HOW WAR CHANGES LAND
THE LEGACY OF US BOMBING ON CAMBODIAN DEVELOPMENT

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Abstract

Political scientists and economists have recently begun to explore why post-conflict political communities vary substantially in the speed and consistency with which they create economic growth following war. There are many existing explanations for this variation, including capital flight, death tolls, loss of social capital, weakened institutions, and the role of international intervention, particularly concerning issues like natural resource governance, aid flows, and military peace-keeping. I offer a new explanation.

I develop a theory of whether and where agrarian economies will recover from war based on the amount of unexploded ordnance left on their land and the consequential long-term impact on rice paddy production and agricultural investment. Unexploded ordnance change people’s relationship with land, due to the fact that farming becomes a dangerous and life-threatening activity. Then, I argue that people’s adaptations to their new post-conflict geography have political consequences. Specifically, unexploded ordnance create physical barriers that limit the state’s ability to provide public goods, which negatively impacts electoral returns for the incumbent party.

Drawing from a declassified dataset of US Air Force sorties flown over Cambodia during the Vietnam War, I identify the location and density of unexploded ordnance by highlighting a mechanism that is well-known in the warfare ecology literature but not elsewhere: that fertile ground provides more of a cushion for the bomb upon impact, so the trigger fuse is less likely to detonate. I show, using a range of archival and contemporary data, that in highly fertile soil, this mechanical failure still impacts land production to this day as the unexploded ordnance in the ground deter farmers from efficiently using their land. I find evidence of secondary effects on an array of economic and political variables, including household poverty, capital accumulation, distribution of state resources, and vote choice.
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To my parents, Yen and Jack, and my sister, Ines.
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Chapter 1

The long-term costs of war:

Looking past the post-conflict decade

Now there are lots of leftover bombs, unexploded ordnance of America, so America should pay more to Cambodia, Vietnam and to take responsibility. But they don't.

Hun Sen, Prime Minister of Cambodia, March 2017
From a panel at World Economic Forum in Davos, Switzerland.

From 1965 to 1973, the US dropped roughly 500,000 tons of explosive bombs onto eastern Cambodia, in an effort to cut off supply routes used by the Viet Cong. While bombs fell upon villages and rural areas, some 2 million farmers, according to Chhang Song, the Information Minister at the time, abandoned their rice paddies and fled to the capital, Phnom Penh. Severe food shortages soon followed, due to the fact that so many people had left the countryside, there was no one left to produce crops.

While the Air Force was bombing the countryside, the US State Department was simultaneously supporting the anti-Communist government in Phnom Penh. This US-allied government, called the Khmer Republic and led by Lon Nol, borrowed $274 million from the US under the “Food for Peace” program, to buy American cotton, rice, oil, and flour.
from the US Department of Agriculture. Today, none of this war-era debt has been repaid. The amount that the Cambodian government owes has climbed to $506 million, including interest and late fees.

Since the 1990s when Cambodia began to stabilize after decades of civil war, the two countries have disagreed on whether or not this debt should be forgiven. The US has insisted on repayment, though it would allow the rescheduling of payments on favorable terms. Yet Cambodia refuses to service the loan, and the unpaid loan has restricted the developing country’s ability to borrow internationally. Instead, the country has become more dependent on soft loans from China, which has provided money to Cambodia since the Khmer Rouge and has already forgiven some of Cambodia’s smaller debts as well as $89 million of more recent debts last year.

Cambodian officials, instead, emphasize the US government’s moral obligation to repair the long-term damage caused by the carpet bombing. Prime Minister Hun Sen has launched a full-scale media campaign, highlighting the lingering effects of the US aerial campaign on Cambodian society. In a speech at the Sea Festival in Sihanoukville, Cambodia, Hun Sen stoked the fire, telling the audience, “I hope the government of Mr. Donald Trump will think about the debt Cambodia owes the United States from the Khmer Republic of General Lon Nol. Should the debt be canceled?” To make his argument, his media campaign focuses on American unexploded ordnance (UXO) left in Cambodia, and points out the continuing harm that UXO inflict on the country. In January 2017, the Cambodia government announced that it would evacuate hundreds of villagers in Koki Commune, so it could remove two tear gas bombs leftover from the US secret bombing. Then in March, the Khmer media reported

Ironically, most of the food aid ended up financing the Cambodian military. Under the Food for Peace program, the Cambodian government bought American commodities and was allowed to sell them on the commercial market. Roughly 80% of the money went into the military budget. This program was largely seen as a way for Nixon and Kissinger to bypass Congressional efforts to limit investment in Indochina. Yet, this extra investment led to uncontrolled corruption, where for instance $2 million a month were used to pay “ghost soldiers,” non-existent people whose salary ended up padding the wages of military officers.
on the removal of two 500-pound general purpose bombs from Tonle Sap lake after fishermen had reported them to local authorities.

Scholars of development economics suggest that unexploded ordnance have the potential to stunt local economies. In “Breaking the Conflict Trap,” Paul Collier and co-authors suggest that the dangers created by the high rate of land contamination (46% of all villages had areas contaminated by UXO and mines in 2001) continue to severely disrupt normal daily activities, including the ability to access “homes, agricultural land, pastures, water sources, forests, schools, dams, canals, markets, business activities, health centers, pagodas, bridges, and neighboring villages” (2003, p.31). They state that unexploded ordnance constitute “a serious obstacle to economic and social recovery” (2003, p.31).

This idea that unexploded ordnance create barriers to post-conflict development directly contradicts the recent economic findings on the long-term impact of bombings. From the fire bombs of World War II to the carpet bombs of the Vietnam War, bombing was found to have little lasting effect on post-war development (Davis and Weinstein 2002; Dell and Querubin 2016). Though death tolls were high, the post-war baby boom brought populations back to pre-war levels (Brakman, Garretsen, and Schramm 2004). The destroyed physical infrastructure was resupplied and redistributed once war was over (Miguel and Roland 2011). In South Vietnam, Dell and Querubin find that “moving from no bombing to sample mean bombing over the course of the war increases equivalent household consumption by a little more than three percentage points, but the results are not statistically different from zero” (2011, p.20). In fact, bombing does not have a significant impact on any long-term outcomes, including land ownership, days spent ill, the share of people employed in state, private, or foreign sectors, and whether local firms have favorable access to land, loans, or administrative procedures (Table A-13). Miguel and Roland, using an instrumental variable method rather than Dell and Querubin’s regression discontinuity design, find evidence of the same trend:
bomber has no negative effect on “local poverty rates, consumption levels, infrastructure, literacy or population density through 2002” (2016, p.1).

Yet when these scholars examine the effect of aerial bombardment, they tend to focus on the immediately destructive “shock,” assuming that released bombs explode and destroy targets within the drop radius (Brakman, Garretsen, and Schramm 2004; Davis and Weinstein 2002; Kocher, Pepinsky, and Kalyvas 2011; Lyall 2013; Miguel and Roland 2011; Pape 2014). I take a new approach. I turn to an interdisciplinary literature from warfare ecology, which examines the variation in weapons failure when bombs hit different types of terrain. In some contexts, up to 30% of bombs fail to detonate, leaving a trail of unexploded ordnance that fundamentally alters the ability of survivors to access and cultivate bombed land (McGrath 2000; McGrath and Lloyd 2000). This suggests that bombs can exert two different types of damage. While detonated bombs create immediate, physical damage, undetonated bombs have latent, unexamined effects on development – effects that are potentially washed away when these two categories are collapsed together.

What are these long-term, unexamined effects? I argue that unexploded ordnance change people’s relationship with land. For instance, two-thirds of irrigation systems in Afghanistan are not fully operational today, mostly due to the fact that landmines prevent routine maintenance and desilting. Since 85% of all crops are grown under irrigation, thousands of farmers are forced to cultivate a smaller yield (Byrd and Gildestad 2001). In Sri Lanka, coastal villages within the Jaffna High Security Zone, a heavily mined battlefield, were entirely abandoned, and residents who once depended on fishing for a living were forced to find alternative sources of agricultural or urban employment (HALO Trust 2016). We know from policy reports that people living on contaminated land have to worry about food insecurity, alternative sources of transit and employment, and a risk of death anytime they try to use their land.
However, scholars are fundamentally uncertain as to whether and when these grievances trigger social instability by, for instance, creating new migratory shifts toward safe land and urban centers, weakening local institutions, and breeding incentives to participate in criminal and political violence. My objective is to demonstrate how war can physically damage land and how people’s adaptations to post-conflict geography have economic and political consequences. I seek to demonstrate how land is a fundamental, but forgotten, driver of economic performance, and can determine whether a society recovers, stagnates, or plunges back into war.

These changes to land have important theoretical consequences as well, particularly in how we conceptualize the costs of war and the degree to which invading countries are obliged to repair the damages they created. For instance, the US State Department argues that the Cambodian state can afford to pay back its war debt, since the Cambodian economy has finally graduated to lower-middle income status; the gross domestic product last year was about $19 billion. In the same vein, the State Department has suggested that by contributing $77.6 million to pay for the removal of unexploded ordnance, it has sufficiently made up its own debt to Cambodia.

However, I suggest that the economic legacies of war persist much longer than previously accepted. The majority of scholarly work on the social and economic costs of war tends to focus on the immediate impacts, in what Paul Collier terms the “post-conflict decade” [Collier, Elliott, Hegre, Hoeффler, Reynal-Querol, and Sambanis 2003]. In the first ten years of peace, he argues that the speed of recovery substantially contributes to the risk reduction of falling back into conflict [Collier, Hoeффler, and Söderbom 2008]. He concludes that the economy matters for peace, particularly in this formative stage of post-conflict stabilization.

2Meanwhile, the Cambodian state is quick to point out that the US bombing led to a refugee crisis that destabilized the country and created so much anti-American sentiment that it drove people to embrace the ultra-communist Khmer Rouge alternative. Most historians have attributed the rise of the Khmer Rouge to other political factors, including Prince Sihanouk’s alliance with the Khmer Rouge and rampant corruption under Lon Nol.
Scholars of post-conflict reconstruction are justifiably preoccupied with this important time period. Foundational studies on the effects of programmatic, post-conflict aid examine programs that take place only a few years after the end of conflict. While these studies vary in topic — from rebuilding social capital (Fearon, Humphreys, and Weinstein 2009; Paluck and Green 2009) and reintegrating ex-combatants (Daly, Paler, and Samii 2015; Gilligan, Pasquale, and Samii 2014) to creating more inclusive political institutions (Beath, Christia, and Enikolopov 2013a; Samii 2013) — they all focus on the same time period: the ten years that follow the end of war.

Focusing on this time period certainly helps us understand how to stabilize fragile states in the short-run, but it means that we unintentionally overlook certain legacies of war that can persist through time. This dissertation highlights one previously neglected variable. Unexploded ordnance are a remnant of war that often remain in the ground decades after the end of conflict. In fact, unexploded ordnance are a legacy of war that still impacts one-third of the countries in the world today. Figure 1.1 displays the countries with casualties from unexploded ordnance in 2012, and we can see that much of the developing world – Asia, the Middle East, Latin America, Eastern Europe – are hindered by UXO. Because they are difficult and dangerous to remove, UXO continue to directly impact the lives and livelihoods of the people who remain on post-conflict land. However, we are ill-informed on how UXO systematically can block growth and create poverty traps.

1.1 The argument

This dissertation demonstrates how an understanding of weapons technology and local environmental conditions can account for why post-conflict political communities vary substantially in the speed and consistency with which they create post-war economic growth. In its simplest form, the dissertation argues that local poverty traps are formed when bombs fail to detonate, and remain in the land, as latent weapons, for many years to come. The
Figure 1.1: One-third of the countries in the world still have casualties from unexploded ordnance.
fear of encountering UXO – more bluntly, the fear of injury or death – are internalized by
individuals and their communities through local communication and personal experience.
These collective fears are preserved and reinforced by local communities in a way that has
two major consequences. First, these fears keep people safe, but they also encourage farmers
to choose economic strategies that prioritize risk-aversion over profit-maximization. This
particular post-conflict geography makes the decision zero-sum, and the dominant choice
leads individuals into a poverty trap.

More broadly, my argument is part of a growing area of research at the intersection of
political economy and environmental studies. I argue that standard explanations of develop-
ment often assume that the environment is an exogenous, structural variable. While scholars
of political geography are closely attuned to the impact of natural resources, weather, and
agricultural land on political outcomes, their accounts use geography as a “random” shock
to human behavior, and do not discuss the ways in which human behavior can modify the
surrounding environment. I propose that political actors, through war, can change nat-
ural 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.

1.2 Empirical strategy of the dissertation

For most post-conflict countries where we would want to examine the effects of unexploded
ordnance on development, there are no comprehensive land surveys or predominant methods
for determining where UXO are located and how densely they are distributed across land.
Unexploded ordnance are difficult to find, oftentimes hidden underneath several inches of
ground. It remains a challenge for farmers, clearance teams, and aid organizations to iden-
tify contaminated areas. While scholars have noted the importance of unexploded ordnance,
studies have been limited by our inability to identify the location and density of these leftover
bombs. For instance, Miguel and Roland state that unexploded ordnance are an important factor in explaining contemporary economic development in Vietnam, but they cannot include this variable in the main analysis because they “do not have complete information on unexploded ordnance” (2011, p.2).

This project aims to improve current knowledge on unexploded ordnance and post-conflict development with the use of geospatial methods. Traditionally, policy makers and aid organizations have relied on high-risk methods to detect the location of unexploded ordnance, like in-person metal detection of contaminated areas where people have already died from UXO. However, these methods require a team of experienced deminers, who can only cover small amounts of land at a time, and teams in the most heavily contaminated countries (like Laos, Cambodia, Colombia, Afghanistan, Angola) have surveyed only a small percentage of suspected UXO land in their respective countries. I rely on the exogenous variation of bomb failure – due to the fact that the impact fuses are more likely to detonate when they hit hard terrains. I highlight a mechanism that is well-known in the warfare ecology literature but not elsewhere: that fertile ground provides more of a cushion for the bomb upon impact, so the trigger fuse is less likely to detonate. This method combines declassified US Air Force data on payload drop sites from the secret bombing of Cambodia with detailed maps of terrain features. I identify the areas that have been bombed, separating them by low soil fertility (where we should expect low failure rates and less unexploded ordnance) and high soil fertility (where we should expect high failure rates and more unexploded ordnance). My dissertation combines archival research with spatial analysis to produce a novel measure of land contamination.

With this strategy in mind, this dissertation employs a multi-layered research design. At the core of the manuscript lies a comparison of production levels of more than 3,600 nationally-representative household rice paddies in Cambodia. This approximates a quasi-random experiment that tests how unexploded ordnance affect farming practices. The rice
paddies, whose locations were geo-coded for this project, are very close to ideal cases for differentiating the effects of post-conflict geography from other alternative explanations. At the time bombs were dropped during the Vietnam War, the US military had used detailed topographic maps to plan the sorties. Because these maps include the placement of rice paddies, households, local markets, paved roads, raised clay walking paths, and barren land, I can determine the local factors that might correlate with bomb density and campaigns, and match rice paddies to ensure that they differ in their exposure to unexploded ordnance but not in other relevant characteristics. The detail in this type of micro-level comparison allows for both the identification of the effects of bombing and the ability to trace the causal mechanisms that link one particular aspect of bombing – bombs that fail to detonate – to long-term development outcomes. Using original source materials gathered from ten months of fieldwork, I trace the most direct impact that unexploded ordnance have on the daily livelihoods of rural Cambodians.

The second layer is an examination of a broader range of economic outcomes. I show that differences in the household’s exposure to unexploded ordnance, combined with other contextual variables, go a long way in predicting whether the household will take advantage of Green Revolution technologies. Specifically, do households on contaminated land invest in industrial equipment, improved rice seed, fertilizer? Drawing on closed archives of the Cambodian Ministry of Planning, I use several questions from the Cambodia Socioeconomic Survey to show that the varying rates of bomb failure, determined by the softness of the soil in the target zone, shape local economic inequalities in the long-run. In particular, individuals in contaminated areas cannot take advantage of recent advances in farming technology, so the Cambodian rural economy is becoming increasing segmented into low producers (who happen to live on unsafe land) and high producers (who tend to live on safe land). This suggests that when a bomb drops, but does not explode, the effects radiate outward, from individual livelihoods to the village economy.
A third empirical layer takes the argument outside of farming communities and into the realm of state-society relations. How does the state distribute resources in a country that is a literal minefield? In turn, how do local communities respond when they receive their allocation? I propose that unexploded ordnance discourage the state from providing public goods in risky areas. Perhaps unsurprisingly, these places – which are stuck in poverty traps in addition to lacking access to public services – tend to vote for opposition parties, which is no small act in Cambodia, a country that has been ruled by the same man (Hun Sen) and same party (the Cambodia People’s Party) for the past thirty years. This suggests that unexploded ordnance, while clearly impacting the day-to-day lives of local constituents, continue to have ripple effects that permeate electoral outcomes and public service provision.

1.3 Structure of the dissertation

The chapters of the dissertation are organized thematically to show how this core insight about the exposure to unexploded ordnance contributes to the explanation of substantive problems, including subsistence farming, economic inequality, and state-society relations. The next three chapters trace out the spread of unexploded ordnance and show its impact on the economy and politics of Cambodia. Chapter 2 demonstrates in detail how the carpet bombing brought different levels of risk to Cambodian farmers today, depending on soil fertility of the area where the bomb was dropped. I find that bombing in high fertility land results in a contemporary decline in rice production and an increased likelihood of subsistence farming due to higher amounts of unexploded ordnance, which makes farming a dangerous and potentially life-threatening activity. Chapter 3 then identifies the patterns of rural inequality in Cambodian villages on safe versus dangerous land, showing that there are clear spatial patterns in how agrarian households invest in industrial equipment and Green Revolution technologies, like high-yield rice seed, fertilizer, and irrigation. The poverty that farmers on contaminated land experience is set off by two inter-related factors: their subsis-
tence levels of production compounded by their inability to adopt new farming technologies. Chapter 4 then takes up the question of the state’s role in post-conflict development, and demonstrates the constraints that unexploded ordnance place on the state’s ability to distribute goods to dangerous land. It first shows that bombing correlates highly with lower levels of infrastructure; in the case of sewer provision, which involves digging up land, this negative relationship is larger in high fertility land, where we would expect more unexploded ordnance. The chapter then provides evidence of that this drop in service provision leads to more people voting for the opposition party, which suggests that long-term clientelistic relationships may be a better predictor of vote choice than short-term vote-buying strategies. In the concluding chapter, I draw out the implications of the durability of unexploded ordnance and discuss future plans to extend these findings across space and time to the legacy of air strikes in the Middle East, particularly in Afghanistan and Iraq, where the United States has contributed to scores of stabilization, development, and peacebuilding missions. However, policy-makers are still fundamentally uncertain as to what interventions are most successful at creating economic opportunities in such environments. Unlike most post-conflict reconstruction research, which focuses on rebuilding human and physical capital, this dissertation suggests that it is our own undetonated weaponry that creates long-term “poverty traps” which stand in the way of local economic development.
Chapter 2

Dangerous land:

The agricultural impact of US bombing of Cambodia

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.

2.1 Introduction

The village of West Father Long lies about five kilometers out of Kampong Thom town, Cambodia, in the southerly direction. Dirt paths run east and west, letting bicycles and farmers travel from the hamlet to the rice paddies, but the only route that travels with any suggestion of efficiency is Highway 6, a paved, two-lane road on which tour buses, jammed
full, carry tourists from Phnom Penh, the capital, to the Angkor Wat ruins near Siem Reap. The landscape is remarkably verdant, but unattended: lopsided rectangular plots of paddy land; pools of fresh rainwater that fill the plots, bordered by raised clay to separate them; the rattan overgrowth and vine-like weeds that take over most paddies, except for certain edges near the dirt paths, where villagers have planted some rice seedlings.

The loose, high-absorption soil, called *Krakor* locally, makes the land ideal for growing rice. For a good harvest, fertilizer need not be applied, nor irrigation lines installed. The village’s location, too, makes it easy to sell surplus rice since it is a short ride on Highway 6 to Kampong Thom market, the busiest in the province. But in reality half the village’s plots lay fallow. Those who do cultivate their land only grow enough for their own consumption, planting 15 to 30% of their field. No one brings their crop to market. And, most of the villagers are poor.

In 2012, the median amount a household spent on non-food items was $502 – for the entire year. This is approximately the cost of a used motorbike. By comparison, in Sweet Gum Tree village, only two and a half kilometers down the road, the median household spent $300 more on non-food purchases that same year. Here, the rice paddies are lush, well-tended, and planted 40 to 50% of their total capacity. Farmers produce triple the amount of rice as in West Father Long Village, both by weight and by price, and excess rice is sold to market.

