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Kazuto OHTSUKI
Waseda Institute for Advanced Study, Waseda University

早稲田大学高等研究所
Waseda Institute for Advanced Study

1-6-1 Nishiwaseda, Shinjuku-ku, Tokyo 169-8050, Japan
Tel: 03-5286-2460 ; Fax: 03-5286-2470

The Logic of Mass Destruction and Contamination: A Political-Economic Approach

Shoko Kohama[1]
Department of Law, Hokkaido University

Kazuto Ohtsuki[2 3 4]
Waseda Institute for Advanced Study, Waseda University

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[2]Corresponding Author, `kohtsuki@aoni.waseda.jp`

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Abstract

We study the *political-economic* determinants and consequences of the use of unconventional, or *dirty*, weapons, such as landmines, chemical and biological weapons, and nuclear arms. Our formal model highlights two distinct consequences of using weapons: instantaneous physical destruction and persistent but fading negative externalities on human activities, such as labor, in the targeted societies. Adversaries seeking post-war rents choose an optimal combination of these effects to solve the dilemma such that destructive arms are effective at winning a war today but diminish future benefits of rents, whereas *dirty* weapons preserve rents but discourage future labor. We demonstrate that *dirty* weapons are chosen over conventional weapons when the targeted territory relies economically on capital-intensive, rather than labor-intensive, industries; produces perishable resources such as oil; and is poor. This study contributes to the literature on conflict and human security by addressing persistent social and economic suffering as a consequence of war.

Keywords: War; civilian targeting; rent seeking; non-proliferation; weapons of mass destruction; landmines; human security

Introduction

The last century witnessed the immense proliferation of unconventional weapons, such as nuclear, chemical and biological weapons, as well as landmines. Among the dramatic transformations that have occurred in the nature of warfare in the last century, the emergence of such weapons is one of the most remarkable. The earliest examples of the mass use of such weapons appeared during WWI. The Second Battle of Ypres in Belgium during spring 1915 is remembered as the first large-scale use of poison gas, or *Yperite*, by Germany (Edmonds and Wynne 1992).

A century later, unconventional weapons have become more widespread. Landmines are especially "popular" weapons, which are still laid in more than 60 countries and regions. Although two decades have passed since the establishment of the Mine Ban Treaty in 1997, states and non-state armed groups, even today, are reported to have installed new landmines in countries such as Columbia, Myanmar, Syria, and Ukraine. Casualties caused by mines and other similar weapons totaled 3,308 in 2013 and 3,678 in 2014, with a significant number of victims still unreported. That is, landmines and similar devices kill at least 10 people, mostly civilians and including children, every day (Landmine and Cluster Munition Monitor 2015).

Among the unconventional weapons that were developed in the last century, nuclear weapons are particularly notable for their massive destructive power and persistent negative impacts on society and the environment. Remarkably, atomic weapons have not been used as a means of solving international disputes since their use by the United States on Japan (Tannenwald 1999, 2005, 2007).

This paper investigates the mechanism through which these weapons are employed in certain conflicts and areas but not in others. To that end, we specifically elaborate on what we call *dirty* weapons, which leave ecological, physiological, and psychological aftereffects, or "*contamination*," on targeted individuals and territory. Such contamination persistently hinders socio-economic activities in the affected societies–such scars compound the difficulty and complexity of recovery and peace building.

Thus, this study is an attempt to address, albeit abstractly, *social suffering* in the theory of conflict. Existing studies treat weapons as a mere means of instantaneous and fatal destruction of the targeted community, which is the source of the "inefficiency of war." Such a framework dismisses the consequences of the destruction and contamination of lands and ecosystems as a "normative" concern, and it also disregards the adversaries' long-term interaction with the targeted territory and society. In reality, however, adversaries in war often continue to engage in activities in the contaminated territory and with the victimized communities and people. Once we address such long-term motivations for conflict, arms selection has political-economic implications.

A Political-Economic Approach

We particularly explore the *political-economic* causes and consequences of the use of *dirty* weapons in a general context, which is applicable to both intra- and interstate conflict. We argue that an adequate understanding of the political-economic aspects of arms selection is key to further promoting the cause of non-proliferation regimes. Tactical considerations may often drive arms selection (at least at the field level); however, political-economic investigations of arms selection are valuable because they are one of the few channels through which social scientists can offer practical policy recommendations to minimize social suffering caused by various weapons and to discourage belligerents from inflicting excessive damage on territories affected by combat.

Despite the rich literature on non-proliferation regimes (see, among others, Cottrell 2009; Nadelmann 1990; Rutherford 2000), the political science literature leaves many questions concerning the use of *dirty* weapons unaddressed. A notable exception is Legro (1995), who argues that the "organizational cultures" of the military explain the Anglo-German use and non-use of submarine attacks, strategic bombing, and chemical warfare during WWII. Complementing Legro's work, our study highlights the incentives and decisions of *political* leaders under whom military bureaucracies operate, and it also provides a framework with which to explain why certain forms of combat are (not) employed *in particular geographical locations*. Another highly relevant study is Addison, Le Billon and Murshed (2002), who formally demonstrate that the availability of lootable resources reduces adversaries' war effort and, therefore, the intensity of violence and destruction. However, studies such as Weinstein (2006) and Lujala (2009) suggest the contrary. We contribute to this literature by shedding light on the heterogeneous aspects of the damages caused by war: massive destruction from conventional weapons and long-term devastation from *dirty* weapons.

The key to our approach is the adversaries' greed for the rents that are extracted from seized territory after war. Adversaries competing for territory resort to violence because the acquisition of the territory is valuable to them in one form or another. Once the war is over, the party that seizes the territory exploits its valuable resources. The territory may be endowed with natural resources such as oil and minerals; it may produce agricultural or industrial commodities; or it may serve strategic purposes such as providing a buffer zone. What naturally follows is that the user of weapons has a strong incentive to preserve the value of the territory. Given the greed for rents, the idea of "war as an instrument of policy" (Von Clausewitz 1976) has a self-contradictory nature because violence undermines the value of the territory that belligerents desire (e.g., Fearon 1995). The desire for post-conflict extraction often provides an incentive to minimize damage to the targeted territory ("inefficiency") at the minimum rather than to fight an absolute war.

However, for a potential victor, the desire for rents poses a difficult dilemma between the pursuit of victory and rents. She must win the war before she can exploit the rents, despite that the more she destroys, the more likely she is to prevail, which is especially the case when relevant resources (e.g., oil, coca, and heavy industry manufacturers) are linked to the opponent's capacity to fight. This critical dilemma is solved by the optimal selection of weapons.

Effectively summarizing this article's motivation, General Raymond Odierno, then-US Army Chief of Staff, responded to Donald Trump's presidential campaign pledge to "knock the hell out of Iraq's oil fields" to weaken ISIS and, consequently, "take back the oil" as follows:

> There are limits to military power ... [Military strategy is] about sustainable outcome. And the problem we've had is, we've had outcomes, but they've been only short-term outcomes because we haven't looked at, we haven't properly looked at,

> the political and economic sides of this. It's got to be all three that come together. And if you don't do that, it's not going to solve the problem (Diamond 2015).

Destruction and Contamination in Warfare

To solve the dilemma between victory and rent-seeking, belligerents exploit two key dimensions of weapons: the instantaneous destruction of the targeted territory and the (long-term) negative externalities on human activities in the area. For simplicity, we hereafter call arms that primarily cause the former *conventional* weapons and those that primarily cause the latter *dirty* weapons. Clearly, the use of any weapon entails both destruction and contamination. The destruction of homes and the loss of family certainly traumatize victimized civilians. However, we conceptually distinguish these functions and explore the mechanism through which each of them is employed on the battlefield.

The use of conventional weapons, such as aerial bombing, damages material resources and the lives of soldiers and civilians. Therefore, they decrease the opponent's capability to counterattack, but they also destroy the resources that are at stake. However, *dirty* weapons are characterized by their (albeit variable) persistent *contamination* of territory, which undermines human activities such as labor rather than causing damage to material resources. For instance, conventional weapons destroy a factory, whereas *dirty* weapons discourage the local population from resuming operations over a certain period of time due to health hazards or psychological apprehension.

