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The Economics of Peace and War

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Budget and Effort Choice in Sequential Colonel Blotto Campaigns

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Abstract

Military campaigns are studied as dynamic best-of-three contests, where final victory is attributed to the first player who wins a critical number of battles. The article studies how overall budget constraints and different assumptions about the destruction of military resources used in a given battle affect the dynamics and overall equilibrium resources in a best-of-three contest. Discouragement effects for players who lag behind and the showdown effect when the campaign reaches a more decisive state vanish if players have to choose an overall budget and can draw on what is left from this budget in the course of the campaign. This is true both in a context in which the resources allocated to a battle are used up there as well as if player's battle resources carry over to future battles. If only the winner's contest resources carryover, this generates precautionary behavior of the leading player and all-in behavior for the player lagging behind. (JEL codes: D72, D74)

Key words: Colonel Blotto, campaign, multi-battle conflict, best-of-n contest, discouragement effect, decisiveness, precautionary behavior, all-in effect, sequential battles

1. Introduction

It has been noted both in economic and political science research that military conflict is a dynamic phenomenon. The campaign by Alexander the Great, Napoleon Bonaparte's campaign against Russia, Hitler's attack on the Soviet Union, among other instances, illustrates the dynamic nature of military campaigns. Campaigns typically consist of a multiplicity of sub-contests or battles. The contestants have to make choices about the stock of military resources they can use. The stock might be given when the campaign starts, either as an exogenously fixed amount or because it has to be chosen at the beginning of the campaign and cannot be adjusted later. The important choices are about the overall size of the budget and how to use it along different paths of the campaign. The resources used in a given battle might be completely used up in this battle. Alternatively, a share of the resources may be recovered for future battles, and the size of this share may differ for the winner and the loser of the battle. Furthermore, rather than being endowed with a fixed overall budget for the whole campaign, it might be possible to replenish military equipment during the campaign. The military resources used in a battle might be chosen freely for each stage of the campaign, even once the campaign has started.

These considerations make it natural to study several possible setups and to compare them. The benchmark framework which we consider is the dynamic Blotto campaign in which the resource budget is determined at its beginning and subsequently used up in the different battles. This benchmark can be compared to several alternative setups. One of these is a campaign with a fixed overall budget that differs from the dynamic Blotto campaign by carryovers: the resources can be used in multiple battles. A second one is a battle series in which only the loser in a battle sacrifices the troops and resources used in a given battle, whereas the battle winner can carry these resources over and re-use them in future battles.[1] Furthermore, the assumption about no carryovers can be kept, but instead of an overall budget that is chosen prior to the start of the campaign, one might assume that the contestants can freely choose the resources expended in any given battle and have to pay for these resources at the point when they decide to expend the respective battle resources. The article describes equilibrium choices in these different frameworks and compares them. A focus of interest is the dynamics of the campaign and how these differ for the cases considered: How a player's lead or a player's lag in battle victories affects the allocation of military resources, and whether battle effort escalates or de-escalates during the campaign?

A motivating example of the types of Blotto campaigns is Napoleon's campaign against Russia in 1812/1813. Napoleon started this campaign with the Great Army. The precise size is difficult to number, but it might have consisted of more than 500,000 infantry, almost 100,000 cavalry, and 1240 guns when crossing the Russian border (Dodge 2008, p. 21 ff.). According to Chandler (1967, p. 853), from the central army group, 'which in its heyday numbered 450,000 combatants; of this vast armament, only 25,000 bedraggled survivors recrossed the Niemen'. McNeill (1982, p. 204) briefly describes Napoleon's efforts and difficulties to 'feed the *Grande Armée* from the rear' and mentions the breakdown of these logistics when the army retreated from Moscow. His campaign had to rely largely on a given military endowment, with limited options to replenish the troops during the campaign. Napoleon had to allocate the resources in a series of battles. The situation on the Russian side may have been slightly different, but given the short duration of the total campaign the Russian side might not have had much discretion and had to draw on a given stock of military forces.

This campaign also illustrates that the different assumptions about carryovers are the polar ends of a wide spectrum of what might happen with the resources used in a given battle. Napoleon eventually lost the vast majority of his troops and equipment during the campaign, but most likely there were carryovers: the losses in each battle were typically smaller than the number of troops used in the battle. The size of the losses in troops or military equipment may depend on winning or losing a respective battle, and on how the winner of

1 See, in particular, Beviá and Corchón (2013), who consider contests in which effort that is expended in a first stage builds up a competitive advantage in a later round. Their framework differs along many dimensions: it is a two-period model with a price allocated in each round, and no fixed budget *ex ante* efforts in the first round affect the productivity of a contestant in the second round in a deterministic fashion and depends only on his own and the competitor's effort. Whether a player wins or loses the first battle does not make a difference.

a battle is able to make use of the victory to delete the enemy troops. Clausewitz (1832/1989, Book 4, Chapter 12) devotes a chapter to describe how the winner of a battle might make use of the victory to damage the enemy further, and what the natural alternatives are and the natural limits to this activity. He writes (p. 266): '…pursuit is now one of the victor's main concerns, and the trophies are thus substantially increased. Even if there are instances among more recent battles where this has not happened, these were exceptions, and unusual factors were always at work'.

Clausewitz writes about the assessments of the contemporaries of Napoleon Bonaparte (p. 259) with respect to the Battle of Borodino: 'Bonaparte has been severely censured, particularly by French historians and great admirers of his (Vaudoncourt, Chambray, Ségur) for failing to drive the Russian army off the field and to use his last remaining strength to crush it. They argue that what was mainly a lost battle could have been an absolute rout'. Being less negative in his assessment of the battle of Borodino, Clausewitz draws attention to the fact that his army had melted already when he reached Borodino. Clausewitz's assessment clearly shows the trade-off between using military resources earlier or later, and that it may be desirable to preserve resources for later. As he writes (p. 266) about Bonaparte:

> …he might have wondered if he had enough to march on Moscow—and it was on Moscow that everything appeared to hinge. The victory he had just won made him reasonably confident of taking the capital; it seemed exceedingly unlikely that the Russians could fight another battle within a week; and it was in Moscow that he hoped to make peace. Admittedly, he could have been more sure of making peace if the Russian army had been completely destroyed; but his first priority was still to get to Moscow, and to get there in enough strength to be in a position to enforce his will on the capital, and thereby on the government and the Russian Empire.

These considerations might illustrate the trade-off faced by a military leader who has to allocate a given amount of military resources over time. In the specific example here the trade-off is on whether to use some resources to exploit a battle victory, or keep these resources for the later showdown. Also, it can be seen as an illustration for possible assumptions about what happens with battle resources. The winning military leader may pursue the enemy troops when they flee from the battlefield and may slaughter as many of them as possible. This might drastically reduce the size of the army which the losing enemy has at his disposal for future battles, whereas there is no similar reason for size reductions in the winning party's army. The possible asymmetry in losses of troops is brought to the extreme in the subsection that considers asymmetric carryovers.

A very different pattern can be found, in which each army leader might be able to replenish and actually choose the size of his army for each battle during the campaign. Alexander's campaign and arms production in Nazi Germany during the Second World War might be examples of such more dynamic flexibility. Reports differ about the size of Alexander's army when he departed from the Hellespont towards Asia. Berve (1926, p. 177) surveys some of the early sources ranging from 30,000 to little above 40,000 foot soldiers and about 4000 to 5000 cavalry soldiers (see also the discussion in Beloch 1923, pp. 356n.). During the campaign that took many years he sacrificed troops, but his army also received a 'steady flow of reinforcements' (Sheppard 2008, p. 86).[2] Nazi Germany also

2 See also English (2010, p. 74) who discusses the role of Persian soldiers in Alexander's army in later years and mentions reports of an army size of 120,000 soldiers at some point of Alexander's campaign.

did not only have to rely on a given initial military endowment. Hitler exploited millions of female labor and foreign manpower as slave labor for the production of war machinery, extracted resources from the conquered territory, and reorganized German industrial production, gearing it toward the production of weapons and other military equipment. As a result, war production reportedly peaked only in July 1944 (see McNeill, 1982, p. 353).

The research focus is somewhat limited by describing a campaign as a best-of-n contest here.[3] This structure is prominent among dynamic contest structures, but there are important alternative structures which are not covered here. The best-of-n contest is finite and ends as soon as one of the players has attained a predetermined number of battle victories. Not all campaigns have a natural finite end point in time. An alternative with an indeterminate end point is the tug-of-war and is a natural description, too. It has a potentially infinite number of sequential battles and ends as soon as one of the players has accumulated a number of battle victories that exceed the number of victories of the other player by a sufficiently large number.[4] An even more important assumption is that players have no other alternative than to fight a battle in any given state prior to the end of the game. This abstracts from other options such as conflict delay or negotiating peace. The conditions for when peace prevails or when conflict is inevitable have been carefully studied in the context of international organization. Limited commitment, time consistency problems, information asymmetries, and other reasons may make a peace treaty infeasible and fighting an inevitable outcome. Fighting may occur sooner or later, and with higher or lower probability.[5] Researchers have also drawn attention to the fact that aspects such as the timing or the likelihood of negotiations, as well as the division of the 'peace rent' between two players may depend on whether negotiations take place during a violent war or in a non-violent status quo (Filson and Werner 2002). The analysis here is not about whether war can be avoided. It studies the dynamics of a war campaign starting with the assumption that the decision on whether to start the campaign has been made.

The analysis also relates to the study of static contests by Che and Gale (1997, 1998). They studied static contests with players who are constrained with respect to the maximum amount of resources that can be mobilized, where players may face different constraints due to their endowments, or because they face external constraints about how many resources are allowed. This article analyzes the micro-structure of how players would make use of such an overall budget if the budget can be used over time on rival tasks/battles, and it endogenizes the budget choice in this context.

3 Variants of this structure have been studied with applications in various contexts, for instance, by Harris and Vickers (1987), Klumpp and Polborn (2006), Konrad and Kovenock (2009), Sela (2011), and Gelder (2014).

4 For analyses of this structure see Harris and Vickers (1987), McAfee (2000), Agastya and McAfee (2006), Konrad and Kovenock (2005), Häfner (2017), Gauriot and Page (2014), and Deck and Sheremeta (2015). Many variants of dymamic contest structures have been analyzed. Some examples are in Rosen (1986), Leininger and Yang (1994), Amegashie (1999), Gradstein and Konrad (1999), Groh et al. (2012), Konrad (2004), Virág (2009), Kahana and Klunover (2018), Fu and Lu (2012), Segev and Sela (2014), and Clark, Nilssen and Sand (2014).

5 Analyses that address the question of when conflict actually arises are Polborn (2006) and Bester and Konrad (2004, 2005). An important insight that draws on the problem of commitment problems which may make an early, violent resolution of conflict superior can be found in Garfinkel and Skaperdas (2000). Experimental work that considers the decision as to whether to fight if players can also bargain is Herbst et al. (2017).

The analysis proceeds as follows: Section 2 offers a formal definition of a campaign as a best-of-n contest with a Tullock lottery contest describing each battle in the campaign for the most parsimonious case with $n = 3$, that is, for the case in which the player who is the first to win two battles wins the war. This basic model is used to consider dynamic Blotto campaigns without and with carryovers (Section 3). Section 4 reviews key results on the best-of-three campaign if players are more flexible about the resource choices during the campaign. Section 5 compares the dynamics and the total resources in these setups. Section 6 concludes.

2. The Best-of-Three Campaign

Our baseline model of a campaign is a dynamic game that follows the rules of a best-of-three contest. We consider two Players, A and B. The two players interact repeatedly in a sequence of up to three battles. We denote Player A as the attacker who initiated a campaign to conquer or defeat Player B. Player B is the defender. In each battle that emerges both players may use non-negative amounts of military resources. One of the two players wins the respective battle. Final victory of the campaign is a function of the numbers of battle victories. While straightforward generalizations come to mind, in its most parsimonious version the sequence of battles comes to an end as soon as one of the two players has accumulated two battle victories. If Player A has two battle victories first, then Player A successfully conquers and takes over the empire/territory of Player B and the game ends. This gives Player A a prize of final victory of size $W > 0$. Player B receives a loser prize of $-L < 0$ in this case. Otherwise, if Player B succeeds and is first to accumulate two battle victories, then this marks the final failure of Player A's attack. In this case Players A and B both receive 0.[6]

The best-of-three version of the multi-battle contest has at least two, and at most three, battles before the game ends. Figure 1 shows this contest with a grid with eight possible states, characterized by their coordinates (i, j). Four of these states are terminal states. The campaign ends once one of these states is reached. Player A wins if one of the terminal states (0, 1) and (0, 2) is reached, Player B wins if one of the terminal states (2, 0) or (1, 0) is reached. The other four states are characterized by $\min\{i, j\} > 0$ and are called interior states. The coordinate i measures the additional number of battle victories which Player A needs to have to reach one of the terminal states in which Player A wins, and j measures the analogous number for Player B. The dynamic contest starts in an interior state $(i, j) = (2, 2)$. In this state Players A and B independently choose non-negative battle amounts of military resources denoted by $x_{(i,j)}$ and $y_{(i,j)}$. A function $p^A_{(i,j)}(x, y)$ of these military resources determines the probability by which Player A will win this battle, and the complementary probability $p^B_{(i,j)} = 1 - p^A_{(i,j)}$ by which Player B will win the battle. If Player A wins the battle at (i, j), the process moves from there to state $(i - 1, j)$, meaning that Player A needs to win $i-1$ further battles to reach final victory, whereas Player B needs

6 For much of the analysis $W = L$ will be assumed, and the size of this prize will be normalized to 1. In particular, the symmetry assumption is used in the best-of-three campaign analyzed first by Klumpp and Polborn (2006) who offer a closed-form solution for the symmetric case of the best-of-three campaign.

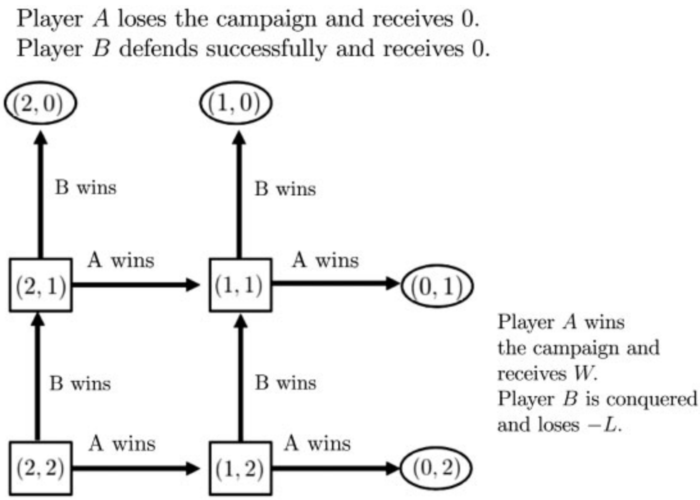

Figure 1. The grid of interior and terminal states in the best-of-three contest. Arrows to the right indicate transitions from states (i, j) to $(i-1,\ j)$ that take place if Player A wins the battle at (i, j). Arrows upwards indicate transitions from states (i, j) to $(i, j-1)$ that take place if Player B wins the battle at (i, j). Interior states are represented by rectangle boxes, and the other states are terminal states.

to win j battles from there. Similarly, if Player B wins at (i, j), the process moves to state $(i, j-1)$.

The battle–win probabilities at a given battle state (i, j) are:

$$p^{A}_{(i,j)}(x_{(i,j)}, y_{(i,j)}) = \begin{cases} \dfrac{x_{(i,j)}}{x_{(i,j)} + y_{(i,j)}} & \text{if} \quad x_{(i,j)} + y_{(i,j)} > 0 \\ \dfrac{1}{2} & \text{if} \quad x_{(i,j)} + y_{(i,j)} = 0 \end{cases}, \tag{1}$$

and $p^{B}_{(i,j)} = 1 - p^{A}_{(i,j)}$. The function (1) is often referred to as the lottery-contest-success function. The function has some natural properties. For instance, the win probability of a player increases in own military resources and decreases in the military resources of the other player. The nature of military battle confrontation depends on the state of technology and other aspects. The function (1) will typically not be a precise description for all types of battle confrontation. It also disregards some of the complexities of a single battle and abstracts from many important aspects that matter in a given battle (see Clausewitz 1832/1989 for a discussion of a number of these aspects). However, this function has been suggested in many contexts, has been axiomatized, and has received a number of microeconomic underpinnings.[7]

Implicitly, (1) assumes that the single battles are technologically independent of each other. In particular, choices on military resources made at state (i, j) determine the win

7 For an overview of different origins and applications of (1) see Konrad (2009). For introducing this function in the area of rent-seeking contests see Tullock (1980). For axiomatizations see Skaperdas (1996) and Clark and Riis (1998). For microeconomic underpinnings see Hirshleifer and Riley (1992), Baye and Hoppe (2003), and Jia (2008).

probabilities at this state, but the resources have no direct impact on the win probabilities in future battle encounters (i', j') with $i' < i$ and/or $j' < j$. At any new state (i', j') both Players A and B independently and simultaneously choose resources $x_{(i',j')}$ and $y_{(i',j')}$. The resources $x_{(i',j')}$ and $y_{(i',j')}$ determine the win probabilities according to the same mapping (1) as in state (i, j). One should note that this assumption is often made. Other assumptions could also be reasonably made (see Beviá and Corchón 2013). After a finite number of battle encounters, the process reaches a state in which either $i = 0$ or $j = 0$. The game ends once such a terminal state is reached.