Unlike in West Father Long, a thick layer of sandy soil, known as *Prateah Lang*, covers much of the area surrounding Sweet Gum Tree village. It is dry and constantly loses water, so irrigation tubes and make-shift water pumps are necessary to supplement the rain. When the water seeps through the surface soil to the subsoil, it takes nutrients with it. To help out the seedlings, most farmers spread chemical fertilizer after transplanting.

So why do people, where the land is worse, grow more rice and make more money – especially when farmers in both villages have good access to the nearby town market to sell their surplus? I believe part of the answer lies in the region’s history of conflict. Both
villages were part of a targeted area in two US aerial strikes (one in 1971 and another in 1973). More than 12,000 unique bombs, weighing a total of 49,000 tons, were dropped in the district, an area roughly one-third the size of Manhattan.

Between 1965 and 1973, Cambodians saw 500,000 tons of US Air Force ordnance drop onto its rice fields, villages, and people, in an effort to root out Vietnamese Communists from the Cambodian countryside. More than a half-century later, it seems as if the effect of the bombing is somewhat mixed. On some bombed land, one can see “crater lakes” in the rice paddies, visible pock-marks of the bombing, which do not seem to hinder agricultural production today. Other bombed areas remain untouched or sparsely planted. 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 this question, I examine the role of soil fertility and bombing intensity on present-day agricultural output and planting decisions. Within the weapons literature, it is widely known 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 in fertile land as the level of historic bombing intensity increases, 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.

In this chapter, I explore the long-run effects of war on agricultural development. 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 contemporary survey data from the closed archives of the Cambodian Ministry of Planning. This chapter 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?

I test this theory using highly spatially disaggregated measures that overcome some of the limitations of district-level data used in prior studies (Kocher, Pepinsky, and Kalyvas 2011; Miguel and Roland 2011). 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 in the amount of rice sold to market. 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 four distinct ways. First, studies on the effects of war on social cohesion (Beath, Christia, and Enikolopov 2013b; Fearon, Humphreys, and Weinstein 2009; Humphreys, De La Sierra, and Van Der Windt 2012; Paluck and Green 2009), economic development (Collier, Elliott, Hegre, Hoeffler, Reynal-Querol, and Sambanis 2003; Sachs 2006), and future conflict (Collier, Elliott, Hegre, Hoeffler, Reynal-Querol, and Sambanis 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 demonstrating 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 (Cilliers, Dube, and Siddiqi 2015; Fearon, Humphreys, and Weinstein 2009; Gilligan, Pasquale, and Samii 2014) and encouraging capital investment (Collier 1999; Collier, Elliott, Hegre, Hoefler, Reynal-Querol, and Sambanis 2003) to labor-specific strategies, such as repopulating the labor supply (Brakman, Garretsen, and Schramm 2004; Davis and Weinstein 2002) and preventing recidivism (Blattman and Annan 2010; Blattman, Jamison, and Sheridan 2017; Daly, Paler, and Samii 2015). By focusing on development strategies that resupply capital and labor, this literature has ignored a key factor endowment – land – and has not yet identified the ways that war can fundamentally change the nature of the landscape. Finally, the literature associated with political geography (Acemoglu, Johnson, and Robinson 2002; Diamond 1999; Herbst 2000; Miguel, Satyanath, and Sergenti 2004; Ross 2006; Sachs 2001, 2003) is closely attuned to the impact of natural resources, weather, and land topography on political outcomes. Unlike the predominant accounts which use geographic variables as “random” shocks 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 made during war. Specifically, this chapter 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.

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 various empirical strategies to deal with endogeneity and mechanisms of persistence. Section six concludes.

2.2 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 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 (Brakman, Garretsen, and Schramm 2004; Davis and Weinstein 2002). 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 mistakenly 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 one of the most intense aerial bombing episodes 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 2.1, 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 1940, it was the third largest rice exporter in the world (Helmers 1997). 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 GDP derived from agriculture, respectively.\footnote{Cambodia’s agricultural economy has been consistent in the past two decades, contributing 30-37% of the GDP from 2000 to 2014.} 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).\footnote{These statistics come from the World Bank Databank accessed January 11, 2016.} But agriculture still employs the majority – 67% – of the Cambodian workforce (Food and Agriculture Organization of the United Nations 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 Khmer expression for “eating a meal” is literally “eating rice.” By the same token, the term for hunger directly translates to “hungry for rice.”
Figure 2.1: 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, as cited in Miguel and Roland 2011.
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 has 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 consisted of up to 108 225-kilogram or 42 340-kilogram bombs. Such loads 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 (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, and 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 remains hard and dry, 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.

2.2.1 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:** Households with fertile but bombed plots should rely on subsistence farming, particularly in comparison to households with fertile, unbombed plots.

### 2.3 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.

Second, 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. Next, 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 fertility. 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 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, does not appear to correlate with any potentially
confounding variables, like agricultural centers and major transit points. Unlike prior stud-
ies, which rely on secondary sources and unvalidated assumptions to alleviate endogeneity
concerns, I use the US Army maps and pilot target reports to determine if bombs were more
likely to be dropped on strategic economic zones or populated areas.

The second concern is about the persistence 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 ordnance still left in the land today.  

2.3.1 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.

Independent Variable: Bomb intensity

The limited number of existing studies on the subnational relationship between aerial bomb-
ing and long-term economic outcomes (namely, Miguel and Roland 2011) use the Southeast

3In the appendix, I show 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.
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. 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 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 2.2, after excluding these categories, we still retain the majority (82.0%) of all payloads.

There are at least two consequential shortcomings in the data, namely that the Air Force pilot’s reports on target type 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’ 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. The bomb sites are depicted on Figure 2.3. With the aid of the Yale Genocide Project, I also acquired the Air Force records

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4 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.”

5 Some of the original tape archives were reportedly damaged, leaving a blank period from July 1971 to September 1971. See Figure 2.14 in the Appendix to see where the missing months stand relative to the rest of the database.
Figure 2.2: 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 ordnances were dropped from our analysis, since the hypothesis only applies to larger, destructive bombs with trigger fuses.
for the reported target and damage assessment for each piece of ordnance in the Southeast Asia Air Combat Dataset.

**Controls: Pre-treatment covariates**

To improve the bombing data, I 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. 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 2.4.

**Outcome variable: Farmer behavior and output**

The 2012 Cambodia Socioeconomic Survey (CSES) is a nationally representative survey of 3,840 households in 384 villages. 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. The surveys, which were designed by the World Bank, are kept in the closed archives of 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
Figure 2.5: Locations of CSES household plots. The white area inside Cambodia represents the Tonle Sap lake.

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 provincial names. I was able to exact match 3,617 plots to their census village, which is approximately 95.7% of the sample. 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.

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.
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 (Cambodia Agricultural Research and Development Institute 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 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 2.5 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 soil fertility as a proxy for wet, soft soil with abundant ground cover, the optimal conditions for detonation failure.

2.3.2 Research design

The existing studies of the long-term impact of bombing on economic development suffer from an endogeneity problem. That is, bomb placement is not random and is potentially in

7Soil 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.
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 me 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.

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 an hour’s 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.\(^8\)

**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 within
the 5-kilometer buffer. I include these five covariates with the propensity score weights
in the linear model, designed to estimate the outcome variables.\(^9\)

Using an Ordinary Least Squares (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

---

\(^8\)Table 2.4 in the Appendix provides the cross-tabulation of bombing intensity and soil fertility.
\(^9\)Figure 2.15 in the Appendix shows the improvement in covariate balance after matching.
groupings of provinces into the plains, the lake (the Tonle Sap), the coast, the mountainous, and the capital regions.\footnote{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.}

In sum, I estimate the following equation:

$$Y_i = \alpha_i + \beta(Bombing_v \times Fertility_v) + X_i + X_v + \gamma_{region} + \varepsilon_i$$  \hspace{1cm} (2.1)

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 or the percent of harvest sold to market; \(Bombing_v\) 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; \(\gamma_{region}\) represents the regional fixed effect, and \(\varepsilon_i\) is the error term.

## 2.4 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 2.1 through 2.2 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.

Figure 2.6: 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.

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 2.1, 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 2.6 presents the predicted rice harvest, in US dollars per square
Table 2.1: Bombs (discrete variable) and rice harvested

<table>
<thead>
<tr>
<th></th>
<th>Full (unweighted) sample</th>
<th>CBPS Matched sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Panel A. Dependent</strong></td>
<td><strong>variable:</strong> Amount of</td>
<td></td>
</tr>
<tr>
<td><strong>variable:</strong> Amount</td>
<td>harvested (USD/m²)</td>
<td></td>
</tr>
<tr>
<td>Low Bombs</td>
<td>−0.106**</td>
<td>−0.245***</td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td>(0.087)</td>
</tr>
<tr>
<td>Med Bombs</td>
<td>−0.129**</td>
<td>−0.242***</td>
</tr>
<tr>
<td></td>
<td>(0.064)</td>
<td>(0.088)</td>
</tr>
<tr>
<td>High Bombs</td>
<td>−0.169***</td>
<td>−0.282***</td>
</tr>
<tr>
<td></td>
<td>(0.063)</td>
<td>(0.082)</td>
</tr>
<tr>
<td>Low Fertility Soil</td>
<td>−0.053</td>
<td>−0.141</td>
</tr>
<tr>
<td></td>
<td>(0.045)</td>
<td>(0.092)</td>
</tr>
<tr>
<td>Medium Fertility Soil</td>
<td>−0.066*</td>
<td>−0.214***</td>
</tr>
<tr>
<td></td>
<td>(0.036)</td>
<td>(0.065)</td>
</tr>
<tr>
<td>Low Bombs: Low Fertility</td>
<td>0.128</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.127)</td>
<td></td>
</tr>
<tr>
<td>Med Bombs: Low Fertility</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.148)</td>
<td></td>
</tr>
<tr>
<td>High Bombs: Low Fertility</td>
<td>0.127</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.118)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>−0.050</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>(0.173)</td>
<td>(0.179)</td>
</tr>
<tr>
<td>R²</td>
<td>0.014</td>
<td>0.016</td>
</tr>
<tr>
<td>Observations</td>
<td>3,617</td>
<td>3,617</td>
</tr>
<tr>
<td>Controls</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Regional fixed effects</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

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
meter, for high fertility soil (right panel) and low (left panel). First, compare the 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/m² to 0.23 USD/m², 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/m² 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. In low fertility fields, the association between bombing and rice production is weakly negative (with predicted output falling from 0.12 USD/m² in the Control to 0.04 USD/m² in the High Bomb Tertile) but statistically insignificant.

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 2.2 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 2.7, conditional on soil fertility.

---

11 The analysis was repeated using kilograms per square meter, as seen in Figure 2.5 in the Appendix. Figure 2.17 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 2.6. Figure 2.18 shows that the trends are the same between the two buffer sizes.
<table>
<thead>
<tr>
<th></th>
<th>Full (unweighted) sample</th>
<th>CBPS Matched sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Panel B. Dependent variable: Amount of rice sold to market (% of total rice harvested)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Bombs</td>
<td>$-0.148^{***}$</td>
<td>$-0.243^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>Med Bombs</td>
<td>$-0.133^{***}$</td>
<td>$-0.247^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>High Bombs</td>
<td>$-0.170^{***}$</td>
<td>$-0.286^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>Low Fertility Soil</td>
<td>0.044***</td>
<td>$-0.173^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
<td>(0.035)</td>
</tr>
<tr>
<td>Medium Fertility Soil</td>
<td>0.031**</td>
<td>$-0.065^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Low Bombs: Low Fertility</td>
<td>0.231***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td></td>
</tr>
<tr>
<td>Med Bombs: Low Fertility</td>
<td>0.257***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td></td>
</tr>
<tr>
<td>High Bombs: Low Fertility</td>
<td>0.344***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.045)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.205***</td>
<td>0.301***</td>
</tr>
<tr>
<td></td>
<td>(0.066)</td>
<td>(0.068)</td>
</tr>
<tr>
<td>R²</td>
<td>0.077</td>
<td>0.095</td>
</tr>
<tr>
<td>Observations</td>
<td>3,617</td>
<td>3,617</td>
</tr>
<tr>
<td>Controls</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Regional fixed effects</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Notes:** Columns (1) and (3) do not include the interaction term while columns (2) and (4) do. Low Bombs represents 0 < 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
A few points should be made, regarding Figure 2.7. 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 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 farmer sees a piece of UXO on her land, he or she does not know if that is the last piece of ordnance or if there are many more on her land. In short, the farmer might as well avoid the land.

For instance, Chim Neth, a farmer in Battambang Province, has found four or five fragments of ordnance while she and her family were plowing 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, “[b]ecause of the munitions in the

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12Some may argue that farmers collect more nuanced information about likelihood of encountering UXO as they plow, 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.
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 their 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.

2.5 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 a “harassment and 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.

### 2.5.1 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 2.4) 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. Then, I use an OLS regression to estimate the pounds of ordnance dropped within the buffer, based on road density, number of settlements, existence of a major waterway, forest cover, rice field cover, and distance from Vietnam.

It is important to note that the 1960s US military map is not complete, and a small number of the points (7 out of 100) were dropped on areas that had no map. Of the 288

\[ \text{Bombing}_j = \alpha_j + \beta \cdot X_j + \varepsilon_j \]  

(2.2)

in which \( j \) denotes random buffer \( j, \ldots, k \). \( \text{Bombing}_j \) 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 \( \varepsilon_j \) is the error term.
total maps that cover Cambodia, I was able to access all but five, as can be seen in Figure 2.19 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 2.3 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 2.19 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.

2.5.2 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,” “Ox-
Table 2.3: Regression results of 1960 conditions on bomb intensity and on likelihood of missing map

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bomb intensity (tons)</td>
<td>Map missingness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OLS (1)</td>
<td>logistic (2)</td>
<td></td>
</tr>
<tr>
<td>Kilometers from Vietnam</td>
<td>−5.385***</td>
<td>0.0042</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.631)</td>
<td>(0.0040)</td>
<td></td>
</tr>
<tr>
<td>Meters of road</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of settlements</td>
<td>−7.893</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(27.764)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent rice paddy</td>
<td>0.479</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10.057)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major waterway</td>
<td>−616.441</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(601.794)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>−685.579</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(423.878)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other country</td>
<td>−354.543</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(707.434)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tons of bombs</td>
<td>−0.595</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(81.337)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>3,777.588***</td>
<td>−2.721**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(969.474)</td>
<td>(1.099)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>93</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.219</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note:*  
*p<0.1; **p<0.05; ***p<0.01
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 2.8 shows these 15 top targets. One-third of bombs (33.2%) were intended to “Confirm Enemy Location” which points to the 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.
Figure 2.8: Of the 179 different types of targets in the pilot logs, these 15 types represent the targets of 83.3% of all payloads.

2.6 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.
2.6.1 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 2014; Kiernan and Boua 1982; Vickery 1984).

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 2.9, took satellite imagery, and identified the Khmer Rouge channel system, according to their unusual linear structure.\footnote{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).} 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).\footnote{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 2.9: A map of the Khmer Rouge irrigation channels from Himel 2007.

Figure 2.10 displays the results. I present the results for agricultural output, although the analysis was repeated for rice sold to market (see Table 2.7 and Figure 2.20 in the Appendix). Recall that, if this alternative explanation is correct, we should expect 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 2.10 we see that Khmer Rouge violence does not have much of an impact on the results. In low fertility soil, the control and 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 2.10: 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.

2.6.2 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 are familiar with effective harvesting and land management practices – would actively try to live on safer, high-quality land. 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 human capital 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 years of schooling 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. 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 2.11 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).

16 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 equal footing by the time the regime fell in 1979. If anyone was educated above a certain threshold, he or she would also have been targeted by the Khmer Rouge as a threat to the communist state.

17 I assume that schooling teaches individuals to read and do arithmetic, which would allow farmers to learn about alternative agricultural techniques and accounting methods that would lead to a more efficient harvest. This type of human capital would thus improve their farming abilities.

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 2.11: 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.

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 2.11 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.
2.6.3 Prohibitive cost of removal

The disposal of large explosive items, like bombs and missiles, is a specialized task and cannot be safely carried out by self-trained individuals or village farming associations. 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 clear the remainder of the land (Freundlich 2014). 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 (Carmichael 2015; Harfenist 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 (Khmer Times 2015).
2.7 Conclusion

This paper has developed an argument that contemporary differences in rice production have both ecological and political causes. Because the detonation of bombs is surface dependent, I hypothesize that high fertility surfaces, which are ecologically more prone to non-detonation, suffer more severe and persistent consequences of bombing since to this day using these sites for rice production will be inherently more risky than producing rice at low fertility locations where the ecology makes non-detonation less likely. Using various datasets, I find that 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 only through death tolls and capital destruction, but also by damaging land and local ecologies in a specific and long-lasting way. While the analysis shown here generally supports the theory most common in the post-conflict reconstruction literature – that violence has legacy effects on development – it suggests that geographic conditions and military technologies should be added to the list of factors that determine why some areas recover faster than others.

Of course, we should abstain from generalizing too far from the analysis, which is limited to Vietnam War-era bombs in Cambodia. It is particularly difficult to assess whether the results extend to other post-conflict countries, particularly ones where the terrain is different (e.g., desert or mountains) and where the aerial attacks have used more advanced weapons (e.g., drones and GPS-guided missiles).

However, journalists reporting on the US war in Afghanistan have documented the high levels of civilian casualties from unexploded ordnance in different regions, including the mountains of Tora Bora, the agricultural plains of Herat, and the deserts of Kandahar (Chivers 2001; Kaplow 2001; Watson and Getter December 1, 2001). Policy reports from demining organizations like HALO Trust and the UN Mine Action Service suggest that people
living on contaminated countries all over the world – from Angola to Sri Lanka to Colombia – have to worry about food insecurity, alternative sources of transit and employment, and a risk of death anytime they try to use their land (UNMAS 2001; HALO 2016).

If weapons leftover from war continue to impact everyday life in this manner, future research should continue to explore the microdynamics between unexploded ordnance and development. What motivates migration to and from UXO-contaminated land? When contaminated land has been demined, does this reverse the poverty trap? Do landmines stifle development through the same mechanism as unexploded bombs? Such questions constitute the frontier on unexploded ordnance in the social sciences. But we can only begin to answer them if we recognize that land is a fundamental, but forgotten, driver of economic performance.

2.8 Appendix

Contemporary explanations for agricultural production. 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 cat-
egorized 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, and rice mills, 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.\footnote{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 2.12 and 2.13 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.}

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 2.12 and 2.13 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.

Table 2.4: Cross-tabulation of bomb intensity and soil fertility.