Therefore, such weapons are distinct in the manner in which the party that seizes the territory (hereafter, the "*victor*") may exploit the territory. Thus, the victor must choose arms of different types and calibers that best serve her interests, taking into account the short- and long-term consequences of arms selection.

It must be emphasized that such decisions are fraught with entangled strategic interactions, rather than being the result of one-sided decision-making. A simple intuition that an aggressor will use *dirty* weapons to avoid the destruction of resources while pursuing victory does not account for the whole story because the opponent can fight harder if the destruction is limited and the resources are preserved. Knowing this, the aggressor may employ the strategy of destruction to discourage counter-attack. If a counter-attack is not waged, however, the destruction is inferior to contamination. Ultimately, combat requires a belligerent to intentionally or unintentionally consider an optimal combination of weapons, taking into account the opponent's reaction.

In this regard, we share interests with the larger body of literature on the effects of natural resource rents on civil war (e.g., Collier and Hoeffler 1998, 2004; Le Billon 2001; Lujala, Gleditsch and Gilmore 2005; Lujala 2009, 2010; Ross 2004, 2012). Specifically, this study sheds light on a novel aspect of the "resource curse:" certain types of resources causes a local population to be victimized by *dirty* weapons and certain resources to be deliberately preserved by *both* sides, which may cause a prolonged war.

Civilian Targeting and Rent Seeking

A long line of research highlights the trade-off between the use of violence and its consequences during civil war by demonstrating that collateral damage predicts higher levels of insurgent violence (Condra and Shapiro 2012) and that indiscriminate killing may undermine civilian support (see, among others, Downes 2007, 2011; Kocher, Pepinsky and Kalyvas 2011). However, there is no firm consensus on the effect of indiscriminate violence targeting civilians. Lyall (2009) finds that the employment of such a form of violence by a government may suppress insurgency, whereas Pape (1996) questions the notion that aerial bombing that targets civilians in an interstate war has decisive effects in coercing the enemy to make peace.

Thus, the question is, who targets civilians and when? Previous research has demonstrated the following: rebels relying on third-party funding have weak ties to the civilian population and thus do not refrain from targeting civilians (Weinstein 2006); the degree and type (discriminate versus indiscriminate) of civilian targeting depends on variations in control over territory within the context of a specific conflict (Kalyvas 2006); and the evenness of the fighting factions' balance of power explains civilian casualties (Balcells 2010). Moreover, rebels commit more civilian killings than governments during civil war (Eck and Hultman 2007).

A common presumption in the literature on civilian involvement in war is that belligerents, i.e., governments and insurgents, rely on informational and logistical support that offered by the local population; therefore, civilians are strategically targeted depending on which side they (are perceived to) take (Berman, Shapiro and Felter 2011; Kalyvas 2006; Shapiro and Weidmann 2015; Valentino 2013; Valentino, Huth and Balch-Lindsay 2004). Civilians may directly provide soldiers with resources to fight (Blattman and Miguel 2010), or insurgents may loot the homes and businesses of civilians to augment their resources (Azam 2002; Azam and Hoeffler 2002). Thus, the literature has assumed that the roles of civilians in war and insurgency have strategic and logistical effects during combat.

However, little theoretical and empirical attention has been devoted to another, yet crucial, role that civilians play *in the aftermath of war*, which thus affects belligerents' strategies *during war*. We depart from the common framework of civilians as players of supportive roles during war, a means for combat, by treating the local population's economic roles as an objective. Moreover, in our framework, ex-combatants decide whether to labor in the ex-combat territory after the war: soldiers "get back to peacetime work." Such a significant overlap between soldiers and the local population, especially in civil war, reinforces belligerents' dilemma between victory and rent-seeking.

The Theory

In the formal model introduced here, two players, Side A and Side B, are in conflict in a territory. Consider A ("she") and B ("he") as the conflicting factions (groups) in a civil war or as states in an interstate war (although we use singular nouns for simplicity). Side B initially possesses the territory that produces rents such as natural resources and industrial commodities if the local population engages in production. In the context of civil war, B can be considered an armed group that is headquartered in the territory, which will still need to engage in economic activities after the war. Alternatively, B may be a collective of the armed group and the local population. They may not share aligned incentives, but the model's simple framework reflects a situation in which the armed group has strong control over the population under its dominion.

Side A pursues a change in the *status quo*, seeking the rents that are extracted from the territory that is at stake. Accordingly, A can be interpreted as the offense side and B as the defense side, although this labeling is ultimately inconsequential. We first introduce the environment in which the arms are selected in the course of war and then proceed to describe the post-war phase in which the victor exploits rents from the seized territory.

Destruction and Contamination in the Course of War

During combat, *A* makes two important decisions regarding the plan of attack. *A* first chooses the level of *physical destruction* of the territory. Suppose that she selects either *low* destruction ($\underline{d}$) or *high* destruction ($\overline{d}$), where $\underline{d} < \overline{d}$. There is an additional property of *A*'s tactics: the level of *contamination* of the territory, which takes either a *low* value ($\underline{e}$) or a *high* value ($\overline{e}$).[1] Therefore, *A* has four potential plans of attack, which are summarized in Table 1.

[Table 1 about here.]

The crucial difference between *physical destruction* and *contamination* is that destruction instantaneously decreases the nominal amount of *material resources*[2] available in the targeted land, whereas contamination inflicts persistent *health threats* on the people who engage in activities in the area. In the course of war, therefore, *A*'s arms selection affects *B*'s *capability* of and *willingness* to counter-attack.

Because *B*'s armaments and production depend on the logistical services and exploitation of energy resources in the area, destruction affects the defender's *material capability* to execute a counter-attack. For analytical simplicity, we assume that the high level of destruction ($\overline{d}$) completely undermines *B*'s ability to fight. Therefore, *A* seizes the territory that potentially produces 1 - $\overline{d}$ unit of rents, with the original endowment of rents normalized to one unit.

However, low destruction ($\underline{d}$) allows *B* to decide whether to fight back to retain its territory after *A*'s plan of attack is executed. If *B* decides to surrender, *A* seizes the entire territory, which potentially produces 1 - $\underline{d}$ unit of rents. Then, the war is over.[3] If *B* fights, he retains a portion $\beta \in (0, 1)$ of the land that produces 1 - $\underline{d}$ unit of rents, but the remainder is completely destroyed

[1] We use the dichotomous choice for simplicity without substantive costs because our primary interest is in highlighting the comparison between conventional and *dirty* weapons.

[2] In this framework, we focus primarily on damage to resources rather than to a targeted population, i.e., human lives. That is, major destruction does not necessarily mean that all of the inhabitants die.

[3] Termination of conflict is a complex phenomenon and is analyzed elsewhere (e.g., Leventoğlu and Slantchev 2007). Nevertheless, we retain the stylized description of war termination

as a cost of the counter-attack. (Thus, each side's attack separately entails the "inefficiency of war.") *B*'s choice is denoted by an indicator variable $f \in \{0, 1\}$, where $f = 1$ indicates that *B* "fights."

Contamination affects *B*'s *willingness* to fight and work in the territory because he is discouraged from staying in the infected region. The level of contamination (e) determines the probability that the population will remain healthy enough to engage in economic activities in the territory in each period, denoted π, which can alternatively be interpreted as the proportion of individuals who are healthy enough to engage in labor, by considering B as a collective. Although we say that π is the probability that *B* "dies," it simply means that he does not make decisions thereafter,[4] and hence the effect may also be psychological. For instance, the threat of mustard bombs could be mostly psychological in the sense that people do not return and work in the targeted areas even after the gas has dispersed.

B is affected by contamination if he decides to fight in the contaminated region, but he is not affected if he does not fight. That is, *B* can relocate himself to avoid exposure. (Relocation is discussed below.) For analytical simplicity, we assume that π is zero if *A* chooses low contamination ($\underline{e}$), while it takes some positive value when *A* chooses *dirty* weapons ($\overline{e}$). *B*'s utility when he is "dead" is normalized to zero. Thus, both destruction and contamination have negative impacts on the defender's counter-attack and post-war production, but in different ways. The sequence of moves is summarized in Figure 1.