One further piece of notation will be useful: denote $v^A_{(i,j)}$ and $v^B_{(i,j)}$ as the continuation values of Players A and B at state (i, j), provided that these continuation values are well defined. For terminal states these continuation values are exogenously given by winner and loser prizes: they are $v^A_{(0,j)} = W$ and $v^B_{(0,j)} = -L$ and $v^A_{(i,0)} = v^B_{(i,0)} = 0$. For interior states (i, j) the continuation values are the expected payoffs which players attain from taking part in the subgame starting in (i, j) in the equilibrium of this subgame. In some of the variants, additional variables other than the state (in particular, the remaining budget available for current and future military resource allocation) co-determine the equilibrium of the subgame in a given state.

Finally, there is no discounting. Players are indifferent to whether the final prize of victory or defeat is handed over at an earlier stage or at a later stage. This is an important assumption (see Gelder 2014 for discounting). Also, players might sometimes obtain some 'status'-rents from winning with a wide margin or negative 'ego'-rents from a devastating defeat in which they were unable to score in a single battle. Such an assumption has also been analyzed by Gelder (2014). Such motives are not considered here. Players are indifferent to their 'score' when they eventually reach a terminal state. The formal description of players' payoffs depends on whether the resources expended are 'use-it-or-lose-it' as in the Blotto campaign, or whether additional resources can be mobilized during the campaign and will be specified for the different cases.

3. The Blotto Campaign

Motivated by the discussion of Napoleon Bonaparte's campaign against Russia, we start with a benchmark case in which both players have to choose their overall budget and allocate their resource budgets in a series of battles that take place over time.

The allocation of a given budget among multiple fronts is an old topic in the context of military strategy. Its game theory origins are often attributed to Borel (1921).[8] In this game the two players have a stock of military resources and choose how to allocate these among several simultaneous battlefields. Much of the literature on this Colonel Blotto game attributes an independent value of winning to each of the single battles. The framework here differs along two important dimensions. First, each player's objective is not to win as many battles as possible, but to win at least a critical number of battles. Second, the different battles occur sequentially. Whether resources that were saved for later battles are still useful and what would be the best use in the remaining battles may depend on the outcomes of earlier battles.

8 Major steps have been made in the analysis of this game more recently by Kvasov (2007), Roberson (2006), and Roberson and Kvasov (2012).

Before Players A and B enter into the campaign, they both choose their own total military budget. This choice is denoted by $a_{(2,2)} \geq 0$ and $b_{(2,2)} \geq 0$. Each player has to pay his budget, $a_{(2,2)}$ and $b_{(2,2)}$, respectively, and the player's cost is equal to the chosen size of the budget. Any amount of resources that is left when reaching a terminal state has no value ('use it or lose it'). Endowed with their budgets players enter into the battle at (2, 2). From there they move to (1, 2) if Player A wins and to (2, 1) if Player B wins, and so on along the grid described in Figure 1. If they are at a particular interior battle state (i, j), they have to decide how many resources to allocate to the battle that is taking place there. They have budgets $a_{(i,j)}$ and $b_{(i,j)}$ at state (i, j). We distinguish between dynamic Blotto contests without and with carryovers. Payoffs depend on the terminal state reached and initial resource effort choices. They are $\pi_A(0,j) = W - a_{(2,2)}$, $\pi_A(i,0) = -a_{(2,2)}$, $\pi_B(0,j) = -L - b_{(2,2)}$ and $\pi_B(i,0) = -b_{(2,2)}$.

No carryovers We first assume that there are no carryovers: the resources that a player allocated to a battlefield (i, j) are completely used up. Accordingly, the players' budgets at later stages consist of the initial budgets $a_{(2,2)}$ and $b_{(2,2)}$ net of resources they have expended in previous battle states. At battle state (i, j) they can choose to allocate any non-negative amounts $x_{(i,j)}$ and $y_{(i,j)}$ to it, as long as these do not exceed their budgets $a_{(i,j)}$ and $b_{(i,j)}$. Budgets develop according to:

$$a_{(i-1,j)} = a_{(i,j)} - x_{(i,j)}$$

$$a_{(i,j-1)} = a_{(i,j)} - x_{(i,j)}$$

$$b_{(i-1,j)} = b_{(i,j)} - y_{(i,j)}$$

$$b_{(i,j-1)} = b_{(i,j)} - y_{(i,j)}.$$

The campaign proceeds until it reaches one of the terminal states. If (0, 1) or (0, 2) is reached then Player A receives W and Player B receives $(-L)$. If (2, 0) or (1, 0) is reached then both players receive 0. Accordingly, the winner payoff for Player A is $W - a_{(2,2)}$, and the payoff for Player B is $-L - b_{(2,2)}$ if terminal state (0, 2) or (0, 1) is reached, and the payoffs are $-a_{(2,2)}$ for Player A and $-b_{(2,2)}$ for Player B if the process ends in (2, 0) or (1, 0). The following proposition holds:

Proposition 1: A subgame perfect allocation of military resources in the sequential best-of-three Colonel Blotto game with initial total budgets $a_{(2,2)} > 0$ and $b_{(2,2)} > 0$ has $x_{(i,j)} = a_{(2,2)}/3$ and $y_{(i,j)} = b_{(2,2)}/3$ for all interior states (i, j).

The result in this proposition is a special case of a general result in Klumpp and Konrad (2017). They show that players in a sequential best-of-n Blotto contest allocate shares $1/(i + j - 1)$ of what remains of their endowments at any possible interior state (i, j) that is reached, independent of whether they have the same or different budgets.[9] Their result

9 There are subgames in Klumpp and Konrad (2017) in which $\min\{a_{(i,j)}, b_{(i,j)}\} = 0$ for some interior states. The subgames might have multiple equilibria, but these are payoff equivalent. Moreover, these subgames are not reached along an equilibrium path.

holds for all finite n, and the result holds for a large and general class of contest success functions that includes the Tullock lottery contest. Their setup allocates a positive winner prize to Player A if a terminal state $(0, j)$ is reached and a positive winner prize to Player B if a terminal state $(i, 0)$ is reached and 0 to the respective losing player. However, the equivalence to the problem here is evident given that Player A wins W if Player A wins, and B wins L—the difference between 0 and (-L)—if Player B reaches one of B's preferred terminal states $(i, 0)$ rather than a state $(0, j)$.

We can use the characterization of this equilibrium for the sequential Blotto contest to ask what the equilibrium budget choice is and how does it depend on the prize valuations W and L. We find:

Proposition 2: If A and B can choose the size of their military budgets prior to entering into the sequential best-of-three Colonel Blotto campaign and if the budget choice is followed by the equilibrium characterized in Proposition 1, then the equilibrium budgets are related to each other by:

$$a_{(2,2)} = \frac{W}{L} b_{(2,2)},$$

with

$$a_{(2,2)} = \frac{6L^2W^3}{W^4 + 4LW^3 + 6L^2W^2 + 4L^3W + L^4}$$

$$b_{(2,2)} = \frac{6L^3W^2}{W^4 + 4LW^3 + 6L^2W^2 + 4L^3W + L^4}$$

for given W and L in a sufficiently close neighborhood of $W = L$. For $W = L$ the equilibrium values are $a_{(2,2)} = b_{(2,2)} = \frac{3}{8}W$ and the resulting equilibrium payoffs are $\pi^A = \frac{1}{8}W$ and $\pi^B = -\frac{7}{8}L$.

The proof is in the Appendix. We keep this result in mind to compare it with the other variants of the best-of-three contest, but first we consider other types of resource carryovers.

Symmetric full carryovers Suppose alternatively that all players' military resources carry over to all future battles,[10] such that budgets develop according to:

$$a_{(i-1,j)} = a_{(i,j)}$$

10 A type of carryover has been discussed by Brahms and Davis (1982) in the context of electoral campaigns. They assume that resources expended in the battle which immediately preceded the new battle affect the battle outcome in the new battle. Dependence between sequential battles also emerges in the work by Beviá and Corchón (2013) where early contest effort improves the technology of the player later. Clark and Nilssen (2013) analyze a related problem, allowing the contestants to become more cost-effective in a future contest by expending effort in a previous contest.

$$a_{(i,j-1)} = a_{(i,j)}$$

$$b_{(i-1,j)} = b_{(i,j)}$$

$$b_{(i,j-1)} = b_{(i,j)}.$$

In this symmetric full carryover case it is a (weakly) dominant strategy for Player B for any given positive budget choices $(a_{(2,2)}, b_{(2,2)})$ to allocate resources such that $b_{(2,2)} = y_{(i,j)}$ for each interior state (i, j) that is reached, and analogously for Player A. Anticipating this behavior by Player B, the payoff of Player A as a function of the budget choices is:

$$\pi^A = \left(\frac{a_{(2,2)}}{a_{(2,2)} + b_{(2,2)}}\right)^2 (1 + 2\frac{b_{(2,2)}}{a_{(2,2)} + b_{(2,2)}})W - a_{(2,2)}. \quad (2)$$

We find:

Proposition 3: For the case of full carryovers, both players use their full budgets at all battles. The budget choices characterized in Proposition 2 are also equilibrium budget choices in the case of a full carryover. For a proof, note that it is a weakly dominant strategy for each player to use his whole budget at all stages that are reached. Furthermore, the expected payoff of Player A is:

$$\pi^A = \left(\frac{a_{(2,2)}}{a_{(2,2)} + b_{(2,2)}}\right)^2 \left(1 + 2\frac{b_{(2,2)}}{a_{(2,2)} + b_{(2,2)}}\right) W - a_{(2,2)},$$

and analogously for Player B. This functional form is the same as in the case without budget carryovers as in (2). Hence, taking into consideration the equilibrium play in the Blotto subgame for given budgets and without carryover, the objective functions for the choice of overall budget size in the problem without carryovers and in the problem with complete symmetric carryovers (2) show that the budget choice problems in these two frameworks are equivalent.

The interesting aspect of the proposition is that the full carryover of resources that had already been used in an earlier battle does not change the equilibrium choices of the contestants' overall budgets.

Winner's carryover The dynamic Blotto games described in the previous sections assume the symmetry of possible carryovers. In the military context the size of the carryover for a player may often depend on whether the player was the winner of the previous battle. Among the reasons for such an asymmetry are the motivational values of winning the battle. Also, it is likely that the loser of the battle will sacrifice a larger share of troops and military equipment. This larger loss is seemingly a natural correlate to losing the battle. Moreover, soldiers who retreat in a disorderly fashion may throw away their guns or leave behind components of their equipment. And finally, the winner may use the momentum of victory, pursue the defeated troops, and reduce their size dramatically.

Analytically this asymmetric carryover corresponds to the assumption that either the amount $x_{(i,j)}$ or $y_{(i,j)}$ is completely sacrificed, depending on who loses the battle at (i, j), whereas the winner can recover the full amount of resources.[11] These stark assumptions provide some indication of the direction in which a winner's carryover affects equilibrium play.

So, let players choose their Blotto budgets $a_{(2,2)}$ and $b_{(2,2)}$ prior to stage (2, 2). Then, during the campaign, they choose $x_{(i,j)}$ and $y_{(i,j)} \in [0, b]$ at an interior stage (i, j) that may be reached and their choice of military resources at a given stage cannot exceed the remaining budget when reaching this stage. Budgets develop according to:

$$a_{(i-1,j)} = a_{(i,j)} \text{ if } A \text{ wins the battle at } (i,j)$$

$$a_{(i,j-1)} = a_{(i,j)} - x_{(i,j)} \text{ if } A \text{ loses the battle at } (i,j)$$

$$b_{(i-1,j)} = b_{(i,j)} - y_{(i,j)} \text{ if } B \text{ loses the battle at } (i,j)$$

$$b_{(i,j-1)} = b_{(i,j)} \text{ if } B \text{ wins the battle at } (i,j).$$

It is difficult to solve for all stages of this dynamic game. But we can make an interesting observation about the stages with $i + j \leq 2$:

Proposition 4: Consider a sequential best-of-three Colonel Blotto game with full carryover for the battle winner and initial total budgets. Let $a_{(2,1)} > 0$, $b_{(2,1)} > 0$, $a_{(1,2)} > 0$ and $b_{(1,2)} > 0$. The equilibrium choices at (2, 1) are $x_{(2,1)} = a_{(2,1)}$ and $y_{(2,1)} = b_{(2,1)}/2$. Similarly, the equilibrium choices at (1, 2) are $x_{(1,2)} = a_{(1,2)}/2$ and $y_{(1,2)} = b_{(1,2)}$.

The proof is in the Appendix and just develops the following intuition more formally. Consider (2, 1): Player A is disadvantaged. With a full winner carryover Player A optimally allocates the full amount of his remaining resource budget to this battle. Only if Player A wins this battle is there a chance to win the overall contest. If Player A loses at (2, 1) there is no second chance. Moreover, if Player A wins the battle, all resources allocated to (2, 1) carry over to (1, 1). So there is no opportunity cost of allocating a larger share of any given budget $a_{(2,1)}$ to the battle at (2, 1). This consideration is independent of Player B's allocation of his military resources. Now, Player B has a reason to be more cautious and does not place everything on one card. This is because should Player B lose, Player B would lose all resources allocated to (2, 1) and would have nothing left to take advantage of Player B's second chance at (1, 1). An equal allocation of effort levels to (2, 1) and (1, 1) turns out to be just optimal.

Thinking again about the battle at Borodino, it might have been this effect that prevented the victorious Bonaparte from pursuing the defeated Russian army. He could have risked more and have forced a final victory, trying to destroy the Russian army completely. But this would presumably have weakened his army and reduced his capacity in the battle for Moscow. It might have been more important to spare his own military resources for later.

11 A more general setup with asymmetry may allow for positive carryovers for both the winner and the loser, but assumes that the winner can recover a larger budget share than the loser. This makes the formal problem even less tractable.

4. Sequential Effort Choices

In this section we remove the key restriction that made campaigns a Blotto game in the previous section. Rather, we allow players to choose (and pay) the full cost of the military resources that they allocate to a given battle. This problem has been studied as the sequential campaign game by Klumpp and Polborn (2006). They do not target the military/war context, but their main application is electoral campaigns. Nevertheless, it is interesting to compare our results with this framework.

At a given battle state (i, j) Players A and B can choose any finite military resources $x_{(i,j)} \geq 0$ and $y_{(i,j)} \geq 0$, and they pay the cost of these at the time of making this choice. Again, the resource cost equals the amount of resources here. Hence, their choice in later battles may depend on the outcome in previous battles, but the expenditure in previous battles does not restrict the players in their resource choices in later stages. A simplifying assumption is that the players' cost is equal to the amount of resources itself—i.e. the units of military resources are measured in units of cost. Resource amounts $x_{(i,j)}$ and $y_{(i,j)}$ translate into battle–win probabilities as in (1). The amount of resources allocated to a battle is sunk, and the player who chooses it needs to pay the cost of it, irrespective of the fighting outcome at a particular battle state. Payoffs depend on the terminal state reached and resource effort choices made in the transition states on the way to the terminal state, with $\pi_A((0,j);H) = W - \Sigma_{(i,j)\in H} x_{(i,j)}$, $\pi_A((i,0);H) = -\Sigma_{(i,j)\in H} x_{(i,j)}$, $\pi_B((0,j);H) = -L - \Sigma_{(i,j)\in H} y_{(i,j)}$ and $\pi_B((i,0);H) = -\Sigma_{(i,j)\in H} y_{(i,j)}$, where we abbreviate H as the record of the set of states that was actually visited before reaching the respective terminal state.

Klumpp and Polborn (2006) assume that the contest is fully symmetric about a winner prize $W = 1$ and a loser prize of 0. Applied to our attack–defense framework, this translates equivalently into prizes in the terminal states (0, 2) and (0, 1) of $W = 1$ and $-L = -1$ for Players A and B, and of 0 for both players in the terminal states (2, 0) and (1, 0).

The assumption that the attacker values winning as much as the defender makes the dynamic contest fully symmetric both at (2, 2) and at (1, 1).[12] For the analytical treatment let us also define players stakes in particular battle states:

$$z^A_{(i,j)} \equiv v^A_{(i-1,j)} - v^A_{(i,j-1)} \text{ and } z^B_{(i,j)} \equiv v^B_{(i,j-1)} - v^B_{(i-1,j)} \tag{3}$$

for states (i, j) with $\min\{i, j\} > 0$. These are the differences in players' continuation values from winning and losing the battle contest at (i, j). We call $z^A_{(i,j)}$ and $z^B_{(i,j)}$ Player A's stake and Player B's stake in the interior state (i, j).