<table>
<thead>
<tr>
<th></th>
<th>Low Fertility Soil</th>
<th>High Fertility Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>110</td>
<td>372</td>
</tr>
<tr>
<td>Low Bomb Tertile</td>
<td>200</td>
<td>178</td>
</tr>
<tr>
<td>Medium Bomb Tertile</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>High Bomb Tertile</td>
<td>252</td>
<td>326</td>
</tr>
</tbody>
</table>

\footnote{I repeat this analysis with alternative measures of the dependent variable (the percent of rice sold) in Figures 2.21 and 2.22 in the Appendix. The results are similar to the ones presented here.}
Figure 2.12: 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.
Figure 2.13: 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.
Figure 2.14: This plot represents the total ordnance dropped on Cambodia during the major air campaigns, from January 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 2.15: Covariate balance is improved when the absolute difference between the standardized means decreases after weighting.
Figure 2.16: Predicted outcomes without matching. Notice how the results hold between the weighted and unweighted models.
Table 2.5: Bombs (discrete variable) and rice harvested

<table>
<thead>
<tr>
<th></th>
<th>Full (unweighted) sample</th>
<th>CBPS Matched sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Panel C.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dependent variable:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount of rice harvested (kg/m(^2))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Bombs</td>
<td>0.116</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>(0.121)</td>
<td>(0.137)</td>
</tr>
<tr>
<td>Med Bombs</td>
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<td>−0.129</td>
</tr>
<tr>
<td></td>
<td>(0.110)</td>
<td>(0.131)</td>
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<tr>
<td>High Bombs</td>
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<td>−0.445***</td>
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<tr>
<td></td>
<td>(0.164)</td>
<td>(0.171)</td>
</tr>
<tr>
<td>Low Fertility Soil</td>
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<td>0.074</td>
</tr>
<tr>
<td></td>
<td>(0.114)</td>
<td>(0.122)</td>
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<tr>
<td>Medium Fertility Soil</td>
<td>0.101</td>
<td>0.103</td>
</tr>
<tr>
<td></td>
<td>(0.094)</td>
<td>(0.099)</td>
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<tr>
<td>Low Bombs: Low Fertility</td>
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</tr>
<tr>
<td></td>
<td>0.219</td>
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<tr>
<td></td>
<td>(0.234)</td>
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<tr>
<td>Med Bombs: Low Fertility</td>
<td></td>
<td>−0.010</td>
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<tr>
<td></td>
<td>(0.253)</td>
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<td>High Bombs: Low Fertility</td>
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<td>Constant</td>
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<td></td>
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<td>✓</td>
</tr>
<tr>
<td>Regional fixed effects</td>
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<td>✓</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Full (unweighted) sample</th>
<th>CBPS Matched sample</th>
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</thead>
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<td>(3)</td>
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<td>(4)</td>
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<tr>
<td><strong>Panel D.</strong></td>
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</tr>
<tr>
<td>Dependent variable: Amount of rice harvested (USD/m²)</td>
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</tr>
<tr>
<td>Low Bombs</td>
<td>-0.046</td>
<td>-0.175**</td>
</tr>
<tr>
<td></td>
<td>(0.046)</td>
<td>(0.079)</td>
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<tr>
<td>Med Bombs</td>
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<td>-0.195**</td>
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<td>(0.077)</td>
</tr>
<tr>
<td>High Bombs</td>
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<td>-0.230***</td>
</tr>
<tr>
<td></td>
<td>(0.052)</td>
<td>(0.079)</td>
</tr>
<tr>
<td>Low Fertility Soil</td>
<td>-0.039</td>
<td>-0.137*</td>
</tr>
<tr>
<td></td>
<td>(0.045)</td>
<td>(0.075)</td>
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<tr>
<td>Medium Fertility Soil</td>
<td>-0.066*</td>
<td>-0.191***</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.056)</td>
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<tr>
<td>Low Bombs: Low Fertility</td>
<td>0.170</td>
<td>0.107</td>
</tr>
<tr>
<td></td>
<td>(0.113)</td>
<td>(0.072)</td>
</tr>
<tr>
<td>Med Bombs: Low Fertility</td>
<td>-0.061</td>
<td>-0.013</td>
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<td></td>
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<td>(0.080)</td>
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<tr>
<td>High Bombs: Low Fertility</td>
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<td>0.132*</td>
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<tr>
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</table>

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 2.17: Even when rice output is measured in a second way (kilograms of rice/m² of rice paddy), the results are the same.
Figure 2.18: The predicted rice outputs when the buffers are 3 kilometers rather than 5 kilometers. The results are similar between the two buffer lengths.
Figure 2.19: Spatial coverage of 1960 US military maps (283 of 288 total panels)
Figure 2.20: 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 2.7: Household plots located within major Khmer Rouge work zones

<table>
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<tr>
<th></th>
<th>Dependent variable:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice harvested (1)</td>
<td>Rice sold to market (2)</td>
<td></td>
</tr>
<tr>
<td>Low Bombs</td>
<td>-0.491**</td>
<td>-0.256***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.195)</td>
<td>(0.058)</td>
<td></td>
</tr>
<tr>
<td>Med Bombs</td>
<td>-0.443*</td>
<td>-0.185***</td>
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</tr>
<tr>
<td></td>
<td>(0.230)</td>
<td>(0.068)</td>
<td></td>
</tr>
<tr>
<td>High Bombs</td>
<td>-0.385**</td>
<td>-0.344***</td>
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<td></td>
<td>(0.163)</td>
<td>(0.049)</td>
<td></td>
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<td>Low Fertility Soil</td>
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<td></td>
<td>(0.167)</td>
<td>(0.050)</td>
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</tr>
<tr>
<td>Medium Fertility Soil</td>
<td>-0.267**</td>
<td>-0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.126)</td>
<td>(0.037)</td>
<td></td>
</tr>
<tr>
<td>Low Bombs: Low Fertility</td>
<td>0.280</td>
<td>0.188**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.262)</td>
<td>(0.078)</td>
<td></td>
</tr>
<tr>
<td>Med Bombs: Low Fertility</td>
<td>0.361</td>
<td>0.208**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.302)</td>
<td>(0.090)</td>
<td></td>
</tr>
<tr>
<td>High Bombs: Low Fertility</td>
<td>0.046</td>
<td>0.490***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.249)</td>
<td>(0.074)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.292</td>
<td>0.453***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.320)</td>
<td>(0.095)</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.028</td>
<td>0.104</td>
<td></td>
</tr>
</tbody>
</table>

| 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 2.21: 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 2.22: 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.
Chapter 3

Barriers to Entry:

the economic impact of bombing

The reason I ask is because if we have that kind of a scattering of unexploded arsenals throughout that country, how is it that they are going to be able to become active in the world economy?

Ambassador Scot Marciel to Congressman Mike Honda, Regarding the legacies of war in Laos at the House Foreign Affairs Committee on April 22, 2010.

A panel of three Southeast Asia experts – a Laotian refugee-turned-NGO director, a bomb disposal officer, and a legal scholar – addressed the US Congress on April 22, 2010, to describe the lasting effect of UXO on village life in Laos. The first to speak was Channapha Khamvongsa, the executive director of Legacies of War, an organization dedicated to bomb clearance. She emphasized the need for more US assistance in bomb clearance and victim rehabilitation, laying out the basic statistics: each year, 300 Laotians die from unexploded ordnance; one-third of them are children. Echoing that sentiment, Professor Virgil Wiebe, a board member of the Mine Advisory Group, agreed that Congress should “scale-up” the number of UXO clearance teams. But the second speaker, Robert Keeley from the Humpty Dumpty Institute, made a different point, arguing:
In the questions that you sent me, you asked me a question about the effects of these weapons on the economy. First of all, as has already been mentioned, most of the economy in Laos is based on agriculture production, and rice in particular. So it is possible to use the opportunity cost of the land that can’t be used as a measure of the impact.

But in the private sector there is an unseen impact. I am not talking about the village level, but the small to medium enterprise level. These costs can act as a barrier to entry, particularly in projects such as forestry or agribusiness where the cost of investing in a project becomes significantly higher because of the cost of the UXO. Unfortunately, we can’t measure this because we don’t know how many people have chosen not to invest in projects because of the cost of the UXO clearance (Legacies of War 2010, emphasis added).

This chapter aims to fill this empirical gap, by providing an estimate of the economic loss from land-owners’ avoidance of agricultural business. I examine whether and where farmers invest in land-intensive projects, focusing on how unexploded ordnance influence their entrepreneurial decisions. While the previous chapter explored the unintended effect of UXO on subsistence farming, this chapter keys into the “unseen impact” that unexploded bombs may have on the land-owner’s ability to modernize his or her land use patterns. In other words, in the prior chapter I provided evidence that households near unexploded ordnance farm less. Here, I suggest that this post-conflict geography makes it too risky to invest in new agricultural technologies, compounding the effect of unexploded ordnance on development.

Specifically, I examine the introduction of new crop technologies – hand-tractors and other mechanized tools, high-yield varieties of rice seed, widely available fertilizer and irrigation services – that allow traditional, small-scale farmers to transform their household operation into a cash crop agribusiness. The average Cambodian household owns 1 to 2 hectares (2.5
to 5 acres), produces 1,300 kilograms of rice, and uses hired draft power and perhaps manure (Helmers 1997, p.11). The World Record of rice produced by one household was set in India in 2013, with 24.7 tons (more than 22,400 kilograms) grown on 2 hectares (Vidal 2013). It used high-yield seeds, mechanical weeders, and fertilizer. When this land management practice, called the “System of Rice Intensification,” was introduced through an NGO in Cambodia in 2000, the 146 households involved saw their yields quadruple (Malloy 2013).

Given the large returns, why don’t more households utilize these new agricultural technologies? The Green Revolution introduced a high-yield variety (HYV) of rice, which depended on fertilizer, irrigation, and mechanical labor in order to produce efficiently. I argue that farmers in Cambodia experienced the Green Revolution later than other countries, due to the fact that the Khmer Rouge ruled at the peak of its popularity. While the rest of South and Southeast Asia adopted these HYV seeds and practices, the Khmer Rouge required Cambodian laborers to farm by hand, lambasting any outside advances that would change the Cambodian way. Since the Khmer Rouge stripped all Cambodians of their titles, assets, and property, once the Khmer Rouge fell in 1979, Cambodian survivors started over with nothing besides their land. This “equal footing” provides a unique opportunity to investigate which households end up turning their family plots into a source of agribusiness, given that all households started off with no capital and no savings.

I test a theory similar to the one presented before. Farmers who live with unexploded ordnance are less likely to own mechanized equipment, due to the fact that they risk their lives when driving over the land. They are also less likely to invest in non-mechanized goods—like seeds, fertilizer, and irrigation— which would increase the amount of time needed to spend on dangerous land. This theory contradicts findings from current studies on the Green Revolution, which assume that a linear relationship between the amount of land-holdings and the investment HYV seeds and related land management practices (Callen, Gulzar, Rezaee, and Shapiro 2015, Dasgupta 2015). Here, I reintroduce the idea that the Green Revolution,
and agricultural modernization more broadly, has distributional consequences (Scott 1983), since few households can afford all the investments required for a full harvest. Unlike Scott, I suggest that even fewer households can invest in the necessary capital in post-conflict communities, since many people’s access to land is restricted due to unexploded ordnance.

In 2012, the Cambodian Ministry of Planning ran a survey, using samples of people in each of the country’s 24 predominantly rural provinces. The Cambodia Socioeconomic Survey (CSES) covered many aspects of agricultural behavior, including the measure of rice production used in the previous chapter, as well as several aspects of agricultural investment, assets, and sales. Here I focus on two sets of questions. The first asks whether a household owns any of the following pieces of equipment: tractors, bulldozers, threshing machines, and semi-tractors. The second asks the household to break down how money was invested in each of their agricultural plots. I look at how these answers vary with respect to the amount spent on chemical fertilizer, improved seed, and irrigation.

The statistical analysis of household investment and asset data confirms a number of earlier findings and also yields some new and different results. For example, the number of machines owned by a household on fertile land drops by if the village has unexploded ordnance. Similarly, investment in seed, fertilizer, and irrigation goes down by 33%, 55% and 82% respectively. Conditional on low soil fertility, the effect of bombing on the amount spent on seed, fertilizer, and irrigation is significant and negative, not insignificant as would be predicted by previous discussion. This suggests that people may still fear unexploded ordnance on low fertility land, even though the risk of encountering them is smaller than on high fertility land. Importantly, neither climate nor soil quality alone determine which villages experience the Green Revolution with greater intensity. Instead, a legacy of war variable – exposure to leftover unexploded ordnance – provides a reliable indicator of the likelihood of local adoption of new agrarian technologies.
One could argue that unexploded ordnance could be an unexpected boon, encouraging households to invest in other non-agricultural businesses. According to this line of thought, unexploded ordnance may not necessarily create poverty traps; they could divert investment in agriculture to other sector, like service or human capital. To test this claim, I isolate the independent effect of unexploded ordnance on household poverty with an instrumental variable strategy. By instrumenting exposure to unexploded ordnance on household rice production, I find calculate the impact of a drop in rice production (due to unexploded ordnance) on household food consumption. The results show that a 1% decline in rice sales leads to a 25% decline in food consumption per capita. This suggests that households on average have limited opportunities in other sectors. Unable to find an alternative economic activity that will supplement their agricultural losses, these households on contaminated land are, in essence, stuck in a poverty trap.

This paper proceeds in five parts. First, I review previous research on the Green Revolution and its economic effects, and introduce a theory of how bombs that were dropped five decades ago continue to impact Cambodian agricultural investment decisions. Second, I introduce a new dataset constructed to measure rising dependence of investment on post-conflict geographic conditions. Third, I report results from this country-wide analysis. Fourth, I discuss the findings and the limitations of the analysis. Finally, I conclude by discussing the implications of these findings: how should we think about the consequences of war and redistribution in an economy increasingly geared toward agricultural modernization?

3.1 Background and theory

In the first half of the twentieth century, the losers of the major international wars, like World War I and II, were already industrialized. It was easy for post-conflict Germany, Hungary, Italy, and Japan “...to catch up with winners in relatively short order,” perhaps due to the “economically developed population...motivated to rebuild” or the “obsolescent plants and
industrial equipment [that] were destroyed” and replaced by improved technology (Organski and Kugler 1977, p.1364). Since the Cold War, conflict often takes place in countries where the economies are poorer, less industrialized, and less developed (Przeworski 2000). From Somalia to the Democratic Republic of the Congo, from Afghanistan to Cambodia, the economies rely heavily on the agricultural sector and on household production of goods.

These post-conflict countries have an added challenge of creating economic growth without a precedent of industrialization. How do theories of modernization apply to the post-conflict environment? Since Marx and Weber, a large body of work has focused on the impact of economic development on two core domains of political life: what groups can access and profit from the modern technologies; and whether or not the advantages of growth are redistributed to the poor (Boix 2003; Iversen and Soskice 2009; Lupu and Pontusson 2011; Piketty 2015). But its focus on stable, advanced democracies has led it to underestimate the effect of development on newer, more unstable democracies. Indeed, for democracies (or quasi-democracies) recovering from war, the effect of development on distribution is difficult to identify, at the very least because state capacity is low, so data on any existing wealth (that hasn’t already fled or been destroyed) are difficult to find.

A recent literature takes advantage of new datasets from the Vietnam War to calculate the legacy of war on long-term development. While there appears to be a positive relationship between bombing and household consumption, scholars remain puzzled as to why. One piece suggests that the “small but statistically insignificant” impact of US bombing of Vietnam on equivalent household consumption is perhaps due to a larger local share of employment in the state sector (Dell and Querubin 2015, p.20). Another provides evidence that the “selective reallocation of capital” particularly toward poorer, bombed districts will prevent poverty traps (Miguel and Roland 2011, p.14). Because we lack data in Vietnam about household economic behaviors through time, it is difficult to isolate a mechanism that explains these trends. Neither piece looks directly at household investment decisions or asset diaries, which
would determine how household resources were directly impacted by war and how the legacy of war influences their ability to participate in a modernizing economy.

The Green Revolution in South and Southeast Asia is characterized to have created rapid growth in the agricultural sector, as well as a “small-scale engineering industry” that supplied durable goods inputs and various farm implements (Child and Kenda 1975, p. 249). With new seed technology that is considerably more sensitive to modern inputs like chemical fertilizer as well as traditional inputs like water, places that were marginally suitable for agriculture saw their value increase more at this specific point in time, relative to areas that were already highly suitable for agriculture. Due to an exogenous change in technology, farmers were given the opportunity to switch from traditional, low-yield methods of farming to a more capital-intensive, high-yield use of their land. While recent pieces have used the Green Revolution as an instrument to explain the effect of empowered farmers on party demise or the effect of increased land value on state incorporation (Callen, Gulzar, Rezaee, and Shapiro 2015; Dasgupta 2015), we know less about the direct impact of the Green Revolution on the farmer and the village social structure.

An older literature associated with the decline of the peasant farmer, is closely attuned to the distributional consequences of the Green Revolution, which its author links to the broader phenomena of capitalist development (Scott 1983). In this chapter, I explore how those trends are paralleled in the post-conflict setting, while answering a basic question in comparative politics: who benefits from modernization?

### 3.1.1 Green Revolution, Interrupted

The Green Revolution is understood to increase crop productivity more in marginal areas than in regions that were already productive (Rezaee, Callen, Gupta, and Shapiro 2015). Advances in seed technology allowed rice and wheat to be grown in less fertile areas that
were originally not suitable for agriculture. These new seeds increased the economies of scale for farmers. Less fertile land could also be planted; crops could be grown twice a year. This attracted new capital into farming, which encouraged mechanization, credit markets, and new management schemes.

In South Asia, the 1960s and the 1970s were the key decades of the Green Revolution (Callen, Gulzar, Rezaee, and Shapiro 2015; Dasgupta 2015). Notably Cambodia also experienced a production boom at the same time. Four wheel tractors and trucks were available since the 1950s when most towns had active assembly plants and manufacturing workshops (Rickman, Pyseth, and Sothy 1996, p.93). The United States Agency for International Development provided substantial aid to construct canals, barrages and reservoirs for four provinces, and its Rice Productivity Program worked to improve the yield and quality of traditional rice seed varieties (Munson, Martindale, McMorris, Parachini, Raiford, and Charles 1968). By 1964 and 1965, rice exports reached an all-time high of 500,000 tons while rough rice production reached 2.5 and 2.75 million tons (Helmers 1997, p.5). In 1969, the country produced 4 million tons of rice, a new record (Montero 2008).

However, policy makers are quick to note that this uptick in production is due to the expansion of cultivated areas, not due to the adaption of new technologies or seed (Whitaker, Heimann, MacDonald, Martindale, Shinn, and Townsend 1973). Most households continued to cultivate by plough or by hand. Large-scale irrigation was not wide-spread, so only 5% of total rice area was planted during dry season. Only 32,000 tons of chemical fertilizer was used in the entire country. Rice research was also limited. French and Japanese aid programs had only begun to experiment with modern International Rice Research Institute (IRRI) varieties in Cambodia, but there is no evidence that any IR seeds made it to the

\footnote{Traditional rice varieties have long stalks. If fertilizer is added to the soil, then plants would grow too tall and collapse. The International Rice Research Institute in Indonesia created a dwarf variety of rice (first called IR8), which had a short stalk. Since the stalk would reach its maximum height quickly, fertilizer compounds would go directly to increase the grain size, which speeds up the maturation process. Thus, this new type of rice seed meant that farming could take place on most types of land, as long as there is enough water and fertilizer to support the plant. This gave birth to the Green Revolution.}
mass market. In short, Cambodia’s agricultural sector was growing during this period, but not due to the Green Revolution.

Despite the centrality of rice to Khmer Rouge’s development plan, the accompanying genocide (1975-1979) caused rice production to plummet. The Five Year Plan aimed to produce two or more rice crops per year, using new, standardized irrigation canals, leveled rice fields, cleared forest land, new high-yield varieties of rice, and a collectivized system of labor. Because the Khmer Rouge rejected imported, modern technology, they razed the industrial factories, and most mechanically-powered tools were left to rust (Gottesman 2004). The majority of the labor force cleared land, built reservoirs and canals, and grew rice all by hand (Chandler, Kiernan, and Boua 1988). While Chinese advisors undertook rice seed research in Battambang (and broadcasted the development of three new seed varieties – Pram Pi Taek, Ramuon Sar, Champas Ko – over the Phnom Penh radio), there was never any evidence that these seeds were delivered and used outside of the laboratory (Dennis 1979). In addition, the irrigation project was far from successful. After the Vietnamese army defeated the Khmer Rouge, reports indicate that 70-80% of the structures were useless (Helmers 1997, p.6).

Soon the liberating forces in charge of rebuilding the country found that agricultural research stations had been destroyed. The agricultural advances made in the 1960s – rice germplasm and technical data – were all lost (Mysliwiec 1988). Since the new government, the People’s Republic of Kampuchea (PRK) was run by the Vietnamese, there was limited foreign aid. Instead, people were divided into krom samaki or solidarity groups, in which clusters of households worked the fields as a collective, sharing the small number of agricultural tools and animals that remained. Eventually the Eastern Bloc introduced some new rice varieties (IR36 and IR42, which matured almost twice as fast as traditional varieties). Yet the PRK did not reestablish an agricultural research institute until 1987, so there was
no agency that could determine what agricultural technologies were appropriate, how they should have been distributed, and what their effects on production were.

When the Vietnamese troops began to withdraw from Cambodia in 1989, the new government, the State of Cambodia (SOC) began to replace the socialist farming practices with more open, market-oriented policies. Communal land was broken up into parcels and divided between families for their private assets. And rice, if any surplus was available, could be traded more freely to cities, towns, and rice-deficient places. Yet, civil war continued until 1998, when the State of Cambodia brokered a truce with the remaining Khmer Rouge faction. So while the country remained at war through most of the 1990s, the agricultural economy was fragmented and highly inefficient (Helmers 1997, p.9). Poor physical infrastructure (roads, bridges, and telecommunications) limited the movement of agricultural products and created regional price distortions, which kept the returns to farmers low. Moreover, most farmers had no access to capital. For instance, none of Cambodia’s banks lent money to agricultural producers (Cameron 1995). Loans were only available through local money lenders, who charged 20 to 30% interest on cash loans and 100% interest on rice loans (Helmers 1997, p. 9).

Once the country stabilized, foreign aid and investment returned. Roads were rebuilt and paved. Phone lines and cellular towers were installed. Although Cambodians began to have access to the improved rice technologies and agricultural machinery, most could not afford the extra cost. By 1996, the majority of rice farmers still farmed by hand or by plough (Nesbitt 1997). Despite these obstacles, the country’s agricultural sector stabilized in 1997, once the civil war with the surviving Khmer Rouge faction reached a stalemate. That year, Cambodia produced almost as much rice as it had in 1969 (Montero 2008).

