2002; Brakman, Garretsen, and Schramm 2004) and preventing recidivism (Blattman and Annan 2010; Blattman, Jamison, and Sheridan 2015; Daly, Paler, and Samii 2015). By focusing on development strategies that resupply capital and labor, this literature has ignored the third key factor endowment – **land** – and has not yet identified the ways that war can fundamentally change the nature of the landscape. Finally, there is small but significant research on the effects of bombing on post-war development

(Davis and Weinstein 2002; Brakman, Garretsen, and Schramm 2004; Miguel and Roland 2011), but these studies rely on aggregate, district-level measures to test more micro-oriented theory, like patterns of town repopulation or a household's ability to find and redistribute capital. With their cross-district comparisons, these authors fail to account for ecological inference problems, providing no reason for why the aggregate trends they identify should have the same effects at the household or village level. I aim to improve upon this research by using a more fine-grain, geospatial dataset, where the empirical unit of analysis matches the theoretical one.

This paper will thus present and test a theory of post-conflict agrarian development. Section two will develop a theory that links local environmental conditions to unexploded ordnance and farmer behavior. It will also provide some background on aerial weapons and on the Cambodian economy. Section three will describe the challenges to causal identification in studies concerning legacies of violence. After describing the data, I summarize the research design and present estimates for the effect of bombing on farming today. Sections four and five provide robustness checks, which use on various empirical strategies to deal with endogeneity and mechanisms of persistence. Section six concludes with a discussion of how this historical finding can relate to modern aerial warfare.

2 Background information and theory

Aerial bombing is one of the most destructive kinds of war-time violence. A formation of six B-52s, dropping their bombs from 30,000 feet, could take out almost everything within a box about five-eighths of a mile wide by two miles long, destroying more lives and more land faster than any battalion (Sheehan 1998). The process of economic recovery from air bombardment is one of the many daunting challenges facing survivors in post-conflict states, as homes and physical capital need to be restored, citizens resettled, and new livelihoods found.

Does the sheer amount of bombing – and its consequent destruction – have any real impact on development later on? After the US bombing of cities in WWII, Japan and Germany were able to quickly repopulate once war ended, and there were no long-term effects of bombing on population growth, compared to pre-war levels (Davis and Weinstein 2002; Brakman, Garretsen, and Schramm 2004). However, given that these analyses are restricted to urban settings, we should not expect the findings to resonate with rural locations, where populations are less dense and more dependent on the land for their livelihood. More recently, Miguel and Roland 2011 argue that high post-war rates of capital accumulation meant that the US bombing of Vietnam had no long-term negative impact on local Vietnamese consumption rates, poverty levels, infrastructure, or population density. Yet because they use aggregate, district-level data to test a more micro-level theory on the household and village ability to collect and redistribute capital, the analysis may suffer from an ecological inference problem, where group-level correlations are mistakely attributed to individual-level causes.

Cambodia is well-suited for study because it has a history of intense aerial bombing and has been a primarily agrarian economy. More specifically, the Vietnam War (which, for comparative purposes, includes the secret bombing of Cambodia and Laos) represents the most intense aerial bombing episode in history. From 1964 to 1973, the US Air Force unloaded 6.16 million tons of bombs and other ordnance onto Vietnam, Cambodia, and Laos (Clodfelter 1995). Less than half of those munitions (2.76 million tons) were dropped in Cambodia (Kiernan and Owen 2006). As seen in Figure 1, the Air Force bombing in Southeast Asia, by weight, represents almost three times the bombing that had taken place during World War II (2.15 million tons in Europe, 0.54 million tons in the Pacific).

Cambodia is also a low-income country that is highly dependent on its agricultural sector. In 2013, roughly one-third of the country's GDP (33.4%) came from the agricultural sector, with the top commodity being rice. For comparison, more developed countries in Southeast Asia, like Thailand and Vietnam, have 11 and 18% of their GPD derived from agriculture, respectively.[1] Given how low the GDP of Cambodia is ($15 billion US in 2013) compared to Thailand ($387 billion) and Vietnam ($171 billion), Cambodia's agricultural economy may seem small (worth $4.6 billion in 2013), especially relative to its neighbors ($42 billion and $31 billion for Thailand and Vietnam respectively).[2] But agriculture still employs the majority – 67% – of the Cambodian workforce (FAO 2014). In fact, rice cultivation is the principal rural activity, occupying 88% of total agricultural area in 1993 (Nesbitt 1997). Rice also has been a staple food for centuries. The term eating a meal in Khmer is literally "to eat rice." By the same token, the term for hunger directly translates to "hungry for rice."

Despite the large portion of society working the land, high-quality soil areas in Cambodia are underperforming. According to the 2012 Cambodia Socioeconomic Survey, 43% of fertile agricultural land is not being farmed. This includes land that has already been cleared for agricultural use, and oftentimes already have

[1] Cambodia's agricultural economy has been consistent in the past two decades, contributing 30-37% of the GDP from 2000 to 2014.

[2] These statistics come from the World Bank Databank, accessed January 11, 2016.

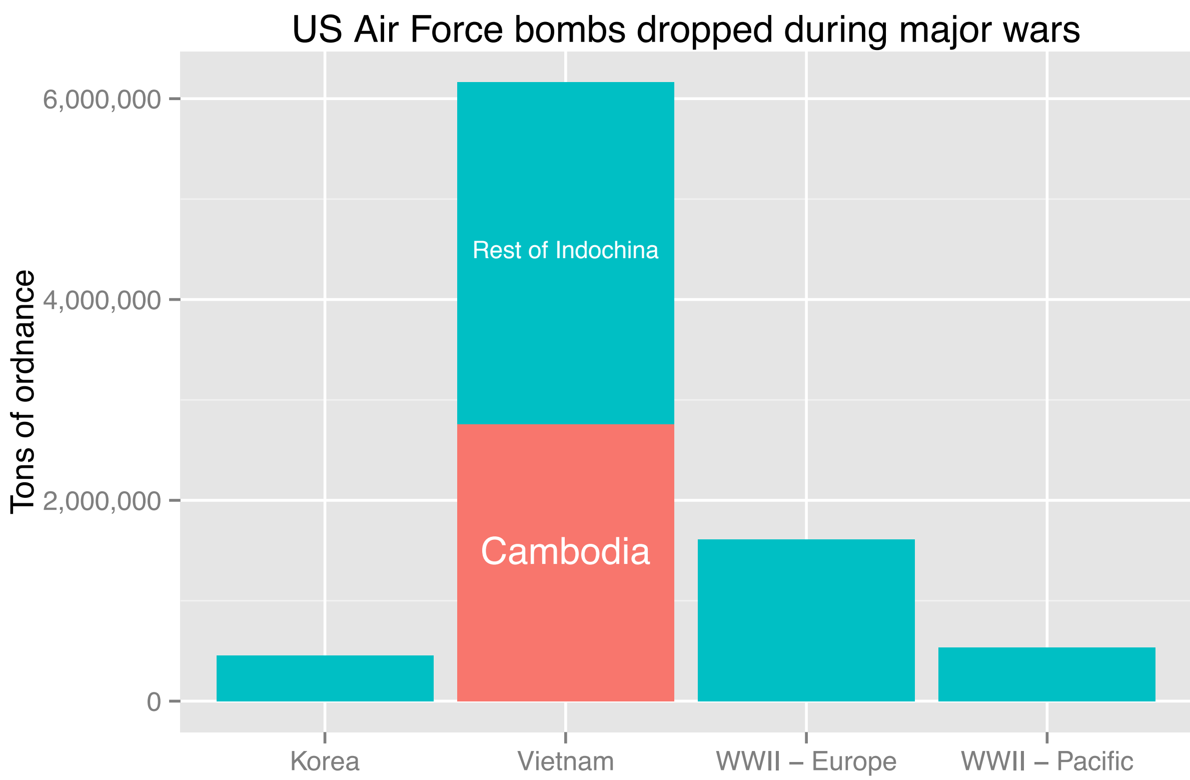

Figure 1: The US bombing of Cambodia involved more tons of bombs (2.76 million tons) than the World War II bombing in the European theater (2.15 million tons), the Pacific theater (0.54 million tons), or the Korean War (0.45 million tons). Data from Clodfelter 1995 and Smith 2001.

raised clay barriers that help keep the paddies flooded and properly irrigated. Why are farmers not utilizing the best land to grow rice?

To answer this question, I focus on the US bombing of Cambodia and the bomb's long-term effects on land. Of the 2.8 million tons of ordnance dropped over Cambodia, about one-half were general purpose bombs. A single B-52D "Big Belly" payload consists of up to 108 225-kilogram or 42 340-kilogram bombs, which were dropped on a target area of 500 by 1500 meters. For each kilogram of munitions expended, about 12.5 square meters of land is exposed to environmentally significant blast and fragmentation damage, meaning a demolished house or vegetation, or a high probability of death for people in that area (Westing 1975). A 250-kilogram general purpose bomb displaces, on average, about 70 cubic meters of soil although this estimate depends on the type of soil and manner in which the bomb detonates (J. P. Robinson 1979). Why would the detonation of a bomb, more than four decades ago, influence contemporary rice practices? I turn to two separate literatures, by weapons specialists and soil ecologists, to suggest why.

First, many bombs, once dropped, do not explode upon impact. In fact, cluster munitions experts call the large numbers of bombs that fail to explode, known as "blinds," one of the major humanitarian concerns of the twenty-first century (GICHD 2007). Descriptively, evidence is emerging that certain ecological factors at the impact area – like heavy, dense vegetation and soft, wet ground conditions – increase the rate of munition failure (Moyes 2002; Feickert and Kerr 2014).

Since most explosive bombs are designed to detonate on impact, if the ground surface does not offer sufficient resistance to impact, the bomb will not detonate. In this context, "impact" means extreme (near instantaneous) deceleration. In other words, the target must offer substantial resistance when it is hit. Soft ground and dense vegetation can cushion the fall enough to prevent an impact fuse from functioning. A general review of cluster munition failures confirms that mud, snow, sand, and surface water all lead to substantial numbers of duds, and also result in bombs penetrating ground cover, going 10 to 20 centimeters below the surface (McGrath and Lloyd 2014, p. 26). This is a common occurrence in, for example, "the mud and jungles of Southeast Asia, the soft peat of the Falklands, the sand desert of the Gulf, and farmland in the Balkans." (King 2000, p. 39). Based on this logic, Southeast Asia specialists claim that wet, muddy ground increases the probability of munition failure, and therefore increases the proportion that remains unexploded (Moyes 2002). Specifically, bombs dropped in paddy fields and irrigation ditches should have higher rates of unexploded ordnance (McGrath and Lloyd 2014, p.29).

We can simplify this argument by using what we know from Cambodian soil ecology. The most fertile land in Cambodia – which stays wet and muddy throughout the year – can grow rice during wet and dry season. Less fertile soil lies dry and dormant for most of the year; even during wet season, the ground remains relatively hard (Nesbitt 1997). By combining these two literatures together, we gain the following insight. Since high fertility land is a wet, muddy rice paddy all year-round, those areas should have higher rates of munition failures and thus higher numbers of unexploded ordnance in the soil. Since low fertility soil stays rocky, then we should expect lower amounts of unexploded ordnance. Most of the ordnance had detonated upon impact. In turn, where there is more unexploded ordnance, farming is a risky and potentially life-threatening activity (Moyes 2002). We thus expect farmers to avoid many of these areas and farm less efficiently per square meter.

2.1 Hypotheses

Building on these insights, the main argument of this theory can be summarized as two main hypotheses:

H1: We are more likely to see a decline in rice output in bombed, highly fertile areas. Conversely, bombing has a negligible impact on rice production in less fertile areas.

H2: These households with fertile but bombed plots should rely on subsistence farming, particularly in comparison to households with fertile, unbombed plots.

3 Causal identification in the study of the legacy of violence

The causal relationship between violence and long-term economic development is largely unexplored, due to several methodological and data-driven issues, as discussed in Blattman and Miguel 2010. The first, and perhaps most obvious, problem concerns lack of data. Whether we are collecting data on the treatment (intensity of violence, location, target), controls (pre-war conditions), and outcome variables (post-war conditions), the information may not exist, or it may not be in the surviving regime's interest to share the data. Even if we are able to collect such a dataset, any study on the legacies of war faces three methodological challenges, if it seeks to make causal claims.

First, concerns about endogeneity – a problem endemic to cross-sectional analyses of postwar data – are still pressing, because the intensity of violence, the treatment variable, may not be random. Indeed, within the substantial literature on the causes of war, we find ourselves with a broad consensus that violence is a product of political strategy and underlying demographics, but also, importantly, is not random. Second, Occam's Razor suggests that an individual's economic decisions are more likely to be shaped by the contemporary conditions and institutions – a simpler explanation compared to reaching back into time to track down a historical explanation. However, if we were to include present-day covariates in our model, along with our historical treatment variable, this could introduce post-treatment variable bias (Gelman and Hill 2007, p. 229). Finally, because historical legacy arguments, by definition, offer an explanation that persists over a long range of time, they need to pinpoint their own causal mechanism but also provide a mechanism of persistence. Why and how is this behavior or strategy passed down through the decades, through the generations?

For these reasons, I test the theory using a unique dataset and a mix of methods, recognizing that conflict is one of several factors that influence today's agricultural practices and one that could be endogenous to pre-war economic conditions. The empirical strategy is three-fold.

In the first section, I construct new dataset. This dataset is comprised of unclassified information from the US Air Force daily air combat pilot records during the Vietnam War (1965-1975) and from high-resolution US Army topographic maps from 1960. I merge this with geolocated information on land fertility and contemporary agricultural decisions and output. Then, with the US Army data on pre-war conditions, I employ a research design that compares like-cases, matching the locations of contemporary agricultural plots based on the economic and demographic conditions of those areas prior to war. In a weighted, regional fixed-effects model, I regress farmer behavior on local bomb intensity interacted with land ferility. My findings support the hypotheses. That is, bombing has a negative effect on rice production in high fertility land, but not in low fertility land. In addition, bombing increases the likelihood of subsistence farming of farmers on high fertility land. Interestingly, for both outcome variables – subsistence farming and rice output – the effect of bombing is binary in high fertility soil. Whether the rice paddy was bombed heavily or lightly, the effect size is the same. I conclude the section by providing qualitative evidence that explains why the amount of bombing does not matter from the standpoint of farmer safety.

After the main analysis, I use the next sections to address on two broad concerns: one, the endogeneity issue, exploring how bombs are dropped strategically and not at-random, and how this impacts the main analysis. I provide multiple tests to show how the placement of bombs, although not exactly random, do not appear to correlate with any potentially confounding variables, like agricultural centers and major transit points. Unlike prior studies, which rely on secondary sources and unvalidated assumptions to alleviate endogeneity concerns, I use the US Army maps and pilot target reports to see if bombs were more likely to be dropped on strategic economic zones or populated areas.

The second concern is about the persistance of unexploded ordnance through time; why do bombs, despite major historical events and incentives to clear them, continue to influence life today? I supply evidence that, despite major historical events like the Khmer Rouge genocide and the 1980s wave of post-Khmer Rouge migration, the effect of the US bombing persists through time. I explain how the complex, capital-intensive nature of demining results in large amounts of unexploded ordance still left in the land today. I end the section by showing how *contemporary* factors do not significantly predict rates of subsistence farming in Cambodia. I test an array of economic and demographic variables, including the size of the plot, crop rotation, soil fertility, family size, village isolation, distance to road, level of poverty, and having a family member employed in salaried, non-agricultural job. I find that the typical controls have no significant impact, which suggests that household investment in land will not overcome the structural issues at hand.