The subgame perfect equilibrium can be characterized as follows. In state $(1, 1)$ the two contestants fight for a payoff difference between winning and losing that is equal to $z^A_{(1,1)} = z^B_{(1,1)} = 1$. This contest is symmetric, and they expend equilibrium efforts $x_{(1,1)} = y_{(1,1)} = \frac{1}{4}$. This determines their continuation values at (1, 1) as $v^B_{(1,1)} = -\frac{3}{4}$ and $v^A_{(1,1)} = \frac{1}{4}$. In state (2, 1), Player B attributes a value $z^B_{(2,1)} = \frac{3}{4}$ to reaching state (2, 0) rather than state (1, 1). Player A attributes a value $z^A_{(2,1)} = \frac{1}{4}$ to reaching state (1, 1) rather than

12 While this symmetry assumption is not innocent, the best-of-n contest with asymmetric prize valuations and without overall budget constraint has, to my knowledge, not been solved analytically. As one departure from this symmetry, Mehlum and Moene (2004) explore the consequences of a payoff asymmetry between attacker and defender and a countervailing asymmetry in their fighting technologies in a different, but related framework.

state (2, 0). Anticipating subgame perfect play in later stages, the battle contest at (2, 1) is described by an asymmetric lottery contest with prizes $z^B_{(2,1)} = \frac{3}{4}$ and $z^A_{(2,1)} = \frac{1}{4}$. The equilibrium of a static Tullock lottery contest with these prizes is well known and given by $x_{(2,1)} = \frac{3}{64}$ and $y_{(2,1)} = \frac{9}{64}$. This implies that $p^A_{(2,1)} = \frac{1}{4}$ and $p^B_{(2,1)} = \frac{3}{4}$ at (2, 1). In turn, this implies that the continuation values of reaching (2, 1) are $v^A_{(2,1)} = \frac{1}{64}$ and $v^B_{(2,1)} = -\frac{21}{64}$. In state (1, 2), Player B attributes a value equal to $z^B_{(1,2)} = \frac{1}{4}$ to reaching (1, 1) rather than (0, 2). Player A attributes a value of $z^A_{(1,2)} = \frac{3}{4}$ to reaching (0, 2) rather than (1, 1). Anticipating subgame perfect play in later rounds, the equilibrium of a static Tullock lottery contest with these prizes is well known and given by $x_{(1,2)} = \frac{9}{64}$ and $y_{(1,2)} = \frac{3}{64}$. This implies that $p^A_{(1,2)} = \frac{3}{4}$ and $p^B_{(1,2)} = \frac{1}{4}$ at (1, 2). In turn, this implies that the continuation values of reaching (1, 2) are $v^A_{(1,2)} = \frac{43}{64}$ and $v^B_{(1,2)} = -\frac{63}{64}$. Finally, in state (2, 2) the two players compete over whether to move to (1, 2), which is the preferred state for Player A, or to (2, 1), which is the preferred state for Player B. The prizes at stake are $z^A_{(2,2)} = v^A_{(1,2)} - v^A_{(2,1)} = \frac{43}{64} - \frac{1}{64} = \frac{21}{32}$ and $z^B_{(2,2)} = v^B_{(2,1)} - v^B_{(1,2)} = -\frac{21}{64} - (-\frac{63}{64}) = \frac{21}{32}$. This shows that the battle contest at (2, 2) is symmetric and that Players A and B are fighting for prizes of size $\frac{21}{32}$. It is straightforward from here to calculate that $x_{(2,2)} = \frac{21}{128} = y_{(2,2)}$ in the subgame perfect equilibrium.

The expected sum of resource amounts for each of the players that emerges in the equilibrium follows from these, taking into consideration that the campaign may, but need not, reach battle state (1, 1). This sum is:

$$x_{(2,2)} + \frac{1}{2}x_{(1,2)} + \frac{1}{2}x_{(2,1)} + \frac{1}{4}x_{(1,1)} = \frac{41}{128}.$$

We summarize these results in a proposition:

Proposition 5: (Klumpp and Polborn 2006): Consider the campaign with unconstrained and independent resource choices at each battle, symmetric prizes from winning the campaign, and symmetric Tullock fighting technology (1). Fighting resources chosen are symmetric at (1, 1) and at (2, 2). Fighting resources are higher at (1, 1) than at (2, 2). Fighting resources are smaller in the asymmetric states (2, 1) and (1, 2) than in the symmetric states (2, 2) or (1, 1). Moreover, they are lower for the disadvantaged (lagging) player in (2, 1) and (1, 2) than for the advantaged (leading) player. The sum of expected military resources used exceeds the amounts of resources chosen in a single battle for the same prize.

5. Comparisons

Let us compare the dynamics of military resources allocated in the course of the campaign. The result by Klumpp and Polborn (2006) highlights two important effects. One effect has been referred to as the discouragement effect. Players who fall behind become discouraged. Consider Player A when the process moves from (2, 2) to (2, 1). The player could try to catch up and return to a strategically symmetric state (1, 1). If successful, the player will then have to fight a decisive and strategically symmetric battle at (1, 1). Efforts at (1, 1) are high. The continuation value at (1, 1) is therefore low. This low continuation value makes it less attractive for Player A to choose much of the costly resources at (1, 2). The advantaged Player B also chooses a low amount of resources in this state, but still three times as much as Player A. Player B's low amount of resources can be interpreted as an equilibrium reaction to the low anticipated amount chosen by the disadvantaged player. The difference in resource amounts causes a momentum effect: the advantaged player wins the battle at this stage in three out of four cases. This is in line with the sometimes articulated hypothesis that players who have just won a battle get a strategic momentum and are more likely to win the subsequent battle. If such a momentum exists it leads to the prediction that in a sequence of battles the winning of players is systematically correlated.

The equilibrium also describes that players expend more resources at (1, 1) than at (2, 2). This effect is referred to as the showdown effect. Intuitively, the players are strategically symmetric in these two states. However, the fight in (1, 1) is decisive and resolves the conflict. The fight in (2, 2) leads to an advantage of one player, but not to final victory. Accordingly, the stakes of both players are higher at (1, 1) than at (2, 2). When they reach (1, 1) they choose their military battle resources according to these higher stakes.[13]

The dynamics of Blotto campaigns without carryovers as well as Blotto campaigns without carryovers follow a different logic. A player who is lagging behind by one battle allocates the same amount of resources at this battle as the advantaged Player B if carryovers are either full or 0, but symmetric. So there is no discouragement effect. And they both allocate the same resource quantities at (1, 1) as they do at (2, 2), so there is no showdown effect either.

Intuitively, there are several effects at work that operate in opposite directions. The battle at (1, 1) is decisive, but the battle at (2, 2) is not. This is a reason to preserve more resources for the decisive battle. But on the other hand, the battle at state (2, 2) always takes place, whereas state (1, 1) may not be reached at all, which happens if the conflict resolves at (2, 0) or (0, 2). So the resources preserved for (1, 1) are useful only with some probability.

The intuition for the absence of a discouragement effect is as follows. In the dynamic contest with full effort flexibility in all stages a player who is lagging behind could purchase a number of military resources at this point, win the battle, and move the game to the symmetric decisive state (1, 1). At this point both players would expend major military resources trying to win. These resources are optimally chosen when (1, 1) is reached, but from the perspective of state (2, 1), they constitute an additional cost. In comparison, in the Blotto version, winning at an asymmetric state does not inflict an additional cost for military resources at (1, 1). All resources that are potentially used have already been chosen and have already been paid for. For this it is important that resources that are not used in the end have a scrap value of 0. They do not directly appear in the continuation payoff functions of players in the subgames. The resources for the final showdown at (1, 1) are already preserved for this battle at (2, 1) or (1, 2), and whether they are used at (1, 1) does not affect a player's overall resource costs.

The problem with full carryovers for battle winner and the battle loser simplifies the dynamics in any subgame tremendously. The full carryover reduces the opportunity cost of

13 Malueg and Yates (2010) find evidence from a tennis application of best-of-three, multi-battle contests that is in line with such strategic momentum. Gauriot and Page (2014) carefully survey the theory and the existing evidence on this phenomenon and address the phenomenon in an empirical paper on tennis. Using an elegant identification strategy that allows them to separate effects of genuine strength of players from strategic momentum, they find momentum effects in line with the theory, particularly for male tennis players. Mago et al. (2013) offer experimental results on a best-of-three contest.

using a military resource at some state to 0. It remains available in the future. So both players use all their resources all the time.[14]

An interesting asymmetry can be observed, however, between the advantaged and the disadvantaged player in case only the winner can carry over all his budget to further battles: in this case the winner at (2, 2) is the advantaged player. This player preserves half of this budget in the next stage for the case that these resources might be needed in a final showdown, should the player not win in the asymmetric state. One may call this a precaution effect. The disadvantaged player, instead, mobilizes all resources that are at his disposal. This all-in effect points in the opposite direction from what has been identified as the discouragement effect.

Finally, one may turn to the expected overall amounts of military resources that are expended in the different types of dynamic contests. This comparison is restricted to the case of symmetric valuations of winning because results for the asymmetric best-of-three contest with flexible battle budgets are not available. For symmetric prizes the equilibrium amounts are the same for the Blotto contest with no carryovers and with symmetric full carryovers. The overall military resources are higher than in case of the best-of-three contest with full *ex post* budget flexibility. The precise comparison for the normalized symmetric prize values $W = L = 1$ is:

$$\frac{3}{8} = 0.375 > 0.320\,31 = \frac{41}{128},$$

with the total Blotto expenditure on the left and the flexible contest expenditure on the right. We conclude that the military budgets that Players A and B choose in the two types of the sequential best-of-three Colonel Blotto campaign exceed the expected expenditure which emerge in the best-of-three multi-battle contest with unconstrained sequential effort choices. This is also an intuitive outcome: military budget has an option value in the Blotto versions. There is no such option value if players are more flexible and do not waste military resources that then remain unused in the fully flexible dynamic contest.

6. Conclusion

The analysis of the sequential best-of-n campaign with endogenous, unconstrained effort choices and variants of the sequential best-of-n Colonel Blotto campaign has different dynamics of the equilibrium allocation of military resources and causes different amounts of overall military effort. As is well known from the literature, the first type of campaign is characterized by discouragement effects for players who fall behind in the score of battle victories, and by escalation due to a showdown effect. In contrast, the sequential Colonel Blotto campaign does not have either a discouragement effect or a showdown effect. The subgame perfect equilibrium in this structure also does not have either de-escalation or

14 For incomplete but symmetric carryovers, the solution is typically less staightforward, but the case of no carryovers and the case of full carryovers are two potentially interesting boundary cases. The higher effort in an earlier state reduces the amount of resources available in a later stage. The rate of substitution is not one-to-one as in the case of no carryovers, but an increase of the resources used in an earlier stage has an opportunity cost and reduces win probability in a later stage.

escalation. The key to this result is that there are two countervailing effects in this type of campaign. The symmetric decisive state has higher stakes than a symmetric non-terminal state further away from the decisive state. This would make resources more valuable at the state of the final showdown battle. But the arrival there is less likely, as the campaign may be resolved at an earlier stage. Any additional resource used in the showdown state needs to be relocated from a battle at earlier states. So the trade-off is to locate resources at a state at which resources have a high impact if the state is reached, compared to locating resources at a state that is more likely to be reached, but that is less decisive.

The results in this article are of a partial nature. It would be desirable to consider the robustness of the results along several dimensions. It would be interesting to address intermediate cases between full carryovers and zero carryovers of military resources used in a battle. The specific Tullock contest success function that has been used to map a given battle is also a limitation. An important alternative description of battle contests assumes that the player who mobilizes more resources in a given battle is certain to win the battle. This all-pay contest success function that was considered by Hillman and Riley (1989) is an interesting candidate.[15] The discontinuity in the allocation of battle success makes the formal analysis of a dynamic Blotto best-of-three contest for this contest success function more challenging.

Another consideration could address the number of battle victories that is needed to win the Blotto contest. It is difficult to obtain closed-form solutions for contests with full resource flexibility at each battle for a larger number of battles, or for asymmetric valuations of winning for the attacker and the defender, as shown in Klumpp and Polborn (2006). The work by Klumpp and Konrad (2017) provides further insights into the dynamic best-of-n Blotto contest. The asymmetry is of particular importance in the context of military campaigns, as the valuations of winning should typically differ between the attacker and the defender.

Another aspect in this context is a potential asymmetry in their ability to mobilize resources over the course of the campaign. It might be easier for the defender to mobilize further resources than it is for the attacker.

From a methodological point of view the paperarticle highlights the fact that the choice of budget and the choice of its sequential use in a series of battles are two separate decisions, and that separating these decisions qualitatively affects the outcome.

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Appendix

Proof of Proposition 2. Consider the payoff of Player A if Players A and B follow the equilibrium allocation of their military budgets as described by Proposition 2. Suppressing the subscripts of $a_{(2,2)}$ and $b_{(2,2)}$ in the remainder of this Appendix, Player A's payoff can be written as:

$$\pi^A = \frac{a^2}{(a+b)^2}\left(1+2\frac{b}{a+b}\right)W - a.$$

Analogously,

$$\pi^B = -L + \frac{b^2}{(a+b)^2}\left(1+2\frac{a}{a+b}\right)L - b.$$

This uses the subgame perfect equibrium budget allocation in stages reached after (2, 2) and describes the choices of *a* and *b* in a reduced form as a one-stage contest with a contest success function:

$$p^A(a,b) = \frac{a^2}{(a+b)^2}\left(1+2\frac{b}{a+b}\right)$$

and $p^B = 1 - p^A$. Let us search for the Nash equilibrium choices of budgets for given *W* and *L* for this problem. The first-order conditions for a local maximum of Player A's objective function is:

$$6ab^2W = a^4 + 4ba^3 + 6a^2b^2 + 4ab^3 + b^4. \tag{4}$$

Similarly, the first-order condition for Player B is:

$$6ba^2L = a^4 + 4a^3b + 6a^2b^2 + 4ab^3 + b^4. \tag{5}$$

Dividing (4) by (5) and solving for *b* yields:

$$b = (a\frac{L}{W}).$$

Inserting into (4) yields:

$$a^* = \frac{6L^2W^3}{W^4 + 4LW^3 + 6L^2W^2 + 4L^3W + L^4},$$

and similarly:

$$b^* = \frac{6L^3W^2}{W^4 + 4LW^3 + 6L^2W^2 + 4L^3W + L^4}.$$

These values are the candidates for budget choices in an interior equilibrium. Let us discuss now whether these values characterize globally optimal best replies to each other. The second-order condition for Player A's choice is:

$$\frac{\partial^2(p^A(a,b)W - a)}{\partial a \partial a} = 6Wb^2\frac{-3a+b}{(a+b)^5}.$$

Given that $b = \frac{L}{W}a$, for $L < 3W$, the solution a^* determines a local maximum. Similarly,

$$\frac{\partial^2(p^B(a,b)L - b)}{\partial b \partial b} = -6La^2\frac{-a+3b}{(a+b)^5},$$

such that b^* is a local maximum if $3b > a$, or $W < 3L$. Hence, (a^*, b^*) characterize locally optimal replies if $W \in \left(\frac{1}{3}L, 3L\right)$.

Note that the interval in which (a^*, b^*) constitute global mutually optimal replies may be smaller. However, assuming symmetry with $W = L$, we can solve the first-order conditions for $W = L$ and find:

$$a^* = b^* = \frac{3}{8}W.$$

Assume now $b^* = \frac{3}{8}W$. Then, given the assumptions about the continuation game, Player A maximizes:

$$\frac{a^2}{(a+\frac{3}{8}W)^2}\left(1 + 2\frac{\frac{3}{8}W}{a+\frac{3}{8}W}\right)W - a.$$

Replace a by αW. Then this problem can be restated as the problem of maximizing

$$\frac{\alpha^2}{(\alpha+\frac{3}{8})}^{2}\left(1 + 2\frac{\frac{3}{8}}{\alpha+\frac{3}{8}}\right) - \alpha \tag{6}$$

in α. Note first that $\alpha \in (0, 1)$ must hold for the optimal α: any negative α is not feasible, and any $\alpha > 1$ is an effort cost that exceeds the whole prize of winning. Note that (6) is convex for $\alpha \in (0, \frac{1}{8})$ and concave for $\alpha \in (\frac{1}{8}, 1)$. It has $v^A = 0$ at $\alpha = 0$ and $\frac{\partial v^A}{\partial a} < 0$ at $a = 0$. The smallest feasible extremum for $\alpha > 0$ is at:

$$a_{(2,2)} = \frac{1}{4}\sqrt[3]{17+3\sqrt{33}} - \frac{1}{2\sqrt[3]{17+3\sqrt{33}}} - \frac{5}{8} = .032767 < \frac{1}{8}.$$

and is therefore a local minimum. For a larger α the value of (6) increases to a local maximum, which is at:

$$\alpha = \frac{3}{8},$$

and then decreases for a higher α in the range $\alpha \in (\frac{3}{8}, 1)$. Hence, v^A is concave for $a \in (\frac{1}{8}W, W)$, and $a^* = \frac{3}{8}W$ is the global maximum on the interval of $a \in [0, W]$. This confirms that $a^* = \frac{3}{8}W$ is a globally optimal reply to $b^* = \frac{3}{8}W$ for $W = L$.

Inserting these equilibrium values for a and b at $W = L$ leads to values of $\pi^A = \frac{1}{8}W$ and $\pi^B = -W + \frac{1}{8}W = -\frac{7}{8}W$.

Note further that with the continuity of π^A and π^B in L and W we can conclude that (4) and (5) determine globally optimal replies for values L and W in a sufficiently close neighborhood of symmetry $W = L$.

Proof of Proposition 4. We first turn to the battle at state (1, 2) which emerges from a victory of Player A at (2, 2). As Player A was victorious, the resources $x_{(2,2)}$ used at (2, 2) carry over for Player A such that $a_{(1,2)} = a_{(2,2)}$, whereas the budget of Player B is given by $b_{(1,2)} = b_{(2,2)} - y_{(2,2)}$.