By 2008, Cambodian rice production reached 1.4 to 2.5 tons per hectare (Montero 2008). Because Cambodia is located at the Mekong River delta, some argue that it has a comparative advantage in rice production, due to the water resources and abundant labor (Estuidillo and
However, the country produces only half of the yield rate of Thailand, which is the world’s largest exporter of rice. America and Australia’s rice growers average 6 to 8 tons per hectare, which constitutes the industry’s gold standard. It seems that despite Cambodia’s ideal location and distribution of factor endowments, the country produces far less than its potential. Why?

It is not labor, since 80% of the population works in agricultural sector \cite{Nesbitt1997}. Yet, the majority of farmers continue using traditional, pre-industrial methods of farming. Of the 2,133 rice-producing households in the CSES, almost half (47.9%) own no mechanized equipment, either farming entirely by hand or relying on rented services and equipment. Conversely, one-third of sampled households own a plough. Only 14 households own tractors, and 3 households own bulldozers. 27 households have thrashers while 242 own handheld tractors, or “semitractors.” 55 households have their own rice mill, and 432 own water pumps. Why do so few households invest in agricultural technology, and how are these assets distributed throughout the country?

3.1.2 The theoretical link between Green Revolution and UXO

Although unexploded ordnance tend to come up in many anecdotal accounts of poverty in post-conflict nations, it is worth formulating, briefly, the theoretical reasons why these war-induced changes to land can be seen as a cause of agricultural under-investment. Bombs dropped decades ago can be expected to impact the prospects of agricultural modernization in three ways.

First, we might expect that contaminated areas – areas with unexploded ordnance – would end up adopting more risk-averse land-use practices, particularly ones that require frequent applications or require people to drive machines over land. The predominant feature of new agricultural equipment, like tractors, threshers, and bulldozers, is that they are vehicles and need to be driven over the field. Even technologies with lower start-up costs, like high-yield
varieties of rice seed, need double or triple the amount of chemical fertilizer that traditional seeds require, as well as regular applications of water (Evenson and Gollin 2003). Because these certain types of agricultural technologies involved more intensive interaction with the land, we would expect farmers living on dangerous land not to adopt these modern forms of farming.

Second, the fear of losing one’s life to unexploded ordnance can outweigh the actual probability of encountering unexploded ordnance. The fear, or the perceived risk, may change behavior more effectively than if people were presented information about the actual likelihood of dying by unexploded ordnance. Theoretically, it is similar to neighborhood responses to a string of robberies. Each robbery by itself is rare event, given the number of residents in the neighborhood, and the victim alone bears the cost (or the majority of it). But the fear of being the next victim is communal. Since community members have incomplete information about the criminal and poor predictive abilities, they regard themselves all at risk and shift their behaviors in similar ways. More broadly, a treatment (like a robbery or an injury from a piece of unexploded ordnance) can occur at the individual level, but it spills over to other people in the village because it activates everyone’s fear of being hit next.

Finally, we should expect that these contaminated areas to be poorer, in general. One could argue that unexploded ordnance merely incentivizes households to take their savings and invest in alternative economic activities. Yet if this were true, then we would expect exposure to unexploded ordnance may increase quality of life, because it forces people to leave a saturated agricultural market and enter a less competitive sector, like service. Based on the findings from the last chapter, however, Cambodian rural households still manage to farm contaminated land, they just do so in a subsistence manner. Therefore, we should expect these households with lower rice yields to be more impoverished.

I use the same empirical strategy to identify areas with unexploded ordnance. That is, since there is a higher failure rate of carpet bombs in soft, fertile soil, we expect more
unexploded ordnance in those areas today. I compare the effects of bombing in low versus high fertility areas, assuming that the low fertility villages are exposed to fewer unexploded ordnance than high fertility ones. I argue that households on bombed, low fertility land may have a lower likelihood of running into unexploded ordnance, but this risk is felt collectively. As a result, we should expect bombing to have a similar impact on low fertility land.

### 3.1.3 Hypotheses

The theory can be summarized into three hypotheses:

**H1:** I expect households with highly fertile, unbombed plots to invest in more modern farming techniques, particularly in comparison to households with equally fertile, bombed plots. This specifically applies to technologies that involve repeated applications or heavy machines disturbing the land.

**H2:** Even if the likelihood of encountering UXO is small, households on bombed, low fertility land will still be risk-averse in their farming investments, compared to households on unbombed, low fertility land.

**H3:** Given the dominance of the agricultural sector in rural areas, when a household’s rice yield falls, we should expect quality of life, including consumption of food, to decrease.

### 3.2 Data and Model

Ideally, we would analyze household spending diaries since the bombs were dropped in the 1960s and the individual perceptions of risk, conditioned for the exact placement and like-

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2This chapter currently tests these three hypotheses, but I have recently discovered a new dataset that provides the location and date of deaths caused by unexploded ordnance from 2005 to 2013. I will be able to test a fourth hypothesis: when unexploded ordnance kill someone, surrounding community members shift their behaviors and become more risk-averse, even if the likelihood of running into unexploded ordnance is low. For the time being, I incorporate this mechanism into Hypothesis 2, which suggests that people on bomb, low fertility land would still fear unexploded ordnance, even if they have a lower likelihood of encountering them compared to farmers on equally bombed, high fertility land.
lihood of detonation for each piece of unexploded ordnance. Unfortunately, there is no country-wide data linking each piece of unexploded ordnance to farmer beliefs. As such, in the main analysis, I focus on household- and village-level variation, and construct a novel dataset to examine diverging economic behaviors, like tool usage and investment. Do households living on contaminated land restrict their agricultural spending? Do bombs dropped during the Vietnam War contribute to food inequality and household poverty today?

3.2.1 Data

I rely on the same large, nationally representative survey, the Cambodia Socio-Economic Survey (CSES) from 2012. The CSES provides information on the agricultural goods purchased by households across all 24 provinces of Cambodia. It also includes how much food is consumed by each household. The Combat Air Activities Southeast Asia Database, which was used in the previous chapter, was declassified by the Department of Defense in 2009, and remains the most comprehensive collection of airstrike information from the Vietnam War. These two databases can be linked using 2008 Cambodian census data. The census data includes the location of each village of the CSES, which proxies for household location. When combined with the 2008 Ministry of Agriculture information on soil types, the census data also include the fertility level – low, medium, and high – of the land. These crucial bridging data allow an accurate snapshot of the degree of unexploded ordnance in different villages, since more unexploded ordnance are found in soft, highly fertile soils, compared to rocky, low-fertility soils where the bombs are more likely to detonate upon impact. Constructing this dataset required merging data across multiple detailed categories of soil fertility, bomb intensity, and household spending and consumption. It allows a novel perspective on the distributional dynamics of post-conflict Cambodia.

The main dependent variable is household investment in agricultural goods. To calculate household investment, I divide agricultural goods into two categories: permanent goods and
annual goods and services. Permanent goods are bought once, and reused each year. Physical equipment, like ploughs, draft animals, and tractors, fall into this category. Annual goods and services are used up by the end of harvest and replenished each season. Primary examples include fertilizer, seeds[^3] and irrigation services (like renting a water pump).

Investments in permanent goods are calculated as the number of modern, land-crossing machines owned by the household. This category includes “modern” machines because these machines must have been acquired post-treatment (that is, after the bombing). Since the Khmer Rouge outlawed modern technology, the regime unintentionally created a “clean slate” in which all post-conflict households had no mechanical equipment. Hand tools, draft animals, and ploughs could have been inherited from the Khmer Rouge or from family prior to Khmer Rouge, which is why I drop those tools from the analysis. In addition, this category specifies “land-crossing” machines because some agricultural machines are physically fixed to the ground while others are mobile, driven directly on top of the soil in order to move, aerate, seed, or harvest land. Why focus on land-intensive machines? On contaminated land, a hand-tractor is probably a bad investment, since using it would involve taking a heavy (and expensive) machine and pushing it across a minefield. However, a rice mill may be a good investment because it can be permanently placed near the household, and farmers from surrounding villages will pay to have their rice milled by machine (rather than by hand). The CSES takes an inventory of all durable assets, including 9 types of agricultural tools or machines: carts, tractors, bulldozers, ploughs, threshing machines, harrows, rakes, spades, hoes, axes, hand tractors, rice mills, and water pumps (CSES 2012, p.35)[^4].

Four of these machines fit the criteria: semi-tractors, tractors, bulldozers, and threshing machines. The “semi-tractor” is known as the “kor yun” in Cambodia, or a hand held walking tractor. It has one axel and two wheels, and the farmer sits behind the motor.

[^3]: Traditional rice seeds can be collected from the previous harvest, but the high-yield varieties require new seeds to be purchased each year for optimal growth.

[^4]: Five tools (harrors, rakes, spades, hoes, axes) were all asked about in one question, so the number of each tool cannot be disaggregated from the total number.
driving the vehicle. They have the work capacity of 4-5 times that of the oxen and plough (1 hectare a day). They are also expensive. A new semi-tractor costs $1,000 to $3,500. On the other hand, a new full-sized tractor$^5$ costs more than $10,000 while a second-hand tractor can be bought for $3,000 to $8,000. Because the tractor tends to be out of reach for most farmers, tractors owners will pay off their vehicle by contracting out their services for $10 to $20 a hectare.

A four-wheel tractor is well-suited to level and till both wet and dry land. It takes about 8 hours to level one hectare with a rear-mounted tractor blade while a tractor can till about 5 to 8 hectares of land a day. Tractor repair and maintenance is still problematic in Cambodia, as local suppliers often do not carry the spare parts (Rickman, Pyseth, and Sothy 1997, p. 94). Bulldozers are used to clear land, typically leveling out idle or forested land for agricultural use. Threshing machines remove the grain from the stalk and husks. As a farmer walks across the land, he or she feeds bundles of the stalks into the hopper. The plant goes through a set of rotating blades that separate the head of the grain from the straw, and then knocks the kernels from the head. All of these machines are imported, usually from Japan, China, Thailand, and Vietnam.

Notably the semi-tractor is half the size (and cost) of the other machines. I place it in its own category of “light” machines. The remaining three machines are in the “heavy” category.

Investments in annual goods and services are calculated as the household’s spending on the main components of high yield rice production: new varieties of rice seed, fertilizer, and irrigation. The CSES asks households to record the costs of crop cultivation for the past

$^5$Cambodia produced tractors in the 1950s, during its “golden age” of industrialization under Prince Sihanouk (who was later ousted by the Khmer Rouge). The Massey Ferguson Tractor Company had a factory that provided around 1,500 tractors for domestic use, but it was largely confined to Battambang Province (Helmers 1997, p.6). However, individual accounts suggest that the machines were left to rust or destroyed by Khmer Rouge cadres (Gottesman 2004; Ung 2012). After the Khmer Rouge, the People’s Republic of Kampuchea, a socialist government that institutionalized collective farming, imported roughly 2,000 tractors from Russia in the 1980s. Once the economy opened up in the 1992, new tractors from China and Russia and used tractors from Thailand and Japan are sold in the capital, Phnom Penh.
year for each agricultural plot they own. There are 15 spending categories total, including seeds and planting material, chemical fertilizers, irrigation, manure, electricity, gasoline, storage items, hired draft power, hired labor, government services, transport, repair, and rental fees (CSES 2012, p.17-18). For rice seed, the survey also asks how much the household spent on “planting materials (seeds, seedlings, and young plants), purchased/supplied from home production” (p.17) The survey asks how much is spent on “Chemical fertilizers, pesticide, weedicide and fungicide” (p.17); irrigation question asks simply about “Irrigation charges” over the past year (p.18).

Finally, food security is calculated as the sum of the food items consumed by household members for the last seven days. The CSES enumerator finds the household member who knows the most about food, beverage, and tobacco consumption in the past week, and asks her about 21 food items, including rice, fish, fresh vegetables, fruit, dried nuts and edible seeds, take-out food, alcoholic beverages, and tobacco products (p.4). Consumption is measured in terms of local currency, Khmer riel. Therefore, the respondent is asked to remember the value of the food, if purchased in cash, or to provide an imputed value if the food was produced at home or received as a gift.

The main independent variables is bomb intensity, interacted with soil fertility. I rely on the measurement rules used in the previous chapter. I also use the same pre-treatment controls as before – the measures of 1960s population density, agricultural land, paved roads, major waterways, and distance to Vietnam – which come from the topographic US Army maps.

The key empirical contribution in this study lies in accurately connecting these data on agricultural investment from the CSES to the data on bombing, soil fertility, and pre-treatment conditions. All landless households are dropped from the sample, as are any agricultural fields not designated for rice production. This leaves a total sample size of 2,048 households and 2,595 rice paddies.
There is one main problem with this approach to linking the CSES with the Combat Air Activities Southeast Asia Database and the Ministry of Agriculture’s soil fertility map. The level of aggregation varies across the merged categories. While the CSES data include household designations, the 2008 Census data, which harmonizes the CSES with the geocoded bombing and soil datasets, only goes down to the village-level. If soil fertility varies within the village, this aggregation leads to measurement error. Similarly, the number of bombs must be allocated up to village level (in this case, the tons of ordnance dropped within five kilometers of the village center), and then allocated down to more precise measures of household behavior. The dataset can show how much aggregate bombing leads to household investments, but not which particular bombs most likely contribute to the household’s strategic behavior. If we had the ability to differentiate which bombs were on which rice paddies, then we could identify households with the real risk of unexploded ordnance (compared to a spillover effect in which neighboring households may not have any UXO on their land, but perceive a risk nonetheless, due to the fact their neighbor has a bomb). It would also help us understand how individuals draw boundaries between safe and contaminated land, if they have incomplete information on UXO location. Because this chapter assumes that the farmer lives in a world of incomplete information, this allocation method likely underestimates the dependence of agricultural investments on UXO.

3.2.2 Model

I use an Ordinary Least Squares (OLS) regression to model the association between unexploded ordnance and agricultural investment. I incorporate the pre-treatment covariates through Covariate Balancing Propensity Scores, which models the treatment assignment while optimizing covariate balance. This ensures that historic trends specific to areas with different endowments unrelated to the central argument in this paper do not drive the re-
sults. For the main analysis, I regress each measure of household agricultural investment on its exposure to unexploded ordnance.

The OLS regression for investment in permanent goods is as follows:

\[ Y_h = \alpha_h + \beta(Bombing_v \times Fertility_v) + X_h + X_v + \gamma_{\text{region}} + \varepsilon_h \]  

(3.1)

in which \( h \) denotes households 1, \( k \), and \( v \) denotes villages 1, \( r \). \( Y_h \) is the dependent variable. The remaining variables take on the same specification as in Equation 2.1. \( Y_h \) is measured three distinct ways: the number of light land-disturbing machines (hand-tractors), the number of heavy land-disturbing machines (tractors, thresher, and bulldozers), and the number of total land-disturbing machines.

Recall that the survey asks about annual goods and services for each household plot, not for each household. The OLS regression for investment in annual goods and services is mostly the same, except for its unit of analysis, which is the rice paddy. I run a separate specification for spending on rice seed, on fertilizer, and on irrigation. The regression form for the last outcome variable, food insecurity, will be covered in the next section.

### 3.3 Results

Table 3.1 Column 1 shows that households more exposed to unexploded ordnance have fewer lightweight farming machines than those with little or no exposure to UXO. Specifically, the regression results indicate that bombing played a large role in the number of hand-tractors owned in high fertility areas, but not low fertility areas. Note that the regression uses the control (non-bombed) and high fertility places as the reference group; therefore, the regression coefficients represent the change in the outcome variable, relative to the non-bombed, high fertility group. The first three rows (Low Bombs, Med Bombs, and High Bombs) show the relationship between bombing and household machines in highly fertile
places. The coefficient refers to change in the number of machines in a bombed area compared to a non-bombed location. In high fertility places, the relationship between bombing and light machines is negative and significant, regardless of the intensity of bombing. Put simply, households at risk of encountering unexploded ordnance (since they live on bombed, high fertility land) own fewer hand-tractors. The next four rows show the results for households in less fertile locales. The Low Fertility coefficient is negative and statistically significant while the interaction coefficients (Rows 5 through 7) tend to cancel out the coefficients of the bombing treatment (Rows 1 through 3).

Next, I focus on the effects of bombing on household ownership of light farming machines, conditional on soil conditions. In Figure 3.1 I plot the average number of hand-tractors, by tertiles of bombs dropped near the village. The layout of these plots will look familiar to readers. The horizontal axis is bomb intensity, separated into four categories: no bombing (control), lowest tertile of bombing (less than 500 tons within kilometers of the village center), the middle tertile (500 to less than 2,000 tons), and the highest tertile (2,000 tons and more). Each point marks the predicted number of semitractors (or hand-tractors) owned in 2012. To compute each quantity of interests, I set the explanatory variables at their means and change the treatment variables from control to low, then medium, and finally high treatment assignments. Since exposure to unexploded ordnance is conditional on soil fertility, the left side represents the predicted outcomes in low fertility soil (where there should be very few UXO) and the right side displays the outcomes in high fertility soil (where there should be many UXO).

While there is mostly little association between the treatment and outcome variable in low fertility soil, for households in high fertility soil the number of hand-tractors drops when the area has been bombed. Households on safe land (the control group) own 0.299 hand-tractors, which is triple the predicted number for the lowest and highest bombed tertile (0.089 and 0.121 respectively). The predicted outcome for the medium bombed tertile is
Table 3.1: The effects of bomb intensity x fertility on agricultural investment

<table>
<thead>
<tr>
<th></th>
<th>Light machines</th>
<th>Heavy machines</th>
<th>All machines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variable: Number of assets</strong></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Low Bombs</td>
<td>−0.210***</td>
<td>−0.032</td>
<td>−0.243***</td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td>(0.048)</td>
<td>(0.069)</td>
</tr>
<tr>
<td>Med Bombs</td>
<td>−0.107**</td>
<td>−0.015</td>
<td>−0.122*</td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td>(0.048)</td>
<td>(0.069)</td>
</tr>
<tr>
<td>High Bombs</td>
<td>−0.178***</td>
<td>0.007</td>
<td>−0.171***</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.045)</td>
<td>(0.063)</td>
</tr>
<tr>
<td>Low Fertility Soil</td>
<td>−0.121**</td>
<td>−0.012</td>
<td>−0.133</td>
</tr>
<tr>
<td></td>
<td>(0.057)</td>
<td>(0.057)</td>
<td>(0.082)</td>
</tr>
<tr>
<td>Low Bombs: Low Fertility</td>
<td>0.219***</td>
<td>0.162**</td>
<td>0.381***</td>
</tr>
<tr>
<td></td>
<td>(0.071)</td>
<td>(0.071)</td>
<td>(0.101)</td>
</tr>
<tr>
<td>Med Bombs: Low Fertility</td>
<td>0.054</td>
<td>−0.013</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>(0.079)</td>
<td>(0.079)</td>
<td>(0.113)</td>
</tr>
<tr>
<td>High Bombs: Low Fertility</td>
<td>0.115*</td>
<td>−0.018</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>(0.068)</td>
<td>(0.069)</td>
<td>(0.098)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.291***</td>
<td>0.007</td>
<td>0.298***</td>
</tr>
<tr>
<td></td>
<td>(0.073)</td>
<td>(0.073)</td>
<td>(0.104)</td>
</tr>
</tbody>
</table>

Observations 2,048 2,048 2,048
R² 0.098 0.015 0.060
Controls ✓ ✓ ✓
Regional fixed effects ✓ ✓ ✓

**Note:** Column (1) reports the OLS estimates for the number of all machines (tractors, bulldozers, threshers, and hand-tractors) owned by the household. Columns (2) and (3) separate machines by weight, so the number of light machines (hand-tractors) versus heavy machines (tractors, bulldozers, and threshers) owned. The first three rows represents the treatment effect of bombing in high fertility soil. 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 3.1: Predicted number of light machines (hand-tractors) owned by the household, 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.

...substantively but not significantly different from the control outcome (0.192 compared to 0.299 hand-tractors). Households at risk of encountering UXO own fewer pieces of mechanical equipment – even the relatively light hand tractor. Conversely, in places where there is very little risk of encountering UXO (bombed, low fertility areas), families own similar numbers of light machines as families in the control group (non-bombed, less fertile areas).
Table 3.1 Column 2 suggests that a household’s acquisition of more expensive, heavy-weight pieces of equipment is not driven by the same causal factors. Rather than looking at the use of hand-tractors on high fertility land, it focuses on heavy farming machines (tractors, bulldozers, and threshers) to emphasize the larger cost and risk when using these machines on contaminated land. None of the coefficients are statistically significant, except for one (the interaction between low fertility and low bombs). The results show a messier relationship, in part due to the small share of households in the sample that can actually afford expensive machinery and in part due to the local practice of renting out large pieces of agricultural equipment (for the remainder of the village purchase the services of a tractor without having to buy and own one themselves).