3.1 Data

The spatiotemporal dataset relies on four distinct sources: (1) the historical database of US Air Force sorties to identify the location and intensity of bombing, (2) the pre-war covariates from the US Army maps to identify the sets of villages most similar to each other prior to war, (3) the 2012 wave of the Cambodia Socioeconomic Survey to identify contemporary farming behaviors and output, and (4) the Cambodian Agricultural Research and Development Institute (CARDI) database, again, which helps us identify the soil fertility of each agricultural plot.

3.1.1 Independent Variable: Bomb intensity

The limited number of existing studies on the subnational relationship between aerial bombing and long-term economic outcomes (namely, Miguel and Roland 2011) use the Southeast Asia Air Combat Data (Smith 2001). The original data system captured daily air combat information on the Vietnam War, and the data, classified top secret, were maintained by the Joint Chiefs of Staff.[3] These data detail the latitude/longitude coordinates of each released piece of ordnance, date of release, ordnance category (e.g., general purpose, ammunition, incendiary, cluster bombs, missile), type of ordnance (e.g., 750-lb general purpose bomb, BLU32 Fire bomb), number of bombs included in the payload, and weight of the payload. Given that the raw data

[3]The database was assembled by the Defense Security Cooperation Agency, housed at the United States National Archives in Record Group 218, called "Records of the U.S. Joint Chiefs of Staff."

include all ordnance and equipment dropped from the planes, including photography equipment and anti-Viet Cong pamphlets, I subset the data to exclude non-combative categories ("Other", "NA's", "Unknown") and smaller ordnance that lacks a trigger fuse ("Ammunition", "Flares"). As seen in Figure 2, after excluding these categories, we still retain the majority (82.0%) of all payloads.

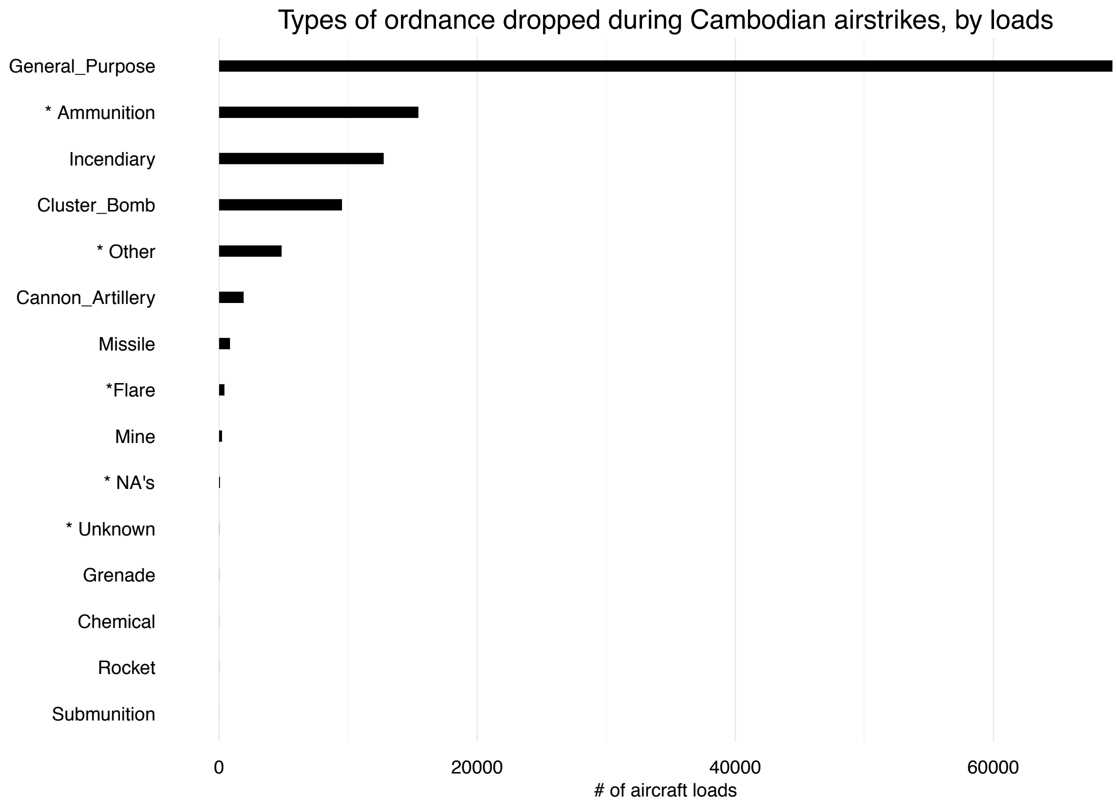

Figure 2: General purpose bombs (like the 500-lb MK82 Low Drag or the 750-lb M117) constituted 61% of all payloads. Starred categories indicate that these types of ordances were dropped from our analysis, since the hypothesis only applies to larger, destructive bombs with trigger fuses.

There are at least two consequential shortcomings in the data, namely that the Air Force pilot's reported target and summary bomb damage assessment are unavailable – which would have revealed what the pilot intended to hit – and there is no additional information on the bombing sites themselves (e.g., population density, proximity to transport lines). This makes it difficult to figure out why certain sites are selected over others. To reduce the possibility of endogeneity, the ideal dataset for the study would include not only the location and the magnitude of bombing, but also the professed target *and* local information on population density, major transport lines, and enemy movement at the time, replicating what informs military leaders'

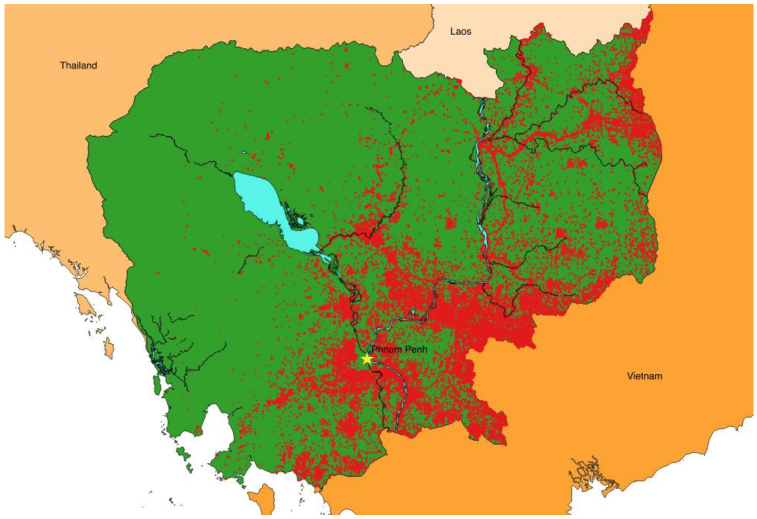

Figure 3: 113,716 sites bombed by the US Air Force in Cambodia, 1965-1973

choice on aerial coverage.

To address these issues, I rely on an improved spatiotemporal database of almost all the US bombs expended in Cambodia from 1965 to 1973,[4] The bomb sites are depicted on Figure 3. With the aid of the Yale Genocide Project, I also acquired the Air Force records for the reported target and damage assessment for each piece of ordnance in the Southeast Asia Air Combat Dataset.

3.1.2 Controls: Pre-treatment covariates

Another way to improve the bombing data is to include pre-treatment variables that may influence the likelihood of bombing or the amount of rice output today. I combine the bombing data with 283 US Army topographic maps from the 1960s. United States Defense Mapping Agency published these maps from the early 1970s through the mid 1990s.[5] The maps are high-resolution, depicting the location of each household in each village, as well as schools, temples, markets, roads, bodies of water, and main agricultural areas. A sample of the topographic maps can be seen in Figure 4.

[4] Some of the original tape archives were reportedly damaged, leaving a blank period from July 1971 to September 1971. See Figure 14 in the Appendix to see where the missing months stand relative to the rest of the database.

[5] The Princeton University GIS library purchased the entire set of Cambodia maps from LandInfo Worldwide Mapping, and they are now available for public access.

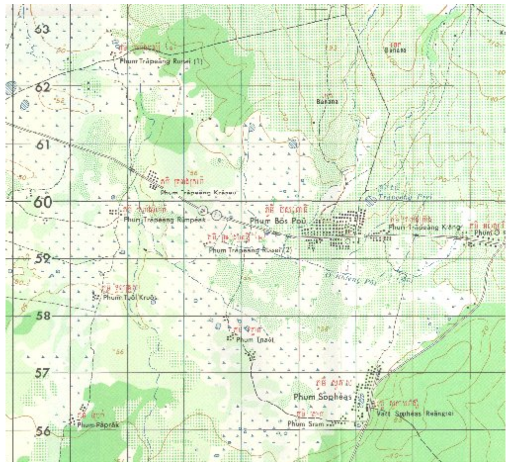

Figure 4: A sample of the US Army topographic map

3.1.3 Outcome variable: Farmer behavior and output

The 2012 Cambodia Socioeconomic Survey (CSES) is a nationally representative survey of 3,840 households in 384 villages.[6] The household survey contains a number of modules with questions related to living conditions, like housing conditions, education, health, expenditure, income, and labor. It is designed to provide information on social and economic conditions of households for policy studies on poverty, household production, and consumption for the National Institute of Statistics, a branch of the Cambodian government's Ministry of Planning.

The respondents are drawn from a stratified, three-stage cluster design. Villages were initially stratified into 45 strata (province, urban/rural), and then selected using systematic sampling with probabilities according to size. One cluster, or census enumeration area, within the village was randomly selected, and then 10 households within the cluster were randomly selected for the survey. The survey is a face-to-face interview and questionnaire, but it is unusual because it requires the enumerators to live in the sampled village for an entire month. Due to this immersive method of data collection, the response rate is nearly 100%. Of the 3,840 households in the survey, 2,171 households farmed a total of 3,781 agricultural plots. All household plots had fully completed land surveys, meaning that responses had no NA answers.

In order to merge the CSES survey with the geo-referenced data on bomb intensity and soil fertility, I geo-reference the household plots, using the GIS coordinates and village identification information from Cambodia 2008 census. The CSES survey includes a village name, in addition to subdistrict, district and

[6] These data, which are typically kept in the closed ministerial archive, were made available with the help of Ministry Archivist Lundy Saint. Librarian Bobray Bordelon and I were later able to acquire the data for the Princeton University Library.

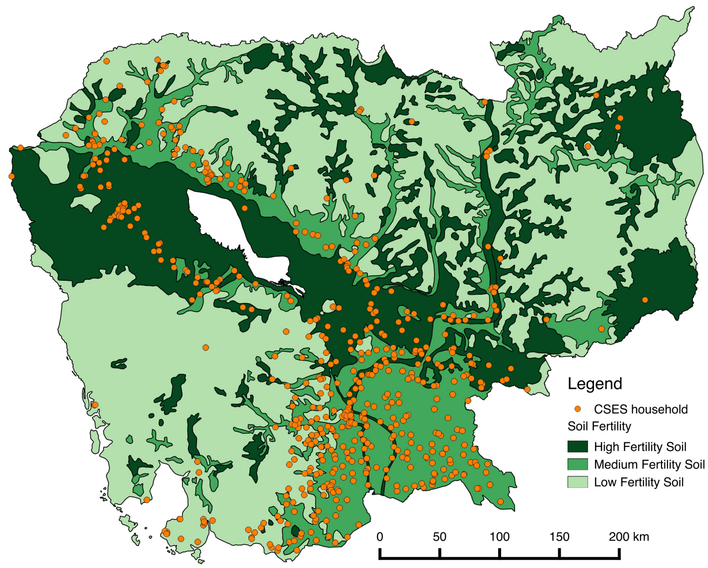

Figure 5: Locations of CSES household plots. The white area inside Cambodia represents the Tonle Sap lake.

provincial names. I was able to exact match 3,617 plots to their census village, which is approximately 95.7% of the sample.[7] Effectively, this means that the household plot's location is calculated using the centroid of a respondent's village rather than the exact plot location. The additional noise may decrease the precision of the model estimates.

3.1.4 Interaction term: Soil Fertility

The Cambodian Agricultural Research and Development Institute has categorized the land in Cambodia into three levels of agricultural productivity (low, medium, and high) based on the main limiting factors for growing rice (CARDI 2009). Low fertility soils are moderately to strongly acidic; with low organic carbon and total nitrogen; very low to moderate extractable phosphorous; very low to low exchangeable potassium; and very low effective cation exchange capacity. Even through good land management, these nutrient limitations are difficult to surmount. The problems of medium fertility soil (strongly acidic, very low in organic carbon and extractable phosphorous, and low in total nitrogen, exchangeable potassium, and effective cation exchange capacity) can be remedied through good land management and planting strategies. High fertility is moderately to slightly alkaline, very low in organic carbon, low to very low in total nitrogen

[7]For 87 plots, I compared the CSES Khmer spellings of the town names with the census ones, and discovered they were not matched due to typos when the translators romanized the Khmer spellings. Upon correcting the typos, I was able to incorporate the 87 households into the main analysis.

content, moderate to low in phosphorous, low in potassium, and moderate to low in effective cation exchange capacity. This soil has few limitations on rice yield.

Figure 5 shows how the majority of high fertility soil bands across the middle of the country, around the Tonle Sap lake and its tributary rivers. This area encompasses the alluvial plains, which are the consistently wet, muddy, high-growth areas of the country. Therefore, I use this measure of land fertility as a proxy for wet, soft soil with abundant ground cover, the optimal conditions for unexploded ordnance.[8]

3.2 Research design

The existing studies of the long-run impact of bombing on economic development suffer from an endogeneity problem. That is, bomb placement is not random and is potentially in response to military threat and local economic conditions. The alternative empirical strategy proposed here is simple: compare the agricultural outcomes in two territories that are each as likely to engage in subsistence farming, one of which has a history of aerial bombing and one which has not. I search, using a simple matching technique, for land that is similar in the five years prior to the start of the US air strikes, based on the set of local covariates and compare the rate of production in each area after three decades have passed.

Within a 5-kilometer radius, the bombing intensity of "treated" villages varies from 549 to 69,000 pounds of ordnance dropped on the area. Given the range, I construct three treatment categories, with cutoffs at the rounded tertiles. I match household plots using covariate balancing propensity score (Imai and Ratkovic 2014), which allows us to balance observed covariates over multiple treatment values.

Two comparisons are constructed using this matching method to test each hypothesis in turn.

*Bomb*Fertility and agricultural output:* compare the rice output in high fertility plots in the three decades after bombing to the rice output in the same time period in similar plots without bombing. In low fertility soil, there is no discernible impact of bombing.

*Bomb*Fertility and subsistence farming:* compare the rate of subsistence farming in high fertility plots in the three decades after bombing to the subsistence farming rates in the same time period in similar plots without bombing.

[8]Soil fertility refers to the ability for soil to supply essential nutrients and water for plant growth and reproduction. Since the main components of soil – minerals, organic content, soil water, soil air, and living organisms – depend on long-term environmental processes like weathering and local geological formations, these physical components of soil change so slowly over time that 2008 measures of soil fertility are accurate measures of 1960s soil fertility.