Suppose $b_{(1,2)} > 0$. At (1, 2), Player B can win only if Player B wins both the battles at (1, 2) and at (1, 1). If Player B loses at (1, 2) the game is over. If Player B wins at (1, 2), then all military resources $y_{(1,2)}$ chosen at (1, 2) carryover. This implies that it is a dominant strategy for Player B at battle (1, 2) to use all the remaining budget: $y_{(1,2)} = b_{(1,2)}$. Given this behavior of Player B, Player A anticipates $y_{(1,2)} = b_{(1,2)}$, and $y_{(1,1)} = b_{(1,2)}$ if Player B wins at (1, 2) such that (1, 1) is actually reached. Player A's expected payoff is:

$$v^A_{(1,2)} = \frac{x_{(1,2)}}{x_{(1,2)} + b_{(1,2)}} W + \frac{b_{(1,2)}}{x_{(1,2)} + b_{(1,2)}} \frac{a_{(2,2)} - x_{(1,2)}}{a_{(2,2)} - x_{(1,2)} + b_{(1,2)}} W.$$

Note that for $b_{(1,2)} > 0$ this payoff $v^A_{(1,2)}$ is a polynomial that is marginally increasing in $x_{(1,2)}$ at $x_{(1,2)} = 0$ and that takes its unique maximum at:

$$x_{(1,2)} = \frac{a_{(1,2)}}{2} = \frac{a_{(2,2)}}{2}. \tag{7}$$

This characterizes the equilibrium of the subgame if $\min\{a_{(1,2)}, b_{(1,2)}\} > 0$. If $b_{(1,2)} = 0$ but $a_{(1,2)} > 0$, then Player A wins the contest with any budget allocation with probability 1 and (7) describes one of many optimal choices.[16] All these subgames are payoff equivalent and lead to the same continuation value for Player A:

$$v^A_{(1,2)} = \frac{\frac{a_{(2,2)}}{2}}{\frac{a_{(2,2)}}{2} + b_{(1,2)}} \left(1 + \frac{b_{(1,2)}}{\frac{a_{(2,2)}}{2} + b_{(1,2)}}\right) W.$$

Analogous considerations hold at (2, 1), replacing Player A by Player B and vice-versa.

16 If $b_{(1,2)} = 0$, then any allocation of the budget in the subgame starting at (1, 2) with a budget $a_{(2,2)} > 0$ will make Player A win at least one of the next battles with probability 1. This generates a multiplicity of equilibrium in this subgame, but in each of these the payoff of Player A is equal to $W = 1$, and Player B has a payoff of $-L$. But note that $y_{(2,2)} = b_{(2,2)}$ that leads to $b_{(1,2)} = 0$ is not optimal, such that a subgame with $b_{(1,2)} = 0$ is never reached.

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Are Drone Strikes Effective in Afghanistan and Pakistan? On the Dynamics of Violence between the United States and the Taliban

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Abstract

Strikes by unmanned aerial vehicles, or drones, have been the primary weapon used by the USA to combat the Taliban and Al-Qaeda in Afghanistan and Pakistan. This article examines the dynamics of violence involving drone strikes and the Taliban/Al-Qaeda in Afghanistan and Pakistan from 1 January 2007 to 30 September 2011. We find that drone strikes have a stronger impact on Taliban/Al-Qaeda violence in Pakistan than in Afghanistan and that these results are robust to examining different time periods and lag structures. We also examine the impact of successful and unsuccessful drone strikes (which did or did not succeed in targeted killing of a militant leader) on terrorist attacks by the Taliban. We find strong effects of unsuccessful drone strikes on Taliban violence in Pakistan, suggesting important vengeance and deterrent effects. (JEL codes: C32, D74).

Key words: time series models, conflict, drones

Attacks by unmanned aerial vehicles, or drones, have been one of the main policies used by the USA to carry out targeted killings of terrorists in Afghanistan and Pakistan. The perceived success of these attacks led to a substantial increase in the use of drones as a strategic tool of the US Central Intelligence Agency and its military around the globe.[1] In Afghanistan and Pakistan, the targets are typically Taliban and Al-Qaeda militant leaders in the Federally Administered Tribal Areas (FATA) of Northwest Pakistan. Although drone strikes have killed important Taliban leaders, their use is unpopular in Pakistan due to the 'collateral' civilian casualties often associated with them, as well as possible retaliation against civilians by the Taliban. For example, after a terrorist attack on a police academy in Lahore in March 2009 in which 18 people were killed, Baitullah Mehsud (then leader of

1 *Washington Post*, 28 December 2011, 'Under Obama, An Emerging Global Apparatus for Drone Killing', http://www.washingtonpost.com/national/national-security/under-obama-an-emerging-global-apparatus-for-drone-killing/2011/12/13/gIQANPdILP_story.html, last accessed 29 August 2017.

the Tehrik-e-Taliban Pakistan) stated that the attack was ‘in retaliation for the continued drone strikes by the United States in collaboration with Pakistan on our people’.[2]

While the primary strategic goal of the USA in using drone strikes in the FATA has been to incapacitate Al-Qaeda and eliminate its capacity to attack the USA, its secondary goals are surely also to reduce terrorist attacks by the Taliban and Al-Qaeda against US and NATO forces in Afghanistan and to assure security of Pakistan’s nuclear weapons. The long-run chances of success for the USA and its allies in the region are likely to be diminished by continued reprisal terrorist attacks by the Taliban and Al-Qaeda against Afghanis and Pakistanis. This article examines the extent to which drone strikes affect subsequent violence by the Taliban and Al-Qaeda – in particular, whether the number and incidence of terrorist attacks increase (through in retaliation and reprisal) or decrease (due to incapacitation and deterrence). Following Jaeger and Paserman’s (2006, 2008, 2009) work on the Second Intifada in Israel, we exploit daily variation in drone strikes and terrorist attacks by the Taliban and Al-Qaeda in Afghanistan and Pakistan from 1 January 2007 to 30 September 2011 to estimate vector autoregressions of the dynamic patterns of violence. We also empirically test whether there is coordination in Taliban violence across the border in Afghanistan and Pakistan.[3]

We examine the efficacy of US counterterrorism ‘stick’ (drone strikes) to combat the Taliban and Al-Qaeda, and examine whether the use of drone strikes affects terrorist actions in Afghanistan, where the USA is directly engaged with the Taliban, and in Pakistan, where, except for the FATA, the USA is not directly engaged with the Taliban. We find that there are stronger effects of drone strikes on subsequent Taliban and Al-Qaeda attacks in Pakistan than there are in Afghanistan. In Pakistan, the probability of a terrorist attack increases in the first week after a drone strike. The impact is negative in the second week following a drone strike, when we examine the number of terrorist attacks by the Taliban and Al-Qaeda. This suggests an intertemporal reallocation of terrorist attacks in Pakistan, which are pushed forward by the Taliban in response to drone strikes. Our results are qualitatively robust to examining different time periods and lag structures.

We contribute to the literatures on counterterrorism measures and asymmetric conflict by using a vector autoregressive approach. Such an approach has been used previously to examine policies to combat transnational terrorism (Enders and Sandler 1993). More closely related to our article are those that look at the violence within one country, such as Hanson and Schmidt (2011), who examine how offensive operations by the coalition of forces operating in Iraq disrupted insurgent activity, but find that such actions may only have led to a subsequent increase in coalition fatalities, and the several papers by Jaeger and Paserman (2006, 2008, 2009), who examined the dynamics of violence between the Israeli military and Palestinian groups, and specifically the effectiveness of targeted killings of Palestinian leaders. Like our papers, these latter papers examine the ‘stick’ (Frey 2004) of specific violent policies within a conflict between insurgent groups and an organized military. Unlike the Iraq and Palestinian–Israeli conflicts, however, we are examining terrorist

2 BBC, 31 March 2009, ‘Lahore “was Pakistan Taleban op,”’ http://news.bbc.co.uk/2/hi/south_asia/7973540.stm, last accessed 29 August 2017.

3 The Taliban are composed of Pashtun tribes located in the border areas of Afghanistan (south and southeast areas) and Pakistan (north and northwest areas). While there are different factions within the Taliban, a general perception is that there is coordination in Taliban violence across the two countries.

actions that are not directed against the military force in question, but rather against (potentially) civilians in third-party states (Afghanistan and Pakistan).

1. Background

The Taliban consists of ethnic Pashtun tribes found along the border areas of Afghanistan and Pakistan. While the Taliban in Afghanistan is a fairly monolithic group, in Pakistan there are several militant groups which are collectively referred to as Taliban. The most important of these is the Tehrik-e-Taliban Pakistan which acts as an umbrella movement for various commanders across the South Waziristan area of the FATA and has been particularly active in carrying out terrorist attacks within Pakistan. The Haqqani faction, which operates in the North Waziristan agency of FATA, is more actively involved in terrorist attacks in Afghanistan.

The recent past has been characterized by periods of conflict and of calm between the Taliban and the Pakistan military, which first entered the FATA in June 2002. Since the FATA have traditionally been semiautonomous, this was the first time since Pakistan's independence in 1947 that the Pakistan Government had directly interfered there. The first drone strike in the FATA by the USA was reported in June 2004. Between 2004 and 2005, the Pakistan military was directly engaged with the Taliban in the northern areas. In September 2006 Pakistan signed the Waziristan Accord, a peace deal with the Taliban, which ended in July 2007 when the Pakistan military laid siege to the Red Mosque (Lal Masjid) in the capital city of Islamabad in which Islamic militants were holed up. Following the Red Mosque siege there was a sharp escalation in terrorist attacks by the Taliban in Pakistan. The number of drone strikes by the USA targeting Taliban and militant leadership in Pakistan continued during this period and increased in frequency. From January to May 2008 and September to October 2008 the Pakistan military was again involved in direct military offensives against the Taliban. Another peace agreement followed between February and April 2009 known as the Malakand Accord. Subsequently, there were further military offensives by the Pakistan military against the Taliban in May 2009 and between October and December 2009. In August 2009 a drone strike by the USA succeeded in killing Baitullah Mehsud, then leader of the Tehrik-e-Taliban Pakistan, who was succeeded by Hakimullah Mehsud. In May 2011 Osama bin Laden was killed in a raid in the city of Abbottabad, Pakistan, which likely limited the subsequent operational capabilities of Al-Qaeda.

2. Data

We use the Worldwide Incidents Tracking System (WITS) database collected by the National Counterterrorism Center as our source of terrorist incidents with perpetrators identified as Taliban or Al-Qaeda in Afghanistan and Pakistan from 1 January 2007 to 30 September 2011.[4] As a robustness check we examine whether the incidents reported by the WITS database are consistent with other databases on terrorist incidents such as the Global Terrorism Database maintained by the National Consortium for the Study of Terrorism

4 The WITS was formerly located at https://wits.nctc.gov/. The WITS was maintained by the National Counterterrorism Center but was discontinued in April 2012. We last downloaded data on 17 January 2012.

and Responses to Terrorism at the University of Maryland and the RAND Database of Worldwide Terrorism Incidents.[5] Although we do not find a perfect correlation in the number of terrorist attacks carried out by the Taliban and Al-Qaeda in the different databases, we did find the WITS database to have the best coverage of such incidents. For instance, we found an almost perfect correlation between the suicide attacks attributed to the Taliban and Al-Qaeda in WITS with a proprietary administrative data source that documented such attacks, while the other databases entirely miss large numbers of such incidents.

Incidents in the WITS database consist of all 'incidents in which sub-national or clandestine groups or individuals deliberately or recklessly attacked civilians or noncombatants (including military personnel and assets outside war zones and war like settings)'. An important consideration concerns what constitutes a 'terrorist act'. Those attacks initiated and carried out by terrorists are included in the database, while spontaneous hate crimes and genocides are not. A potential problem is that it is sometimes difficult to separate crime from terrorist acts. In general, a crime committed in support of terrorism is included in the database, but not otherwise.

Data on incidence and fatalities arising from drone strikes come from the New America Foundation, which collects and provides data on incidence, day, location, fatalities (including those of militant leaders), intended target, and source of information.[6] The sources from which the data are compiled include media organizations such as the *New York Times*, *Washington Post*, and *Wall Street Journal*; news services and networks such as the Associated Press, Reuters, Agence France-Presse, CNN, and BBC; and English language media from Pakistan such as the *Daily Times*, *Dawn*, and the News and GEO TV.

The annual frequency of drone strikes by the USA and terrorist attacks by the Taliban and Al-Qaeda between 1 January 2005 and 30 September is shown in Table 1. Both drone strikes and overall terrorist attacks clearly increased in this period. The success rate of drone strikes declined substantially, however, as did the share of suicide attacks in terrorist actions.

In Figure 1 we show the monthly number of terrorist attacks by the Taliban and Al-Qaeda in Afghanistan and Pakistan as well as the monthly number of drone strikes. Vertical lines indicate important time periods of the conflict: the Red Mosque siege of July 2007 in Pakistan, the start of the Obama administration in office from February 2009, the Malakand accord from February to April 2009, the four different military campaigns by the Pakistan military, and Osama bin Laden's death in May 2011. The frequency of terrorist attacks by the Taliban and Al-Qaeda in Pakistan clearly increased after the Red Mosque siege in 2007. There were large numbers of attacks in 2008 and 2009 but fewer in 2010 and 2011, after the August 2009 killing of Baitullah Mehsud in a drone strike. In Afghanistan, the number of terrorist attacks by the Taliban and Al-Qaeda is about twice as high as in Pakistan, increasing until 2011, when there is a decline. There is also seasonal variation in terrorist attacks by the Taliban and Al-Qaeda in Afghanistan, with the highest number of attacks occurring during the summer months. Drone strikes are fewer in number than terrorist attacks, but they increased after the beginning of 2008. There was also an

5 The Global Terrorism Database is available at http://www.start.umd.edu/gtd/ and the RAND data are available at http://www.rand.org/nsrd/projects/terrorism-incidents.html, both last accessed on 29 August 2017.

6 See https://www.newamerica.org/in-depth/americas-counterterrorism-wars/pakistan/, last accessed 29 August 2017.

Table 1. Annual number of drone strikes by the US and terrorist attacks by the Taliban

Year	2005	2006	2007	2008	2009	2010	2011
Number of drone strikes of which were	2	2	4	34	53	118	60
Successful	2	0	0	11	9	14	3
Number of terrorist attacks in Afghanistan of which were	264	511	636	691	860	1196	590
Lethal	179	292	382	381	460	615	373
Suicide attacks	7	46	52	58	55	54	67
Number of terrorist attacks in Pakistan of which were	3	18	95	273	290	158	98
Lethal	3	14	50	128	149	84	69
Suicide attacks	0	0	8	20	26	26	23

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. Data for 2011 are through 30 September 2011 only. A successful drone strike is one in which a militant leader is reported killed. A lethal Taliban attack is one with at least one reported casualty.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

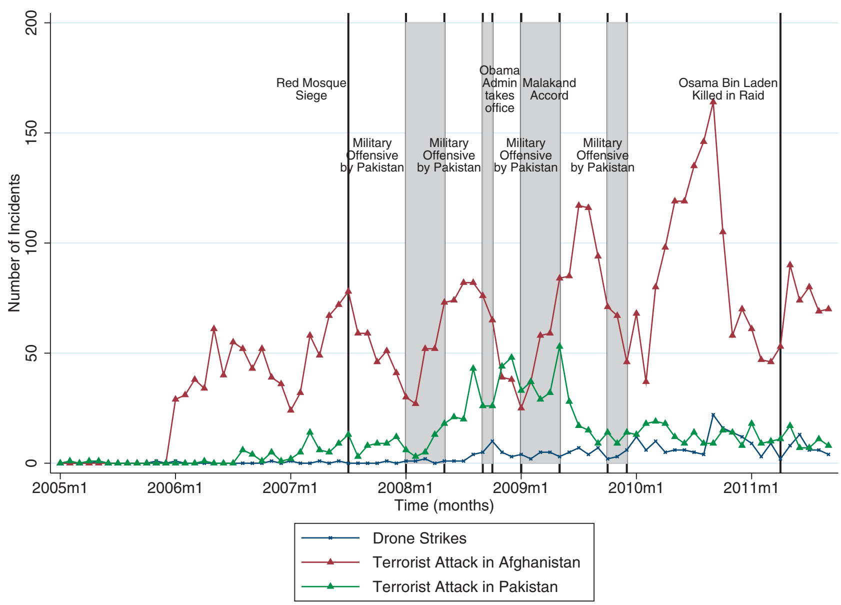


Figure 1. Monthly variation in drone strikes by the US and terrorist attacks by the Taliban, January 2005 to September 2011.

Source: Author calculations using terrorist attack data from the WITS of the National Counterterrorism Center.

increase in the number of drone strikes after the Obama administration took office in 2009, and again in 2010.