In Table 3.1 Column 3, I examine the relationship between unexploded ordnance and investment in agricultural equipment more broadly, in order to see if the same households own both light and heavy machinery. Recall that bombs only had a negative and significant relationship with light machinery, as seen in Column 1. In Column 3, Rows 1 through 3 show that for households on high fertility soil, the association between the treatment and outcome grows in magnitude and remains negative and significant. As seen in Row 4, the relationship between the low fertility dummy and the amount of agricultural equipment is negative, but varies greatly. The next three rows present results that are small and statistically insignificant, except for Row 5 (less bombed and low fertility). This coefficient (0.381) cancels out the negative effect of Low Bombs (Row 1: -0.243) and Low Fertility Soil (Row 4: -0.133), which means that low bombed, low fertility households own roughly the same amount of equipment as the reference group – non-bombed, high fertility households.

Figure 3.2 plots the total machine holdings on a household’s treatment condition across low and high land fertility. In high fertility villages, non-bombed households own more mechanical pieces of equipment than bombed households – three-times more than low bombed households, 50% more than medium bombed households, and two-times more than high
bombed households. While this plot is similar to Figure 3.1 in these data, there are two notable differences. First, households in the lowest bomb tertile in low fertility soil own three times more machines than control, medium treatment, and high treatment households. The second comment pertains to high fertility soil. Specifically, households in the medium bomb tertile own substantively, but not significantly, fewer total machines than control households. By contrast, the predicted values are significantly different for households in the lowest and highest tertile. These two results suggest that households in these categories tend to own heavier equipment, although this trend is not significant, according to Column 2. Nonetheless, the overall trajectory is still apparent: bombing results in a drop in agricultural machines, importantly, only in high fertility soil, where we expect more unexploded ordnance.

Certain treatment tertiles invest more than expected, at the level of unbombed (control) households. For instance, in Figure 3.2 households in the lowest bomb tertile, they own triple the number of agricultural machines (0.337) as households in the middle and high tertiles (0.119 and 0.124 respectively). What can explain this minor inconsistency? One explanation is measurement error in the independent variable. Villages in the lowest bomb tertile could be near non-bombed villages. Recall that household plots are small (on average, 5,000 m²), so agricultural machines are typically rented out. One tractor often services multiple villages. Since the benefits of this purchase spills over to neighboring places, we can imagine that a household in a low bombed village could purchase an agricultural machine to use in neighboring unbombed areas.

Next, consider a smaller annual investment, like a household’s spending on fertilizer, seeds, and irrigation. Compared to the thousands of dollars that is spent on machinery, only $36 is spent on seeds for the average household plot, $61 on chemical fertilizer, and $4 on irrigation (CSES 2012). However, these materials still require individuals to potentially risk their lives when they apply the material by hand or by machine. I expect the same trends as
Figure 3.2: Predicted number of agricultural machines (tractors, combine threshers, bulldozers, and hand-tractors) owned by the household, according to soil fertility (panel) and treatment condition (horizontal).

mentioned previously: households near unexploded ordnance should invest less than control households.

In Table 3.2 Rows 1 through 3 show a negative, significant cross sectional relationship between the treatment and outcome variables: bombing among households on high fertility land is negatively correlated with agricultural spending on seeds, fertilizer, and irrigation.
Row 4 shows that the association between the low fertility dummy and dependent variables is negative but insignificant. The next three rows show that the interaction coefficients (bombing times low fertility soil) are substantively smaller than their respective bombing coefficients – though the coefficient is only marginally significant in two cases (for low bombed, low fertility household’s spending on fertilizer and for high bombed, low fertility household’s spending on irrigation). Rather than canceling each other out (like in the previous table), these results suggest that bombing still impacts the outcome in low fertility soil, just at a smaller magnitude.

Figure 3.3 suggests that bombing changes household investment patterns in seeds across soil conditions. When a village on high fertility soil was bombed, contemporary household spending on rice seed is reduced by one-third ($0.0068 \text{ USD/m}^2$ for control households, compared to $0.0044 \text{ USD/m}^2$ for medium and high treatment households). When a village on low fertility soil was bombed, the investment in rice seed shrinks by a similar margin; there is a 39% decline for medium treatments and a 16% decline for households in the lowest and highest bombing tertile. In both high and low fertility land, the predicted values are not significantly different from the control. One explanation for these insignificant coefficients is measurement error in the dependent variable. We do not directly observe what type of seeds are being acquired – whether they are traditional or high-yield varieties – and why these seeds are being acquired. High-yield variety seeds are hybrid plants, which will not produce uniform offspring. Therefore, farmers must purchase new seeds each year. Traditional varieties tend to produce very similar offspring, so the seeds can be collected and replanted the next season. Buying rice seed can be a measure of two divergent activities: first, some households are forced to consume the rice seeds they intended to save for the next season, due to unforeseen economic circumstances that year. Therefore, before growing season, they buy the cheaper, traditional varieties to make up for their consumption. Second, some farmers
Table 3.2: The effects of bomb intensity x fertility on agricultural spending

<table>
<thead>
<tr>
<th></th>
<th>Seed</th>
<th>Chemical Fertilizer</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variable: Money (USD/m²) spent on</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(1) Low Bombs</strong></td>
<td>$-0.002^{**}$</td>
<td>$-0.013^{***}$</td>
<td>$-0.001^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.002)$</td>
<td>$(0.0004)$</td>
</tr>
<tr>
<td><strong>(2) Med Bombs</strong></td>
<td>$-0.002^{**}$</td>
<td>$-0.010^{***}$</td>
<td>$-0.001^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.002)$</td>
<td>$(0.0004)$</td>
</tr>
<tr>
<td><strong>(3) High Bombs</strong></td>
<td>$-0.002^{*}$</td>
<td>$-0.012^{***}$</td>
<td>$-0.003^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.002)$</td>
<td>$(0.0004)$</td>
</tr>
<tr>
<td><strong>Low Fertility Soil</strong></td>
<td>$-0.001$</td>
<td>$-0.001$</td>
<td>$-0.00003$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.002)$</td>
<td>$(0.0004)$</td>
</tr>
<tr>
<td><strong>Low Bombs: Low Fertility</strong></td>
<td>$0.002$</td>
<td>$0.006^{**}$</td>
<td>$0.0003$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.003)$</td>
<td>$(0.001)$</td>
</tr>
<tr>
<td><strong>Med Bombs: Low Fertility</strong></td>
<td>$0.0002$</td>
<td>$-0.001$</td>
<td>$-0.0004$</td>
</tr>
<tr>
<td></td>
<td>$(0.002)$</td>
<td>$(0.003)$</td>
<td>$(0.001)$</td>
</tr>
<tr>
<td><strong>High Bombs: Low Fertility</strong></td>
<td>$0.001$</td>
<td>$0.004$</td>
<td>$0.001^{**}$</td>
</tr>
<tr>
<td></td>
<td>$(0.001)$</td>
<td>$(0.003)$</td>
<td>$(0.001)$</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>$0.007^{**}$</td>
<td>$0.018^{***}$</td>
<td>$0.002^{*}$</td>
</tr>
<tr>
<td></td>
<td>$(0.003)$</td>
<td>$(0.006)$</td>
<td>$(0.001)$</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>2,595</td>
<td>2,595</td>
<td>2,595</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.041</td>
<td>0.140</td>
<td>0.091</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Regional fixed effects</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

*Notes: Columns (1) through (3) report the OLS estimates for the amount of money the household spent on seed, fertilizer, and irrigation per square-meter of plot. 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
buy the high-yield variety each year in order to produce more rice. This behavior represents a type of investment while the first circumstance is an example of consumption smoothing.

![Figure 3.3: Predicted USD that the household spends on seeds (per m²), according to soil fertility (panel) and treatment condition (horizontal).](image)

I cut down on measurement error by examining the impact of bombing on chemical fertilizer and irrigation. High-yield varieties require 2-3 applications of fertilizer and regular watering in order to reach their growth potential (Foster and Rosenzweig 1995). If households are buying high-yield seeds, then we should expect to see parallel investments in fertilizer.
and irrigation. Conversely, if households are buying traditional seeds to make up for the rice seeds they consumed during the dry season, then we should expect households not to invest in fertilizer and water. When fertilizer is applied to traditional grains, it increases the length of the stalk – not the size of the grain (Evenson and Gollin 2003). Therefore, there is no ecological reason for households to apply fertilizer to traditional seeds.

Figure 3.4 shows a negative relationship between bombing and household spending on fertilizer, both in low and high fertility areas. In high fertility villages, bombing reduces average household spending on fertilizer by half. In low fertility villages, the reduction is about 60% for the low and high treatment tertiles and 50% for the middle tertile. In Figure 3.5, the relationship between bombing and irrigation spending remains similar. Both in low and high fertility areas, non-bombed households have double to triple the irrigation expenses as bombed households.

A few auxiliary findings also require comment. The first concerns the relationship between agricultural spending and crop yields, found in the last chapter. If the control households in low fertility villages are spending just as much on fertilizer and irrigation, then why isn’t their rice production higher? The previous chapter did show that rice yields in control households were substantively more than rice yields in treated households, although this difference was not statistically significant. One reason could be a lack of machines, as seen in Figure 3.2. This suggests that crops are grown by hand, which would slow production.

The second concerns the impact of bombing in low fertility soil. We expected bombs to have negligible impact on investment patterns, since these areas have less unexploded ordnance. Instead, it appears that the threat of unexploded ordnance matters, even when the threat is smaller. People still sense risk in their low fertility land, and the increasing risk in farming lowers their small-scale agricultural investments. This behavior falls in line with the findings from the previous chapter, which shows that bombing has a substantive but insignificant impact on rice production in low fertility areas.
Lastly, which seeds – traditional or high-yield varieties – are being purchased? It appears that both hypotheses are confirmed. On the one hand, control households are spending two to three times more on fertilizer and irrigation than treatment households, and this is true in both low and high fertility villages. It appears that as long as their village was not bombed (so at risk for unexploded ordnance), households are willing to try out more advanced seed technology. This makes sense given what we know about high yield seeds: they increase
Figure 3.5: Predicted USD that the household spends on irrigation (per m$^2$), according to soil fertility (panel) and treatment condition (horizontal).

rice productivity more in marginal areas than in already-productive areas. In other words, these seeds mitigated the importance of crop suitability and thus caused less fertile areas to “catch-up” to other, more fertile districts in potential rice yields.

On the other hand, bombed households spend significantly less on fertilizer and irrigation, regardless of soil fertility type. This points us toward the alternate hypothesis: that these households are buying traditional seeds, fertilizing and irrigating them minimally. Farmers
in these bombed areas seem to be poorer. Since this is true across high and low fertility villages, it could be due to multiple factors, including unexploded ordnance discouraging farming, the direct impact of bombing (which destroys infrastructure and increases death tolls), or the poverty trap created by living in either of those situations. While previous studies on Vietnam show that bombing does not create its own poverty trap (Dell and Querubin 2016; Miguel and Roland 2011), we lack evidence on the independent effect of unexploded ordnance on poverty.

I test this causal relationship by instrumenting for the reduction in rice yield across farming households in the CSES 2012. This instrument should isolate variation in rice production that is due to exposure to unexploded ordnance (rather than other shocks or fluctuations in climate and rice prices). I argue that spatial dispersion of unexploded ordnance is plausibly exogenous to contemporary agricultural behaviors, due to the fact that all dropped bombs were intended to detonate and result in the immediate destruction of the target area, not the long-term decay of the surrounds.

Equipped with this quasi-random treatment, this section takes an instrumental variable identification strategy to measure how UXO-based crop reductions impact household poverty. The first stage regression is the main OLS specification described previously in Equation 2.1, where $Bombing_v \times Fertility_v$ is the excluded instrument, the interaction of a cross-sectional measure of UXO contamination based on bomb intensity with a categorical variable for local soil fertility. I run the first stage twice, with two dependent variables: the amount of rice harvested (per square-meter of plot) and the percent of rice sold to market.

The second stage regression takes the form,

$$W_h = \alpha_h + Y_h + Fertility_v + X_v + \gamma_{region} + \varepsilon_h$$

(3.2)

where $W_h$ denotes the wealth measure. Household food consumption for the past seven days (taken from the CSES 2012) serves as a proxy for wealth. Food expenditure, which
is smoothed out over time, should provide a more reliable measure of wealth than income diaries, which vary widely from month to month due to seasonal labor, informal employment, and windfall gains in remittances. Using food consumption as measure of wealth allows us to include households that rely primarily on barter, trade, and consumption of their own produce. $Y_h$ is the 2012 rice harvest in the first model. In the second model, $Y_h$ is 2012 rice sales. Lower order terms are accounted for in the equation via the same regional fixed effects as in the first stage.

Table 3.3: The Developmental Effects of UXO

<table>
<thead>
<tr>
<th>2nd Stage Dependent Variable:</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food consumption (riel/person)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice harvested (riel/m²) 10.44**</td>
<td>(4.451)</td>
<td>–</td>
</tr>
<tr>
<td>1st stage DV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice sold (%) 7,748**</td>
<td>–</td>
<td>(3,041)</td>
</tr>
<tr>
<td>1st stage DV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant 44,974***</td>
<td>38,852***</td>
<td></td>
</tr>
<tr>
<td>(3,181)</td>
<td>(4,819)</td>
<td></td>
</tr>
<tr>
<td>Observations 3,615</td>
<td>2,997</td>
<td></td>
</tr>
<tr>
<td>R² -0.281</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Regional fixed effects</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Notes: Columns (1) and (2) report the IV estimates for household food consumption in 2012 (riel per person). Instrument is the interaction between soil fertility and cross-sectional measure of bomb intensity. Column (1) uses the household rice harvest as the intermediate variable while Column (2) uses the rice sold to market. For first stage results, refer to Tables 2.1 and 2.2 in the previous chapter. 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
In Table 3.3, Columns (1) and (2) show that the relationship between UXO-impacted rice production and food consumption is positive. Conversely, when households with lower rice yields and sales, due to their exposure to unexploded ordnance, they have lower food consumption levels. A 1 percentage point decrease in rice sales is associated with a 7,748 riel (or $1.75 US) decline in weekly food consumption for each household member. The median household spends $7 per person on food, so this represents a 25% decline in food consumption. Similarly, a 400 riel/m² drop in rice production results in a 4,176 riel decrease in food consumption (which is a 14.8% decline from the median expenditure). These results suggest that unexploded ordnance are one of the causal factors behind household hunger and poverty.

3.4 Discussion

Both the OLS regressions and the instrumental variable analysis provide evidence that unexploded ordnance negatively impacts local economic development. This finding is robust across a series of model specifications, including village-level controls, fixed effects on regional variation, and household weights that balance on pretreatment propensity scores. The magnitude of the effect varies across the different outcome variables. When we compare a non-bombed household to the average bombed household, the number of hand-tractors drops by one-half in highly fertile soil, where we would expect more unexploded ordnance. The number of machines, in aggregate, drops also by 50%. The 2012 amount spent on seed, fertilizer, and irrigation also decreases, by 33%, by 55%, and by 82% respectively. These trends confirm the hypotheses: farmers invest in their land minimally in bombed, high-fertility areas, due to the increased risk of encountering unexploded ordnance.

These leftover weapons, which prevent farmers from producing crop surplus with traditional practices, also hinder development because farmers cannot realize the potential gains from technological advances. The Green Revolution in South Asia opened up new, less fertile
lands to agricultural development, empowering a new set of the land holders that demanded political representation \cite{Callen, Gulzar, Rezaee, Shapiro 2015; Dasgupta 2015}. This trend does not appear to generalize to Cambodia. Although high yield varieties (and the intensive fertilizer and irrigation practices they depend on) came late to Cambodia, it appears that only households with the most geographic advantages end up benefiting from them. To wit, those living in high fertility, unbombed villages buy the machines, seeds, fertilizer, and water necessary to grow the maximum amount of rice that today’s technology will allow. Those living on low fertility, unbombed soil invest in certain aspects of land management, but do not seem to have enough earnings to invest in the large-ticket items, like tractors and threshing machines. Not only that, but low fertility households would need to spend more than high fertility ones on fertilizer and irrigation in order to reach the optimal nutrient profile. The benefactors of the Green Revolution are the ones in the best position to invest: not just land-holders but those with enough surplus, savings, or liquid assets to purchase new equipment and tools. They look more like Marx’s capitalists than his peasants.

Unlike the previous chapter, which found that bombing in low fertility soil had no significant impact, some of this chapter’s findings suggest the opposite. In fact, bombed, low fertility households had predicted values in their fertilizer and irrigation expenses that were significantly smaller than the household expenses on unbombed, but otherwise similar soil. While these results were unexpected, I used findings from the previous chapter to underscore that bombing did have a substantive, but not significant impact on crop production in low fertility villages.

This result yields an important insight. People living on land with low risk of unexploded ordnance – in this case, low fertility, bombed land – farm as minimally as those living on land at high risk of unexploded ordnance – high fertility, bombed land. The effect of living in an area at low risk of unexploded ordnance may have been dampened because these low fertility areas were already in a poverty trap. Since they can produce such little rice to begin
with, any decline due to unexploded ordnance will look small. This chapter suggests that, even in low fertility areas, the slight risk of running unexploded ordnance still deters farmers from investing like their counterparts on safe land.

The analysis presented here has several limitations. Future studies could try to identify the exact placement of unexploded ordnance, rather than relying on a proxy that estimates where UXO should be. Case studies could clarify the boundary conditions and potential spillover effects of living near UXO, especially since the perceived risk of encountering UXO might not mirror the actual likelihood of running into ordnance. Participant observation and interviews could reveal more about the mechanism, particularly how information about UXO location is generated, shared, and acted on. In the theory presented here, there are a variety of factors that could dull the effect of unexploded ordnance on development, such as labor market institutions, increased access to roads, human capital availability, and state efforts to improve agricultural production through subsidies and corporate rice mills. Leftover pieces of ordnance, while important, are not determinative, and based on the estimates in the paper, cannot explain more than a fraction of the country’s unequal economic growth.

However, political scientists have already undertaken an extensive research agenda focused on linking poverty with the legacies of war. Researchers have considered changes in capital markets, examining factors like capital destruction and flight (Collier, Elliott, Hegre, Hoefler, Reynal-Querol, and Sambanis [2003]); social cohesion (Fearon, Humphreys, and Weinstein [2009]); microfinance and increased access to small-capital loans (Alldén [2009]). The findings here suggest that further attention to changes to land could also be generative. Like natural disasters and nuclear explosions, unexploded ordnance can change the physical landscape to the point that the economic capacities of those on safe land are fundamentally different from those living on contaminated land.
3.5 Conclusion

The implications of this analysis are twofold. First, it identifies an aspect of the Green Revolution that does not benefit rural households in general, but rather serves the minority of advantaged farmers. Advances in farming technology could increase in importance as the Cambodian economy continues to shift away from a rural economy of small land-holders and toward one that is more segmented across low and high producing households. Our intuitions about the relationship between the Green Revolution and agricultural output rely on an increasingly outdated and optimistic picture of the rural economy in the developing world. Even critics of the Green Revolution have focused on differentiating between the large land-holders and the wage laborers (Scott 1983) or between progressive, Western-educated farmers and the landless proletariat (Glaeser 1987, p.2). Both of these schemas presuppose that those land owners can access and farm their plots easily, and only lack the start-up capital and minimal land holdings needed to invest in the new technologies and enjoy the economies of scale. This chapter shows that on the contrary, extra risk is generated and encountered by farmers who work on post-conflict land. Just as natural resource researchers examine the distributional consequences on both places that experience a resource windfall and places that do not, analysis of the economic consequences of war should consider differential distributional consequences within both dangerous and safe land. Such an analysis could undermine the real and rhetorical links between exogenous advances in technology and welfare for the average farmer.