[Figure 1 about here.]

The Post-War Extraction of Rents in Recovering Territory

Once the war is over, the players begin to produce and consume. Although most theories in international relations posit that the value of the acquired goods is immediately consumable, we depart from such a setting by explicitly incorporating the process whereby the population

in this analysis because we are interested in the aggressor's arms selection rather than the adversaries' choice to end the war.

[4]That is, he does not "labor," which will be detailed in the following section.

produces valuables. Specifically, the new owner of the land must recruit the local population to produce rents.

Upon seizing the territory,[5] A offers a fixed wage of $w > 0$ to recruit B.[6] He decides whether to work for the wage or to relocate to another area that is not contaminated. B's choice is denoted $l \in \{0, 1\}$, where $l = 1$ indicates that B accepts A's offer and engages in "labor." This exchange of wage and labor is iterated in an infinite time horizon with discrete time, $t = 1, 2..., \infty$. Period $t = 0$ represents the "war phase" that is described above, and $t \geq 1$ is the "post-war phase."

When B relocates, a new job opportunity yields a reservation value of ν, where $0 < \nu < w$. This means that B prefers working in his home territory to relocation unless health threats are severe and he also prefers relocation to "unemployment" (not working) in his home territory.[7] w should be interpreted as B's subjective valuation of the homeland relative to elsewhere, including psychological utility, rather than literally as a wage.

As in the moment of the counter-attack, B is exposed to health threats if he decides to work in the contaminated area, provided that A employed *dirty* weapons in the war phase. Once he is infected, he continues to face the risk of "death" unless he relocates from the area.[8] For example, consider a situation in which A's attack incurs pollution such that $\pi = 0.3$. The likelihood that B survives the period of exposure is 0.7. The likelihood that B survives two consecutive periods,

[5] Recall that A "controls" the territory if A chose high destruction ($\bar{d}$) or if A selected low destruction and B did not fight.

[6] We suppress the choice between slavery and voluntary labor and just assume that A must pay costs for production. Moreover, we focus on the aggressor-defender relationship, i.e, we assume that the source of labor inputs in the territory is B's population, but the same conclusion can be drawn regarding any labor force that does not belong to B, such as contractors from A, who have the same incentive in deciding whether to work in the territory as B does.

[7] Allowing for the possibility that $\nu > w$ does not affect any of our qualitative conclusions.

[8] His health is threatened by the contamination only when he resides in the polluted territory, not when he relocates himself, possibly because he can stop the negative health effects from progressing by taking appropriate medication. This assumption provides him an incentive to relocate from the contaminated territory, even after he fights back at $t = 0$ under certain conditions. Otherwise, he would always stay in the contaminated territory when he fights back.

therefore, is $0.7^2 = 0.49$. Substantively, this implies that his health will not be restored if he is exposed to contamination and as long as he resides in the infected area.

The pollution of the land imposed by *dirty* weapons disappears over time, which allows *B* to return to the territory where he once resided even in a situation in which he prefers to relocate for a certain period of time.[9] The effect of radiation emitted by nuclear weapons diminishes over time, and landmines can be gradually removed by demining.[10] We therefore parametrize the *persistence* of biological or psychological threats by $\lambda \in (0,\ 1)$. The level of contamination in the targeted land in period t + 1 is λ time as much as that in the former period t. Thus, the instantaneous probability that *B* survives when he returns in period t is $1 - \lambda^t\pi$. For example, suppose that $\pi = 0.3$ and $\lambda = 0.9$. Then, the health threat to a person who returns in the initial period is $\pi = 0.3$, that to one who comes back in the next period is $0.9 \times 0.3 = 0.27$, and the figure is $0.9^2 \times 0.3 = 0.243$ at $t = 2$. Taken together, the probability that one who relocates for a while and come back at $t = 2$ survives in the next period is $(1 - 0.243)^2 \approx 0.573$. This motivates *B* to relocate until the health threats of the land are sufficiently reduced.

As contamination fades over time, the targeted territory recovers from physical destruction *provided that production occurs in the territory.* Cities are reconstructed and seeds are sown. The crucial difference between contamination and destruction, however, is that the former does not require labor inputs to recover, whereas the latter does. Therefore, recovery occurs only if the defender chooses to work in the territory. $\epsilon \in (0, 1)$ represents the degree to which the territory recovers from physical destruction in each period when *B* engages in production in the territory. Specifically, when *B* engages in production in the territory for τ periods, the total pie of resources recovers to 1 - $\epsilon^\tau d$. For instance, if *A*'s attack destroys 30% of the territory's

9 Of course, *B* is allowed to opt for the outside option again after returning to the territory, but this does not take place in equilibrium.

10 As noted above, this is not to say that *B*'s health recovers over time; rather, the impact of the instantaneous health threat of the land declines over time. Thus, the instantaneous probability of B's survival is determined by the level of contamination when he returns to work. He is exposed to the pollution when he returns and will continue to suffer from the persistent health effects of the initial exposure, although the pollution of the *land* fades away as time passes.

resources, i.e., $d = 0.3$, the productive power of the land at the moment of war termination is 0.7. Supposing that the territory's productive power recovers as quickly as $\epsilon = 0.1$ and people begin working immediately after the war, their labor reduces the damage of the land from 0.3 to 0.03 in the next period and to 0.003 in the following period. Therefore, the overall production of the territory will increase from 0.7 to 0.97 in the next period and then to 0.997. That is, the remaining damage becomes miniscule as *B* engages in production for a long period of time: $\lim_{\tau\to\infty} \epsilon^\tau d = 0$. Assume that $w < \beta(1 - \epsilon\underline{d})$, meaning that it is not the case that *B* never has an incentive to counter-attack.

Here, we shed light on the characteristics of the targeted territory that affect the degree to which labor input leads to reconstruction, i.e., the value of ϵ. As the example above describes, a larger ϵ denotes a greater reduction in damage at a given time, i.e., a quicker recovery. The degree of recovery in each period may depend on the economic structure of the territory and the *recoverability* of the resources at stake.

One important attribute is the economic structure of the targeted territory. Applying the classical distinction of the factors of production, destruction reduces *capital* input, whereas contamination decreases *labor* input. Once destroyed, a territory with a pre-war economy that relied on capital-intensive industries, compared with labor-intensive industries, recovers more slowly because infrastructure, factories, and machinery must be reconstructed before production can resume. The petroleum, refining, and electricity generation industries are examples of such sectors. In contrast, territory where labor-intensive industries are dominant, *ceteris paribus*, recovers quickly to the pre-war production level once the labor force returns to work.

Another element that influences reconstruction pertains to the nature of the resources embedded in the land: *recoverable* and *perishable* resources.[11] Some resources such as oil and minerals are irrecoverable once they are destroyed, whereas resources such as agricultural commodities and infrastructure are recoverable if a sufficient amount of human effort is invested. A good example of an *irrecoverable* resource is the massive destruction of oil during the Gulf War when the Iraqi forces set fire to oil wells in Kuwait during their withdrawal. The fire continued

[11] Addison, Le Billon and Murshed (2002) also detail the effects of the recoverability (renewability) of resources on the severity of war.

to burn for nearly a year and destroyed approximately one billion barrels of oil reserves. Although other resources, such as minerals, are not as easy to destroy as oil, they are *irrecoverable* because they cannot be recovered by human efforts once they are destroyed.[12]

Analysis of Optimal Arms Selection

In the following analysis, we demonstrate the aggressor's optimal plan of attack under the environment described in the previous section, solving for the unique pure strategy subgame-perfect Nash equilibrium. The equilibrium is formally derived and defined in the appendix, and in what follows, we informally analyze the players' equilibrium behavior and demonstrate the main intuitions of the model.

Destruction Precludes Contamination

The first intuition that we introduce is that the aggressor strategically selects between physical destruction and contamination, depending on the nature of the rents.

Lemma 1 *Side A never combines high destruction and high contamination.*

As noted in the previous section, major destruction deprives *B* of the material resources to launch a counter-attack, which leads to his surrender. Because physical destruction is enough for *A* to win the war, her decision on pollution depends solely on her desire for post-war rents.