In the following section, I briefly describe the data used to construct these comparisons:

Unit of analysis. Each comparison is constructed based on an estimated location of each rice-growing household plot in the Cambodia Socioeconomic Survey 2012. To estimate the location, I draw 5-kilometer buffers around the village center. I prefer this geographic unit because anthropological studies (Ebihara 1971; Roberts 2011) have shown that a Cambodian house is typically located near the village center, where it is clustered with other houses, and agricultural plots tend to be within a few hours walking distance from the hamlet.

Treatment measure. The Southeast Asia Air Combat Data is used to estimate the bomb intensity covering each 5-kilometer buffer. As mentioned in the previous section, I construct three treatment levels (low, medium, and high) with cutoffs at the tertiles. The cutoffs are rounded, and are 500 tons and 2,000 tons of ordnance respectively.

Interaction measure. Again, I rely on the 2008 CARDI database to provide the estimates of land fertility for each plot. I code each plot's soil fertility based on the land fertility where the village center falls.[9]

Outcome measure. For each household plot, I calculate the amount of rice produced in the past year (in US dollars per square meter of paddy). To measure subsistence farming, I calculate the percent of the last year's rice crop sold to market. All of these outcomes are based on survey items from the Cambodia Socioeconomic Survey, 2012.

Covariates. To match the household plots, I use the five pre-treatment variables from the 1960 US military maps – the number of settlements, the meters of highway, meters from Vietnam, percentage of rice fields, and the presence of a major waterway. I include these five covariates with the propensity score weights in the linear model, designed to estimate the outcome variables.[10]

Using an OLS model, I regress the treatment term, multiplied with the interaction term, and the five covariates against each of the outcome variables. I also add fixed effects at the regional level. These fixed effects account for any common level of agricultural output inherent in a region's geography, so due to distance to the capital or land topography. I code region according to the 2004 Ministry of Planning's regional groupings of provinces into the plains, the lake (the Tonle Sap), the coast, the mountainous, and the

[9]Table 2 in the Appendix provides the cross-tabulation of bombing intensity and soil fertility.
[10]Figure 15 in the Appendix shows the improvement in covariate balance after matching.

capital regions.[11]

In sum, I estimate the following equation:

$$Y_i = \alpha_i + \beta(Bombing_v * Fertility_v) + X_i + X_v + \gamma_{region} + \varepsilon_i \tag{1}$$

in which i denotes agricultural plots 1, ... , n, and v denotes villages 1, ..., r. Y_i is the dependent variable, the rice output (in US dollars) per m^2 of plot; $Bombing_v$ is the tons of bombs dropped within 5 kilometers of the village; $Fertility_v$ is the soil fertility (high, medium, or low) of the village; X_i, X_v are the respective vectors of covariates at the plot and village level; γ_{region} represents the regional fixed effect, and ε_i is the error term.

3.3 Results

Two hypotheses are tested in this section: that (1) a decline in rice production is more likely in bombed, highly fertile areas, in comparison to non-bombed and equally fertile areas, and that (2) these households with fertile, but bombed plots should rely on subsistence farming compared to households with similarly fertile plots but no history of bombing. Details, including regression estimates, are presented in Tables 3 through 4 in the Appendix. For comparison, I also provide the regression results of the full (unweighted) sample without the interaction (Model 1) and with the interaction (Model 2), as well as the CBPS-weighted sample without the interaction (Model 3). The hypotheses are tested in Model 4, since it includes CBPS-weighting and the interaction term. Graphically, I only present the results from low and high fertility land because I am theoretically interested in the differences between the most and least fertile land.

Bombing is hypothesized to impact the agricultural productivity in high fertility land, due to a higher risk of injury from unexploded ordnance. A test of this hypothesis is presented here in Table 3, where I examine the conditional effects of bombing on the amount of rice grown. In Model 4, we see that bombing on highly fertile land leads to a decline in rice production, while bombing on low fertility land appears to have no significant relationship with the rice grown. Figure 6 presents the predicted rice harvest, in US dollars per square meter, for high fertility soil (right panel) and low (left panel). First, compare the

[11] I chose regional over provincial dummies due to the fact that Cambodia has 24 provinces, some of which were newly created and redrawn in the past twenty years. For instance, Pailin, Krong Kep, and Krong Preah Sihanouk became provinces by royal decree in 2008 while the boundaries were adjusted between Battambang and Pailin and between Koh Kong and Krong Preah Sihanouk in that same proclamation. In addition, including 24 dummy variables significantly decreased the degrees of freedom in the model.

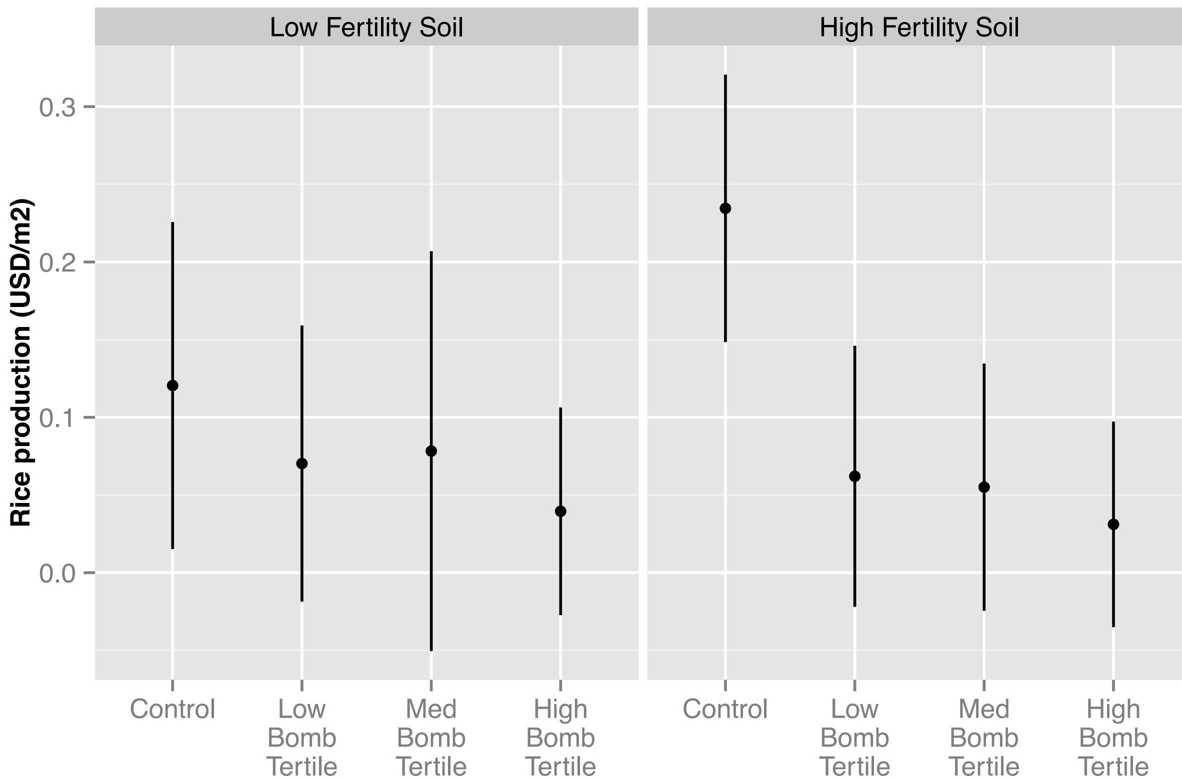

Figure 6: Predicted rice output (USD/m2), according to soil fertility (panel) and treatment condition (horizontal). To compute the quantities of interests, I set the explanatory variables at their means and change the treatment variables from the minimum to the maximum value.

control-group (column Control) predicted rice outputs in low fertility versus high fertility land: the rice output in non-bombed land almost doubles from 0.12 USD/m^2 to 0.23 USD/m^2, although the difference is not statistically significant. Substantively, this correlation falls in line with our *a priori* belief that high fertility land should produce more rice than low fertility land. The positive relationship between fertility and rice output goes away, however, when we introduce bomb intensity as a variable. In high fertility soil, any bombed land (columns Low, Medium, and High Bomb Tertile) produces roughly 0.05 USD/m^2 of rice, which is only 22% of the amount a non-bombed plot produces. Put another way, bombed plots in high fertility land produce the same levels of rice as any low fertility plot. Bombing, effectively, reduces production; so it is as if high fertility soil is limited to producing the same amount of rice as low fertility soil. I should also mention that in low fertility fields, the association between bombing and rice production is weakly negative (with predicted output falling from 0.12 USD/m^2 in the Control to 0.04 USD/m^2 in the High Bomb Tertile) but statistically insignificant.[12]

Next, I identify on the effect of bombing on the amount of rice sold to market, conditional on soil fertility. The outcome variable is calculated as the percent of the total annual rice crop sold (versus kept), by weight. Model 4 in Table 4 establishes that, when the dataset is CBPS-weighted and the model includes an interaction term, bombing reduces the share of rice sold to market in high fertility plots, but not in low fertility areas. Again, for comparison, Model 1 runs a similar regression with the full, unweighted sample and no interaction term while Model 2 includes in the interaction term. Model 3 includes the CBPS weights, but leaves out the interaction term. Since interaction terms are difficult to interpret in the coefficient table, I calculate the predicted values in Figure 7, conditional on soil fertility.

A few points should be made, regarding Figure 7. First, when we compare the control (non-bombed) plots in low fertility and high fertility soil, more fertile plots tend to sell more rice to market: highly fertile plots sell 1.4 more shares of rice than low fertility plots. However, bombing changes this relationship. When we compare each treatment group in low fertility soil to the control group, there is no significant difference in the percent of rice sold to market between bombed plots and non-bombed plots. The opposite is true in high fertility land. Here, bombing appears to have a significant and almost binary impact on rice-to-market behaviors of farmers. The predicted values between the three treatments in the right panel are statistically indistinguishable, with predictions ranging from 16 to 18% of the total crop sold to market. Since non-bombed plots in highly fertile areas sell 42% of their total crop, bombing effectively reduces the share of rice sold to

[12]The analysis was repeated using kilograms per square meter, as seen in Figure 5 in the Appendix. Figure 17 show that the findings are consistent between the two measures of rice output. I also conduct the analysis using 3 kilometer (rather than 5 kilometer) buffers, which can be seen in Table 6. Figure 18 shows that the trends are the same between the two buffer sizes.

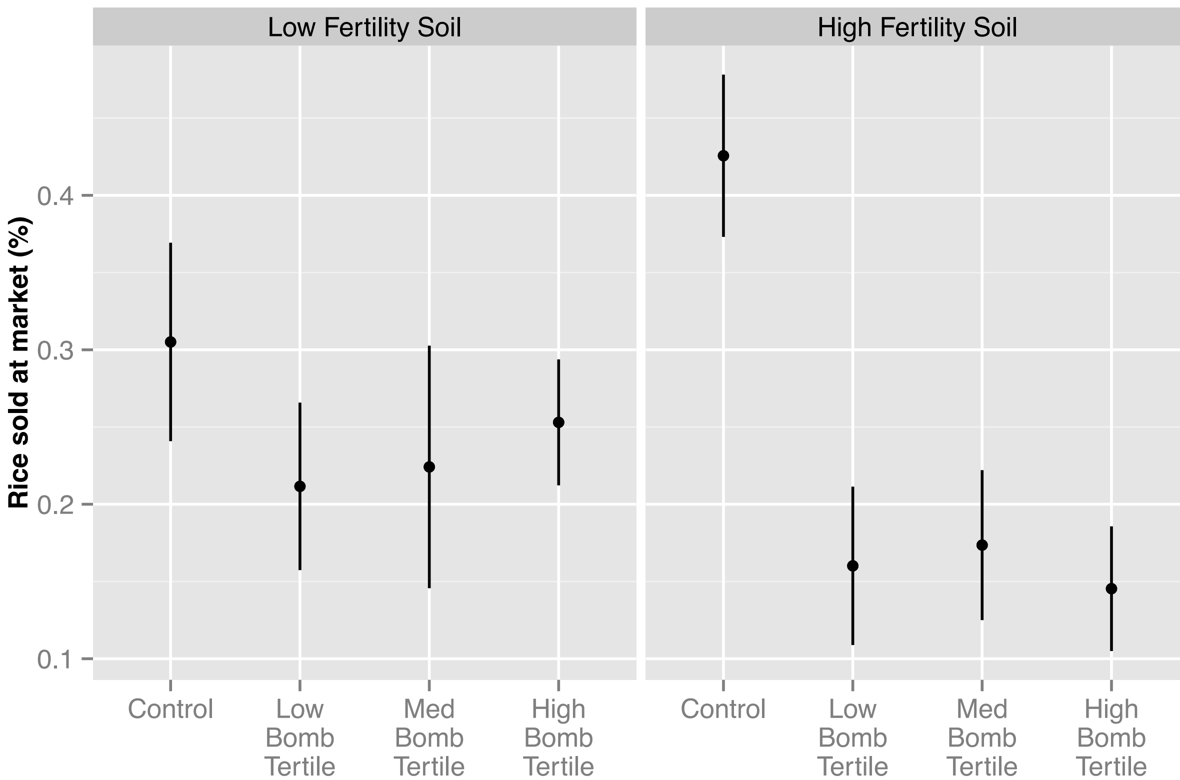

Figure 7: Predicted rice sold to market (% of total harvested), according to soil fertility (panel) and treatment condition (horizontal) Like before, I calculate the predicted values by setting controls at the mean and changing the treatment status.

market by more than half.

The results can be summarized into two main points. First, when bombs fall on low fertility land, the bombing has a small substantive, negative impact on farming today. However, this effect is statistically insignificant. Second, the long-term effect on high-fertility land is also negative, but it is strong and statistically significant. It is also binary. Whether a rice paddy was heavily or lightly bombed, it does not matter; the effect size is the same.

Why is this effect binary? I argue that farmers make decision based on the incomplete and binary information they have on bomb location. Information is binary because individuals know whether or not the village has been bombed, either from personal experience, from physical evidence (like bomb craters), or from survivors. Anything more precise – like the location of the drop sites, the exact number of bombs dropped, and the number that have already detonated – the farmer does not know. Even professional removal teams, when they survey the ground with a specialized instrument called a locator, are only able to find bombs at easily detectable depths (McGrath 2000, p.159). Plus, even if the average farmer see a piece of UXO on her land, she does not know if that is the last piece of ordnance or if there are many more on her land. In short, she might as well avoid the land.[13]

For instance, Chim Neth, a farmer in Battambang Province, had found four or five fragments of ordnance when she and her family were ploughing her field. Now, she reports, "I don't dare step on my land for farming." In order to get money for food, she works for her neighbors, and sends her sons to work "far, far away" (Freundlich 2014). Similarly in Rise Up and Stand (Kork Chor) Village, Rah Srei said that, "Because of the munitions in the field, I could not do anything on our land... I just took care of the children" (Freundlich 2014). Neither Chim nor Rah knew the exact number or placement of bombs on her land. Each knew that at least part of the land was contaminated, and stopped using the entire swath of farmland, even if this meant not being able to grow her own rice to feed her family.

To summarize, there is some qualitative evidence that farmers have limited information when they calculate their likelihood of getting hurt while farming. The most important factor is whether or not the land has been bombed – not how many bombs have been dropped – although future research may determine if, when given more precise information on the location of bomb drops, farmers choose to use this information to grow crops on the less dangerous areas.

[13] Some many argue that farmers collect more nuanced information about likelihood of encountering UXO as they plough, plant, and cultivate. However, there are been instances where farmers had used their land for years without an incident, and then accidentally uncover or detonate a bomb (Seangly 2002; Kim 2013). That is why land may not necessarily be "safe," even if the family has planted it in prior years.