Second, this chapter traces a pathway through which unexploded ordnance can affect local development through unrealized gains and through lower social welfare. The OLS analysis on investment patterns shows that the potential loss can operate at the high end of soil advantages and in less fertile places far removed from the Mekong Delta, or the “rice basket” of Cambodia, which has received the most attention around agricultural production. The instrumental variable analysis indicates that these losses in rice production result in
less food consumed by each household member. In an economy marked by agricultural
dependence, the dynamics here could grow in importance.
Chapter 4

Local Infrastructure and Elections: the effect of bombs on Cambodian politics

This chapter examines the political repercussions of unexploded ordnance, with particular focus on how the state distributes resources in this altered post-conflict geography, and how local grievances in contaminated areas are mobilized into political behaviors. Unlike the previous chapters, which examine how individuals alter their agricultural strategies when they fear unexploded ordnance, this chapter explores the way that the state treats contaminated and uncontaminated areas differently, altering the state-society relationship. It shows how unexploded ordnance make it difficult for the state to build local infrastructure. Specifically, I demonstrate that contaminated areas receive lower levels of public goods, due to the fact that it is unsafe for the state to build infrastructure on land that has unexploded ordnance. In return, local constituents respond at the polls, voting for the opposition party over the incumbent party.
In Chapter 3 I highlight the negative compounding effect that unexploded ordnance have on local quality of life. Not only do unexploded ordnance deprive farmers of a sense of safety and of commercial rates of production, but they also make it difficult for individuals to access public goods. Many post-conflict governments avoid distributing goods, like public infrastructure or social services, to contaminated areas. For instance, the Ministry of Rural Rehabilitation and Development in Afghanistan would not prioritize contaminated communities for infrastructure development until their lands had been cleared of mines and UXO (HALO Trust 2015). Some of the most contaminated provinces in Cambodia – Banteay Meanchay, Oddar Meanchey, and Preah Vihear, all part of the “K5 mine belt” – have the lowest levels of public investment in the country (Klugman and Taliercio 2003, Table 4).

I argue that unexploded ordnance create a physical barrier that prevents the state from distributing goods to unsafe areas. By testing this claim across multiple types of public infrastructure, we can better understand the diverse downstream effects of land contamination – how UXO impact meso-level political variables in addition to micro-level economic outcomes explored in earlier chapters. The meso-level, state-society dynamic is important because if these constituents are poor and feel like they are forgotten by the state, their grievances can easily manifest into pro-opposition behaviors. This is particularly true in Cambodia, where the Cambodia People’s Party (CPP) has governed continuously since 1998, resulting in a close tie between the state and the incumbent party.

In this chapter, I use the exogenous variation in the rate of bomb failure as an instrumental variable for the availability of state infrastructure. Using this instrumental variable strategy, I estimate the impact of public goods provision on vote choice. The quasi-random placement of unexploded ordnance is a plausible instrument for local infrastructure for three reasons: one, unexploded ordnance directly limit the state’s ability to safely build; two, the reason why the unexploded ordnance is there – the mechanical failure of a carpet bomb dropped during the Vietnam War – is plausibly independent from the local socioeconomic
conditions (i.e., prior voting record, social cleavages) that would influence public goods provision today. Finally, most large-scale projects – like piped water, electricity grids, and sewage systems – were not built in Cambodia until after 1998, when the civil war ended and donor agencies could enter the country and provide ministries with funding and technical assistance. Since donors placed restrictions on the disbursement of funds – requiring them to go to the poorest areas first – but did not provide additional funds for the removal of UXO, ministries were unable to build infrastructure in communes with UXO in the land. The instrumental variable method makes it credible to assert that the association between service provision and vote returns is a causal relationship rather than a correlational one.

Why choose electoral returns as the quantity of interest for political behavior? After all, the ballot box is not the only way constituents express their dissatisfaction with government. Individuals choose from a variety of techniques. Using their “voice” option, they could protest or openly communicate their preferences in town hall meetings or to the village chief and commune council (Hirschman 1970). Though these democratic institutions exist in Cambodia, the state is quite repressive under Prime Minister Hun Sen, who has ruled for three consecutive decades. In the past year alone, notable opposition figures, like political commentator Kem Ley or environmental activist Chut Wutty, have been publicly assassinated. Hun Sen biographer Sebastian Strangio notes that prior to elections, “Hun Sen tightens the screws, people are hauled into court, and defamation cases fly. Then, after a period of tightening which keeps the opposition off balance, the shackles are released and there’s a period of loosening designed to placate international critics” (Ramzy 2016). Unsurprisingly, many Cambodians are averse to openly expressing their political preferences, especially if they are against the incumbent regime.

Given the remaining options, social scientists are limited in the ways we can observe behavior that provide some indicator of political preferences. If public discourse is discouraged, then individuals could communicate their preferences in their “hidden transcripts,” which
are occasionally publicized through foot-dragging, jokes, evasion, false compliance, sabotage, and gossip (Scott 1990). However the legacy of the Khmer Rouge, which had persecuted Cambodians who dragged their feet, gossiped about the regime, or demonstrated any lack of enthusiasm, has made even these behaviors seem dangerous (Chandler, Kiernan, and Boua 1988; Kiernan 2014; Ung 2012). Another option is “exit,” in which dissatisfied individuals could leave the village (Hirschman 1970). But as we have seen in the past two chapters, ties to land are notoriously sticky, and individuals appear to remain on their ancestral land, despite their inability to generate revenue from contaminated land. If people are staying in their ancestral villages in a country with a politically repressive climate, what is the most reliable way to track political opinion?

I choose electoral returns for the following reasons. The first democratic elections in 1998 were heavily monitored by the United Nations, which set up a strict administrative procedure for election monitoring and an intensive media campaign that educated Cambodians on their electoral rights, like a secret ballot and the public counting of ballots in each polling station (Heder and Ledgerwood 1995; Ledgerwood 1994). Since then, elections have been monitored by international and domestic organizations, including Transparency International and the National Democracy Institute, which document the degree to which elections are free and fair. Based on the resulting reports, the actual process of voting and counting ballots is widely seen as free and fair (Un and Ledgerwood 2002), although there is evidence that the incumbent party’s control of the media and repression of the opposition significantly impacts the opposition’s ability to sway voters at the polls (Hughes, Sedara, and Sovatha 2004). Yet if this was to bias the analysis, it would do so in my favor; that is, any evidence

1I aim to test these statements with data. First, the CSES 2009 contains a unique battery of questions on migration status, including the district from which the household had migrated from. I will calculate the number of people who leave contaminated districts and the number of people who enter contaminated districts. Then, I will provide descriptive statistics to understand the education and poverty levels of those who migrate. I will use this analysis to motivate a new chapter on the patterns of post-conflict migration, due to unexploded ordnance.
of unexploded ordnance’s electoral effect would over-ride all the CPP’s attempts to repress or scare constituents into voting for them.

The electoral returns from the 2013 National Election were the first government-released results of the vote returns at the local level. I find that, in high fertility, bombed communes (areas with the most exposure to unexploded ordnance), there is an 8.0% drop in the proportion of households with sewer access. This results in a 6.7% rise in vote share for the opposition party, the Cambodia National Rescue Party (CNRP). Interestingly, bombed, low fertility communes also experience a significant but smaller drop (3.5% to 4.3%) in households with sewers. I find similar results for two other types of public infrastructure. Regardless of fertility type, bombing decreases electricity connections by 10 to 15%, which leads to a 5.2 to 7.9% increase in CNRP vote share. The effect size of bombing on water infrastructure is the same for both low and high fertility communes. The 7.5% drop in households with piped water (from bombing high or low fertility land) results in a 7.8% rise in CNRP vote share. These results suggest that if the state does not provide local infrastructure, constituents express their dissatisfaction in the least risky way possible – by rewarding the opposition party at the polls.

This chapter unites two somewhat distinct literatures in comparative politics: one on public goods provision in the developing world and one on post-conflict elections. Political scientists have puzzled over the variation in governmental public goods provision, examining the role of strong democratic and bureaucratic institutions (Dahl 1973; O’Donnell 1996; Rose-Ackerman 2005), civil society and social capital (Boix and Posner 1998; Putnam, Leonardi, and Nanetti 1994), and ethnic diversity (Alesina, Baqir, and Easterly 1999; Habyarimana, Humphreys, Posner, and Weinstein 2007; Lieberman 2009; Miguel and Gugerty 2005). I

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2 Prior to 2013, electoral results were provided at the provincial level. Is the decision to release the results a political one? For instance, the electoral commission could strategically choose to release the disaggregated electoral results to showcase the CPP’s continued dominance. Although the CPP retained control in the 2013 election, it won with the smallest margin of victory. Releasing the commune-level results of this more contested election could signal that the CPP is aware of its loyal communes and has its eye on the opposition communes.

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offer a different explanation. I suggest that the state may be willing, but unable to supply public services in places that are too dangerous. While recent research has shown that programmatic aid during war is most effective in places with less violence (Sexton 2016), this finding suggests this relationship may endure long after war is over. Decades after the end of war, these areas may still not enjoy the full benefits of donor packages or state programs because organizations cannot build where there are unexploded ordnance.

In comparative politics and security studies, recent research examines how post-conflict elections contribute to ensuring a successful transition to democracy and peace. A large body of work has focused on the impact of elections on regime stability across countries (Brancati and Snyder 2013; Cederman, Gleditsch, and Hug 2013; Dunning 2011; Dunning, Brancati, and Snyder 2011; Flores and Nooruddin 2012), but its focus on cross-national trends has led it to underestimate the impact of local grievances and electoral dynamics. A slightly older literature associated with war and democratization (Bermeo 2003, 2007) is closely attuned to the challenges that face elites in emerging, post-conflict democracies. However, these pieces fail to account for the variation in stability and political preferences within the region, providing little explanation for why the political trends they identify vary widely across local districts. In this chapter, I suggest that in post-conflict communities, unexploded ordnance give opposition parties an unexamined advantage. By making the distribution of state resources difficult and dangerous, these explosive remnants of war create a service inequality between communes and throws a wrench in the CPP’s standard electoral strategies of vote-buying and clientelism. While unexploded ordnance do not appear to sway enough voters to turn an election, the findings suggest that some votes are just too expensive to be bought with rally gifts and cash hand-outs when deprived of essential services.

To make this case, this chapter proceeds in five sections. First, I explain the theory and briefly describe the context of sewage, water, and electricity provision in Cambodia today. In the second section, I detail a unique dataset of all communes in Cambodia and explain
the statistical model. Third, I present the main results. I show that bombing negatively impacts contemporary service provision, and that these reductions in services lead to more oppositional support. Fourth, I discuss the results as well as the limitations in the analysis. The last section concludes.

4.1 Theory and Context

This is a two-part theory. First, unexploded ordnance impact the distribution of state resources, by placing physical and sometimes imagined barriers in between the state and its constituents. Second, areas that receive fewer resources express their dissatisfaction with the state in the national elections.

My argument challenges the predominant view of how the dominant party in Cambodia and other developing countries win elections. In the developing world, dominant political parties (which, by definition, win consecutive elections) are typically thought to use many coercive and economic tools to convince voters to turn out and choose them at the polls. Elections help parties identify their loyal constituents, so winners can reward their supporters and punish their opposers after the election (Brownlee 2007; Magaloni 2006). They distribute benefits to constituents in direct exchange for political support. Scholars have explored patterns of clientelism during elections (Nichter 2008; Stokes 2005; Wantchekon 2003) as well as beyond the electoral cycle (Scott 1977). Given the abundance of strategies to win votes, elections become a show of strength for the dominant party, and the resultingly overwhelming electoral victories often are intended to signal to the opposition that their efforts are futile (Magaloni 2006, Malesky and Schuler 2008). In this situation, opposition parties usually cannot compete with the dominant party in offering material resources or intimidating voters. So it is not necessarily clear what drives voters to go to the polls and choose the opposition.
My theory suggests that structural limitations, rather than ideology, impacts one’s likelihood to vote for the opposition. Scholars suggest that opposition supporters appear to be more “highly ideological” (Gandhi and Lust-Okar 2009, p.409). In explaining the decline of the PRI in Mexico, recent research indicates that “the only citizens willing to pay high costs and reap uncertain benefits are those who strongly disagree with the status quo policies offered by the incumbent” (Greene 2007, p.5). Simply put, building large-scale infrastructure projects is a more effective, albeit expensive, way to win votes. A dominant party’s typical array of coercive and clientelistic strategies does not seem to work in places that do not receive the public infrastructure.

The Cambodian People’s Party has relied on a mixed set of strategies that use social control, clientelism, and information gathering to ensure elections go in their favor, “from vote-buying, sponsoring of development initiatives and mass gift-giving programs to the formation of groups of households under a group leader who is responsible for finding out voting intentions of households and ensuring those that intend to vote CPP go and vote on the day” (Hughes 2015, p.10). However, the 2013 results, in which the opposition party made a surprisingly strong showing, capturing 45% of the popular vote (a 16% improvement from the last election), were not predicted by the CPP, which had believed its methods of social control were relatively sophisticated and fine-tuned. Despite the fact the CPP relied on the same methods of coercion and clientelism in this election, the 2013 vote patterns suggest that the electorate was voicing its dissatisfaction with the status quo. This chapter demonstrates that some of these grievances stem from a critical juncture five decades prior: when US bombs had failed to detonate.

I posit that certain local groups can have disadvantages, due to their post-conflict geographies. Our understanding of postwar societies tends to focus on interpersonal relations – trust, social cohesion, cooperation – but we do not know how these impact long-term political processes, like elections and the dominance of certain party machines. Importantly,
many studies focus on the link between local cooperation and the bottom-up provision of public goods – for instance, the degrees to which the road, school, or pre-existing infrastructure can be maintained by local groups (Fearon, Humphreys, and Weinstein 2009; Gilligan, Pasquale, and Samii 2014). However, much of public infrastructure depends on the top-down distribution of state resources. I suggest that unexploded ordnance impacts the distribution of state resources, particularly the state’s ability to provide or rebuild infrastructure.

4.1.1 Hypotheses

Building on these insights, the main argument of this chapter can be captured in two hypotheses:

**H1:** First, individuals on contaminated land are more likely to be deprived of state services, since the state is less likely to send building crews and public servants to dangerous areas. Put another way, UXO areas are less likely to benefit from recent investment in public infrastructure, due to the costliness of UXO removal.

**H2:** In places with less public infrastructure, we should expect more support for the opposition party and consequently less support for the incumbent political party.

4.1.2 Public Goods in Cambodia

I test these hypotheses by examining the impact of UXO contamination on three types of public infrastructure: electricity grids, sewers, and piped water. These three public services represent types of large-scale infrastructure that require some form of federal assistance in capital, expertise, supplies, and ministerial permissions. These are categorically distinct from public goods that can be provided more locally, like maintaining roads and cleaning school buildings. Roads, schools, and hospitals also represent large-scale infrastructure. They were first provided in the colonial era, during French Indochina, and went through
major expansion during post-colonial independence under the Sihanouk regime, known to be the main period of Cambodian modernization. While these facilities and roads have been improved over time, their location tends to predate the US bombing. This means that unexploded ordnance may impact an individual’s access to these public goods, but they do not impact the actual location of them.\(^3\)

Electricity, sewage, and piped water were more recently introduced to rural Cambodia, as the government has only begun to invest in these projects since the start of the 21st century. Next, I will describe the current state of each type of infrastructure.

**Electricity in Cambodia.** The electricity sector in Cambodia is an unusual mix of a donor-funded state utility expansion and hundreds of small, private providers distribute electricity to customers in off-grid areas. Where there is no grid, rural electricity entrepreneurs can generate electricity using diesel generators. International donors, like the World Bank and JICA, have played a vital role in shaping Cambodian electricity policy and distribution. Based on the guidelines in the 2003 Renewable Electricity Action Plan, the World Bank provides technical assistance and grants so that Cambodia could increase its rural cover-

\(^3\)Though unexploded ordnance may not change the location of these goods, the bombing may have destroyed some of the original village infrastructure, like schools and roads. Although I do not discuss the degree to which public goods are rebuilt following war in this dissertation, I intend to study the effect of bombing on public goods rebuilding and the impact of unexploded ordnance on access to public goods, like schools, roads, health clinics, with a team of student researchers Summer 2017. In Cambodia, foreign powers extensively mapped the Cambodian landscape for their own geo-strategic interests – the US in the 1960s, the Soviets in the 1980s, and the Japanese in the 1990s. Each country had sent its own mapping agents into the country to collect village names and verify geographic information that had been collected from aerial photographs (or satellite imagery in the case of Japan). The maps are inherently rich in the detail, depicting the location of each household in each village, as well as schools, temples, markets, roads, bodies of water, and main agricultural areas.

With our team of student researchers, we will code the locations of settlements, agricultural fields (separated by crop type), and highly frequented public spaces (markets, schools, district halls) for each series of maps. Once the maps are coded, we will be able to see how UXO contamination during the Vietnam War changed settlement patterns, since we will have the household locations prior to bombing (1960 series) and after bombing (1979 series). In addition, we will be able to see how long these settlement patterns persist, by seeing if UXO areas are still populated, even when people have known for years about the dangers of the land. Using data from the Cambodia Socioeconomic Survey, we will determine if rates of school attendance, health clinic usage, and travel decrease in areas with high levels of unexploded ordnance. Finally, we will also see if places where UXO in places with high foot traffic (roads, schools, markets, village hamlets) are more likely to be abandoned, compared to places where UXO fall mainly on privately held, agricultural land.
age from 13% in 2008 to 70% by 2030. In 2004, the World Bank provided $15 million of loans and grants to establish a Ministry of Industry, Mines, and Energy. This Ministry is responsible for providing equitable electrification coverage to the rural population, so that it can decrease its use of diesel generators. Since 80% of villages and households lie within 40 kilometers of provincial towns, JICA provided more funds to extend the medium voltage line grids (Ryder 2009).

**Sewage in Cambodia.** Traditionally, rural residents have used rice paddies, banana groves, and streams or lakes for defecation (Mukherjee 2002). In 2004, only 17% of Cambodians had access to improved sanitation, meaning access to a latrine with a properly hygenic disposal system (World Bank 2008). The majority of that percentage represented Cambodians living in urban areas; only 8% of the rural population in Cambodia had access to improved sanitation. While aid organizations, like Resources Development International - Cambodia, have devised a pit latrine system that costs less than $12 to construct, 54% of homes have no toilet facilities. The cost of constructing a toilet connected to a sewer is about $8, which is not prohibitive for the poorest quintile, for which average per capita consumption is $256 per year (ABD 2014). The Asian Development Bank, World Bank, International Monetary Fund, and United Nations International Children’s Emergency Fund all have projects that provide funding for rural sanitation. This funding is channeled through the Ministry of Rural Development, and has had some success in improving sanitation conditions in Cambodia. By 2013, 38.5% of the rural population had a toilet in the household premises. 13% of the rural population had toilets with sewer access while 22% had toilets connected to a pit latrine (World Bank 2015, p.32)

**Water systems in Cambodia.** Many areas of Cambodia have plentiful supplies of surface water, so surface water is traditionally the main source of drinking water (Irvine, Murphy, Sampson, Dany, Vernette, and Tang 2006). However, most surface water is unsafe

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4 The majority of urban households (54%) are connected to the electricity grid. 18% of the population is connected to an electricity grid (Ryder 2009).
to drink without proper filtration and chlorination. In addition, when households do not have access to piped water, their waste water (and sewage) are not safely disposed of or treated. This can lead to increased water pollution due to sewage and gray water leftover from bathing, cleaning, and laundry being dumped back into ponds or lakes. In 2005, only 282,000 households in Cambodia had piped water (less than 1% of the total population), and the majority of these households were in urban areas (World Bank 2008, p.87). Since then, the Asian Development Bank has been the largest partner in rural water supply. By 2012, 66% of the rural population reported having improved access to water, though only 5% was estimated to have a piped water connection in the household (World Bank 2015, p.23).

4.2 Data and measurement

To test these hypotheses, I create a unique dataset compiled from four sources: the declassified US payload drops, the 2008 census, the 2013 electoral returns, and Royal Government of Cambodia data on land usage and soil fertility. Because the electoral returns were tabulated at the commune-level, all other measures are calculated at the commune-level. Unlike previous chapters, which relied on a sample of villages and households, this analysis includes all communes.

4.2.1 Bombing data

I rely on the Southeast Asia Air Combat dataset, which provide the coordinates of the aerial drop sites during the Vietnam War. I calculate the pounds of ordnance dropped within each commune, divide it by the surface area of the commune, and create a measure of bombing density (pounds of ordnance/hectares of land). I construct two treatment levels (low and high) with cutoffs at the median. The cutoff is rounded and is at 125 pounds of ordnance.

\[\text{Bombing density} = \frac{\text{Pounds of ordnance}}{\text{Hectares of land}}\]

\[\text{Cutoffs} = 125 \text{ pounds of ordnance}\]

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5 The commune is the administrative level above the village. There were 1,621 communes in Cambodia at the time of the 2008 census. As a reference, there were 14,703 villages.
per hectare, which translates to 1 carpet bomb (a 500-lb general purpose bomb) for every 10 acres of land. To estimate the amount of unexploded ordnance, I condition the impact of bombing on soil fertility, which will be discussed in more detail in the section on “Other local characteristics.”

4.2.2 Data on development

The 2008 Cambodian census provides data on the number of households with access to public infrastructure, including the sewer, electricity grid, and piped water. More specifically, households are asked if there is a toilet facility on the premises. If there is, the enumerator identifies whether the waste is deposited in a pit latrine or in the sewer. A separate question asks the type of lighting used in the house most of the time. Households are given the options of electricity, generator, electricity and generator, kerosene, candles, or battery. I collapse the electricity and the electricity and generator categories into one. Households are also asked about their main source of drinking water. Is water piped? Does the household buy its water? Or does the household collect water from the well, rain, or river? The enumerators record each answer in the census.