Terrorist attacks also vary spatially, and in Figure 2 we show the distribution of the aggregate number of terrorist attacks by the Taliban and Al-Qaeda in Afghanistan across its 35 states between 1 January 2007 and 30 September 2011. The geographical concentration of terrorist attacks is, not surprisingly, in areas dominated by the Taliban in the south and southeast of Afghanistan. Similarly, Figure 3 shows the spatial distribution of the aggregate

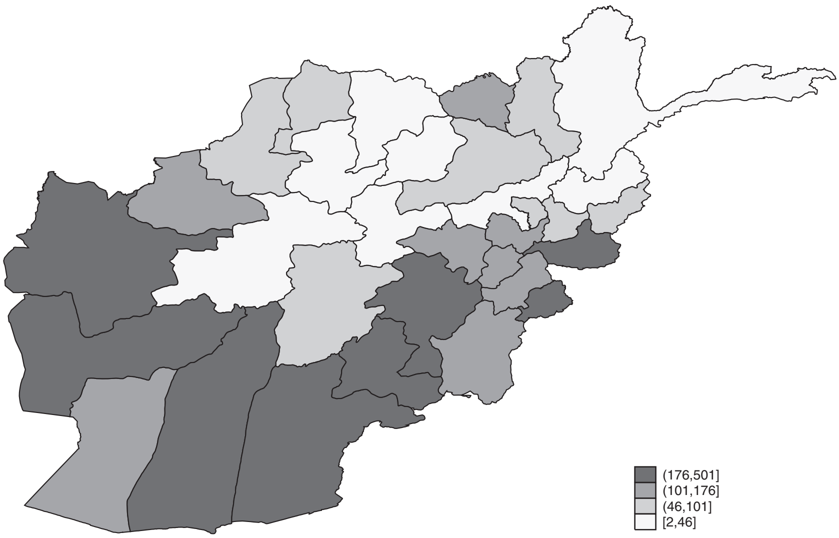


Figure 2. Spatial variation in terrorist attacks by the Taliban in Afghanistan, January 2005 to September 2011.

Source: Author calculations using terrorist attack data from the WITS of the National Counterterrorism Center.

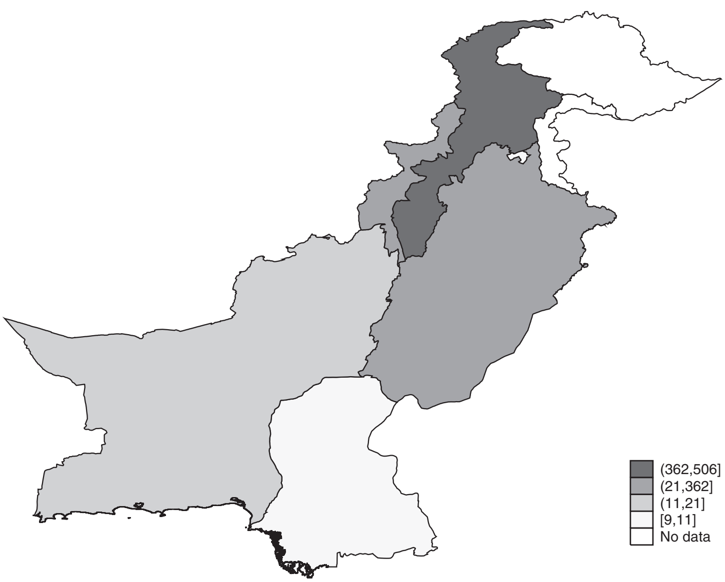


Figure 3. Spatial variation in terrorist attacks by the Taliban in Pakistan, January 2005 to September 2011.

Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

number of terrorist attacks in Pakistan across its four states in the same period. Most of the terrorist attacks are geographically concentrated in the north and northwest of the country, close to the FATA where the drone strikes take place.

Because Al-Qaeda has directly claimed responsibility for a very small number of terrorist attacks (nine incidents in Pakistan and none in Afghanistan), in the rest of the article we will refer to the 'Taliban' as the terrorist actor in the analysis.

3. Empirical Strategy

To examine the effects of drone strikes on Taliban violence in Afghanistan and Pakistan, we posit a simple vector autoregressive model similar to that of Jaeger and Paserman (2008). We are particularly interested in whether drone strikes reduce subsequent Taliban violence. For the Taliban in Afghanistan, we estimate reaction functions of the form:

$$T_t^A = f_i(D_{t-1}, \ldots, D_{t-p}, T_{t-1}^P, \ldots, T_{t-p}^P, T_{t-1}^A, \ldots, T_{t-p}^A, X_t), \tag{1}$$

and in Pakistan,

$$T_t^P = f_i(D_{t-1}, \ldots, D_{t-p}, T_{t-1}^A, \ldots, T_{t-p}^A, T_{t-1}^P, \ldots, T_{t-p}^P, X_t), \tag{2}$$

where T_t^A, T_t^P, and D_t represent period t terrorist attacks by the Taliban in Afghanistan, terrorist attacks by the Taliban in Pakistan, and drone strikes, respectively, p is the maximum number of lags that have a nonzero effect, and X_t is a vector of variables that may shift the reaction function up or down or change the parameters of the reaction function. We also estimate the reaction functions for the US Government in its exercise of drone strikes in the FATA:

$$D_t = f_i(T_{t-1}^A, \ldots, T_{t-p}^A, T_{t-1}^P, \ldots, T_{t-p}^P, D_{t-1}, \ldots, D_{t-p}, X_t). \tag{3}$$

3Drone strikes are likely based on intelligence gathered on high-value Taliban and terrorist targets. To the extent that this intelligence gathering (and the timing of drone strikes) is independent of the unobserved determinants of Taliban actions, our estimates of these parameters in the Taliban reaction functions can be viewed as the causal effects of drone strikes on Taliban actions (Granger 1969). We have also included an exhaustive set of controls to mitigate concerns of omitted variable bias, which we describe in the next section.

In both of the Taliban equations, we pay particular attention to the signs of the coefficients. We hypothesize that drone strikes can lead to subsequent reductions in terrorist activity if they incapacitate the Taliban or deter the Taliban from further violence. On the other hand, drone strikes may induce further violence through vengeance. If the coefficients on the $D_{t-1}, \ldots, D_{t-p}$ variables are negative, then the incapacitation and deterrence effects dominate (on net), while if they are positive, then the vengeance effect dominates (on net). We also estimate a specification (in Section 6) in which we separate successful drone strikes (ones which killed a militant leader) from those which were not successful (one which did not kill a militant leader). We expect the coefficients associated with successful drone strikes to capture the incapacitation, deterrence, and vengeance effects, while the coefficients associated with unsuccessful drone strikes potentially capture the deterrence and vengeance effects only, provided of course that unsuccessful drone strikes do not have any impact on the operational capabilities of the Taliban. Our empirical strategy also allows us to test whether there is any coordination in Taliban violence across the border in Afghanistan and Pakistan by exploiting geographic variation in drone strikes, and examine whether drone strikes in Pakistan affect terrorism in Afghanistan and in Pakistan.

4. Baseline Results

We estimate the reaction functions defined by equations (1) and (2) by estimating ordinary least squares (OLS) regressions where we correct for both heteroscedasticity and autocorrelation in the disturbance terms using Newey–West (1987) standard errors. We choose a lag length of 21 days in our baseline estimation.[7] We estimate two different specifications: in the first specification (which we refer to as the incidence specification), T_t^A, T_t^P, and D_t are dummy variables for whether there was any terrorist attack by the Taliban in Afghanistan, by the Taliban in Pakistan, or whether there was any drone strike on day t. In the second specification (which we refer to as the levels specification), T_t^A, T_t^P, and D_t are the number of terrorist attacks by the Taliban in Afghanistan, by the Taliban in Pakistan, and the number of drone strikes on day t. In each of the tables, Panel A shows the impact of drone strikes on the outcome variables, Panel B shows the effect of terrorist attacks by the Taliban in Afghanistan on the outcomes, and Panel C shows the effect of terrorist attacks by the Taliban in Afghanistan on the outcomes.

All regressions include day of week indicators and an indicator for the months in the Muslim calendar with traditionally reduced fighting (Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab). We also include a linear time trend in all regressions.[8] We also include a series of indicators to control for the different periods in the conflict that we outlined above: (i) after the Red Mosque siege of 4 July 2007, marking the end of the Waziristan Accord, a peace deal signed by Pakistan with the Taliban in September 2006, and which triggered widespread terrorist violence within Pakistan, (ii) after the Obama administration took office from 21 January 2009, as there was a clear policy shift toward greater use of drone strikes, (iii) during the time of the Malakand accord from 15 February to 13 April 2009, when it was an anticipated that the Pakistani army would cede control of the Swat district to the Taliban, (iv) after Osama bin Laden was killed in a raid in Abbottabad on 2 May 2011 because bin Laden's death influenced the institutional capabilities of Al-Qaeeda

7 We also estimated but do not report a negative binomial specification with robust standard errors. We find that our results are qualitatively quite similar. These results are available from the authors by request.

8 We have also produced results that do not control for trend or control for a quadratic trend. The results are qualitatively similar to the ones we present in the article and are available from the authors by request.

and potentially also the Taliban, and (v) dummy variables for each of four military campaigns undertaken by the Pakistan military against the insurgents.[9] These military campaigns likely shifted the Taliban's underlying agenda, particularly with regard to Pakistan, and potentially influenced the level of drone strikes. As such these are important omitted variables that we control for in our empirical analysis. We show the coefficients for these variables in Panel D in the tables.

We present estimation results of the reaction function of the Taliban in Afghanistan in Table 2. The first set of columns gives the estimation results for the incidence specification, while the second set of columns gives estimates for the levels specification. The results suggest that drone strikes by the USA do not have an impact on terrorist attacks by the Taliban in Afghanistan in the incidence specification, but have some impact in the levels specification in the form of reduced number of attacks 21 days after a drone strike by the USA. In the incidence specification, the 21 coefficients on lagged drone strikes are not jointly statistically significant in the incidence specification (at the 5% level), but are jointly significant at the 5% level in the levels specification. The sum of coefficients on 21 lags of terrorist attacks by the Taliban in Pakistan is not statistically significant for both the incidence and levels specifications. Impulse response functions based on the coefficients from Table 2 are shown in Figure 4.

Estimates of the reaction functions of the Taliban in Pakistan are shown in Table 3, which is structured in the same way as Table 2. We find stronger effects of drone strikes on subsequent Taliban violence in Pakistan than in Afghanistan, although the sign of these effects is somewhat mixed and suggests a potential reallocation of attacks moved forward by the Taliban in response to a drone strike. We find that a terrorist attack by the Taliban in Pakistan is 9.0% more likely to occur 5 days after a drone strike and 7.4% more likely to occur 6 days after a drone strike, and these effects are statistically significant at the 1 and 2.5% level of significance. There are also 0.113 fewer terrorist attacks 12 days after a drone strike. This effect is significant at the 1% level. When we test for joint significance of all lags of drone strikes on terrorist attacks by the Taliban in Pakistan, we find that these lags are jointly significant (at the 5% level) in explaining such attacks in both the incidence and levels specifications. We also find that Taliban violence in Pakistan is negatively associated with Taliban violence in Afghanistan; 0.020 fewer terrorist attacks occur 16 days after one terrorist attack in Afghanistan (not shown in the table). In a test of joint significance of all lags of terrorist attacks in Afghanistan, we find these lags to be jointly significant in the levels specification but not in the incidence specification. Impulse response functions based on the coefficients from Table 3 are shown in Figure 5.

We present estimates of impact of terrorist attacks in Afghanistan and Pakistan on drone strikes in Table 4. We do find a statistically significant and generally positive relationship between terrorism in Afghanistan and drone strikes. The relationship between terrorism and drone strikes in Pakistan is less strong. In the incidence specification, the 21 lags are not jointly statistically significant nor is the sum of coefficients. In the levels specification, the evidence is mixed, with two positive and two negative statistically significant coefficients. Identification of the reaction functions for the Taliban rests on the assumption that there are no unobserved factors that determine both drone strikes and terrorist attacks, conditional on the lagged values of each. The results from the drone strike reaction function suggest that controlling for a rich set of other covariates is important, which motivates our inclusion of

9 These military campaigns occur from 1 January to 31 May 2008, from 23 September to 31 October 2008, from 1 to 31 May 2009 and from 18 October to 12 December 2009.

Table 2. Daily Taliban reaction functions in Afghanistan

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
A. Drone strikes				
$t-1$	0.022	(0.026)	−0.081	(0.132)
$t-2$	−0.035	(0.027)	−0.001	(0.098)
$t-3$	0.001	(0.028)	0.263	(0.310)
$t-4$	0.033	(0.026)	0.379	(0.331)
$t-5$	0.067***	(0.021)	−0.262	(0.228)
$t-6$	−0.031	(0.026)	−0.107	(0.169)
$t-7$	−0.021	(0.029)	−0.112	(0.101)
$t-8$	0.011	(0.025)	−0.047	(0.144)
$t-9$	−0.019	(0.028)	0.089	(0.155)
$t-10$	−0.004	(0.023)	0.334	(0.555)
$t-11$	−0.008	(0.026)	−0.099	(0.156)
$t-12$	−0.003	(0.025)	0.019	(0.174)
$t-13$	<0.001	(0.025)	−0.160	(0.157)
$t-14$	0.046*	(0.023)	0.111	(0.125)
$t-15$	0.012	(0.024)	0.256	(0.360)
$t-16$	0.018	(0.026)	−0.167	(0.148)
$t-17$	0.030	(0.025)	−0.199	(0.175)
$t-18$	0.026	(0.022)	0.044	(0.150)
$t-19$	0.028	(0.024)	0.026	(0.149)
$t-20$	−0.029	(0.029)	0.007	(0.187)
$t-21$	−0.028	(0.023)	−0.313*	(0.142)
Joint significance of 21 lags		[0.064]		[0.032]
Sum of coefficients	0.115	[0.216]	−0.020	[0.985]
B. Terrorist attacks by Taliban in Afghanistan (21 lags)				
Joint significance of 21 lags		[<0.001]		[<0.001]
Sum of coefficients	0.453	[<0.001]	0.595	[<0.001]
C. Terrorist attacks by Taliban in Pakistan (21 lags)				
Joint significance of 21 lags		[0.117]		[0.020]
Sum of coefficients	0.144	[0.039]	0.188	[0.455]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege (03 July 2007 and after)	0.060	(0.040)	0.350	(0.242)
Obama Administration (20 January 2009 and after)	0.122**	(0.051)	0.754***	(0.286)
Malakand Accord (15 February–30 April 2009)	−0.068	(0.060)	−0.471	(0.281)
Post-Bin Laden death (02 May 2011 and after)	0.069	(0.036)	−0.037	(0.219)
Pakistan Offensive 1 (01 January–31 May 2008)	0.013	(0.043)	−0.007	(0.209)

(continued)

Table 2. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
Pakistan Offensive 2 (23 September–31 October 2008)	−0.062	(0.059)	0.128	(0.246)
Pakistan Offensive 3 (01 May–31 May 2009)	−0.020	(0.035)	−0.207	(0.385)
Pakistan Offensive 4 (18 October–17 December 2009)	<0.001	(0.040)	−0.372	(0.297)
Other controls:				
Indicator for months with reduced fighting	−0.040	(0.023)	−0.204	(0.171)
1000s of US troops deployed in Afghanistan	0.003*	(0.002)	0.016	(0.009)
Time trend (days/365)	−0.128**	(0.052)	−0.543*	(0.262)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. *p*-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

different time periods, as well as the number of US troops in all regression. In the rest of the article, we focus on the Taliban reaction functions in Afghanistan and Pakistan.

We next carry out a number of robustness checks to determine whether these baseline results persist when we when we vary the lag structure, the level of aggregation, and focus on lethal Taliban attacks.[10]

5. Robustness Checks

5.1 Lag structures

Although we chose the lag length for the results in Tables 2 and 3 based on likelihood ratio statistics, it is well known that Granger causality results are sensitive to the number of lags included in the analysis. To check the robustness of our results, in Table 5, we present *p*-values for tests of joint significance of drone strikes and the sum of the coefficients on drone strikes

10 In results available from the authors by request, we have also estimated the baseline specifications only for the 2008–2010 period, when drone strikes began to be used in significant numbers, as well as the period after the Red Mosque Siege in July 2007, which was a triggering event for elevated terrorist activity. The results are qualitatively similar to those presented in Tables 2 and 3.

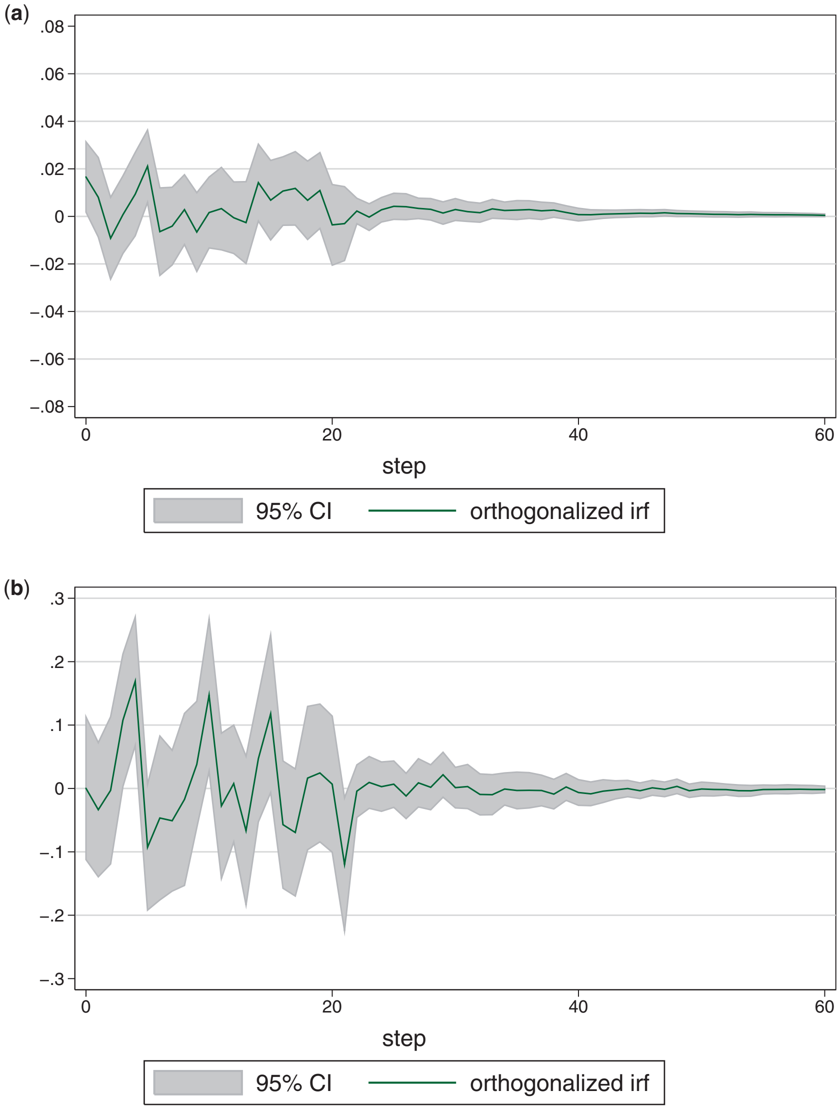


Figure 4. Impulse response functions for terrorist attacks by the Taliban in Afghanistan.