4 Is bombing endogenous?

One of the central estimation concerns is that US bombs were dropped non-randomly, particularly in response to military strategy and local economic conditions. For instance, should bombs have been mainly dropped on major transit points, it may be the loss of main roads and increased transaction costs that dissuade farmers from growing a surplus of rice today. A convincing causal model requires an identification strategy that can, at the very least, pinpoint and control for the variables that predict the treatment assignment. In Miguel and Roland 2011's analysis of Vietnam, the authors rely on the secondary literature to show that the US Air Force followed a standardized barrage pattern known as "harassment and interdiction," meaning that it aimed to disrupt enemy troop movements and supply routes rather than explicitly destroy infrastructure (p.7). As a result, they use distance from the North-South Vietnam border as an instrumental variable, which predicts bombing intensity.

The Cambodia campaign also was an aerial interdiction campaign, but to verify, I rely on two empirical strategies. First, with the pre-war, US Army topographic maps, I can identify the degree to which bombs were dropped on settled areas, transport hubs, and agricultural zones. Second, an examination of the Air Force pilot reports can reveal the specific types of target that pilots intended to hit. The goal in both of these tests is to determine the geo-strategic patterns – if there are any – of bomb intensity.

4.1 Geographic, economic, and military determinants of bomb intensity

In this first test, I estimate likelihood and degree of bombing, given pre-bombing population density, strategic location (proximity to major roads and waterways), economic value (pre-bombing amount of cultivated rice paddy), forest cover, and distance from Vietnam. The 1960s US military maps (seen in Figure 4) show how the location of each household is marked, along with village names, dominant crop types, major and minor roads, and industrial sites. To measure the likelihood of bombing, I drop 100 random points within the country boundary, and draw a 5-kilometer buffer around each random point. I then count the number of settlements, the meters of two-lane roads, and the intensity of bombing (in terms of tons of ordnance). I also create dummy variables to signify if the buffer is mostly forested and if it includes a major waterway. Finally, I calculate the distance of each point from the Vietnam border, and I estimate the percentage of the buffer that is rice fields.[14] Then, I use an OLS regression to estimate the pounds of ordnance dropped within the

[14]This is a discrete variable, in which 0, 25, 50, or 100 percent of the buffer is rice field.

buffer, based on road density, number of settlements, existence of a major waterway, forest cover, rice field cover, and distance from Vietnam.[15]

It is important to note that the 1960s US military map is not complete, and a small number of the points (93 out of 100) were dropped on areas that had no map. Of the 288 total maps that cover Cambodia, I was able to access all but five, as can be seen in Figure 19 in the Appendix. Although this is to be expected of archival data, this omission may not be random. It could be the case that maps of highly bombed places were selectively left out. To test this, I also regressed likelihood of having a buffer having no map, based on distance from Vietnam and bombing intensity.

The findings in Table 1, Column 1 confirm what is readily apparent from other sources – that bombing was more intense closer to the Vietnam border. For every kilometer that a village is closer to the Vietnam border, it will have, on average, 5.4 tons more bombs dropped on it. However, because there is so much variation in the relationship between bomb intensity and the remaining variables, it is difficult to believe that bombs were more likely to target transit points (major roads or waterways), agricultural zones, or forested areas. This suggests that the US Air Force, indeed, followed an interdiction strategy, intending to follow and disrupt Vietcong supply lines. It does not appear that there was any priority to destroy Cambodian infrastructure. In addition, the second column (the model on missingness) suggests that there is no relationship between bombing intensity and map missingness, which suggests that the US did not selectively release maps of unbombed areas. This confirms what we see in Figure 19 in the Appendix: most of the missing maps are along the Thai-Cambodia border, as well as random parts in the middle of the country.

4.2 Intended targets from pilot reports

My second test examines the daily air force pilot reports, which describe the intended target of each payload. The Yale Genocide Project, with the help of Professors Benedict Kiernan and Taylor Owen, procured the pilot's record of the intended target and the summary bombing assessment of each released piece of ordnance. For the purpose of this analysis, I focus on the intended target. The raw data indicate that the range of targets varies, from the strategic "Artillery" and "Troops in Contact" to the more benign "Bicycle/Scooter,"

[15]The OLS equation is written as the following:

$$Bombing_j = \alpha_j + \beta * X_j + \varepsilon_j \tag{2}$$

in which j denotes random buffer j, ... , k. $Bombing_j$ is the dependent variable, the tons of bombs dropped within the 5 kilometer random buffer; X_j is the vector of covariates (number of settlements, kilometers of road, if the buffer is forested, if there is a waterway, and kilometers from Vietnam); and ε_j is the error term.

Table 1: Regression results of 1960 conditions on bomb intensity (1) and on likelihood of missing map (2)

	Dependent variable:	
	Bomb intensity (tons)	Map missingness
	OLS	*logistic*
	(1)	(2)
Meters from Vietnam	-0.005^{***}	0.00000
	(0.002)	(0.00000)
Meters of road	0.018	
	(0.015)	
Number of settlements	-7.893	
	(27.764)	
Percent rice paddy	0.479	
	(10.057)	
Major waterway	-616.441	
	(601.794)	
Forest	-685.579	
	(423.878)	
Other country	-354.543	
	(707.434)	
Tons of bombs		-0.595
		(81.337)
Constant	$3{,}777.588^{***}$	-2.721^{**}
	(969.474)	(1.099)
Observations	93	100
R^2	0.219	
Note:		*p<0.1; **p<0.05; ***p<0.01

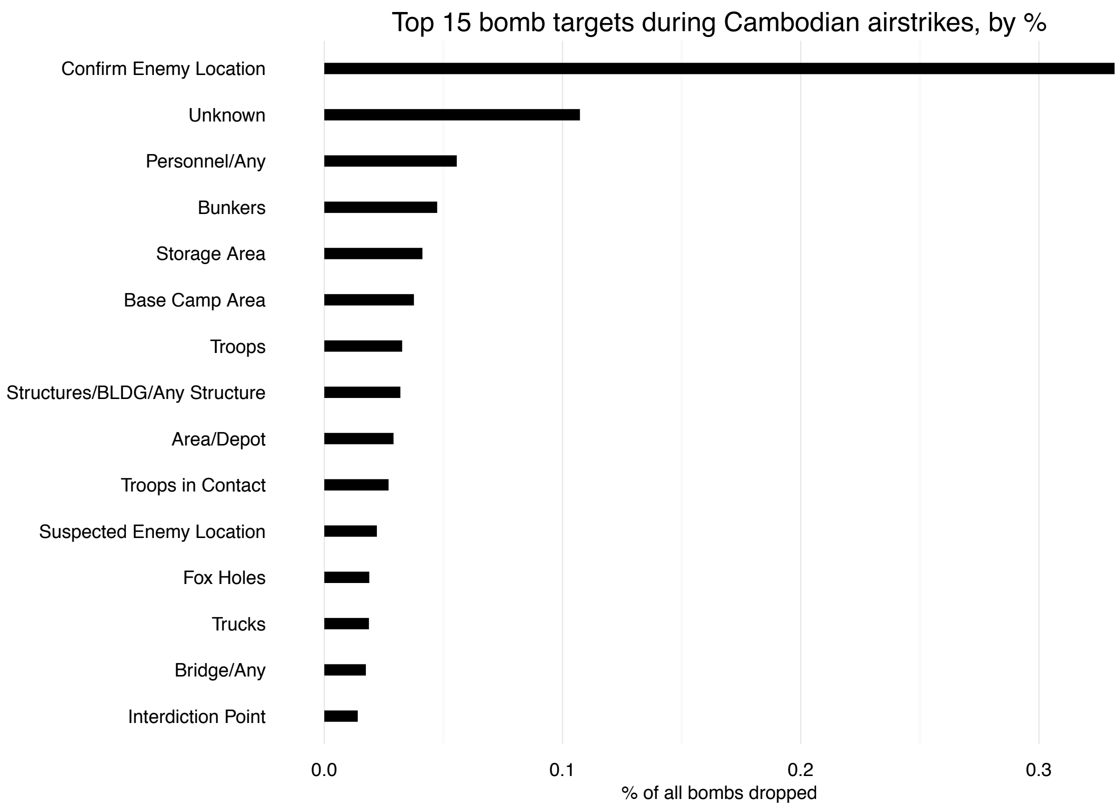

Figure 8: Of the 179 different types of targets in the pilot logs, these 15 types represent the targets of 83.3% of all payloads.

"Ox-Cart," and "Structures/BLDG/Any Structure." The specificity of pilot reports also varies: 10.8% of the all bombs were targeted at "Unknown," "Unknown/Unidentified," or "ERROR/UNKNOWN" targets. These examples provide a glimpse of the 179 different types of targets in the registry, although only 15 types represent 83.3% of all payloads. Each of the remaining 164 target categories comprise less than 1% of the dropped payloads.

Figure 8 shows these 15 top targets. One-third of bombs (33.2%) were intended to "Confirm Enemy Location" which points to Air Force's intention to identify intransigent and armed areas. 10.7% hit an "Unknown" target, underscoring the ambiguity of the mission hits and the degree to which targets were based on the pilot's discretion. The next eight targets ("Personnel\Any", "Bunkers", "Storage Area", "Base Camp Area", "Troops", "Structures\BLDG\Any Structure", "Area\Depot", "Troops in Contact") sum to almost one-third (30.3%) of dropped bombs, and the categories suggest that there was some strategic targeting against troops and military infrastructure. The last three categories ("Trucks", "Bridge\Any", "Interdiction Point") suggest that at least 9% of targets intended to disrupt transport routes or infrastructure.

To sum, the pilot reports appear to verify prior claims: that the aerial bombing was intended to disrupt troop movements and supply lines. Although there is some degree of discretion in the reports (the large number of "Unknown" targets or the ambiguity of bombs "Confirming Enemy Location"), the evidence suggests that the Cambodia air strikes did follow an interdiction strategy. The bombing did not favor transport lines, compared to general concerns over enemy locations. Paired with our prior analysis of pre-war maps, the results indicate that bombing intensity is not best predicted by proximity to transport hub or population density; rather it can be best predicted by distance from Vietnam and forest cover.

5 Exploring mechanisms of persistence

Why should bombs continue to impact everyday life in Cambodia today? Major historic events – like the Khmer Rouge genocide and the return of survivors following the genocide – should change who returns to bombed land. In addition, individuals and institutions have incentives to remove unexploded ordnance. Why wouldn't land be cleared as time moves forward? In this section, I study the correlation between Khmer Rouge work sites and agricultural production today.

5.1 Khmer Rouge violence

In the discussion of the long-term effects of conflict, we have temporarily ignored the question of how the Khmer Rouge genocide, a civil conflict that killed 1.7 million people, could impact contemporary farming practices today. Are certain villages, based on their proximity or exposure to genocide, more likely to be poor and trapped in poverty, due to the immense loss of human life?

The logic behind this hypothesis is simple. Villages near major areas of Khmer Rouge violence are more directly impacted by the genocide. They are more likely to experience higher rates of death and starvation. The loss of life leads to a loss of human capital, specifically the knowledge of the local growing practices. Therefore, Khmer Rouge violence mitigates the treatment effect in two ways: one, fewer people make it back to their homeland, and two, fewer people know the local techniques of farming the land. To proxy for Khmer Rouge violence, I use historical maps of the irrigation channels designed and built by the Khmer Rouge. These channels were the focal point of the Khmer Rouge development strategy, as Pol Pot and his right-hand man Khieu Samphan believed that lack of reliable water prevented the Cambodian economy from producing and exporting surplus rice. Due to the harsh working conditions, these irrigation sites tended to be some of the most violent and deadly places in Cambodia: Khmer Rouge soldiers would punish and sometimes kill workers perceived to be slacking off, and workers experienced high rates of starvation due to lack of food and long work hours (Kiernan and Boua 1982; Vickery 1984; Kiernan 2014).

To test this hypothesis, I estimate the location of Khmer Rouge work sites, using a 2007 map from a water management specialist (Himel 2007). This map, as seen in Figure 9 took satellite imagery, and identified the Khmer Rouge channel system, according to their unusual linear structure[16] I drew boundaries that hugged the channels, and then I analyzed the CSES household fields that existed within the Khmer Rouge zones (2,215 rice paddies).

Figure 10 displays the results. I present the results for agricultural output, although the analysis was repeated for rice sold to market (see Table 7 and Figure 20 in the Appendix). Recall that, if this alternative explanation is correct, we should the households in Khmer Rouge major work zones to have a more difficult time producing rice, due to loss of life and human capital. The rice outputs should skew downward; that is, less rice should be produced across control and treatment statuses. Interestingly, in Figure 10, we see that Khmer Rouge violence does not have much of an impact on the results. In low fertility soil, the control and

[16] Traditional Cambodian irrigation systems are small, rectangular, and self-contained while Khmer Rouge architects designed long, linear, and interconnected channels (Hawken 2013, p.350-351).

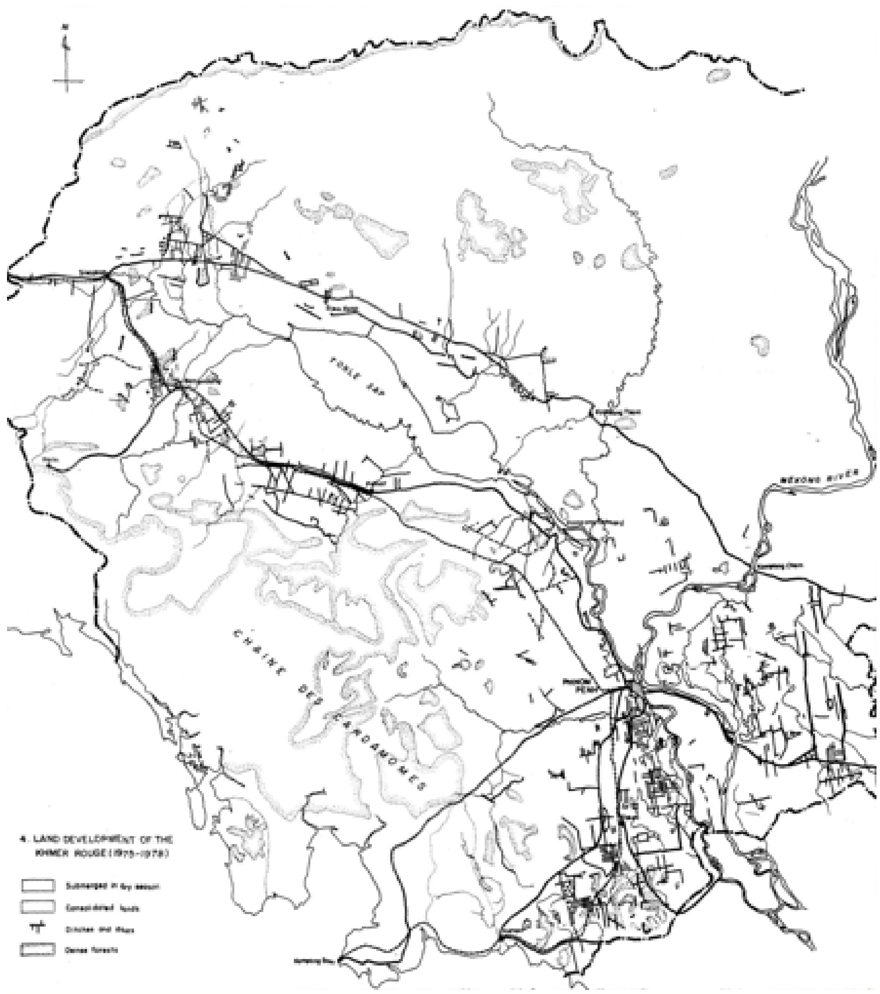

Figure 9: A map of the Khmer Rouge irrigation channels from Himel 2007.

the treatment groups have roughly the same predicted rice outputs. However, treated households on high fertility soil produce less rice compared to their control counterparts. To sum, for households near Khmer Rouge work sites, the finding is the same: if high fertility land is bombed, recovery is slowed.