One could argue that the inability to access to public services is simply a function of poverty. Therefore, poverty, not a lack of public goods provision, drives vote choice. Since the first three measures focus on access to different public services (sewer, electricity, and water), the last measure captures the number of households that are poor and do not access public goods. Specifically, the census asks about the main type of cooking fuel. Respondents are given the choice of firewood, charcoal, kerosene, gas, electricity, or none. I include the percentage of households that use firewood, the cheapest type of fuel, in order to measure the level of household poverty. That is, they do not rely on public infrastructure and continue to use the lowest quality form of fuel.
4.2.3 Electoral data

I use the electoral returns from the 2013 Cambodian general election. In the general election, which has taken place every 5 years since 1993, voters cast ballots for their representative to parliament, which then elects the Prime Minister Hun Sen, who was appointed Prime Minister by the Vietnamese in 1985, managed to win a close election in 1993. Even though he narrowly lost the 1998 elections, Hun Sen launched a coup against the winner of the election Prince Norodom Ranariddh, who immediately fled to country. Since then, the Cambodia People’s Party (CPP) began to win substantially in the two local and one national elections between 2002 and 2008. Though there have been multiple opposition parties, including Sam Rainsy Party, the Human Rights Party, and FUNCINPEC, they tend to be fragmented and factionalized. But in 2012 the two largest opposition parties (Sam Rainsy and Human Rights) combined forces as the Cambodia National Rescue Party (CNRP). Surprisingly, the CNRP managed to win 44.5% of the popular vote in the 2013 election, resulting in the closest election since 2003.

In Cambodia today, electoral returns are one of the few measures of political behavior available to study. While many authoritarian regimes manipulate electoral results, I have reason to believe the electoral returns are reliable. The 2013 elections were observed by international and independent monitors, including Transparency International and the National Democracy Institute. According to Human Rights Watch, most of the electoral corruption occurred prior to the ballot box – unequal media access for opposition parties, lack of an independent dispute resolution mechanism, officials with CPP bias working for the electoral apparatus, extra campaigning by the CPP, and the alleged manipulation of voter rolls (HRW 2013). However, the voting process itself was overseen by independent monitors, the high turnout rate (68.5%) and the public counting of the ballots provide some assurance that the

---

6Local elections, which have taken place every 5 years since 2002, elect representatives to the commune council.
vote returns are perhaps the most accurate measures of political preferences in Cambodia today.

### 4.2.4 Other local characteristics

The 2011 Commune Database of Cambodia comes from the National Committee for Sub-National Democratic Development, Royal Government of Cambodia. It documents the proportion of the commune that is dedicated rice land. Since the unexploded ordnance are more likely to impact poverty rates of villages that depend on agricultural production, this measure proxies for the degree to which the commune’s economy depends on rice.

Finally, I calculate the soil fertility of the commune using the 2008 Ministry of Agriculture’s land fertility map. Each village in Cambodia is given a soil fertility score of 1 (Low Fertility Soil), 2 (Medium Fertility), or 3 (High Fertility), based on the score at the village centroid. Then, I average the village score across each commune. I choose this method, rather than calculating the amount of high/medium/low fertility soil across the entire commune, because it allows me to account for village clustering around more geographically desirable areas. For instance, if a commune contains mostly low fertility land but the majority of villages are clustered around the high fertility riverbank, then I would want the commune fertility measure to reflect where most residents live.

### 4.3 Estimation

I estimate the effects of unexploded ordnance on electoral outcomes in two stages. The first stages uses the following model:

\[
\text{Development}_c = \alpha_1 + \beta_1(\text{Bombing}_c \times Fertility_c) + X_c + \varepsilon_{1c}
\]  

(4.1)
Rate of bomb failure, as captured by the interaction between soil fertility and bomb intensity \((Bombing_c \times Fertility_c)\), is used to instrument for local levels of development in the first stage, with other commune characteristics controlled for \((X_c)\). Regional fixed effects \((\alpha_1)\) are included to capture area-specific characteristics that may be related to local development. The 1 denotes the equation number, and \(c\) denotes a commune. \(\varepsilon_{1c}\) is the disturbance term, and these disturbances are allowed to be correlated in the same commune in all regressions.

The second-stage equation estimates the impact of local development on electoral outcomes.

\[
Vote_c = \alpha_2 + \beta_2 Development_c + X_c + \varepsilon_{2c}
\] (4.2)

In this model, \(Vote_c\) is the electoral outcome, which denotes the margin of victory by the Cambodia People’s Party or the vote share of the opposition party, the Cambodia National Rescue Party. I perform an IV-2SLS estimation with corrected standard errors.

4.4 Results

Table 4.1 Models 1 through 3 show that control (unbombed) communes have a higher proportion of households with access to public goods, like sewers, electricity, and piped water. In order to calculate the effect of bombing, the treatment coefficients (Rows 2 and 3) are added to the respective interaction coefficient (Rows 5 and 6), conditioning on soil fertility. Across these three columns, the coefficient for the control groups is larger than the coefficients for the treatment groups and their interaction coefficients. In addition, while the treatment terms are positive and significant for the first three models, the interaction terms are negative, but small (ranging from \(-0.001\) in Model 3 to \(-0.022\) in Model 1). In other words, as soil fertility increases, the effect of bombing diminishes, but slightly. For instance

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Table 4.1: The effect of unexploded ordnance on commune poverty

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sewer connection</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Control</td>
<td>0.619***</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
</tr>
<tr>
<td>Treatment high</td>
<td>0.605***</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
</tr>
<tr>
<td>Treatment low</td>
<td>0.596***</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
</tr>
<tr>
<td>Soil fertility</td>
<td>0.013*</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
</tr>
<tr>
<td>Treatment high * fertility</td>
<td>−0.022**</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
</tr>
<tr>
<td>Treatment low * fertility</td>
<td>−0.020**</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
</tr>
<tr>
<td>Commune land dedicated to agriculture</td>
<td>−0.020**</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,566</td>
</tr>
<tr>
<td>R²</td>
<td>0.719</td>
</tr>
<tr>
<td>Regional fixed effects</td>
<td>✓</td>
</tr>
</tbody>
</table>

Notes: The dependent variables measure the percentage of households in the commune that have that particular access or engage in that particular behavior. Treatment low represents 0 > and < 125 pounds of ordnance dropped in each hectare of the commune. Treatment high signifies > 125 pounds of ordnance per hectare. The fixed effects model used five geographic dummies to capture within-region variation. *p<0.1; **p<0.05; ***p<0.01
in Model 1, the treatment effect of high bombing decrease by 6.6% when we move from a low fertility commune \((Fertility = 1)\) to a high fertility commune \((Fertility = 3)\).

Model 4 shows that control (unbombed) communes have a lower proportion of households that cook with firewood, a signifier of poverty since it is the cheapest fuel. We should take note of two trends. First, there is a positive association between treatment and firewood usage, as evidenced by the coefficients in rows 2 and 3. The interaction terms in rows 5 and 6 are small (roughly 6-7% of the size of the treatment coefficient) and statistically insignificant. Importantly, these interaction terms \((-0.019\) across both treatment conditions) cancel out with the effect of soil fertility \((0.019)\). This suggests that the interaction terms do not substantively change the impact of bombing.

Next, I use the regression results to predict the fraction of households that are connected to sewers, electricity, and piped water. Holding the control variable at its mean, I vary the independent variable (from control to low treatment to high treatment) and the interaction term (from low to high fertility) and display the predicted outcomes in Figures 4.1 through 4.3. The plots take the same format as before. The left-side panel shows the results for communes on low fertility soil while the right-side panel presents results for high fertility soil. The x-axis represents the bombing intensity, separated into three categories of control (no bombs in the commune), low treatment (less than 125 pounds of ordnance per hectare), and high treatment (more than 125 pounds per hectare). The y-axis displays the predicted percentage of households in the commune with access to that type of infrastructure.

The results in Figures 4.1 to 4.3 can be summarized in two main points. First, when bombs fall on high fertility land, the bombing has a negative and statistically significant impact on the local level of service provision. This falls in line with the the first hypothesis: areas with bombed, high fertility land tend to have more unexploded ordnance, which would negatively affect that rates of infrastructure development. Second, and perhaps more surprisingly, the long-term effect of bombing on low fertility land is also negative and sta-
tistically significant. For the first dependent variable (sewer access), the effect size is larger as land fertility improves. For the other three outcomes, land fertility does not matter; the effect size is the same.

These results suggest that there is no direct correlation between the density of unexploded ordnance and the amount of infrastructure in place. Instead, the relationship appears to be attenuated by the perceived risk of unexploded ordnance, and this creates a binary effect. That is, whether the commune was lightly or heavily bombed, the effect size is still the same. Why? The state may be more risk-averse than the individual farmers discussed in previous chapters. The information concerning land contamination that state bureaucrats use may be quite coarse and even more incomplete than the information that farmers have. Since state officials do not live on the land, they have no local knowledge to make their risk assessment. Therefore, they have even less information than farmers do, and the coarseness of their behaviors reflects the coarseness of the information they have.

In particular, Figure 4.1 shows that sewer access declines if a commune has been bombed, and that the decline is larger in high fertility communes than low fertility ones. In communes with low soil fertility, unbombed communes have roughly 1.5-times the sewer connections as bombed communes (11.2% of households for controls, compared to 6.91% for low treatment and 7.59% for high treatment). The disparity is even wider on high fertility soil. In the average control commune, 13.7% of households are connected to the sewer, which is 2.5-times the percentage in treatment communes (5.45% for low bombs and 5.71% for high bombs).

Control communes in high fertility land tend to perform better than control communes in low fertility (13.7% compared to 11.2%). Conversely, treated communes in high fertility soil tend to do worse than their analogues in low fertility soil. Take, for instance, the predicted outcome of high treatment communes, 5.71% compared to 7.59%. These substantive differences across fertility level, though not statistically significant, suggest an important trend:
that high fertility soil does improve local sewer access compared to low fertility soil, as long as the land is not bombed. If bombed, the relationship flips. The level of infrastructure is worse in high fertility land than in low fertility land. Since the danger of unexploded ordnance is greater in soft, fertile land, then this finding falls in line with the theoretical expectations. Communes at high risk for unexploded ordnance (that is, high fertility and bombed) experience the sharpest decline in their access to public goods, in this case, sewers. In essence, they become the most impoverished.

In Figure 4.2, unbombed communes tend to have more electrical hook-ups than bombed communes. In low fertility areas, 21.6% of households in unbombed communes use electricity whereas 8.91% of low bombed communes and 12.2% of high bombed communes have an electrical hook-up. This disparity is more or less repeated in high fertility communes. 26.3%
of households in unbombed communes can access electricity. That proportion drops by 58% for low treatment communes (11.1% of households) and by 39% for high treatment communes (16.1% of households).

Why don’t we see a more pronounced drop in electricity access in high fertility, bombed areas? Sewer systems can be dug with local equipment and capital, like bulldozers and back-hoes. Electricity grids require some external actor (the state, a private company) to build the capital-intensive infrastructure and connect it to the power source.

Figure 4.3 shows the proportion of households with piped water increases when a commune is left unbombed. In low fertility areas, 12.9% of households have their water piped in. A similar percentage (13.7%) is found in high fertility control communes. When the commune experiences low levels of bombing, the percentage of households drops by more than
Figure 4.3: Predicted percentage of households in the commune that have water piped to the house, according to soil fertility (panel) and treatment condition (horizontal).

60% (4.83% in low fertility communes, and 5.43% in high fertility communes). Interestingly, as bomb intensity increases in high fertility communes, the fraction of households with piped water increases as well (9.21%).

The predicted outcomes for control and low treatment are strikingly similar across fertility types. Then, the high treatment results appear to go in the opposite direction. Bombing has a larger effect in low fertility soil than high fertility soil. What could explain this discrepancy? Unlike sewage systems and electricity grids, which require brand-new infrastructure to be built, water will only be piped in if the household lacks direct access. For instance, households on lakes or rivers take their water directly from the source. In addition, households near wells and groundwater do not pipe their water either. Since high fertility areas are typically more flooded and have better access to water, there is probably less of a need to pipe water into the
In Figure 4.4, the relationship between bombing and firewood usage, the cheapest fuel option in Cambodia, is positive. Across low and high fertility, 94% of households in bombed communes rely on firewood as their dominant cooking fuel. This statistic remains the same for both treatment conditions, low and high. In low fertility areas, 80.0% of households in unbombed communes use firewood, which is statistically indistinguishable from the 83.7% of households in high fertility, unbombed communes that use firewood.

Again, the results are quite similar across low and high fertility. This suggests that as units are aggregated (from rice paddy-level analysis in Chapter 3 and household-level analysis in Chapter 4 to commune-level analysis here), the effects of unexploded ordnance...
are amplified. The inherent danger in working contaminated rice paddies encourages risk-averse, subsistence farming behaviors. The drop in agricultural production creates worsening economic conditions that reverberate across the village and the commune. It is more difficult for households to adopt new commercial technologies. It is even harder for them to provide public goods for themselves or for external actors to do it for them.

Figures 4.1 through 4.4 portray the relationship between commune poverty and exposure to different levels of unexploded ordnance. This relationship is the first-stage of an instrumental variable analysis, in which unexploded ordnance creates a plausibly exogenous shock to commune poverty rates. The second stage estimates the impact of differential poverty rates on electoral behavior in the 2012 national election. Table 4.2 reports the IV regression estimates of the effect of sewer access, electricity connection, piped water, and firewood usage on the dominant party’s margin of victory.

Recall from Figure 4.1 on sewer access; in high fertility soil, a bombed commune experiences a 8% drop in households with toilets are connected to sewer. An 8% decline in sewer usage due to Vietnam War-era bombing reduces the 2012 Cambodia People’s Party margin of victory by 14%. Bombing in high fertility soil also results in a 10 to 15% dip in the percent of households connected to the electricity grid. The relationship between electricity usage and CPP victory margin is roughly one-to-one. A 10 to 15% drop in electricity access – from bombing high fertility soil – results in a 10 to 15% decline in the CPP margin. This trend continues in regards to water-related infrastructure. Again, in high fertility soil, bombing reduces the fraction of households with piped water by 5 to 8%. As a result, the CPP’s margin of victory drops by 8 to 13%.

With the last poverty variable, firewood usage, I expect and observe the opposite relationship. Since firewood is the cheapest fuel option (followed by charcoal and then gas), then firewood use should correlate with poverty, whereas the three previous variables (sewer, electricity, and piped water access) should correlate with increased wealth. Figure 4.4 shows
Table 4.2: IV analysis: the electoral effects of unexploded ordnance through commune poverty

<table>
<thead>
<tr>
<th>2nd stage dependent variable:</th>
<th>CPP margin of victory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Households connected to sewer</td>
<td>168.577***</td>
</tr>
<tr>
<td></td>
<td>(48.741)</td>
</tr>
<tr>
<td>Households with electricity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Households with piped water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Households that cook with firewood</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Commune soil fertility</td>
<td>−1.535</td>
</tr>
<tr>
<td></td>
<td>(1.311)</td>
</tr>
<tr>
<td>Commune land dedicated to agriculture</td>
<td>−14.285***</td>
</tr>
<tr>
<td></td>
<td>(2.784)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,566</td>
</tr>
<tr>
<td>R²</td>
<td>0.014</td>
</tr>
<tr>
<td>Regional fixed effects</td>
<td>✓</td>
</tr>
</tbody>
</table>

Notes: The 2nd stage dependent variable is the Cambodia People’s Party margin of victory. The 1st stage dependent variables measure the percentage of households in the commune that have that particular access or engage in that particular behavior. The instrument is a categorical measure of bomb intensity (control, treatment low, and treatment high). The fixed effects model used five geographic dummies to capture within-region variation. *p<0.1; **p<0.05; ***p<0.01
that when a high fertility commune is bombed, the proportion of households that rely on firewood to cook increases by 11%. An 11% jump in firewood usage translates to a 12% drop in the CPP’s margin of victory.

I run the instrumental variable model on a second electoral variable, the main opposition party’s vote share in the commune. Since two parties, the Cambodia People’s Party and the Cambodia National Rescue Party, received an overwhelming majority of votes in the 2012 election (93.3%), the CPP margin of victory is captured by the dominant party’s vote share minus the opposition party’s vote share. Therefore, the two electoral outcomes are inter-dependent. Where we see a decline in the Cambodia People’s Party’s margin of victory in Table 4.2, we should observe a rise in the share of votes won by Cambodia National Rescue Party.

Regression results for the CNRP vote share are in Table 4.3. In high fertility communes, an 8.0% drop in sewer access due to bombing increases opposition support by 6.7%. Similarly, when bombing decreases electricity connections by 10 to 15%, opposition vote share increases 5.2 to 7.9%. A 5 to 8% drop in households with piped water (from bombing high fertility land) results in a 4.9 to 7.8% rise in CNRP vote share. 11% more households rely on firewood for fuel in bombed, high fertility communes, and this leads to a 6.8% CNRP bump.

In short, the relationships between bombing and fertility, local development, and electoral outcomes are consistent between the models. Unexploded ordnance, which is proxied by differential levels of bombing and land fertility, tend to lower the level of commune infrastructure. The lack of development corresponds with more oppositional support and a smaller CPP margin of victory. Conversely, as local development improves, the dominant party is rewarded with more electoral support.
Table 4.3: IV analysis: the electoral effects of unexploded ordnance through commune poverty

<table>
<thead>
<tr>
<th>2nd stage dependent variable:</th>
<th>CNRP vote share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Households connected to sewer</td>
<td>$-83.922^{***}$</td>
</tr>
<tr>
<td></td>
<td>(24.645)</td>
</tr>
<tr>
<td>Households with electricity</td>
<td>$-52.418^{***}$</td>
</tr>
<tr>
<td></td>
<td>(20.311)</td>
</tr>
<tr>
<td>Households with piped water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Households that cook with firewood</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Commune soil fertility</td>
<td>$1.396^{**}$</td>
</tr>
<tr>
<td></td>
<td>(0.663)</td>
</tr>
<tr>
<td>Commune land dedicated to agriculture</td>
<td>$7.401^{***}$</td>
</tr>
<tr>
<td></td>
<td>(1.407)</td>
</tr>
</tbody>
</table>

Observations: 1,566
R²: 0.087 0.049 -0.217 0.187
Regional fixed effects: ✓ ✓ ✓ ✓

Notes: The 2nd stage dependent variable is the Cambodia National Rescue Party vote share. The 1st stage dependent variables measure the percentage of households in the commune that have that particular access or engage in that particular behavior. The instrument is a categorial measure of bomb intensity (control, treatment low, and treatment high). The fixed effects model used five geographic dummies to capture within-region variation. *p<0.1; **p<0.05; ***p<0.01
4.5 Discussion

What does the statistical analysis of post-conflict geography, public infrastructure, and electoral returns tell us about why some communities seek to oppose the dominant party in Cambodia while other communities remain loyal?

The secret bombing continues to have a significant, negative effect on the amount of public goods provision in the commune. The consequences of this variation in public infrastructure were quite striking. Across multiple types of infrastructure, there is almost a one-to-one ratio in the relationship between the percentage of the commune with access to the public good and the percentage of the commune’s electorate that votes for the opposition.

The analysis provided here has several limitations. First, one could argue that the measure for public infrastructure – the proportion of the commune with access to sewers, electrical grids, and piped water – does not capture the real level of service provision. It measures poverty instead. Indeed, previous chapters have gone to great lengths to show how unexploded ordnance impoverish local farming communities. Since the villagers on contaminated land tend to compose of poor, subsistence farmers, it is their lack of income that prohibits them from connecting their toilet to the sewer or connecting to the electricity grid. In other words, these pieces of infrastructure may already exist in the commune, but the poor will not be able to reap any benefit from them until they can afford to have someone hook-up these services to their houses.

One could take a slightly different, more psychological approach to this alternative explanation. Since unexploded ordnance create a collective fear in the community, this fear makes people more hesitant to access public infrastructure that may already exist. For instance, household members who are fearful of UXO may choose not to connect to the village sewer line, especially they would have to dig up a dangerous part of their land in order to connect to the sewer.
In fact, the regression results from Model 4, which examines the percentage of households that rely on firewood as their main source of fuel, provide further evidence of this point. In communes that experienced bombing, the rate of households that use firewood significantly increases, compared to control communes. Since firewood usage is a common metric for poverty, we see that poverty strongly correlates with voting for the opposition. Put simply, the Cambodia People’s Party’s popularity comes from its richer constituents.