Remembering that the production of rents relies on *B*'s labor, *A* can acquire larger rents by having *B* stay in the territory and work for wages. Therefore, *A* never contaminates the area because health threats will prompt *B* to relocate from the infected area for a certain period of time. Although *B* will return when the pollution fades sufficiently that his income in the infected territory becomes equally or more attractive than his income in another location, *A*'s gain until *B* returns always falls short of that with *B*'s full labor.

This implies that adversaries in general refrain from the tactical use of nuclear weapons, which is characterized by both high destructive power and hazardous post-explosive contamination. This implication is consistent with empirical regularity. Although we agree that deterrence is the primary logic behind the non-use of nuclear weapons, scholars argue that a "nuclear

[12]Note that destruction of *irrecoverable* resources is an off-path choice and is unlikely to occur in reality. The degree to which a resource is recoverable should be considered continuous.

taboo" also discourages nuclear powers from employing such arms, emphasizing that they have not used even been used in confrontations between nuclear powers, such as the Kargil War, or even against non-nuclear states, for example, in the Korean War (Tannenwald 1999, 2005, 2007). Our explanation here helps us to better comprehend the emergence of such a norm by illuminating the mechanism by which a critical mass of states commits to the non-use of such weapons before the idea reaches the "tipping point" of a norm cascade, where an increasing number of followers imitate the behavior of the critical mass (Finnemore and Sikkink 1998).

Contamination and Surrender

Next, we analyze B's optimal decision on whether to surrender or counter-attack when A initially chooses low destruction. In contrast with the previous scenario, in this situation, B is capable of conducting a counter-attack. Because he must compare the benefit of retaining his land and the risk of "death," his decision is conditional on A's choice of contamination. In the following section, we first examine B's decision under high contamination and then that decision under low contamination.

Lemma 2 *If Side A chooses low destruction and high contamination, Side B fights back if the territory's economy relies on labor-intensive industries or recoverable resources, whereas he surrenders if the territory's economy relies on capital-intensive industries or perishable resources.*

First, consider a situation in which A imposes high contamination, following low destruction. If B surrenders and A gains control over the entire territory, B, in each period after the conclusion of the war, compares his utility from staying away from the polluted territory and returning to work for a wage under health threats. As the health threats fade over time and, hence, his utility of working under A gradually increases, there is a point in time $\tilde{t}$, at which these options become equally attractive. Once B returns at $t = \tilde{t}$, staying and working for a wage in the territory continues to be his best choice. Note that recovery from physical destruction does not affect B's decision when he surrenders because he works in exchange for a constant wage, whereas A exploits all of the benefits from reconstruction.

If B fights and retains a portion β of the territory, he returns to the territory for production earlier than when he would after surrendering. A crucial difference between the cases of surrender and counter-attack is that in the latter case, B himself can consume the entire rents produced by his labor. That is, he can enjoy the benefit of recovery if he works in the reconstruction. Recalling that B's labor is necessary for the territory to recover from physical destruction, B has a strong incentive to return at some time $\hat{t}$ that is smaller than $\tilde{t}$. It is intuitive that B is more motivated to work for his own land than for another's. Thus, if he fights, he is exposed to more severe health threats.

The timing of B's return is also affected by the characteristic of the territory, i.e., the degree of recovery from physical destruction given the labor input. For example, if the territory's economy relies on heavy industries, B's labor does not quickly recover the potential of the land because such industries require capital and infrastructure before restarting production. Similarly, natural resources such as oil cannot be reconstructed once destroyed. In contrast, if the economy relies on light industries, such as textiles and food, recovery is relatively easy as long as workers return. Intuitively, B returns earlier if the territory's economic structure is such that human labor matters more for reconstruction because his labor under health threats will be greatly rewarded.

Then, B's decision between surrender and counter-attack largely depends on the magnitude of health threats π and the economic structure of the territory represented by ϵ. If the health threats are extremely high, such that π approaches 1, B always surrenders and relocates to avoid exposure to contamination. In contrast, if the health threats are extremely low, such that π approaches 0, B always fights back and retains the fruits of the territory.

When the health threats π take any intermediate value, therefore, B's choice depends on the external environment, especially ϵ. Fighting becomes more desirable as ϵ decreases, that is, as resources recover more quickly. One interpretation of this is that B is more likely to resist in the case in which adversaries fight over territory with labor-intensive industries that can be quickly restored by B's labor. Another way of interpreting the lemma is that B is more likely to surrender when rents from the territory come from perishable resources, such as oil. The intuition is that B has a greater incentive to fight to recapture the territory and control production if he directly internalizes the benefit of recovery. Thus, the primary effect of contamination is to discourage B from engaging in activities in the targeted area, rather than depriving him of his life.

Lemma 3 *If Side A chooses low destruction and low contamination, the defender always fights back, regardless of the nature of the rents (territory).*

In contrast with the scenario of high contamination, B always chooses to engage in counter-attacks if A chooses low contamination with low destruction. B is essentially eager to fight back and retain his land, knowing that his labor will be exploited by A once she occupies the territory. In the case of low destruction and low contamination, therefore, B retains both the capability and willingness to fight.

To Destroy or To Contaminate?

We now complete the analysis by highlighting A's choice of arms selection in anticipation of B's reactions, as characterized above.

Lemma 4 *Side A's optimal choice is either high destruction with low contamination or low destruction with high contamination.*

Because greedy belligerents seek to exploit the occupied territory after victory, they are motivated to preserve either natural resources or human labor for future extraction and, hence, pursue victory by attacking either the capability or morale of the adversary. They do not attack *both* because destroyed and uninhabited land will offer little value.

Specifically, in the previous section, we demonstrated that A never imposes *both* high destruction and high contamination because massive destruction is sufficient for victory and contamination only incurs unnecessary health threats that discourage the local population from working for A, the new ruler.

Moreover, low destruction combined with high contamination always yields an equally desirable or better outcome than low destruction with low contamination.[13] Additionally, the

[13] Note that A is not affected by contamination because she can let B work in the polluted area.

previous section shows that low destruction with low contamination always induces B's counter-attack, in which case A gains nothing. Because the worst-case scenario with low destruction and high contamination is that B fights back, low destruction with high contamination is a (weakly) better option than low destruction with low contamination. Thus, A's optimal strategy is to rely on *either* conventional or *dirty* weapons but not both.

Lemma 5 *Side A selects destructive weapons with low contamination when the resources at stake are labor-intensive or recoverable and selects low destruction with high contamination when the resources at stake are capital-intensive or irrecoverable.*

Finally, A chooses whether to employ the destructive strategy (high destruction and low contamination) or the *dirty* strategy (low destruction and high contamination), while anticipating B's reaction during and after the war. Recall that the destructive strategy completely nullifies B's armament and, hence, A can exploit rents once B returns to the territory. The *dirty* strategy may or may not force B to surrender, depending on the characteristics of the resources available in the territory. B surrenders if capital-intensive industries or irrecoverable resources are at stake, whereas he fights back if labor-intensive industries or recoverable resources are at stake because he wishes to obtain the benefits of reconstruction rather than to work for a fixed wage in the latter case.

Thus, it is straightforward to understand that A employs the destructive strategy if B is anticipated to resist the *dirty* strategy, i.e., when the resources at stake are labor-intensive or recoverable. As B's surrender is anticipated following the *dirty* strategy, i.e., when the resources at stake are capital-intensive or irrecoverable, A employs the *dirty* strategy if she is patient enough to highly appreciate B's future production after his temporal relocation. Moreover, A relies on a *dirty* strategy when destruction imposes sufficiently serious damage on the targeted territory, knowing that capital-intensive industries are difficult to reconstruct, and resources such as oil and minerals do not recover once they are destroyed.