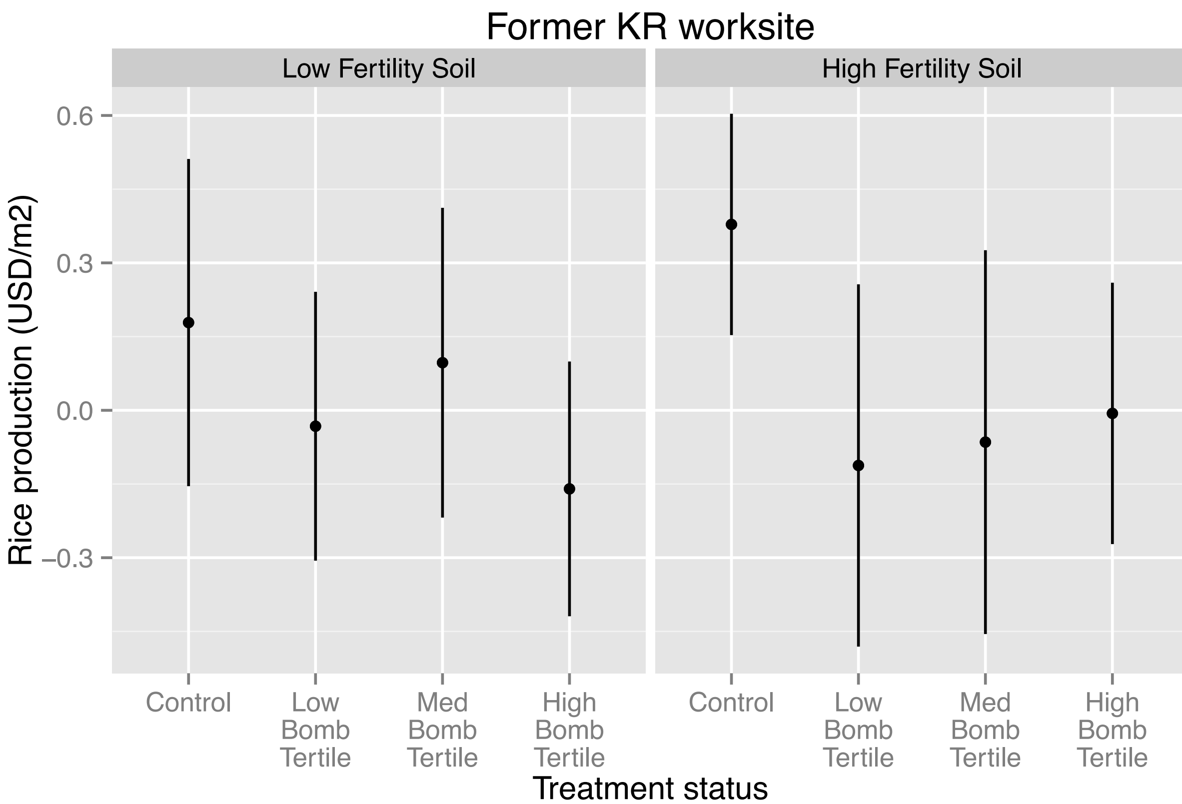

Figure 10: Predicted harvest for the year, according to land fertility (each panel) and bomb intensity (horizontal axis). Note how control households in high fertility land produce more rice than the households in any of the treatment conditions. This suggests that even high rates of genocide do not change the long-term effect bombing has on local development.

5.2 Selective migration

A simple example of an endogenous mechanism can be found when we examine how human capital can determine migration patterns. According to this line of reasoning, people with more human capital will avoid dangerous land. If we assume that it is obvious what land has been bombed (either through personal experience or physical evidence, like bomb craters), people who have higher levels of human capital – that is, they know the land well and are familiar with effective harvesting and land management practices – would actively try to live on safer, high-quality land.[17] In this scenario, high-capital migrants snatch up the good, safe land. The bombed and unsafe land is the leftover land – land that low-capital refugees have no choice but to settle. Therefore, this section asks an empirical question with theoretical implications: are there differential levels of education in the people who migrate back to safe versus dangerous farmland?

To answer, I examine 2012 CSES data on household member education and model the association between pre-treatment human capital and their likelihood to have safe farmland. An advantage of using the CSES data is that I have microdata on individual age and education, which is information that is typically aggregated in the census. For each household, I calculate the years of education for each household member born after 1963.[18] This proxies for the pre-Khmer Rouge education levels. Then, I take the average for each household, subsetting for individuals in this particular birth cohort. Figure 11 plots the commune level of bombing against the pre-Khmer Rouge education of adult migrants, splitting the results with low fertility fields on the left and high fertility fields on the right. Recall, in this case, how "high-risk" land is high fertility, heavily bombed land (right panel, right side) while "low-risk" land is low fertility land (regardless of bombing intensity) and non-bombed fertile land (right panel, left side).

If it is true that more educated people would move to less risky land, then we should expect there to be a negative relationship between amount of bombing and years of education in high fertility land. For low fertility land, there should be no significant relationship between bombing and education. Instead, the findings in Figure 11 show there is no significant relationship between pre-war human capital and the likelihood to live on safe land. There is a statistically and substantively zero-effect between the two variables for low fertility land. The figure also shows the same relationship for high fertility land, suggesting that individuals with more human capital did not selectively migrate to unbombed areas.

5.3 Prohibitive cost of removal

The disposal of large explosive items, like bombs and missiles, is a specialist task and cannot be safely carried out by self-trained individuals or village farming networks. Because of the dangers associated with large ordnance, the cost of clearing land is often prohibitive. The Cambodia Mine Action Center (CMAC), the state organization in charge of demining the country, estimates that it will cost more than $500 million to

[17]This argument highlights human capital rather than physical capital due to the fact that the Khmer Rouge stripped all citizens of any assets, leaving all survivors on relatively even terrain by the time the regime fell in 1979. If anyone was educated above a certain threshold, they would also have been targeted by the Khmer Rouge as threats to the communist state.

[18]People in this birth cohort would be at least 16 years old during the fall of the Khmer Rouge in 1979. Therefore, I classify them as "adults" during the peak migration time – that is, when people were relocating from labor camps to their homelands.

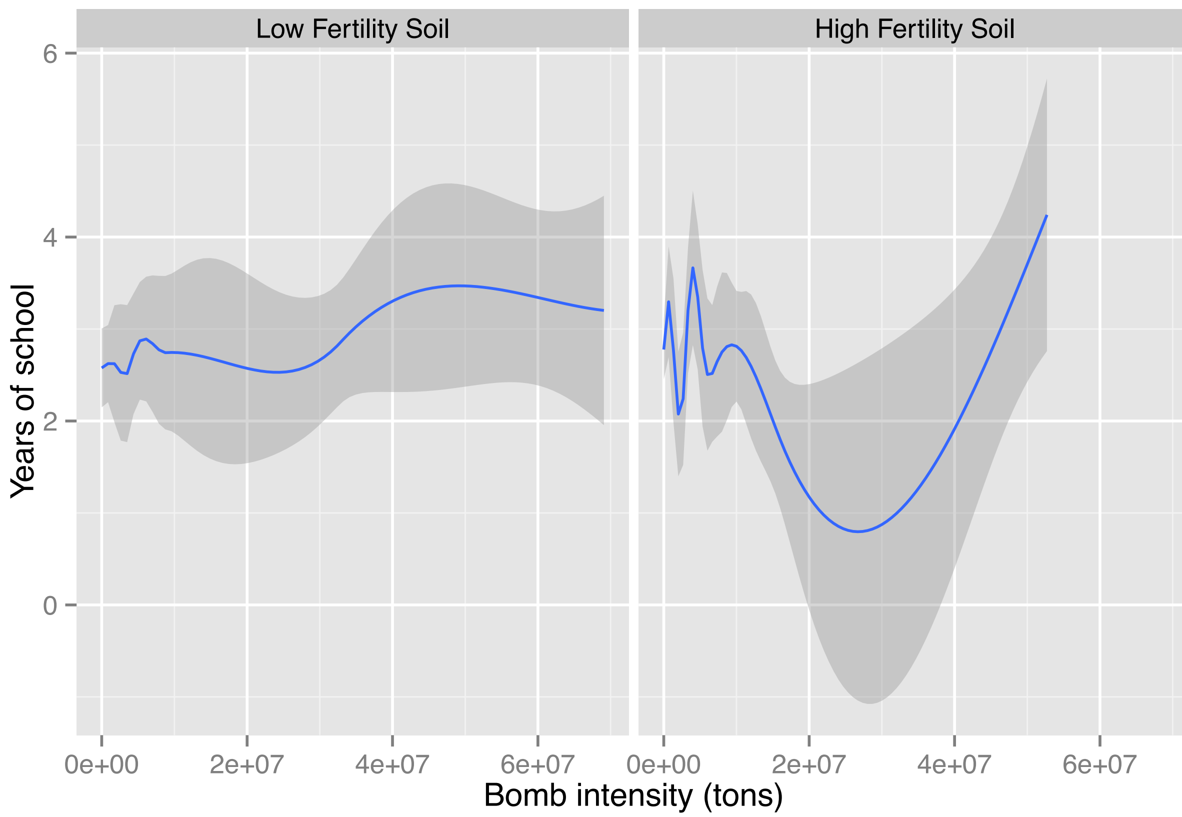

Figure 11: Placebo test of education levels of Khmer Rouge migrants to the level of bombing in their current residence with 95% confidence intervials. This figure shows no relationship between bombing and years of schooling across low and high fertility land, suggesting that individuals with more human capital did not selectively migrate to unbombed areas.

clear the remainder of the land (Freundlich 2014). However, CMAC's budget relies entirely on foreign aid, and the primary donor, the US State Department, has provided 13% of that amount ($65 million) in the past 20 years.

The cost is prohibitive due to the capital needed to remove bombs safely. Given the blast radius of an MK82 General Purpose bomb is 200 meters, making a mistake while removing the bomb can be fatal. According to the Cambodia Mine Action Center's guidelines, a remote lift bag (essentially a large balloon) should be placed underneath the bomb and used to lift the bomb out of the ground. Once it is excavated, the bomb, which can contain 500 to 750 pounds of ammunition, needs to be towed to a designated safe location, where nearby residents have been told to avoid. Then, using a wirelessly controlled bandsaw, the trigger fuses at the nose and the tail are cut off (Harfenist 2015; Carmichael 2015). Such a large amount of capital is needed to safely defuse large bombs, it is virtually impossible for local, farm-based villages to have the infrastructure needed to clear its rice paddies. Given the cost of the equipment (remote-controlled saw, insulated towing device, and a remote lift bag), the cost of removal is estimated to be more than $1,000 US per piece of ordnance ("UXO's Found at Land Clearing Site" 2015).

5.4 Contemporary explanations

A growing puzzle in social science is that post-conflict communities vary substantially in the speed and consistency with which they create agricultural production and economic growth following war. There are many existing explanations for this variation, including plot size (Stifel and Minten 2008), transportation costs and village isolation (Stifel and Minten 2008; Bell and van Dillen 2012; Wantchekon and Stanig 2015; Gollin and Rogerson 2014), economic insecurity (Stifel and Minten 2008), crop diversification (Stifel and Minten 2008), rice seed and improved technology (Ali 2010), fertilizer (Christiansen and Demery 2007), human capital investment (Bell and van Dillen 2012), soil quality (Sanchez 2002; Yamano and Kijima 2010; Wantchekon and Stanig 2015), and the number of people in the family (Banerjee and Duflo 2011).

To test the rival hypotheses, I turn to straightforward statistical analyses that compare the impact of soil quality on subsistence farming practices with the influence of crop diversification, plot size, fertilizer, seed, irrigation, prevalence of rice farming in the community, household expenditure, steady employment in industry, and the number of people in the family. I first explain how I measure each variable.

Soil fertility. The Cambodian Agricultural Research and Development Institute has categorized the land in

Cambodia into three levels of agricultural productivity (low, medium, and high) based on the main limiting factors for growing rice – that is, the water retention rate and nutrient level of the soil (CARDI 2009).

Local rice supply. With their land usage database, CARDI also provides statistics on the amount of land used to grow rice in each subdistrict. I use this as an ecological proxy for the local supply of rice, which may have some impact on price.

Fertilizer. The CSES records if the household had made any added investments on each plot in the past year, including investing in chemical fertilizer.

Irrigation. Another survey item asks the same question, but in regards to irrigation.

Seeds. The survey also asks how much the household spent on "planting materials (seeds, seedlings, and young plants)" for the past year.

Capital. The CSES also takes an inventory of all agricultural assets, including tractors, bulldozers, threshing machines, semi-tractors, rice mills, and water pumps, which I add to create a measure of the number of agricultural machines in a household's possession.

Plot size. The CSES documents the size of the plot, as well as the types of crops grown on each plot.

Crop rotation. Although I limit the analysis to plots that grow rice, in certain areas rice is grown during wet season as well. Therefore, I include a dummy for when rice is grown during wet season in addition to dry season.

Economic insecurity. I code the household yearly expenditure on non-food items, to proxy for wealth.

Non-farm job. I also create a dummy that signifies when a household has one family member with a stable, salaried job since households with reliable income may be less likely to rely on farming.

Human capital. Lastly, I include the number of people in the household, in case having more family members means that more people are able to help farm.