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Impulse response functions are generated by estimating a VAR (vector autoregressive) model of daily drone strikes, terrorist attacks in Afghanistan, and terrorist attacks in Pakistan with up to 21 lags and the set of exogenous variables specified in Section D from Tables 2 and 3 as well as day of week indicators. Confidence bands around the impulse response functions are constructed using the bootstrap.

Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

Table 3. Daily Taliban reaction functions in Pakistan

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
A. Drone strikes				
$t-1$	0.053	(0.043)	0.023	(0.047)
$t-2$	−0.049	(0.035)	−0.069	(0.043)
$t-3$	−0.041	(0.035)	−0.048	(0.037)
$t-4$	0.024	(0.036)	0.031	(0.042)
$t-5$	0.090***	(0.033)	0.048	(0.037)
$t-6$	0.074*	(0.033)	0.083	(0.048)
$t-7$	0.013	(0.035)	0.002	(0.040)
$t-8$	−0.011	(0.037)	0.043	(0.047)
$t-9$	0.017	(0.033)	0.031	(0.039)
$t-10$	0.071	(0.037)	0.024	(0.050)
$t-11$	0.007	(0.040)	0.000	(0.041)
$t-12$	−0.046	(0.034)	−0.113***	(0.037)
$t-13$	−0.060	(0.036)	0.016	(0.044)
$t-14$	−0.017	(0.032)	−0.011	(0.040)
$t-15$	−0.008	(0.034)	−0.020	(0.041)
$t-16$	0.041	(0.040)	0.046	(0.046)
$t-17$	0.044	(0.038)	0.043	(0.051)
$t-18$	0.021	(0.036)	−0.003	(0.039)
$t-19$	0.031	(0.035)	0.001	(0.045)
$t-20$	−0.046	(0.042)	−0.053	(0.041)
$t-21$	0.011	(0.032)	0.032	(0.051)
Joint significance of 21 lags		[0.011]		[0.047]
Sum of coefficients	0.221	[0.062]	0.109	[0.445]
B. Terrorist attacks by the Taliban in Afghanistan (21 lags)				
Joint significance of 21 lags		[0.217]		[0.002]
Sum of coefficients	−0.072	[0.341]	0.040	[0.096]
C. Terrorist attacks by the Taliban in Pakistan (21 lags)				
Joint significance of 21 lags		[0.007]		[<0.001]
Sum of coefficients	0.120	[0.187]	0.217	[0.065]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege (03 July 2007 and after)	−0.052	(0.066)	−0.167	(0.104)
Obama Administration (20 January 2009 and after)	−0.118	(0.061)	−0.388***	(0.148)
Malakand Accord (15 February–30 April 2009)	0.056	(0.056)	0.138	(0.132)
Post-Bin Laden death (02 May 2011 and after)	−0.093	(0.062)	−0.234**	(0.099)
Pakistan Offensive 1 (01 January–31 May 2008)	−0.185***	(0.053)	−0.284***	(0.088)

(continued)

Table 3. Continued

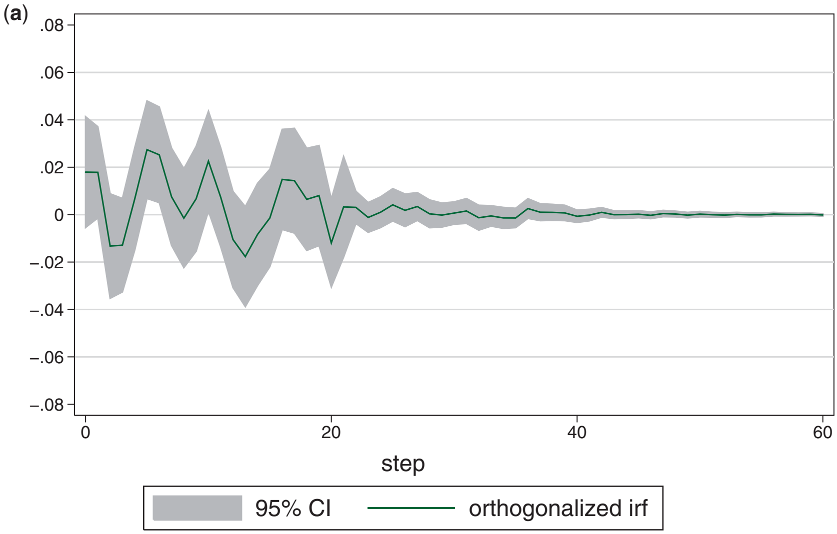
	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
Pakistan Offensive 2 (23 September–31 October 2008)	−0.035	(0.089)	−0.183	(0.145)
Pakistan Offensive 3 (01 May–31 May 2009)	0.208***	(0.060)	0.669	(0.447)
Pakistan Offensive 4 (18 October–17 December 2009)	−0.121***	(0.044)	−0.179*	(0.083)
Other controls:				
Indicator for months with reduced fighting	0.011	(0.027)	0.043	(0.048)
1000s of US troops deployed in Afghanistan	−0.011***	(0.002)	−0.024***	(0.005)
Time trend (days/365)	0.299***	(0.069)	0.681***	(0.145)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include up to 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. p-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

for the Taliban reaction functions in Afghanistan and Pakistan, using lags from 1 to 10 weeks (7–70 days, respectively). For lag lengths of 35 days or less, the results are generally qualitatively similar to those in Tables 2 and 3. Increasing the number of lags does lead to the more frequent rejection of the null of no effect for the number of attacks in Afghanistan as well as in Pakistan. The results in the incidence specification are generally qualitatively similar to those in Table 2 and 3 regardless of the number of lags. Qualitatively our conclusion that drone strikes have a stronger impact on terrorism in Pakistan than in Afghanistan continues to hold.

5.2 Time aggregation

In our baseline specification, we examined short-run (3 weeks) dynamics of violence and found that there is less effect of drone strikes on Taliban actions in Afghanistan and a larger and significant, but somewhat mixed, effect on Taliban actions in Pakistan. Unlike the Palestinians in Israel, we expect that the Taliban has somewhat greater ability to act, particularly in Afghanistan. It is possible, however, that using high-frequency data masks some longer-term reaction (or deterrence) of Taliban actions. To explore this issue, in Table 6 we estimate models similar to those in Tables 2 and 3, but using weekly and monthly aggregation of the data. We find no significant effects of drone strikes on Taliban violence in Pakistan when we aggregate to weeks, although the significant effect returns at a monthly frequency. This is perhaps consistent with a temporal reallocation of attacks by the Taliban



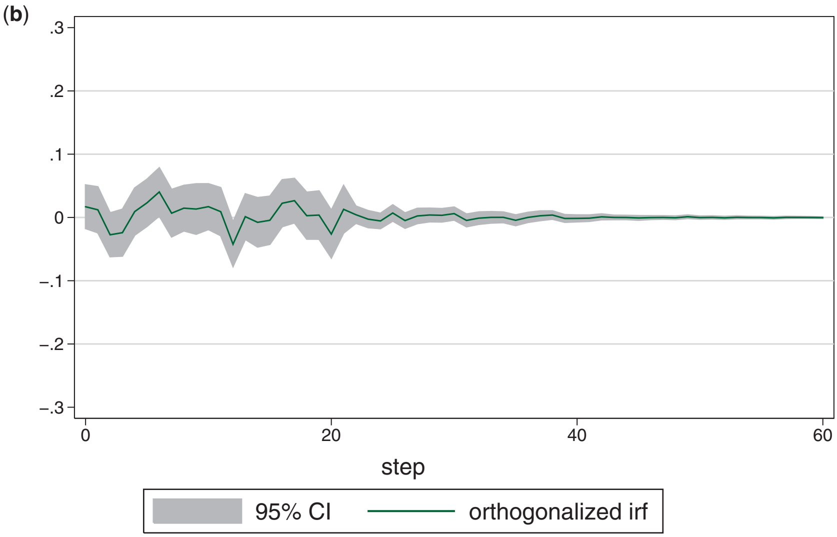


Figure 5. Impulse response functions for terrorist attacks by the Taliban in Pakistan.

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include up to 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variancecovariance matrices calculated using the Newey–West (1987) method. p-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.

Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

Table 4. Daily drone strike reaction functions

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
A. Drone strikes				
Joint significance of 21 lags		[0.124]		[0.006]
Sum of coefficients	0.319	[0.041]	0.255	[0.042]
B. Terrorist attacks by the Taliban in Afghanistan (21 lags)				
$t-1$	0.017	(0.325)	0.002	(0.004)
$t-2$	−0.039*	(0.049)	0.004	(0.003)
$t-3$	−0.010	(0.659)	−0.003	(0.004)
$t-4$	0.030	(0.133)	0.012	(0.006)
$t-5$	−0.018	(0.368)	−0.006	(0.004)
$t-6$	0.004	(0.878)	−0.005	(0.003)
$t-7$	0.005	(0.823)	0.008*	(0.003)
$t-8$	−0.036	(0.112)	0.005	(0.007)
$t-9$	−0.007	(0.750)	0.004	(0.004)
$t-10$	−0.007	(0.700)	0.005	(0.005)
$t-11$	−0.018	(0.325)	−0.007	(0.004)
$t-12$	−0.004	(0.810)	−0.004	(0.003)
$t-13$	−0.027	(0.218)	−0.004	(0.004)
$t-14$	0.042*	(0.035)	0.010	(0.007)
$t-15$	0.015	(0.418)	−0.006	(0.004)
$t-16$	−0.006	(0.745)	<0.001	(0.004)
$t-17$	−0.001	(0.963)	−0.001	(0.004)
$t-18$	0.062***	(0.000)	0.014***	(0.005)
$t-19$	0.023	(0.298)	0.001	(0.005)
$t-20$	−0.009	(0.635)	0.012*	(0.005)
$t-21$	0.026	(0.218)	−0.003	(0.004)
Joint significance of 21 lags		[0.030]		[<0.001]
Sum of coefficients	0.041	[0.048]	0.037	[0.085]
C. Terrorist attacks by the Taliban in Pakistan (21 lags)				
$t-1$	0.015	(0.431)	0.001	(0.014)
$t-2$	−0.006	(0.752)	0.007	(0.013)
$t-3$	−0.013	(0.431)	−0.019	(0.010)
$t-4$	−0.036	(0.050)	−0.041***	(0.011)
$t-5$	−0.006	(0.663)	0.020	(0.014)
$t-6$	−0.002	(0.904)	−0.008	(0.013)
$t-7$	0.016	(0.297)	0.027*	(0.013)
$t-8$	0.013	(0.465)	−0.003	(0.012)
$t-9$	0.035**	(0.016)	0.025**	(0.011)
$t-10$	0.001	(0.967)	0.020	(0.014)
$t-11$	0.018	(0.275)	0.006	(0.015)
$t-12$	0.005	(0.761)	0.022	(0.014)
$t-13$	−0.006	(0.717)	−0.018	(0.014)
$t-14$	0.006	(0.760)	0.002	(0.013)
$t-15$	0.016	(0.394)	0.020	(0.013)

(continued)

Table 4. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
$t-16$	−0.003	(0.886)	−0.010	(0.015)
$t-17$	−0.006	(0.722)	< 0.001	(0.012)
$t-18$	−0.026	(0.173)	−0.033***	(0.012)
$t-19$	−0.003	(0.851)	−0.002	(0.011)
$t-20$	<0.001	(<0.001)	0.002	(0.014)
$t-21$	−0.001	(0.920)	−0.003	(0.011)
Joint significance of 21 lags		[0.294]		[0.004]
Sum of coefficients	0.016	[0.813]	0.014	[0.728]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege (03 July 07 and after)	−0.024	(0.284)	−0.064*	(0.031)
Obama Administration (20 January 2009 and after)	0.034	(0.423)	0.033	(0.061)
Malakand Accord (15 February–30 April 2009)	−0.007	(0.844)	0.014	(0.052)
Post-Bin Laden death (02 May 2011 and after)	−0.052	(0.242)	−0.048	(0.061)
Pakistan Offensive 1 (01 January–31 May 2008)	0.002	(0.929)	0.028	(0.028)
Pakistan Offensive 2 (23 September–31 October 08)	0.085	(0.061)	0.134*	(0.061)
Pakistan Offensive 3 (01 May–31 May 2009)	−0.062	(0.205)	−0.088	(0.058)
Pakistan Offensive 4 (18 October–17 December 2009)	−0.075**	(0.014)	−0.130***	(0.042)
Other controls:				
Indicator for months with reduced fighting	<0.001***	(<0.001)	<0.001***	(<0.001)
1000s of US troops deployed in Afghanistan	≤0.001	(0.001)	−0.001	(0.002)
Time trend (days/365)	0.042	(0.035)	0.067	(0.048)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include up to 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. p-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

Table 5. Robustness tests: lag structures

Lags	Incidence of attacks		Number of attacks	
	Joint	Sum	Joint	Sum
Daily Taliban reaction functions in Afghanistan				
(7, 7, 7)	0.052	0.606	0.528	0.591
(14, 14, 14)	0.209	0.326	0.603	0.654
(21, 21, 21)	0.064	0.216	0.032	0.985
(28, 28, 28)	0.035	0.581	0.001	0.598
(35, 35, 35)	0.052	0.895	<0.001	0.118
(42, 42, 42)	0.040	0.807	<0.001	0.031
(49, 49, 49)	0.049	0.766	<0.001	0.006
(56, 56, 56)	0.008	0.549	<0.001	0.010
(63, 63, 63)	0.008	0.738	<0.001	0.004
(70, 70, 70)	<0.001	0.926	<0.001	0.005
Daily Taliban reaction functions in Pakistan				
(7, 7, 7)	0.003	0.099	0.112	0.459
(14, 14, 14)	0.010	0.215	0.124	0.576
(21, 21, 21)	0.011	0.062	0.047	0.445
(28, 28, 28)	0.000	0.026	0.006	0.105
(35, 35, 35)	<0.001	0.010	0.026	0.030
(42, 42, 42)	<0.001	0.011	<0.001	0.006
(49, 49, 49)	<0.001	0.013	<0.001	0.010
(56, 56, 56)	<0.001	0.027	<0.001	0.042
(63, 63, 63)	<0.001	0.005	<0.001	0.013
(70, 70, 70)	<0.001	0.007	<0.001	0.003

Notes: Entries in the table are p-values. 'Joint' indicates the p-value for a χ^2 test for the joint significance of the relevant lags. 'Sum' indicates the p-value for a χ^2 test that the sum of the coefficients is equal to 0. Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Tests of significance are carried out on OLS regressions of daily terrorist attacks in Afghanistan and Pakistan on lags of drone strikes, terrorist attacks in Afghanistan, and terrorist attacks in Pakistan. Regressions are estimated with the given lag length. Each regression includes the controls specified in (D) in Tables 2 and 3 as well as day of week indicators. Tests based on heteroscedasticity/autocorrelation corrected Newey–West (1987) variance–covariacne matrices.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

in response to a drone strike. We find also find an effect only at a monthly frequency in Afghanistan. In this regression, the coefficient on drone strikes is negative and highly significant—indicating that drone strikes may have a deterrence or incapacitation effect on longer-run violence in Afghanistan.