It must be stressed that the aggressor's selection of *dirty* weapons on capital-intensive and irrecoverable resources cannot simply be explained by the intuitive logic that valuable resources should not be destroyed because destroying such resources dramatically increases the odds of winning. Thus, the aggressor, as our model explicitly highlights, faces a trade-off between the probability of victory and the extraction of rents, which, importantly, depends on the defender's (local population's) incentives to fight now and to work later. She can *afford to use dirty weapons because she knows that the opponent will be unwilling to launch a counter-attack when irrecoverable resources are at stake, knowing that his resistance will significantly undermine the value of the territory that he is fighting for today.* This is why it seems *as if* they *agree* not to fight destructively in certain areas.

Equilibrium and Empirical Implications

We are now able to define the equilibrium behavior.

Proposition 1 *The subgame-perfect equilibrium behavior of the game is as follows: when the resources are labor-intensive/recoverable, A chooses* $\{\overline{d}, \underline{e}\}$ *and B begins production in the first period; when the resources are capital-intensive/irrecoverable, A chooses* $\{\underline{d}, \overline{e}\}$ *and B chooses* f*=0 and begins production at* $\hat{t}$*. All off-path behavior is as previously described.*

This can be rephrased in conventional terms as follows (summarized in Table 2):

Proposition 2 *When the resources at stake are labor-intensive or recoverable, destructive, conventional weapons are more likely to be employed; when the resources at stake are capital-intensive or irrecoverable, dirty weapons without much destructive capacity are more likely to be employed.*

[Table 2 about here.]

It is worth stressing that the above proposition allows a contextual interpretation of the effects of the nature of rents on arms selection: belligerents optimize their selection of arms *given an available set of resources*, that is, the associations between specific rents and warfare depend on the *combination* of available rents. Thus, it is possible that in one country a certain natural resource may be contaminated by *dirty* weapons and survive destruction, whereas it is destroyed in another country. For example, a belligerent lacking capital may seek to protect electricity generation facilities with landmines, whereas one possessing abundant capital may not hesitate to destroy such facilities.

The model also yields the following implication regarding the area to be targeted by *dirty* weapons.

Proposition 3 *Holding the resource endowment and all else constant, wealthier societies are less likely to be affected by dirty weapons and are more likely to experience destruction than poorer societies, and vice versa.*

Recall that after A wins the territory, B returns to the field for production if he prefers working in the territory to relocation and earning a reservation value (ν). Therefore, a higher reservation value (ν), which captures the abundance of economic opportunities, implies that relocation is more favorable to B and, hence, labor input recovers very slowly. If A anticipates that the locals, i.e., the workforce, will not return due to abundant economic opportunities outside of the territory, she has little incentive to preserve a clean working environment for the future workers. Thus, she is better off maximizing the present chance of victory with destructive weapons if the society in which they are fighting is wealthy and provides decent employment opportunities. This proposition makes a prediction regarding which countries are more susceptible to massive aerial bombing: for instance, Germany and Japan during WWII.

Conversely, in underdeveloped societies, people often have no choice but to stay and work in a contaminated area. If that is the case, the aggressor does not hesitate to use *dirty* weapons and preserve material resources because the aggressor does not need to preserve clean working conditions for future workers to incentivize them to return. This explains the tragic tendency that people in underdeveloped societies are more likely to be victimized by *dirty* weapons and that they are likely to stay in (or return to) their contaminated homeland and suffer, as we witness in parts of Vietnam affected by "Agent Orange."

An Illustration: Landmines and Bombing in Cambodia

As is commonly understood, landmines are designed to defend military positions and to channel enemy forces' movement, and they are also used to secure economic assets. Nevertheless, the *determinants* of the use of landmines remain under-studied, despite the rich literature on the economic and social *consequences* of landmines (see, e.g., Andersson, Palha da Sousa and Paredes 1995; Gibson et al. 2007; Merrouche 2008; Roberts 2011).

What specific assets, then, do belligerents "protect" with landmines? One straightforward answer is that landmines are planted to protect valuable assets and resources from opposition forces. For instance, oil refineries are one of the most heavily mined assets. During the Libyan Civil War, Gaddafi's troops allegedly used thousands of landmines in the oil refinery town of Brega to keep the rebel forces away from the assets (Birsel 2011). However, this remains an insufficient account, as landmines are often entrenched in countries and areas that are poor in natural resources. Cambodia during its civil war provides illustrative example as an agrarian society that was one of the most heavily mined countries in the world.

Cambodia's dominant source of revenue before the civil war was agricultural commodities, especially rice. The value added by agriculture to its GNP was approximately 50% in the late 1960s; cultivated land represented just 16.7% of the country, while 73% of the land was covered by state-owned forest. The percentage of the population engaged in agriculture reached as high as 76% in the mid-1960s. In this predominantly agrarian country, 84% of the cultivated land was used for rice cropping. Rice was also the major export: 96% of the export value in 1968 came from agricultural commodities, and half a million tons of rice (30% of its production) was exported to foreign countries every year (Takahashi 1965; Yamashita 1980). The dependence on rice grew during the civil war because the Khmer Rouge pursued a purely agrarian society, holding out the ideal of a "food supply which would feed the country and provide a large surplus, particularly of rice, for export ... [w]ith all but a handful of the population put into agricultural labor" (Vickery 1984, Ch.3).

Given the resource-scarce nature of Cambodia, it is not straightforward to predict which areas would be more likely to be victimized by landmines as opposed to conventional attacks such as aerial bombing. If landmines are used only to protect valuable assets, were rice paddies guarded by mines? The answer is simply "no."

Data collected by the Cambodian Mine Action and Victim Assistance Authority (CMAA) and the Cambodian Genocide Program[14] show that aerial bombing was concentrated in the eastern regions of the country, especially the Kampong Cham, Kandal, Prey Veng, Svay Rieng and Kandal provinces. In contrast, the western part, consisting of the provinces of Pailin and

[14]The Cambodian Mine Action and Victim Assistance Authority (`http://www.cmaa.gov.kh/`). The Cambodian Genocide Program at Yale University (`http://gsp.yale.edu/case-studies/cambodian-genocide-program`) (both accessed July 15, 2016).

western Battambang, was one of the world's most heavily mined areas, and the local population still suffers from remaining mines today.

A commonly accepted account of these patterns is that the landmines were entrenched to protect the headquarters of the Khmer Rouge in the Pailin-Battambang region, while the bombing targeted base areas of Vietnamese communists along the border between Cambodia and South Vietnam. It is documented elsewhere that the Khmer Rouge, during the later days of its guerrilla warfare, was headquartered in Pailin. Moreover, massive bombing in the eastern region was conducted primarily by the United States to pave the way toward the "Vietnamization" of the Vietnam War. During an operation called "Menu," which began in March 1969, B-52 bombers conducted aerial campaigns against several base areas along the border. This was followed by massive air strikes, which were called "Operation Freedom Deal," and "incursions" by ground troops intended to clear the communists' sanctuaries.

Our theory highlights a mechanism by which rents affected arms selection and complements those tactical factors. According to our theory, *dirty* weapons are more likely to be employed when the resources at stake are perishable or capital-intensive because an aggressor *contaminates* to expel adversaries while preserving the resources, anticipating the future return of the labor force. Conversely, conventional weapons are more likely to be used when the resources at stake are labor-intensive; the aggressor can deter counter-attack by destroying the resources that sustain the rebels' capability to fight and can still recover economic activities by simply bringing labor back.[15]

Again, agriculture was the dominant source of income for Cambodia. Because most of the country was covered by forest, only limited plots were suitable for farming. Cultivated plots were concentrated in the Mekong basin in the eastern region, and they were also sparsely located around Lake Tonle Sap (Central Intelligence Agency 1972; Crocker 1962). Nevertheless, there

[15] Landmines are typically considered "defensive" weapons, whereas our theory distinguishes between the "aggressor" and the "defender." Our theoretical framework, however, is applicable to landmines because the "aggressor" in the context of the use of landmines simply refers to a party using the weapons and the "defender" refers to local or any other contracted labor on whom the former relies in producing and exploiting rents.

was another notable source of income: gemstones in Pailin. It was widely known that the town of Pailin had an abundant reserve of rubies and sapphires, which the Khmer Rouge, of course, attempted to monopolize (Prasso 1994). The smuggling of gems, especially to Thailand, financed the Khmer Rouge's guerrilla warfare (Diffidenti 1994; French 2002).