The outcome variable is measured from a CSES survey question that asks, in the past year, how much rice (in USD) was harvested in each household plot. To calculate the outcome variable, I divided this amount by the total plot size.[19]

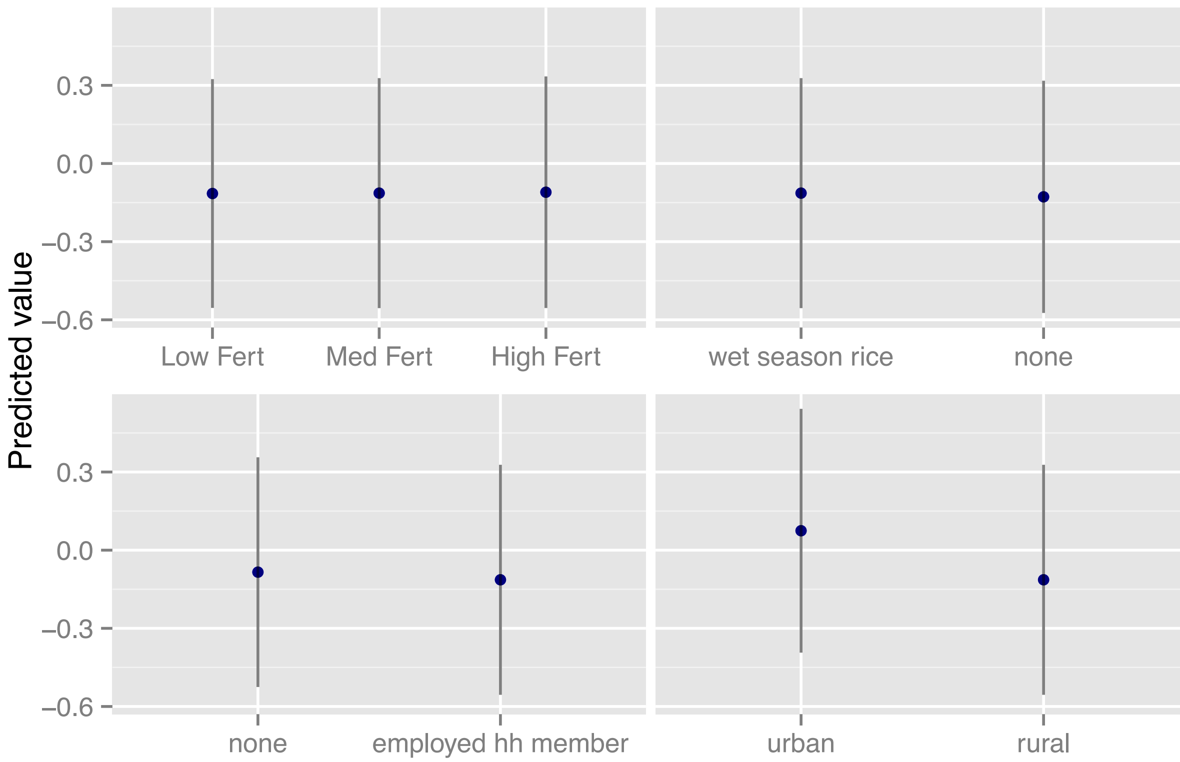

Figure 12: Predicted amount of rice grown (USD/m2), based on an OLS regression of contemporary variables. I compute quantities of interests through the most common way – setting the explanatory variables at their means (the default) and changing the treatment variable from the minimum to the maximum quantity.

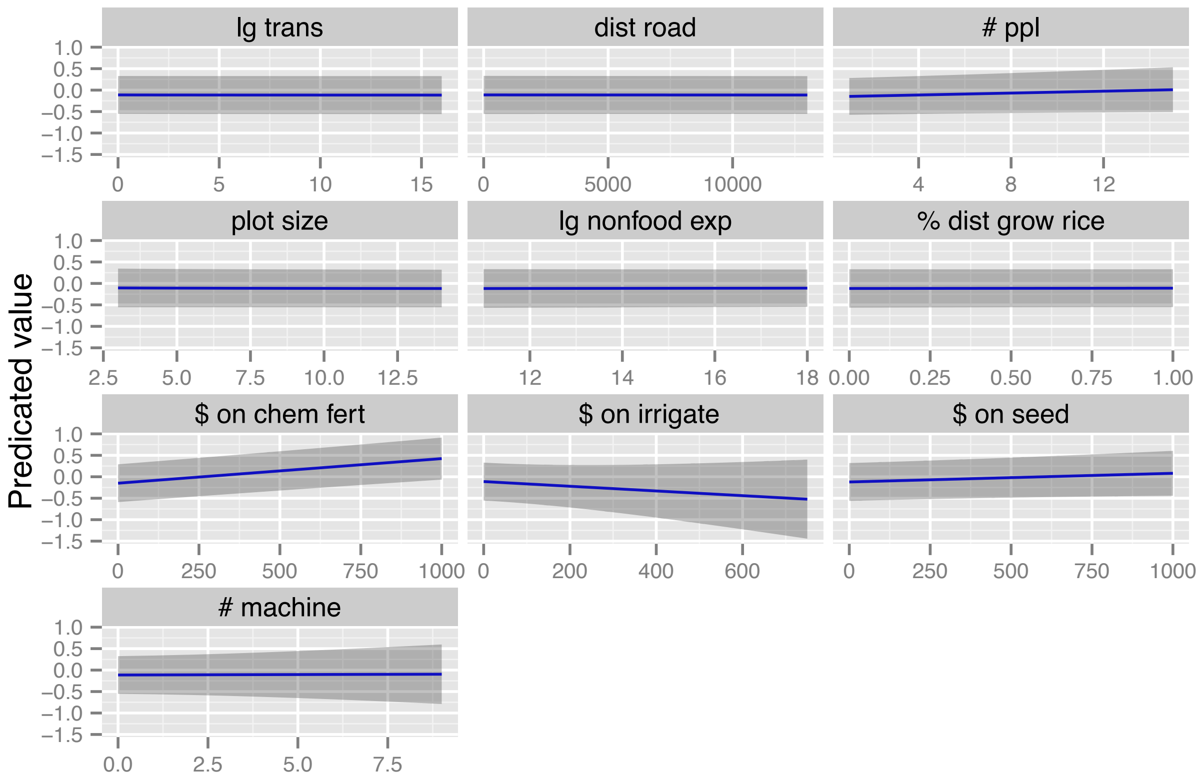

Figure 13: The predicted values are calculated in the same way as before. Here are the results for the continuous variables: the logged transport costs (logged Khmer Riels), distance from road (meters), number of people in the family, the plot size, the logged expenditure on nonfood idtems, the percent of the district that grows rice, the money spent on fertilizer (USD), the money spent on irrigation (USD), the money spent on rice seed (USD), and the number of machines that the household owns.

To conduct some basic statistical tests of these hypotheses, I choose a simple cross-sectional OLS regression as my estimation procedure and applied it to the entire sample of household plots from the CSES 2012. The findings in Figures 12 and 13 confirm what is suspected – that none of these contemporary explanations account for the variance in subsistence farming. Again, these explanations sit poorly with the results of the empirical analysis, which show no significant impact. This suggests that even if a household tried to improve the paddy through the use of fertilizer, tractors, or crop rotation, the effect would be small, especially compared to the large effect of bombing.

6 Conclusion

This paper has developed an argument that contemporary differences in rice production have both ecological and political causes. Bombs have no significant long-term impact on less fertile, hard soil while more fertile, soft soil is much more likely to see the negative effects of bombing on agricultural production.

This conditional effect supports the theory that war hinders development, not just by human loss and capital destruction, but by damaging land and local ecologies in a specific and long-lasting way. While the results shown here generally support the theory most common in the post-conflict reconstruction literature – that violence has legacy effects on development – they supplement it with an understanding of the geographic conditions that make such legacies possible. As such, the result belongs squarely within the tradition of theories discussing the impact of political geography. By showing that human actions have consequences for countryside, the paper emphasizes the dynamic relationship between human actors and land. This change happens not just through conflict, but also through industry, environmental exploration, and human settlement. This makes us question theories of land and capital, which take land as a given. I have provided evidence that the nature of land can change, and this has implications for human development, as it can mean the difference between wealth and poverty – and even between life and death.

Just as striking, from both a Southeast Asian and a comparative perspective, is the sizable legacy in the extent of bombing, which serves as a reminder that war not only has immediate, pernicious consequences, but also longer, more underlying effects that must considered as well. Though, with the rise of drone warfare, carpet bombing and indiscriminant aerial violence may seem like a relic of the past, the 2001-2002 US air campaigns in Afghanistan suggests just the opposite. During the first six months of Operation Enduring

[19] I repeat this analysis with alternative measures of the dependent variable (the percent of field harvested) in Figures 13 and 21 in the Appendix. The results are similar to the ones presented here.

Freedom, the US Air Force attacked in ways that "maximized violence," including carpet bombing, dropping cluster munitions, and conducting weeks of air strikes (Chivers 2012). In 232 air strikes, the US dropped 248,056 bomblets over areas including Kabul, Herat, Mazar, the Shomali Plain, Kunduz, Kandahar, and Tora Bora. Soon after, journalists began reporting about the aftereffects of the cluster strikes – particularly, civilans killed by the unexploded ordnance that covered the country (Kaplow 2001; Chivers 2001; Watson and Getter 2001).

If aerial campaigns continue to be carried out in this manner, then the US bombing of Cambodia remains a salient topic today. When we debate the increasing American reliance on air power and drones to fight wars in Iraq, Afghanistan, Pakistan, and Syria, we should consider the long-term impacts of aerial bombs as well as the short-term. That is, we may need to divert some policy attention to understanding whether and where bomb-damaged land will be able to support economic development and growth in poor, rural areas in the decades following war.

6.1 Appendix

Table 2: Cross-tabulation of bomb intensity and soil fertility. Note two trends: 1) the equal distribution of households across the second and fourth rows (Low and High Bomb Tertiles). For these two treatment conditions, equal numbers of households are found across low and high fertility soil. 2) High fertility soil has more than triple the number of households in the control group and the medium bomb tertile group, compared to low fertility soil.

	Low Fertility Soil	High Fertility Soil
Control	110	372
Low Bomb Tertile	200	178
Medium Bomb Tertile	80	200
High Bomb Tertile	252	326

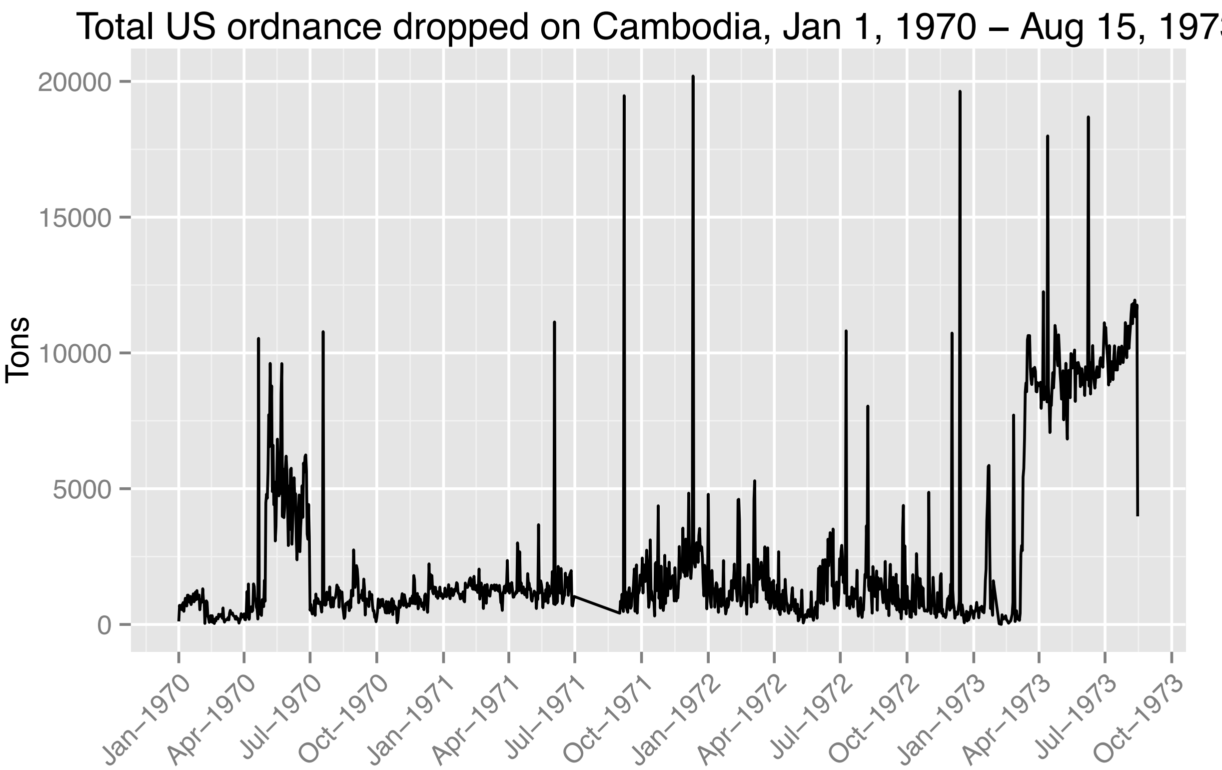

Figure 14: This plot represents the total ordnance dropped on Cambodia during the major air campaigns, from Jauary 1970 to August 1973. Although the archives includes sorties from October 1965 to December 1969 and August 1973 to May 1975, the ordnance released during these periods were minimal. They total 1.1 million pounds, which represents 0.01% of the total amount of explosive ordnance dropped over the course of the secret bombings.

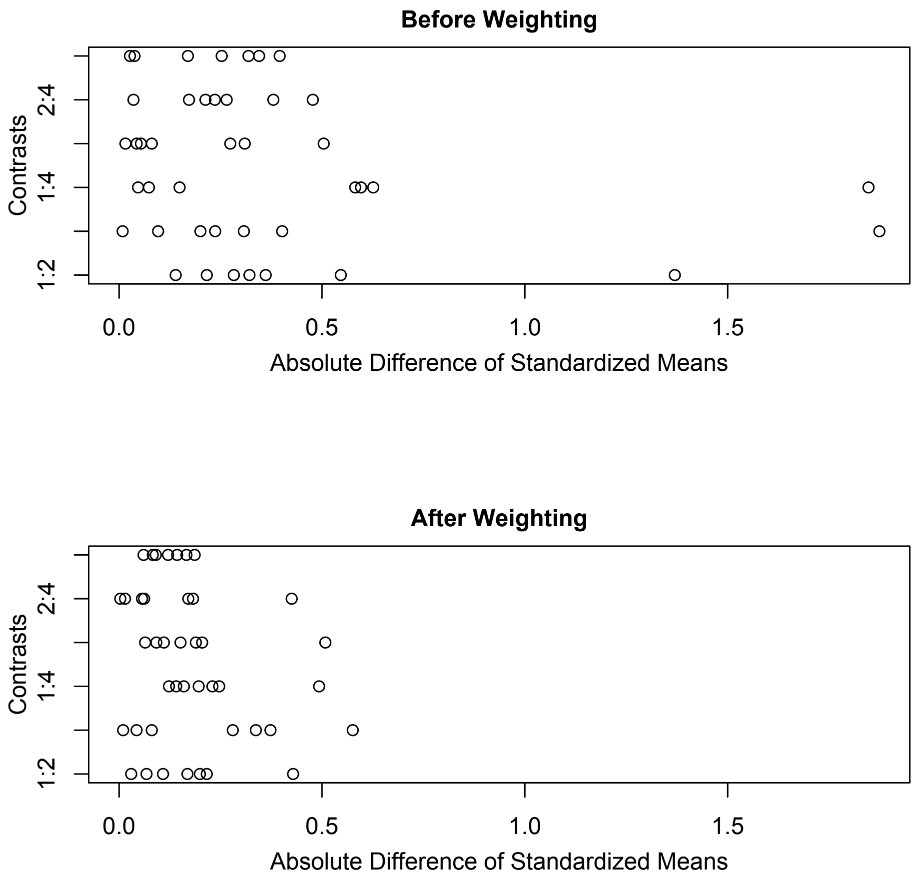

Figure 15: Covariate balance is improved when the absolute difference between the standardized means decreases after weighting.