5.3 Outcome measure

We have thus far measured intensity of Taliban actions only by using the incidence or number of terrorist attacks. To explore this issue further, we now look at two somewhat different outcomes by examining either those Taliban actions that resulted in at least one fatality

Table 6. Robustness tests: time aggregation

Time aggregation	Number of attacks	
	Joint	Sum
Taliban reaction functions in Afghanistan		
Daily, 21 lags	0.032	0.985
Weekly, 3 lags	0.204	0.803
Monthly, 1 lag	<0.001	<0.001
Taliban reaction functions in Pakistan		
Daily, 21 lags	0.047	0.445
Weekly, 3 lags	0.360	0.281
Monthly, 1 lag	0.010	0.010

Notes: Entries in table are *p*-values. 'Joint' indicates the *p*-value for a χ^2 test for the joint significance of the relevant lags. 'Sum' indicates the *p*-value for a χ^2 test that the sum of the coefficients is equal to 0. Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Tests of significance are carried out on OLS regressions of terrorist attacks in Afghanistan and Pakistan on lags of drone strikes, terrorist attacks in Afghanistan, and terrorist attacks in Pakistan. Regressions are estimated with the given time aggregation (daily, weekly and monthly) and lag length. Each regression includes the controls specified in (D) in Tables 2 and 3 as well as a linear time trend in weeks/months. Tests based on heteroscedasticity/autocorrelation corrected Newey–West (1987) variance–covariacne matrices.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

Table 7. Robustness tests: the effect of drone strikes on lethal and suicide attacks

Type of Taliban attack	Incidence of attacks		Number of attacks	
	Joint	Sum	Joint	Sum
Daily Taliban reaction functions in Afghanistan				
All	0.064	0.216	0.032	0.985
Lethal attacks	0.195	0.704	0.332	0.514
Suicide attacks	0.252	0.354	0.581	0.526
Daily Taliban reaction functions in Pakistan				
All	0.011	0.062	0.047	0.445
Lethal attacks	0.038	0.372	0.032	0.611
Suicide attacks	0.029	0.551	0.162	0.867

Notes: Entries in the table are *p*-values. 'Joint' indicates the *p*-value for a χ^2 test for the joint significance of the relevant lags. 'Sum' indicates the *p*-value for a χ^2 test that the sum of the coefficients is equal to 0. Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Tests of significance are carried out on OLS regressions of daily terrorist attacks in Afghanistan and Pakistan on 21 lags of drone strikes, terrorist attacks in Afghanistan, and terrorist attacks in Pakistan. Regressions are estimated with terrorist attacks restricted to all, lethal, or suicide terrorist attacks. Each regression includes the controls specified in (D) in Tables 2 and 3 as well as a linear time trend and day of week indicators. Tests based on heteroscedasticity/autocorrelation corrected Newey–West (1987) variance–covariance matrices.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

or only those in which a suicide attack occurred. We use data on incident description and fatalities in WITS to construct the incidence and number of lethal and suicide terrorist attacks by the Taliban in Afghanistan and in Pakistan. We return to the model with 21 lags from Tables 2 and 3.

Tests of joint significance are reported in Table 7. The effect of drone strikes on both lethal and suicide attacks in Afghanistan is similar to the baseline specification, little or no effect on either incidence or levels. The results in Pakistan are somewhat more mixed, where we find that drone strikes have a jointly significant (at the 5% level) effect on lethal attacks, and on incidence of suicide attacks but no significant effect on level of suicide attacks. This is consistent with the evidence from the Palestinian–Israeli conflict, where Jaeger and Paserman (2009) found that Israeli counterterrorism measures had little predictive power for suicide attacks, perhaps because suicide attacks take longer to organize than other types of violence and require elements of surprise to be effective.

6. Extensions

6.1 Haqqani and Mehsud factions of the Taliban

We have treated the Taliban as a monolithic group, with the only distinction being in terrorist attacks carried out across the border in either Afghanistan or Pakistan. Two distinct factions within the Taliban have been targeted by drone strikes in recent years, however, and these factions have a base of operations in different parts of the FATA. The Haqqani faction of the Taliban is based in North Waziristan, while the Tehrik-e-Taliban Pakistan (thereafter referred to as the Mehsud faction of the Taliban) is based in South Waziristan areas of FATA. Drone strikes carried out in North Waziristan target the Haqqani faction, while drone strikes in South Waziristan target the Mehsud faction. The Haqqani faction of the Taliban carries out terrorist attacks in parts of Afghanistan, while the Mehsud faction carries out terrorist attacks in the FATA areas of Pakistan. The two groups may have different strategic aims given their sphere of influence, and we estimate reaction functions for each faction by using geographical information on terrorist attacks and drone strikes. We estimate the reaction function for the Haqqani faction of the Taliban by using data on terrorist attacks by the Taliban in parts of Afghanistan which are believed to be the Haqqani areas of combat operations; these include the eastern states of Khost, Paktia, Paktika, Ghazni, Logar, Wardak, and Kabul in Afghanistan. We estimate reaction functions for the Mehsud faction of the Taliban by using data on terrorist attacks by the Taliban in the FATA areas of Pakistan which are believed to be the Mehsud areas of combat operations.

For the Haqqani faction of the Taliban, the reaction functions we estimate are of the form:

$$T_t^{Haqqani} = f_i(D_{t-1}^{Haqqani}, \ldots, D_{t-p}^{Haqqani}, T_{t-1}^{Haqqani}, \ldots, T_{t-p}^{Haqqani}, X_t), \tag{4}$$

where $T_t^{Haqqani}$ represents terrorist attacks by the Taliban in the eastern states of Khost, Paktia, Paktika, Ghazni, Logar, Wardak, and Kabul in Afghanistan at time t, and $D_t^{Haqqani}$ represents drone strikes in North Waziristan at time t. As above, p is the maximum number

Table 8. Daily Haqqani reaction functions

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
A. Drone strikes in Haqqani base of operations				
$t-1$	0.003	(0.036)	−0.032	(0.051)
$t-2$	−0.022	(0.038)	−0.093	(0.053)
$t-3$	0.013	(0.039)	0.071	(0.089)
$t-4$	0.021	(0.050)	0.087	(0.102)
$t-5$	−0.015	(0.038)	−0.078	(0.082)
$t-6$	−0.021	(0.043)	0.040	(0.069)
$t-7$	0.031	(0.044)	−0.015	(0.051)
$t-8$	0.083	(0.045)	0.061	(0.068)
$t-9$	0.023	(0.036)	0.115	(0.077)
$t-10$	0.026	(0.040)	0.158	(0.163)
$t-11$	−0.039	(0.047)	−0.078	(0.084)
$t-12$	0.033	(0.046)	−0.006	(0.074)
$t-13$	0.017	(0.041)	−0.043	(0.048)
$t-14$	0.033	(0.041)	0.040	(0.057)
$t-15$	−0.070	(0.048)	0.085	(0.129)
$t-16$	−0.030	(0.043)	−0.061	(0.065)
$t-17$	−0.083*	(0.040)	−0.111	(0.062)
$t-18$	−0.021	(0.043)	−0.061	(0.057)
$t-19$	−0.050	(0.042)	−0.046	(0.061)
$t-20$	0.006	(0.041)	−0.025	(0.061)
$t-21$	−0.005	(0.036)	−0.041	(0.065)
Joint significance of 21 lags		[0.242]		[0.867]
Sum of coefficients	−0.066	[0.648]	−0.034	[0.880]
B. Terrorist attacks by Taliban in Haqqani areas of combat operations (21 lags)				
Joint significance of 21 lags		[<0.001]		[0.867]
Sum of coefficients	0.065	[<0.001]	0.622	[0.879]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege (03 July 2007 and after)	0.058	(0.061)	0.154	(0.134)
Obama Administration (20 January 2009 and after)	0.047	(0.053)	0.134	(0.106)
Malakand Accord (15 February–30 April 2009)	−0.057	(0.074)	−0.123	(0.158)
Post-Bin Laden death (02 May 2011 and after)	−0.009	(0.051)	−0.011	(0.085)
Pakistan Offensive 1 (01 January–31 May 2008)	−0.056	(0.051)	−0.074	(0.108)
Pakistan Offensive 2 (23 September–31 October 2008)	−0.033	(0.052)	−0.016	(0.108)
Pakistan Offensive 3 (01 May–31 May 2009)	−0.018	(0.057)	0.037	(0.152)

(continued)

Table 8. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
Pakistan Offensive 4 (18 October–17 December 2009)	−0.080	(0.045)	−0.134*	(0.079)
Other controls:				
Indicator for months with reduced fighting	−0.066***	(0.024)	−0.140***	(0.050)
1000s of US troops deployed in Afghanistan	0.001	(0.002)	0.002	(0.003)
Time trend (days/365)	−0.054	(0.050)	−0.142	(0.098)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. Haqqani base of operations are all areas in North Waziristan, Pakistan. Haqqani areas of combat operations are all areas in the states of Khost, Paktia, Paktika, Ghazni, Logar, Wardak, and Kabul (in Afghanistan). The sample is also restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include up to 21 lags of terrorist attacks in the Haqqani areas of combat operations (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. *p*-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

of lags that have a nonzero effect, and X_t is a vector of variables that may shift the reaction function up or down or change the parameters of the reaction function.

Our empirical strategy is the same as before, with estimation of empirical reaction functions by OLS with 21 lags and Newey–West standard errors. The estimation results are reported in Table 8, with the first set of columns giving the estimation results from the incidence specification and the second set of columns giving the estimation results from the levels specification. A terrorist attack in the Haqqani areas in eastern Afghanistan is 8.3% less likely to occur 17 days after a drone strike in North Waziristan, indicating the incapacitation/deterrence effect dominates the vengeance effect, although this result is statistically significant at the 5% level. Overall, there does not appear to be a strong effect of drone strikes in North Waziristan on attacks by the Haqqani faction in Afghanistan (neither the sum of the coefficients on lags of drone strikes nor these coefficients jointly are statistically different from 0). In results that are not reported, the incidence and number of terrorist attacks by the Haqqani faction are reduced during the Muslim months in which fighting is traditionally forbidden.

For the Mehsud faction of the Taliban, the reaction functions we estimate are of the form:

$$T_t^{Mehsud} = f_i(D_{t-1}^{Mehsud}, \ldots, D_{t-p}^{Mehsud}, T_{t-1}^{Mehsud}, \ldots, T_{t-p}^{Mehsud}, X_t), \qquad (5)$$

where T_t^{Mehsud} represents terrorist attacks by the Taliban in the FATA areas of Pakistan at time t, and D_t^{Mehsud} represents drone strikes in South Waziristan at time t. As before, p is

Table 9. Daily Mehsud reaction functions

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
A. Drone strikes in Mehsud base of operations				
t−1	−0.005	(0.057)	−0.023	(0.057)
t−2	−0.030	(0.051)	−0.036	(0.041)
t−3	0.055	(0.047)	0.050	(0.048)
t−4	0.012	(0.059)	0.010	(0.055)
t−5	0.051	(0.050)	0.113	(0.066)
t−6	0.059	(0.052)	0.103	(0.066)
t−7	−0.034	(0.055)	−0.035	(0.052)
t−8	−0.063	(0.053)	−0.035	(0.057)
t−9	0.065	(0.056)	0.032	(0.055)
t−10	0.099	(0.060)	0.068	(0.055)
t−11	0.127**	(0.054)	0.129	(0.082)
t−12	−0.066	(0.046)	−0.072	(0.040)
t−13	0.079	(0.060)	0.039	(0.044)
t−14	−0.116***	(0.043)	−0.119***	(0.033)
t−15	−0.025	(0.051)	−0.075*	(0.035)
t−16	−0.028	(0.053)	−0.028	(0.049)
t−17	−0.002	(0.056)	−0.016	(0.046)
t−18	−0.052	(0.047)	−0.053	(0.041)
t−19	−0.037	(0.058)	−0.027	(0.053)
t−20	−0.013	(0.061)	−0.015	(0.051)
t−21	0.019	(0.055)	−0.008	(0.050)
Joint significance of 21 lags		[0.004]		[<0.001]
Sum of coefficients	0.094	[0.686]	0.002	[0.992]
B. Terrorist attacks by Taliban in Mehsud areas of combat operations (21 lags)				
Joint significance of 21 lags		[0.003]		[<0.001]
Sum of coefficients	0.218	[0.010]	0.281	[0.010]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege(03 July 2007 and after)	−0.033	(0.053)	−0.053	(0.065)
Obama Administration (20 January 2009 and after)	−0.047	(0.050)	−0.107***	(0.069)
Malakand Accord (15 February–30 April 2009)	0.044	(0.060)	0.049	(0.081)
Post-Bin Laden death (02 May 2011 and after)	−0.102***	(0.037)	−0.141	(0.050)
Pakistan Offensive 1 (01 January–31 May 2008)	−0.060	(0.038)	−0.066	(0.058)
Pakistan Offensive 2 (23 September–31 October 2008)	−0.084	(0.052)	−0.138*	(0.065)
Pakistan Offensive 3 (01 May–31 May 2009)	0.072	(0.080)	0.071	(0.082)

(continued)

Table 9. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
Pakistan Offensive 4 (18 October–17 December 2009)	−0.085**	(0.034)	−0.082	(0.051)
Other controls:				
Indicator for months with reduced fighting	0.010***	(0.019)	0.019	(0.028)
1000s of US troops deployed in Afghanistan	−0.007***	(0.002)	−0.008***	(0.002)
Time trend (days/365)	0.176***	(0.056)	0.240***	(0.073)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. Mehsud base of operations are all areas in South Waziristan, Pakistan. Mehsud areas of combat operations are all areas in the FATA in Pakistan. The sample is also restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include up to 21 lags of terrorist attacks in Mehsud areas of combat operations (coefficients not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. *p*-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

the maximum number of lags that have a nonzero effect, and X_t is a vector of variables that may shift the reaction function up or down or change the parameters of the reaction function.

The estimation results are reported in Table 9, with the first set of columns giving the estimation results from the incidence specification and the fourth column giving the estimation results from the levels specification. We find that a terrorist attack by the Mehsud faction in FATA is 12.7% more likely 11 days after a drone strike in South Waziristan but that it is 11.6% less likely 14 days after a drone strike in South Waziristan. There are also 0.119 fewer terrorist attacks 14 days after a drone strike (everything else constant). Overall, there appear to be vengeance effects but also large deterrent/incapacitation effects occurring in the second week after a drone strike for the Mehsud faction of the Taliban. Coefficients on lags of drone strikes are jointly statistically significant from 0 in both the incidence and levels specification. Unlike the Haqqani faction, the incidence and number of terrorist attacks by the Mehsud faction are not affected during the Muslim months in which fighting is traditionally forbidden.

6.2 Successful and unsuccessful drone strikes

Jaeger and Paserman (2009) found differential effects of successful and unsuccessful assassination attempts of Palestinian leaders. We employ a similar strategy here by exploiting information on whether a particular drone strike was successful in eliminating a militant leader. By decomposing the drone strikes into those which were successful and not

Table 10. Daily Taliban reaction functions in Afghanistan to successful and unsuccessful drone strikes

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
A1. Successful drone strikes (21 lags)				
t−1	0.010	(0.078)	−0.175	(0.247)
t−2	0.031	(0.054)	0.317	(0.314)
t−3	−0.009	(0.058)	−0.076	(0.313)
t−4	0.088*	(0.042)	0.036	(0.221)
t−5	0.107***	(0.031)	0.034	(0.265)
t−6	0.019	(0.057)	0.123	(0.266)
t−7	−0.028	(0.057)	0.326	(0.348)
t−8	−0.045	(0.059)	0.569	(0.374)
t−9	−0.047	(0.065)	0.201	(0.355)
t−10	−0.067	(0.062)	−0.436	(0.307)
t−11	−0.045	(0.055)	−0.317	(0.232)
t−12	0.003	(0.060)	−0.104	(0.301)
t−13	−0.042	(0.056)	−0.463*	(0.225)
t−14	0.035	(0.058)	0.203	(0.351)
t−15	0.054	(0.053)	0.098	(0.344)
t−16	0.084	(0.054)	0.115	(0.266)
t−17	0.042	(0.053)	0.042	(0.287)
t−18	0.077	(0.050)	0.372	(0.265)
t−19	0.041	(0.055)	0.081	(0.335)
t−20	−0.020	(0.064)	0.023	(0.291)
t−21	−0.077	(0.063)	−0.104	(0.323)
Joint significance of 21 lags		[0.161]		[0.101]
Sum of coefficients	0.210	[0.403]	0.864	[0.568]
A2. Unsuccessful Drone Strikes (21 lags)				
t−1	0.018	(0.026)	−0.053	(0.139)
t−2	−0.053	(0.031)	−0.039	(0.105)
t−3	0.003	(0.030)	0.308	(0.359)
t−4	0.020	(0.029)	0.420	(0.367)
t−5	0.053**	(0.023)	−0.329	(0.253)
t−6	−0.048	(0.028)	−0.155	(0.193)
t−7	−0.009	(0.031)	−0.181	(0.108)
t−8	0.032	(0.025)	−0.139	(0.183)
t−9	−0.027	(0.031)	0.091	(0.171)
t−10	0.017	(0.023)	0.449	(0.622)
t−11	0.001	(0.027)	−0.064	(0.171)
t−12	0.000	(0.026)	0.068	(0.210)
t−13	0.002	(0.029)	−0.103	(0.168)
t−14	0.044	(0.026)	0.098	(0.135)
t−15	0.001	(0.026)	0.266	(0.407)
t−16	0.007	(0.027)	−0.215	(0.182)
t−17	0.022	(0.028)	−0.236	(0.192)
t−18	0.017	(0.024)	0.008	(0.169)
t−19	0.020	(0.028)	0.018	(0.152)

(continued)

Table 10. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [p-value]	Coefficient	(Standard error) or [p-value]
t−20	−0.024	(0.031)	−0.002	(0.200)
t−21	−0.014	(0.026)	−0.335**	(0.136)
Joint significance of 21 lags		[0.190]		[0.011]
Sum of coefficients	0.081	[0.379]	−0.123	[0.915]
B. Terrorist attacks by Taliban in Afghanistan (21 lags)				
Joint significance of 21 lags		[<0.001]		[<0.001]
Sum of coefficients	0.462	[<0.001]	0.599	[<0.001]
C. Terrorist attacks by Taliban in Pakistan (21 lags)				
Joint significance of 21 lags		[0.163]		[0.051]
Sum of coefficients	0.147	[0.042]	0.440	[0.440]
D. Additional controls				
Indicators for important periods:				
Post-Red Mosque Siege (03 July 2007 and after)	0.061	(0.041)	0.367	(0.239)
Obama Administration (20 January 2009 and after)	0.123**	(0.051)	0.761***	(0.287)
Malakand Accord (15 February–30 April 2009)	−0.060	(0.061)	−0.415	(0.328)
Post-Bin Laden death (02 May 2011 and after)	0.070	(0.037)	−0.011	(0.230)
Pakistan Offensive 1 (01 January–31 May 2008)	0.015	(0.044)	0.014	(0.224)
Pakistan Offensive 2 (23 September–31 October 2008)	−0.055	(0.057)	0.126	(0.242)
Pakistan Offensive 3 (01 May–31 May 2009)	−0.018	(0.035)	−0.219	(0.388)
Pakistan Offensive 4 (18 October–17 December 2009)	0.001	(0.042)	−0.328	(0.293)
Other controls:				
Indicator for months with reduced fighting	−0.040	(0.023)	−0.208	(0.172)
1000s of US troops deployed in Afghanistan	0.004*	(0.002)	0.018	(0.011)
Time trend (days/365)	−0.133**	(0.055)	−0.606*	(0.297)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. p-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks).