Thus, gemstones were the major *irrecoverable* source of income, whereas rice represented the primary *recoverable/labor-intensive* resource. Although mining is usually considered a labor-intensive industry, gem-mining in Cambodia was less labor-intensive *relative to* rice cropping with underdeveloped technologies.

Closer observation reveals that bombing reached far beyond the base areas and the region within 21 miles of the border that were set as the primary targets of U.S. operations. This is because the U.S. shifted its goal from Vietnamization to the protection of the anti-communist regime as the domestic power struggle in Cambodia intensified. For this reason, the bombardment targeted broad areas across the Mekong basin, although U.S. policy-makers, such as Henry Kissinger, and Prince Norodom Sihanouk, Cambodia's head of state until he was overthrown by General Lon Nol in March 1970, emphasized that the bombing exclusively targeted rebel bases (Kissinger 1979, pp.250-254). The victimized areas coincided with the locations of farmland, or more precisely, specific soils that were suitable for agriculture (e.g., alluvial soil) (Crocker 1962). For instance, the northern part of Prey Veng province was covered by hydromorphics that were unsuitable for rice cultivation and was scarcely attacked, while the surrounding regions were burnt out. Additionally, a considerable amount of unexploded ordnance has been found in affected farmland (Owen and Kiernan 2006, p.62). One possible explanation for this coincidence is that the bombing targeted inhabited areas. Nevertheless, the important factor here is that the bombing did not exclusively target guerrilla bases in the mountainous areas but instead populated farming areas with the potential to provide human and material resources to the rebels.

In contrast, landmines were heavily planted in the areas surrounding the gem mines (Pailin and western Battamban). Although it is difficult to investigate the decision-making process within the leadership of the Khmer Rouge because of the lack of reliable information, we can nevertheless logically infer that the gem mines must have affected the decision to engage in *con-*

tamination. The clear contrast between western Battamban, which contained the gem mines, and eastern Battamban, which was fertile farmland, is noteworthy. The former was contaminated by landmines, whereas the latter was affected by bombing, and there was almost no overlap between the use of the two types of arms. This is not because guerrilla activities were concentrated only in the mining regions: they were also reported in other provinces, such as Kampong Cham and Prey Veng, which suffered conventional attacks.

This leads to a rethinking of the causal relationship between resources and contamination. In the case of Cambodia, for example, historical evidence indicates that the Khmer Rouge contaminated its headquarters region to defend the gems. However, our logic suggests that this is only part of the story. Our logic suggests the possibility that insurgents choose regions where irrecoverable, rather than recoverable, resources are available *because they anticipate that the government has little incentive to bomb and destroy such rents* even if the resources fund rebel activities: it is the (low) likelihood of destruction, and hence the ease of defense, that determines where insurgents settle.

In addition to the observed patterns in arms usage, the way in which the local population reacted to the two types of attacks appears to be consistent with the theory. It suggests that recoverable and labor-intensive resources are associated with resistance by the locals and destruction, while perishable and capital-intensive resources tend to lead to displacement and contamination. Moreover, in a global-level comparison, its serious lack of economic opportunities exacerbated Cambodia's landmine contamination by rationalizing the Khmer Rouge's expectation that locals would return in the future to labor in the contaminated areas despite the danger.

Historical accounts document that the unprecedented scale of bombardment motivated the targeted population to join in rebel activities, rather than to surrender. A local man is said to recall that "often people were made angry by the bombing and went to join the revolution." One of the leaders of the Khmer Rouge, Chhit Do, also said that "[i]t was because of their dissatisfaction with the bombing that they kept on cooperating with the Khmer Rouge, joining up with the Khmer Rouge, sending their children off to go with them" (Werner and Huynh 1994, p. 225).

In contrast, many of the local population in the Pailin-Battamban region fled into Thailand. Consequently, the Khmer Rouge had to lease concessions to Thai mining companies, which sent their own labor to exploit the gemstones, while the physical "risks to the concessionaires ... were considerable" (French 2002). Later, the locals gradually returned. Until the 1990s, thousands of miners, fearing the landmines, still paid tolls to the Khmer Rouge for the opportunity to search for gems, especially rubies (Magistad 1989).

Furthermore, the theory provides an explanation for why there is surprisingly little overlap between the regions that were affected by the destruction of bombing and those that were contaminated by landmines. Combatants even seem to *agree* on the selection of arms, despite the intuitive logic that if one party protects resources using landmines, the opposing party should have a considerable incentive to destroy those resources to weaken the adversary.[16] The party in possession of the resources may also be willing to sabotage such resources before they are lost to the enemy. Contrary to intuition, adversaries appear to have *cooperated* to refrain from destroying perishable resources or industries that are difficult to recover. Indeed, the town in Pailin did not suffer any major destruction during the civil war or during the capture of the town by the government and its recapture by the Khmer Rouge in 1994.

This brief description of the Cambodian civil war shows that the country's economic structure was in part responsible for the pattern of destruction and contamination, as well as of displacement, during and after the war. On the one hand, resource-intensive commodities such as gemstones, one of Cambodia's few commodity exports other than rice during the war, were targeted by landmines, but they did not suffer the immediate destruction of conventional battle and bombing because they are perishable. On the other hand, rice fields, the source of the predominant labor-intensive commodity, were victimized by conventional, destructive arms.

Finally, it must be noted that, in Cambodia, conventional attacks also left devastating aftereffects as landmines dis. Even today, unexploded ordnance (UXO) discovered in villages and farmlands still threaten people's lives. In this regard, bombardment was definitely a *dirty* campaign. However, this does not necessarily blur the theoretical distinction between *destruction*

[16]Recall that Legro (1995) also focuses on "cooperation" regarding the forms of combat during WWII.

and *contamination* because adversaries must not have considered the contamination that was caused by UXO *ex ante* arms selection. Nevertheless, this does not imply that the unintended contamination by bombardment is less important than the intended devastation of social activities. Instead, we aim to highlight one of many significant aspects of warfare and its aftermath in this particular study.

Concluding Remarks

This paper is motivated by a question that we believe is theoretically, empirically, and normatively significant: why and under what conditions do belligerents use *dirty* weapons such as landmines, chemical and biological weapons, and nuclear arms? In contrast to existing studies focusing on the tactical and normative aspects of such arms, this paper highlights the *political-economic* causes and consequences of using *dirty* and destructive weapons. Although we acknowledge that tactical considerations are crucial determinants of arms selection, it is worth elucidating the *political-economic* aspects of arms selection because they may illuminate the only, if any, window of opportunity for scholars to influence policy-makers' decisions regarding the use of *dirty* weapons.

Our theory departs from the conventional framework for studying war in two respects. First, we extend the analytic time horizon to the post-war period, whereas existing studies treat weapons merely as a means of the instantaneous and fatal destruction of targets and disregard the victor's long-term interaction with the destroyed territory and society. Second, we highlight adversaries' greed for rents extracted from seized territory after war and their dilemma between the pursuit of victory and rent-seeking. In this framework, adversaries have *political-economic* motivation to carefully select arms, taking into account the trade-off between *destroying* and *contaminating* the rents.

The theory yields three sets of results. First, an aggressor does not use weapons that are characterized by both high destruction and contamination, such as nuclear arms. Moreover, the choice of weaponry in warfare largely depends on the degree to which the targeted territory recovers from physical destruction given its labor inputs. In general, the aggressor relies more on *dirty* weapons if the economy of the territory relies on capital-intensive industries such as oil refining and heavy industry and if she seeks rents from resources that cannot be restored once destroyed, such as oil. Finally the theory also demonstrates that contamination is most likely in poor societies endowed with natural resources, while wealthier societies tend to experience higher degrees of destruction.

The extant theoretical literature on war has immensely advanced our understanding of the causes of war. Nevertheless, a more comprehensive understanding of the substantive particularity of *war*, not as a mere "costly lottery," will be possible if we shed light on the elements of war that frighten us more than any other political event. We posit that the fact that war ruthlessly changes the way in which we live, both physically and economically, is one such element. To our knowledge, this study is one of the first steps toward incorporating the perspective of human security into a formal model of conflict, and it addresses the oft-neglected issue of protecting people from traditional military threats, health threats associated with war, and economic suffering in the aftermath of war. However, our study illuminates just one important aspect of social suffering and the aftereffects caused by *dirty* weapons. Therefore, there are many important issues to be addressed in future research.