Table 3: Bombs (discrete variable) and rice harvested

	Full (unweighted) sample		*CBPS Matched sample*	
	(1)	(2)	(3)	(4)
Panel A. Dependent variable: *Amount of rice harvested (USD/m^2)*				
Low Bombs	-0.106^{*}	-0.245^{***}	-0.081^{***}	-0.172^{***}
	(0.056)	(0.087)	(0.027)	(0.057)
Med Bombs	-0.129^{**}	-0.242^{***}	-0.115^{***}	-0.179^{***}
	(0.064)	(0.088)	(0.029)	(0.057)
High Bombs	-0.169^{***}	-0.282^{***}	-0.120^{***}	-0.203^{***}
	(0.063)	(0.082)	(0.026)	(0.052)
Low Fertility Soil	-0.053	-0.141	-0.017	-0.114^{*}
	(0.045)	(0.092)	(0.028)	(0.062)
Medium Fertility Soil	-0.066^{*}	-0.214^{***}	-0.015	-0.087^{*}
	(0.036)	(0.065)	(0.023)	(0.047)
Low Bombs: Low Fertility		0.128		0.122
		(0.127)		(0.082)
Med Bombs: Low Fertility		0.172		0.137
		(0.148)		(0.097)
High Bombs: Low Fertility		0.127		0.122
		(0.118)		(0.075)
Low Bombs: Med Fertility		0.241^{**}		0.114^{*}
		(0.100)		(0.065)
Med Bombs: Med Fertility		0.190^{**}		0.065
		(0.096)		(0.063)
High Bombs: Med Fertility		0.196^{**}		0.094^{*}
		(0.087)		(0.056)
Constant	-0.050	0.014	0.046	0.097
	(0.173)	(0.179)	(0.074)	(0.085)
R^2	0.014	0.016	0.012	0.013
Observations	3,617	3,617	3,617	3,617
Controls	✓	✓	✓	✓
Regional fixed effects	✓	✓	✓	✓

Notes: Columns (1) and (3) do not include the interaction term while columns (2) and (4) do. Low Bombs represents $0 >$ and < 500 tons of explosive ordnance dropped within 5 kilometers of the village. Med Bombs: > 500 and $< 2,000$ tons. High Bombs: $> 2,000$ tons. Controls include 1960 pre-treatment variables: the number of settlements, meters of highway, percent of land that is agricultural, major waterway in the 5 kilometer buffer. *p<0.1; **p<0.05; ***p<0.01

Table 4: Bombs (discrete variable) and amount of rice sold to market

	Full (unweighted) sample		*CBPS Matched sample*	
	(1)	(2)	(3)	(4)
Panel B. Dependent variable: *Amount of rice sold to market (% of total rice harvested)*				
Low Bombs	-0.148^{***}	-0.243^{***}	-0.274^{***}	-0.266^{***}
	(0.022)	(0.033)	(0.017)	(0.035)
Med Bombs	-0.133^{***}	-0.247^{***}	-0.270^{***}	-0.252^{***}
	(0.024)	(0.033)	(0.018)	(0.035)
High Bombs	-0.170^{***}	-0.286^{***}	-0.320^{***}	-0.280^{***}
	(0.024)	(0.031)	(0.016)	(0.032)
Low Fertility Soil	0.044^{***}	-0.173^{***}	0.046^{***}	-0.121^{***}
	(0.017)	(0.035)	(0.017)	(0.038)
Medium Fertility Soil	0.031^{**}	-0.065^{***}	0.060^{***}	0.130^{***}
	(0.014)	(0.025)	(0.014)	(0.029)
Low Bombs: Low Fertility		0.231^{***}		0.172^{***}
		(0.048)		(0.050)
Med Bombs: Low Fertility		0.257^{***}		0.171^{***}
		(0.056)		(0.059)
High Bombs: Low Fertility		0.344^{***}		0.228^{***}
		(0.045)		(0.045)
Low Bombs: Med Fertility		0.138^{***}		-0.045
		(0.038)		(0.040)
Med Bombs: Med Fertility		0.162^{***}		-0.053
		(0.037)		(0.039)
High Bombs: Med Fertility		0.138^{***}		-0.108^{***}
		(0.033)		(0.034)
Constant	0.205^{***}	0.301^{***}	0.307^{***}	0.304^{***}
	(0.066)	(0.068)	(0.045)	(0.052)
R^2	0.077	0.095	0.217	0.233
Observations	3,617	3,617	3,617	3,617
Controls	✓	✓	✓	✓
Regional fixed effects	✓	✓	✓	✓

Notes: Columns (1) and (3) do not include the interaction term while columns (2) and (4) do. Low Bombs represents $0 >$ and < 500 tons of explosive ordnance dropped within 5 kilometers of the village. Med Bombs: > 500 and $< 2,000$ tons. High Bombs: $> 2,000$ tons. Controls include 1960 pre-treatment variables: the number of settlements, meters of highway, percent of land that is agricultural, major waterway in the 5 kilometer buffer. *p<0.1; **p<0.05; ***p<0.01

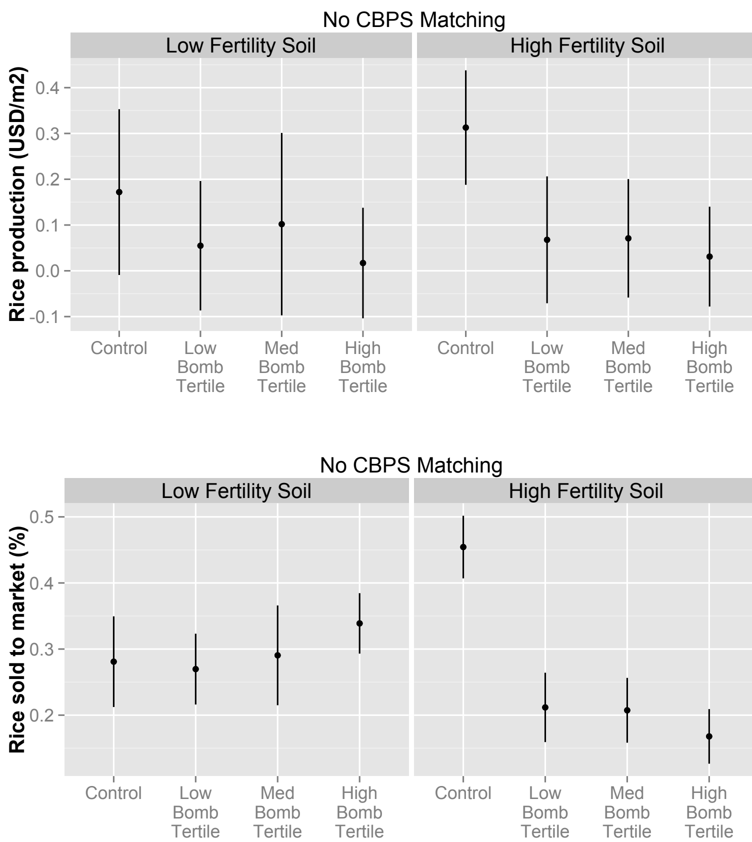

Figure 16: Predicted outcomes without matching. Notice how the results hold between the weighted and unweighted models.

Table 5: Bombs (discrete variable) and rice harvested

	Full (unweighted) sample		*CBPS Matched sample*	
	(1)	(2)	(3)	(4)
Panel C. Dependent variable: *Amount of rice harvested (kg/m^2)*				
Low Bombs	0.116	0.126	0.129*	0.128
	(0.121)	(0.137)	(0.067)	(0.082)
Med Bombs	−0.060	−0.129	−0.002	−0.056
	(0.110)	(0.131)	(0.069)	(0.084)
High Bombs	−0.453***	−0.445***	−0.346***	−0.352***
	(0.164)	(0.171)	(0.072)	(0.085)
Low Fertility Soil	0.122	0.074	0.036	0.038
	(0.114)	(0.122)	(0.074)	(0.081)
Medium Fertility Soil	0.101	0.103	0.009	0.016
	(0.094)	(0.099)	(0.060)	(0.064)
Low Bombs: Low Fertility		0.219		0.189
		(0.234)		(0.157)
Med Bombs: Low Fertility		−0.010		−0.048
		(0.253)		(0.168)
High Bombs: Low Fertility		−0.236		−0.216
		(0.219)		(0.144)
Low Bombs: Med Fertility		0.231		0.037
		(0.179)		(0.115)
Med Bombs: Med Fertility		−0.255		−0.151
		(0.187)		(0.124)
High Bombs: Med Fertility		−0.199		−0.005
		(0.173)		(0.104)
Constant	−0.625	−0.696	−0.123	−0.169
	(0.577)	(0.587)	(0.250)	(0.263)
R^2	0.013	0.015	0.012	0.013
Observations	3,617	3,617	3,617	3,617
Controls	✓	✓	✓	✓
Regional fixed effects	✓	✓	✓	✓

Notes: Columns (1) and (3) do not include the interaction term while columns (2) and (4) do. Low Bombs represents $0 >$ and < 500 tons of explosive ordnance dropped within 5 kilometers of the village. Med Bombs: > 500 and $< 2,000$ tons. High Bombs: $> 2,000$ tons. Controls include 1960 pre-treatment variables: the number of settlements, meters of highway, percent of land that is agricultural, major waterway in the 5 kilometer buffer. *p<0.1; **p<0.05; ***p<0.01

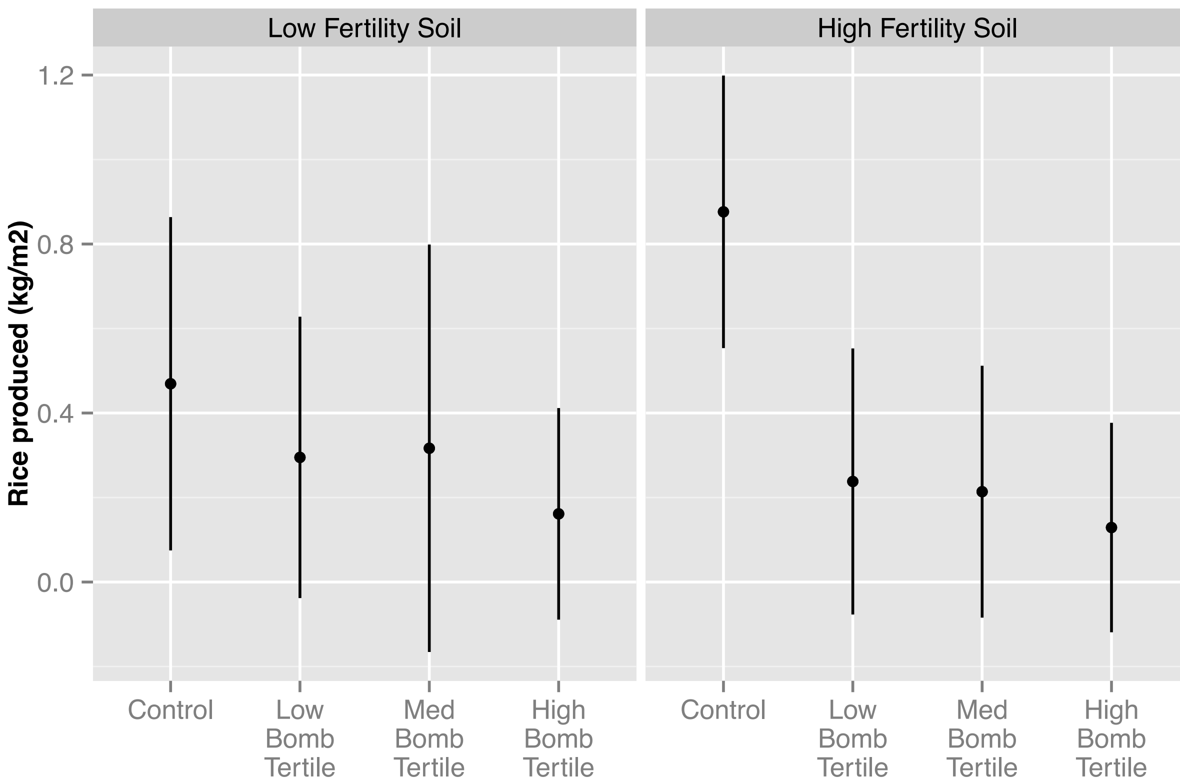

Figure 17: Even when rice output is measured in a second way (kilograms of rice/m2 of rice paddy), the results are the same.

Table 6: Bombs (discrete variable) and rice harvested. Buffers have a 3 kilometer radius.

	Full (unweighted) sample		*CBPS Matched sample*	
	(1)	(2)	(3)	(4)
Panel D. Dependent variable: *Amount of rice harvested (USD/m^2)*				
Low Bombs	-0.046	-0.175^{**}	-0.040^{*}	-0.091^{**}
	(0.046)	(0.079)	(0.024)	(0.045)
Med Bombs	-0.093^{*}	-0.195^{**}	-0.078^{***}	-0.095^{**}
	(0.050)	(0.077)	(0.025)	(0.046)
High Bombs	-0.085^{*}	-0.230^{***}	-0.058^{**}	-0.126^{***}
	(0.052)	(0.079)	(0.026)	(0.049)
Low Fertility Soil	-0.039	-0.137^{*}	-0.020	-0.084
	(0.045)	(0.075)	(0.028)	(0.052)
Medium Fertility Soil	-0.066^{*}	-0.191^{***}	0.001	-0.042
	(0.035)	(0.056)	(0.022)	(0.041)
Low Bombs: Low Fertility		0.170		0.107
		(0.113)		(0.072)
Med Bombs: Low Fertility		-0.061		-0.013
		(0.154)		(0.080)
High Bombs: Low Fertility		0.201^{*}		0.132^{*}
		(0.109)		(0.074)
Low Bombs: Med Fertility		0.188^{**}		0.061
		(0.093)		(0.056)
Med Bombs: Med Fertility		0.178^{**}		0.030
		(0.088)		(0.055)
High Bombs: Med Fertility		0.211^{**}		0.081
		(0.088)		(0.058)
Constant	-0.140	-0.084	-0.052	-0.052
	(0.165)	(0.168)	(0.075)	(0.077)
R^2	0.020	0.023	0.009	0.011
Observations	3,617	3,617	3,617	3,617
Controls	✓	✓	✓	✓
Regional fixed effects	✓	✓	✓	✓

Notes: Columns (1) and (3) do not include the interaction term while columns (2) and (4) do. Low Bombs represents $0 >$ and < 200 tons of explosive ordnance dropped within 3 kilometers of the village. Med Bombs: > 200 and $< 1,000$ tons. High Bombs: $> 1,000$ tons. Controls include 1960 pre-treatment variables: the number of settlements, meters of highway, percent of land that is agricultural, major waterway in the 3 kilometer buffer. *p<0.1; **p<0.05; ***p<0.01

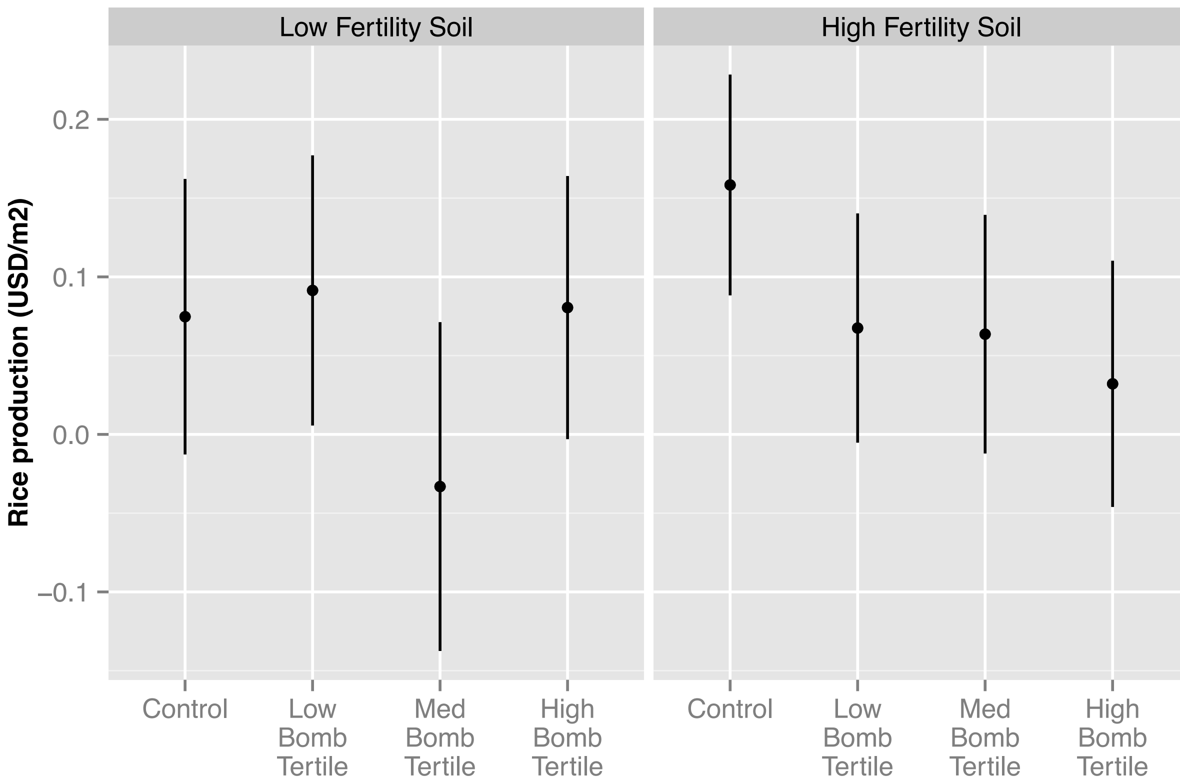

Figure 18: The predicted rice outputs when the buffers are 3 kilometers rather than 5 kilometers. The results are similar between the two buffer lengths.