Future studies could try to distinguish the electoral effect of poverty from the effect of public infrastructure. This study would ideally take place at the individual level. It would examine an individual’s access to public services, her income, and her consequent vote choice as well as an indicator of whether or not that service exists in the neighborhood. This analysis would provide some means to spatially differentiate the household location from the surrounding agricultural land. In particular, household members may perceive a particular threat level of unexploded ordnance on their rice paddy, but there could be a different threat level in their village hamlet, which tends to be more tightly clustered and have heavier foot traffic.

In the current study, it is also difficult to determine the effect of clientelism on voter behavior. In a purely clientelistic model, the winning party would reward loyal communes with more public services following the election. In this analysis, I am constrained by data availability. The census measure of public infrastructure is from 2008 and the national election results are from 2013, but I would ideally add another political variable in the model – the election results in the 2008 national election. Since these results are only available at the province-level, I may have to wait for the 2018 election results, which will hopefully be released at the commune-level. After I collect these data, I could determine how much voter behavior might have shifted due to political party strategy, particularly the provision of public infrastructure, or due to more micro-level poverty rates.
4.6 Conclusion

In comparative politics, it is a commonly believed that extreme levels of poverty tend to weaken local institutions, making people more susceptible to corruption, vote-buying, and clientelism. The literature on elections in developing democracies suggests that political parties offer resources to poor blocs of voters in exchange for electoral support. Low-income voters are targeted in particular because they sell their votes at higher rates and because those votes, on average, are cheaper to buy (Stokes, Dunning, Nazareno, and Brusco 2013). If it is indeed easier, cheaper, and more efficient to “buy off” poor voters as the literature suggests (Hicken 2011), we should expect voters in UXO-laden land to be more likely to respond to monetary incentives compared to similar voters elsewhere, who would be more responsive to party ideology.

However, the findings here suggest the opposite. Voters in places with unexploded ordnance are already poorer and more likely to subsistence farm. But they still do not respond to rallies or vote-buying techniques, if we assume (as the majority of the Cambodia studies literature does) that CPP rallies are uniformly distributed throughout the country (Hughes 2015; Hughes, Sedara, and Sovatha 2004; Strangio 2014). Instead, this suggests a higher level of sophistication from poor, rural voters than previously expected. Rather than voting myopically, trading a vote for a pair of glasses or a $5 hand out, they are willing to hold-out for larger infrastructure projects.

Though we must be careful in drawing general lessons from such a narrow comparison, the specificity of the model has also made it possible to measure critical variables that are omitted from prior analyses and to examine the causal links between unexploded ordnance, public infrastructure, and electoral outcomes. The findings here suggest that post-conflict geography plays a significant role and that oppositional support may flow out of long-term grievances, due to being stuck in a UXO-caused poverty trap. The cyclical relationship between poverty and lack of public services may reflect underlying differences in the types
of land that people are living on – differences that have eluded measurement until now. The rate of bomb failure varies across communes in ways that are measurable and also contribute to our understanding of the factors that lead individuals to support the opposition in an authoritarian regime.
Chapter 5

Conclusion

The weapons left behind from war – like carpet bombs, cluster munitions, and landmines – pose a significant risk to the communities that continue to live on that land. In Cambodia, although civil war ended in 1991, more than two people are injured or killed by unexploded ordnance (UXO) every day (Collier, Elliott, Hegre, Hoeffler, Reynal-Querol, and Sambanis 2003). In Afghanistan, UXO from post-9/11 airstrikes, which relied on carpet bombs and cluster munitions, restricted farmers’ access to fields, disrupting daily routines to schools, markets, and neighboring villages (Chivers 2001; Watson and Getter 2001). The presence of UXO and mines in Pakistan has compelled many Kashmir residents to move to refugee camps, due to loss of jobs and poor access to agricultural lands (Moyes 2005, p.132-33). Even weapons testing can have pernicious consequences, as in Vieques, Puerto Rico, where dangerously high levels of carcinogens were found in the waters and coral reefs surrounding the corroding live bombs dropped by the US Navy (Porter, Barton, and Torres 2011). It is alleged to contribute to unusually high rates of cancer in fish-consuming households near the exposed reef (Wargo 2009). According to the Landmine Monitor and Cluster Munition Monitor in 2013, one-third of the countries in the world have unexploded ordnance left

\footnote{Carpet bombs and other munitions commonly used during the Vietnam War were associated with high failure rates. For instance, 1966 tests of BLU-32 submunitions at Nellis Air Force base revealed in ideal conditions a 26% failure-to-explode rate (McGrath 2000).}
on their land, but we know little systematic information on UXOs impact on agricultural production, economic activities, migration, and conflict.

In this dissertation, I have been concerned with the legacy of war on development. I argue that unexploded ordnance change people’s relationship with land – creating fears and physical barriers to access – that force residents to adapt to the new environmental conditions by subsistence farming and choosing risk-averse rather profit-maximizing economic strategies. Then, I explain how people’s adaptations to post-conflict geography have political consequences. Not only are these people less likely to access public services, but they also tend to vote for the opposition – notably in a country that has been ruled by the same dominant party for thirty consecutive years.

However, this dissertation leaves aside the innovations in weapons technology, as the US Air Force now relies on a repertoire of increasingly precise weapons, such as GPS- and laser-guided missiles that are dropped from drone strikes and checked with real-time satellite feed. Nor do I engage in the literature on political violence that has produced excellent studies on the strategic use of indiscriminate versus selective violence. In terms of scope, this dissertation focuses on the long-term costs of indiscriminate violence on economic development, and has made no prediction on how the costs of war change as aerial strikes become more targeted and more precise.

In this chapter, I describe the next steps of my research agenda that seek to address this question.

5.1 Redefining the costs of war

I argue that both indiscriminate and selective bombing can have a latent impact on development, although the rate of detonation failure varies between the two types\(^2\) Though

\(^2\)I distinguish violence in the same manner as Kalyvas (2006), where violence is “selective” when there is an intention to ascertain individual guilt and “indiscriminate” violence entails collective targeting (p.142).
the US military uses GPS and lasers to guide ordnance to specified coordinates and checks real-time satellite images to confirm a hit, accident investigation reports indicate drones malfunction in a myriad of ways, including mechanical breakdown, bad weather, and human error\cite{Whitlock2014}. The Pentagon estimates that 10-15% of laser-guided missiles do not land where intended. In fact, precision targeting still left behind unexploded ordnance in Libya and Yemen although NATO and the US Air Force have yet to release information on the locations and types of unexploded ordnance from their strikes\cite{Chivers2011,Devereux2013}.

Whether a bomb is intended to hit a selective or indiscriminate target, if it fails to detonate, it creates an economic disruption that is often borne collectively. For instance, where there are infrastructure projects in Laos, like dams, paved roads, or hydroelectric power, UXO clearance adds about 30 to 40 cents per square meter, an extra line item in the budget that can delay or permanently stall the project\cite{Legacies2010}. The prohibitive costs of removal also act as a barrier to entry for small to medium entrepreneurs, particularly for private investors in forestry or agribusiness\cite{Legacies2010}. This means that many of these rural, post-conflict communities never have the opportunity to modernize their farming techniques or grow beyond a subsistence level.

A set of inter-related questions thus motivate the next research project: Does selective bombing lead to long-term economic disruption? What are the latent costs of targeted violence, and are they applied indiscriminately across the post-conflict population? How does this compare to the legacy effects of indiscriminate bombing?

The answers to these questions will provide valuable insight into our understanding of selective versus indiscriminate violence, which serves as the conceptual basis for many political science theories on military coercion, civil war, and counterinsurgency\cite{Kalyvas2006}. 

\cite{3}The Washington Post reported that more than 400 military drones have crashed in major accidents since 2001\cite{Whitlock2014}. The International Institute for Strategic Studies dataset on drone stocks indicates that the US had at least 678 drones in service in 2012.
Kalyvas and Kocher 2007; Lyall 2009; Pape 2014; Weinstein 2006). The distinction between these two types of violence relies on the ability to target violence to specific individuals. We typically operationalize the distinction by identifying steps to personalize targeting for selective violence (Kalyvas 2006, p.142). Conversely, violence is considered indiscriminate “when selection criteria are rough” (Kalyvas 2006, p.148). Selective bombing fits oddly in both categories because the bombs are targeted to a particular person or building, but when they fail to detonate, the unexploded ordnance threaten more widely.

The next project tests an alternative hypothesis: selective violence may lead to indiscriminate violence later on. When we include unexploded ordnance in the study of violence, it forces us to consider how the destructive lifespan of bombs becomes much longer than intended. We also must question how well our current understanding of violence applies to an extended time horizon. While many scholars rightly focus on the immediate destruction created by aerial strikes, ground combat, or guerrilla warfare, Kalyvas actually notes that violence need not be “public, prompt, or necessary” (2006, p.142, fn.42, italics added).

The distinction between immediate targeted violence and latent indiscriminate violence is important because it complicates liberal military doctrine, like the Obama doctrine, which emphasizes proportionality and restraint. This doctrine assumes that the costs of selective violence are felt immediately. If in the long term the costs of selective violence are substantial and borne widely, then the administration would lose some of the political advantages of this strategy. For example, “hearts and minds” in Afghanistan may not be easily won when unexploded ordnance prevent people from using land, particularly when rural livelihoods depend on agricultural production. I propose an overarching framework that outlines the costs associated with selective and indiscriminate violence over time, informed by extended research on aerial strikes during the Vietnam War and in Afghanistan, and tested with an original dataset of unexploded ordnance, using on a new method that identifies bomb craters.
5.2 The research agenda

I propose three linked activities: a theoretical framework and two empirical projects.

5.2.1 Theoretical development (with Matthew Birkhold)

Since Saint Augustine, political theorists and legal scholars have discussed the conditions needed to justify violence and engagement in war. One of the conditions requires that the war must be proportional; the total cost of the war cannot outweigh the benefits achieved. However, the current practice in international law focuses on the immediate damage caused by war – the death and injury tolls, displacement rates, economic and cultural costs calculated by comparing what existed prior to war to what is left over when war is over. This project challenges current practice by quantifying the latent costs of war and by suggesting that these should be added to our calculations to the price of aerial bombing.

We apply these ideas to the Iraq War, one of the most hotly contested examples of a Just War in the 21st century. Specifically, we examine declassified records from previous air raids during the Gulf War (specifically, the 1991 bombings of an infant formula production plant in Abu Graib and air raid shelter in Amiriya) to learn how the military quantified the short and long-term impacts of air raids on civilian targets. Then, we see how these studies played a role in guiding Bush administrations decision to conduct massive aerial strikes during the 2004 assault on Fallujah and the 2005 campaigns in Al Anbar and Karabilah.

5.2.2 Legacy of selective and indiscriminate air strikes in Afghanistan

(with Andrew Beath and Rongjun Qin)

The war in Afghanistan reflects a marked change in the logic of violence in aerial war. While initial Air Force strategy emphasized the use of indiscriminate violence for “maximum psychological effect,” the Obama administration used military force only when necessary,
many times signaling a commitment to realist-driven restraint \cite{Chivers2012}. This strategy of “targeted killing” relied on improved technology – real-time satellite data, drones and GPS-guided missiles – in order to minimize noncombatant casualties. The number one priority, in the words of General Commander Stanley McCrystal, was “to secure the population so normal life could resume.”

We estimate the location of unexploded ordnance with a remote-sensing method developed by Rongjun Qin, a computer engineer who specializes in image processing. By scanning commercial satellite images of areas that are known bombing zones (taken from weekly US army briefings and newspaper reports), the machine-learning model searches for bombs craters and indented landmasses to estimate the amount of ordnance that detonated and the amount that remain unexploded. The Air Force bombed selectively and indiscriminately, using cluster munitions in 2001-2002, GPS strikes in 2006-2007, and minimal aerial strikes after 2008. We identify the long-term effects of each strategy, using Landsat imagery to measure agricultural productivity over time and observing how changes in agricultural production predict local support for rebel violence and rates of geo-located violence incidents.

\subsection*{5.2.3 Legacy of indiscriminate bombing during the Vietnam War
(with Andrew Beath and Obert Pimhidzai)}

Vietnam, Cambodia, and Laos’s ongoing recovery from the Vietnam War provides a rich example of the long-term impact of US carpet bombing on local development. Like Afghanistan, these countries were (and remain today) predominantly agricultural states that had not gone through mass industrialization. We examine how unexploded ordnance affect the success of the developmental state, by focusing on three different economic models: crony-capitalist (Cambodia), semi-open socialist (Vietnam), and closed-socialist (Laos). How do unexploded ordnance interfere with state plans to development the economy – particularly, to industrialize or to commercialize agricultural production? While the Cam-
bodian government has been the most laissez-faire in rural economy, making few if any attempts to modernize the rice cultivation process, the Laotian and the Vietnamese state are interventionist states with state elites implementing more developmental agricultural policy to help the post-conflict economy. Given this difference in economic policy, we may see more aggressive production rates in Laos and Vietnam, despite the danger of UXO.

We will first conduct interviews with policy-makers and bureaucrats from the each state’s Ministry of Agriculture in order to understand the role, if any, unexploded ordnance have in influencing that state’s agricultural policies. Then, we seek to quantify the long-term economic costs of UXO of indiscriminate bombs across these three states, to see how between-state differences in terrain and development policy impacts the effect of UXO on local development. We have data covering all US bombs dropped in the Southeast Asian theater from 1965 to 1973, weekly Landsat images of land use patterns, and nationally-representative household surveys from Cambodia, Laos, and Vietnam, conducted yearly from 2003 to 2015, with updates available. We propose using these to test the local, long-term impacts of bombing and unexploded ordnance on household economic growth and attitudes toward the state, conditioning on state industrial policy.

5.3 New geospatial methods to detect UXO

In April 2010, Ambassador Scot Marciel and Representative Mike Honda had a short exchange at the US Congressional Hearing on the “Legacies of War: Unexploded Ordnance in Laos.” Their exchange summarizes the current state of UXO identification.

    **Mr. Honda:** Thank you, Mr. Chairman. In our arsenal of technologies, do we have the ability to be able to detect metal from the air and metal or explosive kinds of chemicals that are on the ground by sweeping over the terrain?
Ambassador Marciel: Mr. Congressman, I am afraid I don’t know the answer to that. I am not aware that we do, but I will certainly check and see if that is something – certainly if we had that technology it would be very useful for something like this. [A written response later confirms that no existing technology can reliably detect mines or UXO from the air.]

Mr. Honda: I must be, too. So I would appreciate it if somewhere along the line we could get some information on that. I saw your head nodding “no,” but it seems to me we have all kinds of technology from satellites that we could pinpoint individuals in terms of body heat. It seems to me that with some work on programming, we would be able to detect metal objects on the ground.

A separate project with Rongjun Qin aims to improve current knowledge on unexploded ordnance and post-conflict development with the use of advanced geospatial methods. We propose the use of remote sensing and image processing to locate UXO contamination zones on high-resolution satellite data. With these methods, we can see how UXO impact contemporary agricultural productivity and planting patterns; this will allow us to examine the diversity of ways in which communities adapt to their post-conflict geographies. Do farmers, for instance, abandon contaminated land, or do they continue to plant it but less frequently, or plant only the safe corners of land? We also apply these methods to a demined village, with help from our community partner, Halo Trust. Specifically, we image-process the agricultural fields in this village before and after UXO clearance in order to determine how demining changes local production rates. Does demining reduce the collective fear of the land? Or, do individuals continue to plant scarcely, despite the demining?

For each village, we have collected 6 unobscured Landsat images (low spatial and high temporal resolution) to represent two calendar years, as well as 2 high-resolution commercial images (e.g. IKONOS, Worldview). With each image, we identify the boundaries of local plots and classify each plot by crop type and level of plant growth. We also overlay the high
resolution images to identify the bomb craters within the village boundaries and estimate the amount of UXO leftover.

This method combines declassified US Air Force data on payload drop sites with high-resolution maps of terrain features and contemporary vegetation. The US Air Force data provide the number of bombs that were dropped in each payload, with the coordinates of each drop site. Bomb craters represent physical evidence of the number of bombs that have detonated within each drop zone. Since, for each payload, we know the total number of bombs dropped and the number of bombs detonated, we can estimate the number and density of unexploded ordnance left within each drop zone.

The process is divided into three phases. In Phase 1, we will identify craters on the MODIS high resolution satellite images for each village. Students are taught to detect bomb craters from satellite imagery, focusing on the land within 1 kilometer of a payload drop. They code all target areas within the village boundary and geotag these locations in ArcGIS. Repeating this process for all MODIS high resolution images provide information on how bomb craters look different through the seasons.

In Phase 2, we will develop novel feature extraction methods that are sensitive to non-random shapes characterized by terrain features and vegetation. Classifiers trained with features extracted from part of the coded areas are used to identify bomb craters for predicting detonation failure. This method will be validated using supplemental human coded areas as test samples. This validation is the key for further crafting the features for learning. We will test this classifier with the 12 MODIS images from the second village in our sample. Once the training exercise is complete, in Phase 3 we incorporate the remaining data to an optimized classifier and to produce spatial predictions of all the bomb craters (exploded ordnance) in each village. Based on the assumption that the spatial distribution of the UXO should follow the same patterns as the bomb craters, the geotagged payload data of each
drop zone will be used to estimate the density of the UXO by integrating the zone-level statistics of the bomb craters.

We use MODIS Landsat imagery to identify crop activity and yield, relying on both temporal and reflective spectral statistics to generate granular data on cultivation and crop productivity. Because different crops produce distinguishable levels of spectral radiation and periodical agricultural activity, we can distinguish active and passive agricultural zones using the reflective radiance from seasonal satellite Landsat images. We differentiate agricultural land from grassland using the high-resolution images, and extract their temporal patterns of NDVI (Normalized Difference Vegetation Index) from the low-resolution images, with a two-class classifier that identifies the amount of agricultural lands. Each pixel represents a small segment of land – 225m$^2$ to be precise – so we can generate plot-level measures of growing calendars, crop rotation, and exposure to crop loss. These remotely sensed images have been captured, rendered, and disseminated every 16 days since 1998 through a US government initiative, so based on our method in this project, we can develop a rich sense of land use patterns for the past two decades.

Halo Trust has already provided their entire database of cleared land in Cambodia. This includes the geo-coded polygons of each area (e.g., a field or road) that has been demined. In addition, each clearance team drew a map of the cleared field and the location of each piece of ordnance found within the field. Therefore, we can cross-validate our UXO-prediction model with the actual locations of UXO found by Halo Trust. Since the Halo Trust data are time-stamped, we can compare the agricultural growth rates the wet season before and the wet season after the demining date.

The impact of UXO on the quantity of agricultural land can be estimated from these data using maximum likelihood techniques or a threshold regression model. By the end of data collection, we will be able to estimate the degree to which UXO change the total area of active agricultural land, and how persistent this effect is in the present day. In addition, we
will also write short case-studies of how specific villages have adapted to this post-conflict geography, for instance, by planting rice more densely together on safe land or by switching to a higher-yield variety of rice. Finally, we can conduct a simple difference-in-difference calculation in order to estimate the effect of demining on agricultural productivity.

5.4 Rethinking how war changes land

Though the US military has adopted new technologies that improve detonation rates and pinpoint the location of released ordnance, the US has strategic interests in areas where other international actors continue to use the old weapons, like artillery rockets, cluster munitions, and conventional contact-initiated warheads. For instance, many of the most dangerous areas in Syria, Afghanistan, Libya, Ukraine, and Sudan are littered with unexploded ordnance dropped by international or rebel forces. In these post-conflict settings, scores of stabilization, development, and peacekeeping missions are taking place in literal minefields, where we have little information on hot spots boundaries and the location of explosive remnants of war.

A remote-sensing method to identify the location of unexploded ordnance would help operational teams more safely traverse conflict-affected regions. Beyond logistical support, it would contribute to demining programs, providing a faster, more efficient alternative to identifying contaminated land, compared to the default system of call-in reports and expensive surveys. The same framework would also help guide policy to set the foundations for long-term growth in areas that still suffer from the threat of violence. Since the process of demining is an expensive and time-intensive one, this framework helps to identify the most vulnerable areas that should be demined first. Meanwhile, the findings would help inform how, in contaminated regions, information on ordnance location should be shared, how food and economic aid should be optimally distributed, what capacities local health clinics and
social services should have – allowing us to apply hard-learned lessons from past conflicts to enhance stability in fragile regions around the world.

The dissertation opened with the debate between Cambodia and the US, concerning the costs of the secret bombing of Cambodia. I suggest that war – particularly unexploded bombs – can significantly alter land, which many people depend on for their livelihoods. This alternative model of post-conflict development does not imply lesser roles for capital, labor, or state policy in the economy or in society. Rather, it involves an emphasis that land, in addition to these factors, can determine if a local economy succeeds or falls into a poverty trap. Importantly, it can also determine the difference between life and death.
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