One immediate step to advance the current framework is to extend the logic presented in this study to nuclear deterrence. For such deterrence be effective, it is necessary that both parties be able to credibly commit to using a weapon that both destroys physical resources and contaminates the targeted territory. Given the implications drawn from the model, such a commitment is expected to be a function of the nature of the belligerents' motives, including rents and regime claims, as well as of their political institutions.

Empirical investigations of the implications that can be drawn from this article, of course, is another further step that is necessary to advance our understanding of the patterns of arms selection and their aftermaths. Regarding the manner in which the data are collected in mined fields, we suggest that landmines should be distinguished from unexploded ordnance (UXO). Currently, many data sets on landmines also include UXO because most international and national institutions that monitor landmine contamination pool landmine and UXO contamination in their data. This practice, of course, has a practical reason: once used, the problems pertaining to landmines and UXO are essentially equivalent (see, e.g., Roberts 2011). However, the differences between the two weapons *ex ante* lead to starkly contrasting predictions regarding their use. Moreover, the disaggregation of "primary commodities," which is suggested in the civil war literature, is also important in the context of arms selection (Collier and Hoeffler 2004; Fearon and Laitin 2003). As we demonstrated, in Cambodia, gems and rice are both primary commodities, but arms selection varied considerably between areas specializing in the former and those dominated by the latter.

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Tables

Table 1: Plans of attack

	low destruction ($\underline{d}$)	high destruction ($\overline{d}$)
low contamination ($\underline{e}$)	(no aggression)	conventional weapons
high contamination ($\overline{e}$)	*dirty* weapons	nuclear bombs

Table 2: Types of resources and predicted arms.

Characteristics of Territory		**Predictions**		
resources	recovery (ϵ)	destruction (d)	contamination (e)	arms
capital-intensive	slow	low	high	*dirty*
labor-intensive	fast	high	low	conventional
perishable	never recover	low	high	*dirty*
recoverable	fast	high	low	conventional

FIGURES

War phase
(t=0)

Post-war phase,
if A wins. (t $\geq$ 1)

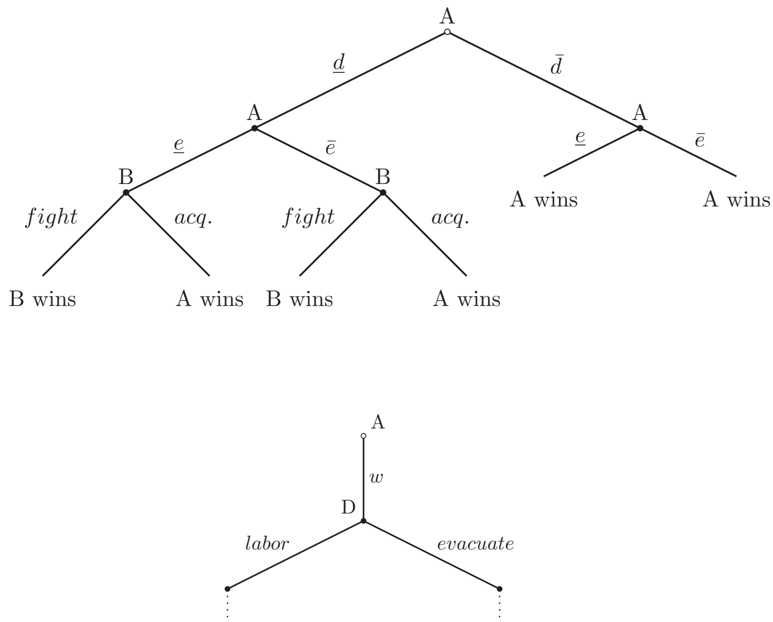

Figure 1: Sequence of moves.

Online appendix

Proof 1: high destruction

Given $\overline{e}$ (*dirty* weapons) chosen by A, B needs to find the optimal time to come back to the territory that is now under control of A. In period t, B's instantaneous utility to engaging in production in the territory is

$$(1-\lambda^t\pi)w.$$

Since B is offered a fixed amount of wage by A (i.e., the history of B's production does not affect his income), B comes back when

$$(1-\lambda^{\tilde{t}}\pi)w \geq \nu,$$

where $\tilde{t}$ is the earliest period in which B has an incentive to engage in production in the territory. Then, we can implicitly approximate $\tilde{t}$ as

$$\lambda^{\tilde{t}} \approx \frac{1}{\pi} - \frac{\nu}{\pi w}.$$

This is an approximation because time is discrete. But without any substantive costs we can assume that the above expression holds with equality:

$$\lambda^{\tilde{t}} = \frac{1}{\pi} - \frac{\nu}{\pi w}. \tag{1}$$

When A has chosen conventional ("clean") weapons, B begins production from the first period because $w > \nu$. A's utility depends on B's production. When $e = \overline{e}$, A needs to wait until $\tilde{t}$ for B to come back and begin producing, but production takes place in every period if $e = \underline{e}$. A's utilities to $\overline{e}$ and $\underline{e}$ given $\overline{d}$ are, respectively,

$$u_A(\underline{e}|\overline{d}) = \frac{1-w}{1-\delta} - \frac{\overline{d}}{1-\delta\epsilon}$$

and

$$u_A(\overline{e}|\overline{d}) = \delta^{\tilde{t}} \left(\frac{1-w}{1-\delta} - \frac{\overline{d}}{1-\delta\epsilon} \right),$$

where $u_A(\underline{e}|\overline{d}) > u_A(\overline{e}|\overline{d})$. Thus, *A*'s choice of high destruction leads to his use of clean weapons. The intuition is that when the defender is unable to counter-attack due to high destruction, the aggressor does not have any incentive to delay production by imposing negative externalities.

Proof 2: B's choice of surrender under low destruction

First, consider *B*'s production decision when $e = \overline{e}$ and $f = 0$, i.e., he does not counter-attack. *B* comes back for production when expression 1 holds because *B* works for a fixed wage. *B*'s continuation value to coming back in $\tilde{t}$ is

$$\begin{aligned} V_{B,\tilde{t}}(l = 1|\underline{d}, \overline{e}, f = 0) &= (1-\lambda^{\tilde{t}}\pi)w + \delta(1-\lambda^{\tilde{t}}\pi)^2 w + ... \\ &= w\left[\frac{1-\lambda^{\tilde{t}}\pi}{1-\delta(1-\lambda^{\tilde{t}}\pi)}\right]. \end{aligned}$$

Again, if *B* has an incentive to work in the territory in any t, he has an incentive to stay there thereafter. Given the above continuation value, *B*'s utility to $f = 0$ is

$$u_B(f = 0|\underline{d}, \overline{e}) = \nu + \delta\nu + ... + \delta^{\tilde{t}-1}\nu + \delta^{\tilde{t}} V_{B,\tilde{t}}(l = 1|\underline{d}, \overline{e}, f = 0) \tag{2}$$

$$= \frac{\nu(1-\delta^{\tilde{t}})}{1-\delta} + \delta^{\tilde{t}} \frac{w(1-\lambda^{\tilde{t}}\pi)}{1-\delta(1-\lambda^{\tilde{t}}\pi)}. \tag{3}$$

Next, we characterize the period in which *B* begins production in the territory when he fights. He begins production in period $\hat{t}$ such that

$$(1-\lambda^{\hat{t}}\pi)\beta(1-\epsilon\underline{d}) \geq \nu. \tag{4}$$

$$\lambda^{\hat{t}} \approx \frac{1}{\pi} - \frac{\nu}{\pi\beta(1-\epsilon\underline{d})} \tag{5}$$

The first LHS element of (4) represents a negative health effect incurred when he comes back to the territory after relocation for several periods. The remaining part indicates the value that the territory produces and he consumes. Thus, $\hat{t} < \tilde{t}$ because we assumed $w < \beta(1 - \epsilon \underline{d})$. Since $(1 - \lambda^t \pi)\beta(1 - \epsilon \underline{d}) < (1 - \lambda^{t+1}\pi)\beta(1 - \epsilon^2 \underline{d})$ for any t, if *B* comes back at t, he will remain in the territory in any following period.