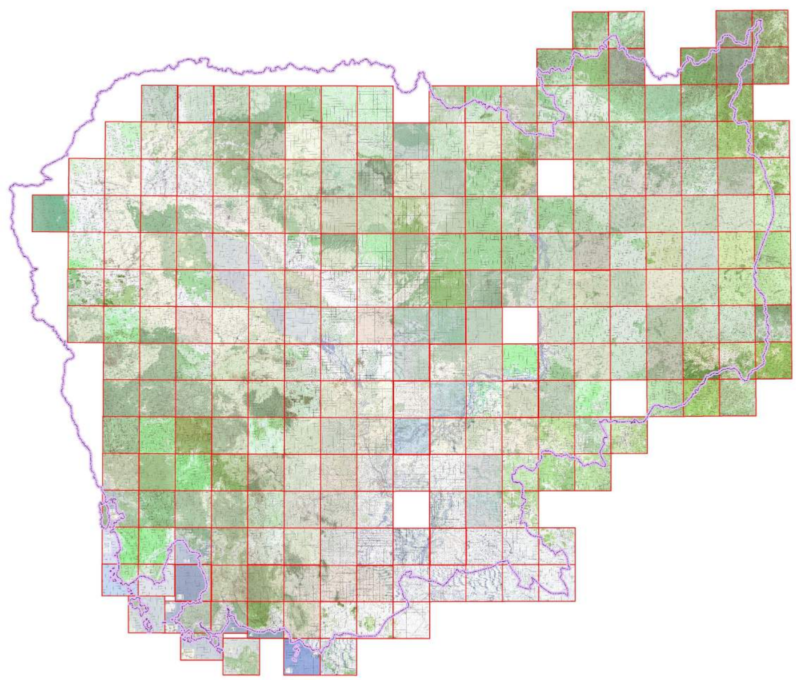

Figure 19: Spatial coverage of 1960 US military maps (283 of 288 total panels)

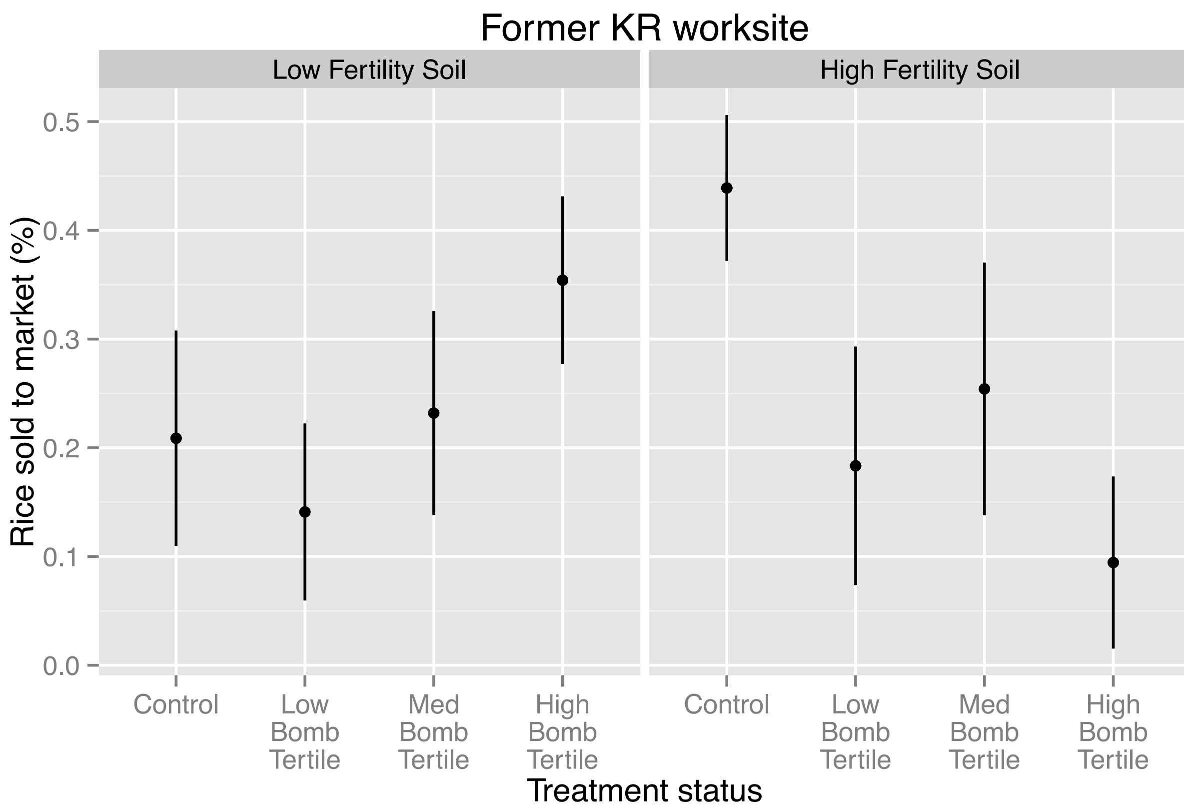

Figure 20: Predicted harvest for the year, according to land fertility (each panel) and bomb intensity (horizontal axis). Note how control households in high fertility land produce more rice than the households in any of the treatment conditions. This suggests that even high rates of genocide do not change the long-term effect bombing has on local development.

Table 7: Household plots located within major Khmer Rouge work zones

	Dependent variable:	
	Rice harvested	Rice sold to market
	(1)	(2)
Low Bombs	-0.491^{**}	-0.256^{***}
	(0.195)	(0.058)
Med Bombs	-0.443^{*}	-0.185^{***}
	(0.230)	(0.068)
High Bombs	-0.385^{**}	-0.344^{***}
	(0.163)	(0.049)
Low Fertility Soil	-0.200	-0.230^{***}
	(0.167)	(0.050)
Medium Fertility Soil	-0.267^{**}	-0.015
	(0.126)	(0.037)
Low Bombs: Low Fertility	0.280	0.188^{**}
	(0.262)	(0.078)
Med Bombs: Low Fertility	0.361	0.208^{**}
	(0.302)	(0.090)
High Bombs: Low Fertility	0.046	0.490^{***}
	(0.249)	(0.074)
Low Bombs: Med Fertility	0.531^{**}	0.064
	(0.223)	(0.066)
Med Bombs: Med Fertility	0.344	0.011
	(0.240)	(0.072)
High Bombs: Med Fertility	0.257	0.092^{*}
	(0.176)	(0.052)
Constant	-0.292	0.453^{***}
	(0.320)	(0.095)
R^2	0.028	0.104
Observations	2,125	2,125
Controls	✓	✓
Regional fixed effects	✓	✓
CBPS weights	✓	✓

Notes: Low Bombs represents $0 >$ and < 500 tons of explosive ordnance dropped within 5 kilometers of the village. Med Bombs: > 500 and $< 2,000$ tons. High Bombs: $> 2,000$ tons. Controls include 1960 pre-treatment variables: the number of settlements, meters of highway, percent of land that is agricultural, major waterway in the 5 kilometer buffer. *p<0.1; **p<0.05; ***p<0.01

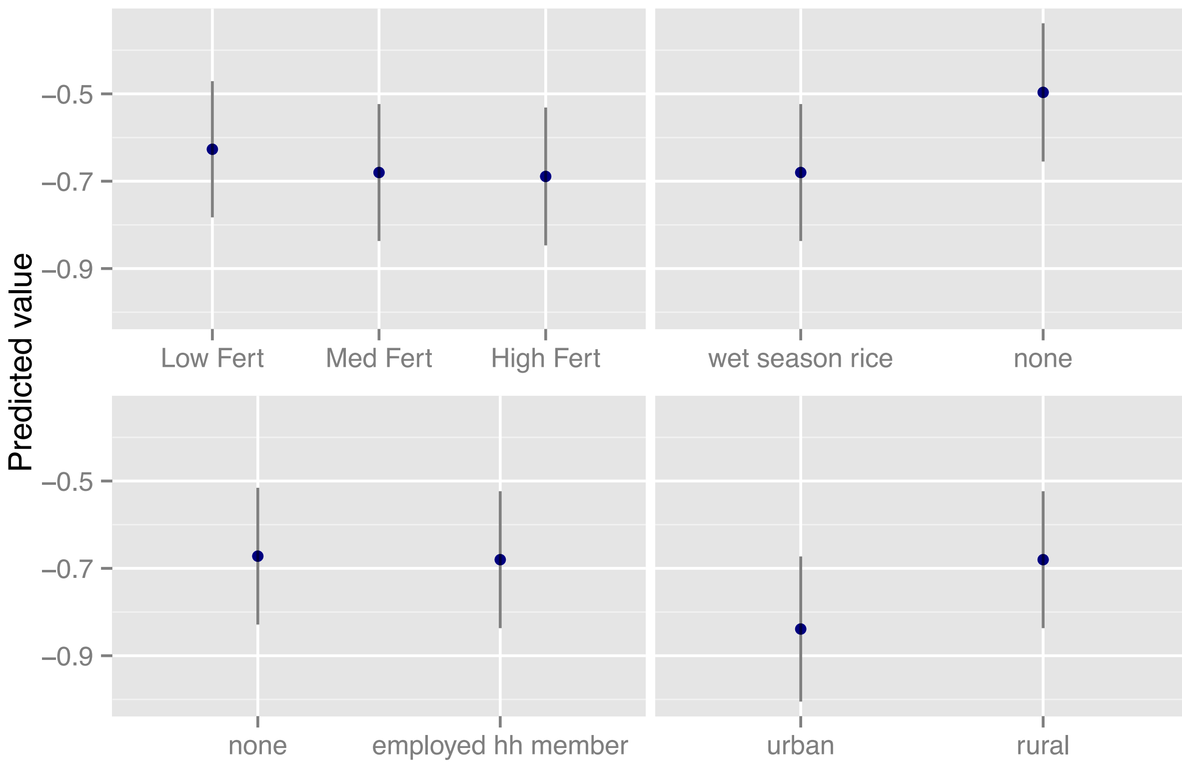

Figure 21: Predicted amount of rice sold (% of total harvest), based on an OLS regression of contemporary variables. I compute quantities of interests through the most common way – setting the explanatory variables at their means (the default) and changing the treatment variable from the minimum to the maximum quantity.

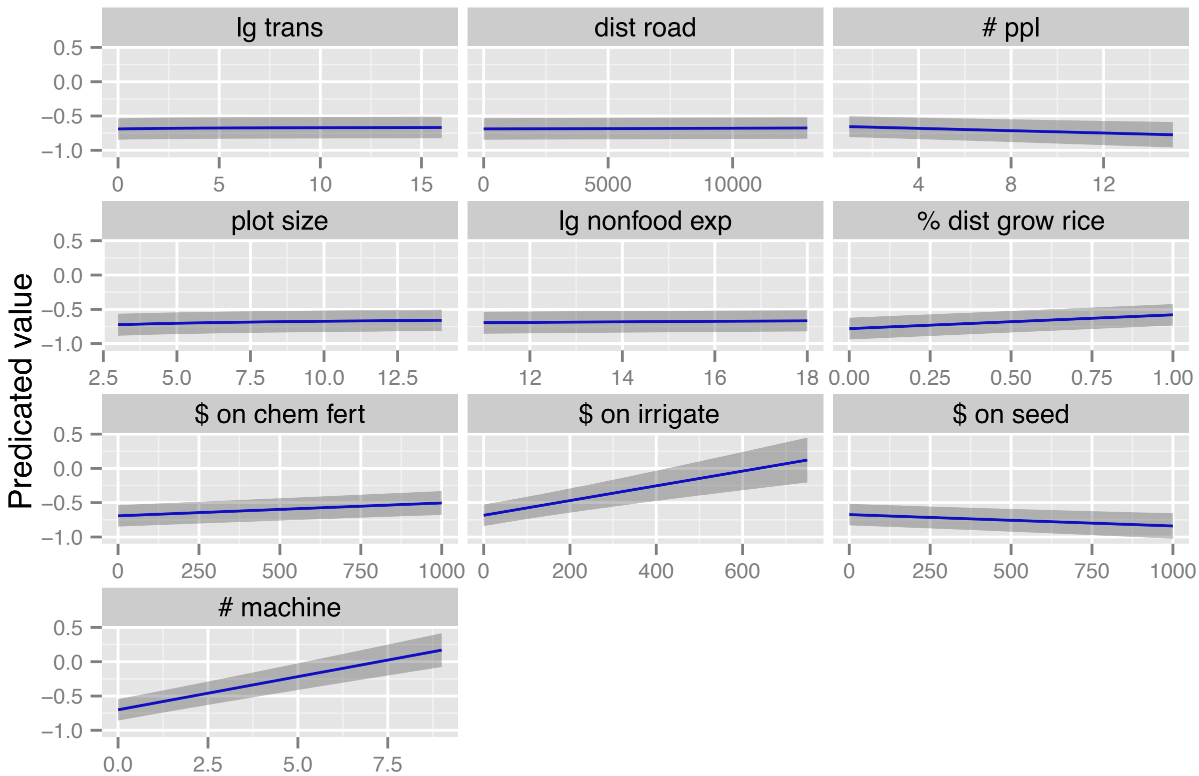

Figure 22: The predicted values are calculated in the same way as before. Here are the results for the continuous variables: the logged transport costs (logged Khmer Riels), distance from road (meters), number of people in the family, the plot size, the logged expenditure on nonfood idtems, the percent of the district that grows rice, the money spent on fertilizer (USD), the money spent on irrigation (USD), the money spent on rice seed (USD), and the number of machines that the household owns.

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