Given $\hat{t}$, we characterize *B*'s utility to fighting.

$$u_B(f = 1|\underline{d}, \overline{e}) = (1 - \pi)[(\nu + \delta\nu + \delta^2\nu + ... + \delta^{\hat{t}-1}\nu) \tag{6}$$

$$+\delta^{\hat{t}}(1 - \lambda^{\hat{t}}\pi)\beta(1 - \epsilon\underline{d}) + \delta^{\hat{t}+1}(1 - \lambda^{\hat{t}}\pi)^2\beta(1 - \epsilon^2\underline{d}) + ...] \tag{7}$$

$$= (1 - \pi)\left[\frac{(1 - \delta^{\hat{t}})\nu}{1 - \delta} + \delta^{\hat{t}}\left(\frac{(1 - \lambda^{\hat{t}}\pi)\beta}{1 - \delta(1 - \lambda^{\hat{t}}\pi)} - \frac{(1 - \lambda^{\hat{t}}\pi)\beta\epsilon\underline{d}}{1 - \delta(1 - \lambda^{\hat{t}}\pi)\epsilon}\right)\right] \tag{8}$$

B suffers the initial health threat in period t = 0 due to the counter-attack, avoids it by relocating until period $\hat{t}$ -1 if he survives, and suffers again from period $\hat{t}$, which accumulates thereafter.

Let us now examine cases in which $\epsilon \to 0$ and $\epsilon \to 1$ to make an explicit contrast between the different rents. From expression (5), we can implicitly characterize t in which *B* comes back in each case, which is given by $\hat{t}0 \equiv \lim_{\epsilon\to 0} \hat{t}$ and $\hat{t}1 \equiv \lim_{\epsilon\to 1} \hat{t}$, respectively. Then, $\hat{t}0 \leq \hat{t}1$ is directly derived from the same expression (5).[17] Analyzing *B*'s utility in each extreme case with $\hat{t}0$ and $\hat{t}1$, we obtain that B's utility to fighting when $\epsilon \to 0$ is greater than when $\epsilon \to 1$ because of - $\underline{d}$.

Now we can characterize the conditions under which *B* prefers surrender (f = 0) to counter-attack (f = 1), comparing $u_B(f = 0|\underline{d}, \overline{e})$ and $u_B(f = 1|\underline{d}, \overline{e})$ given by expressions (2) and (8).

We let $\nu \to 0$ without any substantive costs because the value of relocation is assumed to be small (close to 0). $u_B(f = 0|\underline{d}, \overline{e}) > u_B(f = 1|\underline{d}, \overline{e}, \epsilon \to 0)$ if

$$\delta^{\tilde{t}}w\left[\frac{1 - \lambda^{\tilde{t}}\pi}{1 - \delta(1 - \lambda^{\tilde{t}}\pi)}\right] > (1 - \pi)\delta^{\hat{t}0}\beta\left[\frac{1 - \lambda^{\hat{t}0}\pi}{1 - \delta(1 - \lambda^{\hat{t}0}\pi)}\right], \tag{9}$$

[17] $\hat{t}1$ is *weakly* larger because *B* may come back in t = 1 in both scenarios if π is very small.

and $u_B(f=0|\underline{d},\overline{e}) > u_B(f=1|\underline{d},\overline{e},\epsilon\to 1)$ if

$$\delta^{\tilde{t}} w \left[\frac{1-\lambda^{\tilde{t}}\pi}{1-\delta(1-\lambda^{\tilde{t}}\pi)}\right] > (1-\pi)\delta^{\hat{t}1}\beta(1-\underline{d}) \left[\frac{1-\lambda^{\hat{t}1}\pi}{1-\delta(1-\lambda^{\hat{t}1}\pi)}\right]. \tag{10}$$

Expression (10) is more likely to be satisfied than expression (9) because B's utility to fighting is greater when $\epsilon\to 0$, i.e., $u_B(f=1|\underline{d},\overline{e},\epsilon\to 0) > u_B(f=1|\underline{d},\overline{e},\epsilon\to 1)$; it is never the case that expression (9) holds while (10) does not. It is straightforward to see that when the health risk is sufficiently severe, i.e., π is large, condition (10) holds, but (9) requires higher π to be satisfied. To simplify the equilibrium behavior (to rule out "overlapping" behavior across different types of resources), we focus on a case in which only (10) holds, that is, π is reasonably high but does not immediately kill B. In other words, the health threat has a weaker effect on *B*'s *ability* to launch a counter-attack compared to physical destruction; $\overline{e}$'s *unique* effect is through disincentivizing *B* to engage in any activity in the contaminated territory due to the health threat.

Definition *Dirty* weapons are arms that pose health threat in t = 1 with probability $\pi\in(0,1)$ such that expression (10) holds but expression (9) does not hold.

Finally, when $e=\underline{e}$ given $\underline{d}$,

$$u_B(f=0|\underline{d},\underline{e}) = \frac{w}{1-\delta}$$

and

$$u_B(f=1|\underline{d},\underline{e}) = \frac{\beta}{1-\delta} - \frac{\beta\epsilon\underline{d}}{1-\delta\epsilon}.$$

$u_B(f=0|\underline{d},\underline{e}) < u_B(f=1|\underline{d},\underline{e})$ because $w<\beta(1-\epsilon\underline{d})$, and thus *B* fights regardless of the value of ϵ. It follows that when damage is recoverable or resources are labor-intensive ($\epsilon\to 0$), *A* is indifferent between $\overline{e}$ and $\underline{e}$ given $\underline{d}$.

Proof 3: A's choice

When the value of ϵ is such that *B* chooses to surrender after $\underline{d}$ and $\overline{e}$, or $\epsilon \to 1$, *A*'s utility to $d = \overline{d}$ is

$$u_A(\overline{d}, \underline{e}|\epsilon \to 1) = \frac{1 - \overline{d} - w}{1 - \delta}$$

and *A*'s utility to $d = \underline{d}$ is

$$u_A(\underline{d}, \overline{e}|\epsilon \to 1) = \delta^{\hat{t}1} \frac{1 - \underline{d} - w}{1 - \delta},$$

where $u_A(\overline{d}, \underline{e}) < u_A(\underline{d}, \overline{e})$ when states are patient or if $\overline{d}$ is large enough. It is reasonable to suppose that the difference between $\underline{d}$ and $\overline{d}$ is large enough to cause a substantive effect, which eliminates pair $\{\overline{d}, \underline{e}\}$ from equilibrium when $\epsilon \to 1$.

When the value of ϵ is such that *B* chooses to fight after $\underline{d}$ and $\overline{e}$, or $\epsilon \to 0$, *A* chooses pair $\{\overline{d}, \underline{e}\}$ because low destruction will end with *B*'s counter-attack.

Proof of Proposition 4

From expression 1, the time in which B returns to work is

$$\hat{t} = log_\lambda \left[\frac{1}{\pi} - \frac{\nu}{\pi\beta(1 - \epsilon\underline{d})} \right] = log_\lambda \frac{1}{\pi} + log_\lambda \left[\beta(1 - \epsilon\underline{d}) - \nu \right] - log_\lambda \beta(1 - \epsilon\underline{d}).$$

$\frac{\partial \hat{t}}{\partial \nu} > 0 \; \forall \nu < w$ because $\lambda \in$ (0,1) and $\beta(1 - \epsilon\underline{d}) - \nu > 0$ which follows from $\nu < w < \beta$(1 - $\epsilon\underline{d}$). When $\epsilon \to 1$, from Proof 3, $u_A(\underline{d}, \overline{e}|\epsilon \to 1)$ is decreasing in $\hat{t}1$ because $\delta \in$ (0,1), which is true for any $\epsilon \in$ (0,1). Therefore, an increase in ν makes the selection of destructive arms more attractive for A.