Table 11. Daily Taliban reaction functions in Pakistan to successful and unsuccessful drone strikes

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
A1. Successful drone strikes (21 lags)				
t−1	0.079	(0.081)	0.160	(0.111)
t−2	0.041	(0.085)	−0.103	(0.106)
t−3	−0.177**	(0.072)	−0.178	(0.143)
t−4	−0.033	(0.078)	−0.083	(0.135)
t−5	0.037	(0.073)	0.144	(0.153)
t−6	0.027	(0.080)	−0.028	(0.156)
t−7	0.048	(0.076)	0.115	(0.148)
t−8	0.020	(0.089)	0.045	(0.145)
t−9	−0.089	(0.070)	−0.112	(0.144)
t−10	0.115	(0.086)	0.206	(0.131)
t−11	−0.090	(0.081)	0.068	(0.171)
t−12	0.076	(0.077)	−0.062	(0.109)
t−13	0.059	(0.078)	0.150	(0.168)
t−14	−0.135*	(0.065)	−0.283**	(0.122)
t−15	0.050	(0.076)	−0.039	(0.120)
t−16	0.011	(0.071)	0.111	(0.160)
t−17	0.074	(0.084)	0.047	(0.177)
t−18	0.054	(0.089)	−0.020	(0.147)
t−19	−0.055	(0.086)	−0.250*	(0.126)
t−20	0.003	(0.089)	0.009	(0.142)
t−21	0.090	(0.077)	0.125	(0.154)
Joint significance of 21 lags		[0.191]		[0.013]
Sum of coefficients	0.203	[0.538]	0.022	[0.969]
A2. Unsuccessful drone Strikes (21 lags)				
t−1	0.043	(0.044)	0.002	(0.050)
t−2	−0.059	(0.036)	−0.064	(0.044)
t−3	−0.011	(0.039)	−0.024	(0.041)
t−4	0.032	(0.040)	0.047	(0.047)
t−5	0.097***	(0.037)	0.041	(0.039)
t−6	0.076*	(0.037)	0.099*	(0.046)
t−7	0.006	(0.035)	−0.015	(0.038)
t−8	−0.013	(0.037)	0.043	(0.047)
t−9	0.042	(0.036)	0.047	(0.040)
t−10	0.060	(0.041)	−0.010	(0.057)
t−11	0.026	(0.041)	−0.004	(0.037)
t−12	−0.075*	(0.037)	−0.121***	(0.038)
t−13	−0.087**	(0.036)	−0.002	(0.043)
t−14	0.019	(0.037)	0.024	(0.046)
t−15	−0.025	(0.039)	−0.019	(0.046)
t−16	0.047	(0.043)	0.041	(0.047)
t−17	0.038	(0.044)	0.052	(0.052)
t−18	0.023	(0.040)	−0.002	(0.042)
t−19	0.048	(0.037)	0.027	(0.048)

(continued)

Table 11. Continued

	Incidence of attacks		Number of attacks	
	Coefficient	(Standard error) or [*p*-value]	Coefficient	(Standard error) or [*p*-value]
t−20	−0.065	(0.045)	−0.068	(0.042)
t−21	−0.016	(0.036)	0.017	(0.057)
Joint significance of 21 lags		[0.001]		[0.037]
Sum of coefficients	0.208	[0.112]	0.113	[0.472]
B. Terrorist attacks by Taliban in Afghanistan (21 lags)				
Joint significance of 21 lags		[0.204]		[0.002]
Sum of coefficients	−0.073	[0.354]	0.040	[0.101]
C. Terrorist attacks by Taliban in Pakistan (21 lags)				
Joint significance of 21 lags		[0.009]		[<0.001]
Sum of coefficients	0.129	[0.174]	0.218	[0.067]
D. Additional controls				
Indicators for important periods				
Post-Red Mosque Siege (03 July 07 and after)	−0.050	(0.066)	−0.169	(0.104)
Obama Administration (20 January 2009 and after)	−0.120*	(0.061)	−0.391***	(0.146)
Malakand Accord (15 February–30 April 2009)	0.058	(0.055)	0.133	(0.141)
Post-Bin Laden death (02 May 2011 and after)	−0.092	(0.062)	−0.236**	(0.146)
Pakistan Offensive 1 (01 January–31 May 2008)	−0.183***	(0.052)	−0.285***	(0.088)
Pakistan Offensive 2 (23 September–31 October 2008)	−0.040	(0.086)	−0.183	(0.150)
Pakistan Offensive 3 (01 May–31 May 2009)	0.210***	(0.064)	0.671	(0.451)
Pakistan Offensive 4 (18 October–17 December 2009)	−0.117**	(0.046)	−0.178*	(0.087)
Other controls:				
Indicator for months with reduced fighting	0.058	(0.066)	−0.169	(0.104)
1000s of US troops deployed in Afghanistan	−0.011***	(0.002)	−0.024***	(.005)
Time trend (days/365)	0.296***	(0.071)	0.686***	(0.146)

Notes: Terrorist attacks are restricted to those where the perpetrator was identified as Taliban or Al-Qaeda. The sample is further restricted to 1713 days between 1 January 2007 and 30 September 2011. Regressions include 21 lags of terrorist attacks by the Taliban in Afghanistan and in Pakistan (coefficients are not reported for brevity but are available from the authors on request). All regressions include day of week indicators. Months with traditionally reduced fighting in the Muslim calendar are Muharram, Dhu al-Qidah, Dhu al-Hijjah, and Rajab. Variance–covariance matrices calculated using the Newey–West (1987) method. *p*-values are given in brackets. Standard errors are given in parentheses. For coefficients, * indicates significance at the 5% level, ** indicates significance at the 2.5% level, and *** indicates significance at the 1% level.
Source: Author calculations using data from the New America Foundation (drone strikes) and the WITS of the National Counterterrorism Center (terrorist attacks). Shaded periods indicate Pakistan military offensives.

successful, we are able to investigate the individual deterrence and incapacitation effects of drone strikes on terrorist violence.

For the Taliban in Afghanistan, the reaction functions we estimate are of the form:

$$T_t^A = f_i(D_{t-1}^S, \ldots, D_{t-p}^S, D_{t-1}^U, \ldots, D_{t-p}^U, T_{t-1}^P, \ldots, T_{t-p}^{Pakistan}, T_{t-1}^A, \ldots, T_{t-p}^A, X_t), \quad (6)$$

where D_t^S and D_t^U represent drone strikes that were successful and that were not successful in killing a militant leader at time t, respectively. The estimation results are reported in Table 10. We find that a terrorist attack in Afghanistan is 10.7% more likely 5 days after a successful drone strike and 5.3% more likely 5 days after an unsuccessful drone strike. At the same time there are 0.463 fewer terrorist attacks 13 days after a successful drone strike and 0.335 fewer terrorist attacks 21 days after an unsuccessful drone strike. There do not appear to be differential impacts of successful and unsuccessful drone strikes on terrorist attacks by the Taliban in Afghanistan.

For the Taliban in Pakistan, the reaction functions we estimate are of the form:

$$T_t^P = f_i(D_{t-1}^S, \ldots, D_{t-p}^S, D_{t-1}^U, \ldots, D_{t-p}^U, T_{t-1}^A, \ldots, T_{t-p}^A, T_{t-1}^P, \ldots, T_{t-p}^P, X_t), \quad (7)$$

with the variables defined as above. The estimation results are reported in Table 11. We find that a terrorist attack in Pakistan is 17.7% less likely to occur 3 days after a successful drone strike. At the same time we find that a terrorist attack is 9.7 and 7.5% more likely to occur five and 6 days after an unsuccessful drone strike, and that a terrorist attack is 7.5 and 8.7% less likely to occur 12 and 13 days after an unsuccessful drone strike. There are 0.283 fewer terrorist attacks in Pakistan 15 days after a successful drone strike, 0.099 more terrorist attacks in Pakistan 6 days after an unsuccessful drone strike, and 0.121 fewer terrorist attacks in Pakistan 12 days after an unsuccessful drone strike (all else constant). These effects are statistically significant. Because all of the statistically significant coefficients on successful drone strikes are negative, it appears that there is an incapacitation effect of the Taliban due to a lost militant leader. The mixed pattern of coefficients on unsuccessful drone strikes indicates that the intertemporal allocation of terrorist attacks that we noted earlier is in response to these kinds of drone strikes, rather than drone strikes which are able to take out a militant leader.

7. Conclusion

We examine the dynamics of the conflict involving the Taliban across Afghanistan and Pakistan and the use of drone strikes as a counterterrorism policy to combat the Taliban. We test the following hypotheses: Do the Taliban increase or decrease terrorist attacks following drone strikes which target militant leaders of the Taliban? How do the impacts differ across the border in attacks carried out by the Taliban in Afghanistan and attacks carried out by the Taliban in Pakistan? Is there a cycle of violence associated with the use of drone strikes by the US government in Pakistan? Does US policy to combat the Taliban and Al-Qaeda (in the form of drone strikes) have some impact on terrorist activities of the Taliban in neighboring Afghanistan?

We find that there is little significant impact of drone strikes on Taliban attacks in Afghanistan but that there is a significant impact of drone strikes on Taliban attacks in Pakistan. This impact varies from a positive vengeance effect in the first week following a drone strike to a negative deterrent/incapacitation effect in the second week following a drone strike, when we examine the incidence of terrorist attacks by the Taliban. The impact is negative in the second week following a drone strike, when we examine the number of terrorist attacks by the Taliban.

We also examine whether drone strikes in North Waziristan have an impact on Taliban violence in parts of Afghanistan under the control of the Haqqani faction of the Taliban. We examine whether drone strikes in South Waziristan have an impact on Taliban violence in the FATA under the control of the Mehsud faction of the Taliban. We find some vengeance effects of drone strikes on violence by the Mehsud faction but also deterrent/incapacitation effects of drone strikes on violence by both the Haqqani and Mehsud factions of the Taliban. We estimate the differential effects of successful and unsuccessful drone strikes (which kill and do not kill a militant leader) on Taliban violence in Afghanistan and in Pakistan. We find strong positive and negative impacts of unsuccessful drone strikes on Taliban violence in Pakistan, showing a possible reallocation of attacks over time in response to these kinds of strikes.

The differential effects of drone strikes in Pakistan, where they appear to increase terrorist violence, and in Afghanistan, where they appear to have a smaller effect, if any, are likely driven by the presence of the US military in Afghanistan. Terrorist attacks there may be more likely to reveal operational information about the Taliban that would make it easier for the US military or drones to target. It also seems possible to us that terrorism in Pakistan would be more likely to pay off in terms of shifting policy there than in Afghanistan, where the government in this period was substantially dependent on US aid. Terrorism against civilians may change the ‘hearts and minds’ of the Pakistani population if they perceive it is a consequence of the Pakistani Government’s cooperation with the USA. The benefits (to the Taliban) of terrorism in Pakistan may therefore be greater, particularly if those actions are rhetorically linked to drone strikes, as Baitullah Mehsud claimed in 2009.

Our work has relevance for US drones policy in Pakistan as well as possible use of the policy in other parts of the world. While drone strikes may be an effective policy for reducing the threat of terrorism against the US homeland, there may be unintended consequences closer to where the drone strikes take place. Terrorist groups may decide not (or be unable) to retaliate against the USA but may choose to retaliate against local regimes that are perceived to be friendly to the USA. In the case of Pakistan, retaliation by the Taliban against civilians in Pakistan may have political consequences there that could lead to deterioration of the USA–Pakistan relations.

We have also provided empirical evidence of deterrence effects of a specific counterterrorism policy across different factions of a larger group with a common ideology (the Taliban). We find that these effects can vary across the different factions, with vengeance effects being stronger for some factions than for others. Our most important finding is that drone strikes matter, but primarily for Taliban violence in Pakistan. There is less of an effect of drone strikes on Taliban violence across the border in Afghanistan.

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Review

Economic Development in Peacekeeping Host Countries

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Abstract

To what extent does United Nations peacekeeping assist in laying the foundations for economic development? We conduct the first exploratory analysis of the effect of peace operations on the economic development of the host countries. We highlight the need for new inferential methods to reveal the extent to which robust conclusions about the success of missions can be drawn. We then apply synthetic control methods to 11 peace operations deployed since the end of the Cold War. Our results suggest that, in seven cases, peacekeeping does not seem to significantly affect economic rehabilitation. In two of the remaining four cases, the impact is negative rather than positive, pointing to persistent hurdles to identification. (JEL codes: D74 and P16).

Key words: economic development, peacekeeping, treatment effects

1. Introduction

Economics and security are heavily intertwined: economic motivations often exert an important role in affecting the decision to go to war, whereas conflict matters for the economy and can shape the paths to economic development. According to the World Development Report 2011, countries trapped in repeated cycles of war and violent crime are badly served by the global framework for peacekeeping relief. The report argues that there is currently a lack of external support for restoring peace and creating jobs in the short term to reduce the attractiveness of turning to violence. In fact, the current arrangements for dealing with conflict—with distinct roles for military peacekeeping to bring conflicts to an end—reflect the 20th-century pattern of relatively clearly defined civil and interstate war. Yet, breaking the cycle of violence requires an international system 'refitted to address 21st century risks' (World Bank 2011, p. 3). The UK's Department for International Development, the world's second-largest donor of development assistance, has also been reassessing the need to work alongside military peacekeeping missions in promoting reconstruction and development (see e.g. FT, 11 April 2011).

This article is part of a growing debate about the relationship between peacekeeping interventions and state-building. More precisely, we investigate whether and to what extent military peacekeeping can assist in laying the foundations for economic development. The first United Nations (UN) peacekeeping mission was deployed in 1948 to keep a truce after the creation of Israel and was a small, unarmed observer force. Since 1948, the UN has launched more than 70 operations and at the time of this writing (December 2016), the global number of current operations is 16, with almost 105,000 military personnel. The number of UN peace operations has particularly increased after the end of the Cold War. Whereas during the entire Cold War, the UN launched just 18 missions, since 1990, the UN has launched nearly 50 missions. Crucially, as part of this expansion, UN peacekeeping missions play an increasing role in implementing and enforcing peace agreements in war-torn societies. Moreover, many missions launched since 1999 have carried the mandate to fight to protect civilians, a sharp break from the pre-Cold War era when peacekeepers used force only in self-defense.

The 1990 s and 2000 s were also characterized by a sharp decline in most deadly civil conflicts numbers. The Human Security Report 2005 attributes the decline in the number and intensity of wars to the increase in the deployment of these peace and security operations.[1] Most of the empirical research on the performance of peacekeeping suggest indeed that peacekeeping reduces the probability of a conflict resuming (Fortna 2004, 2010; Sambanis and Doyle 2007; Sambanis 2008; Doyle and Sambanis 2010).

Yet, in the past two decades, UN peace operations have seen drastic changes in the framing of their mandate, which often includes development assistance, economic recovery, and institution building. In fact, the UN has long been concerned with helping countries torn by conflict by creating the conditions for lasting peace. In October 2014, Secretary-General Ban Ki-moon established a High-level Independent Panel on UN Peace Operations to make an assessment of the state of UN peace operations today. The report suggests that 'inclusive and equitable economic development is a pillar for sustaining peace. The UN should take into account economic dimensions, including livelihoods and jobs and transparent and accountable management of natural resources, including revenues, land and, particularly in zones of conflict, basic services' (High-Level Independent Panel on UN Peace Operations 2015, p. 37). The report also states that the deployment of UN peacekeeping can act as an economic and capacity stimulus to the local community.

There is surprisingly little research on the economic impact of peacekeeping, and non-security-related outcomes have been rarely a focus of research. Against this background, we offer a novel analysis of the economic impact of peacekeeping missions in the host country.[2] Peacekeeping operations are normally carried out in poor countries with nearly absent state capacity and large informal markets. This situation makes them very susceptible to external shocks. Their primary contributions to economic development are indirect and lie in restoring or maintaining the security needed to engage in economic activities. A state of security is both a prerequisite for a functioning formal economy and an incentive for

1 'The 80% decline in the most deadly civil conflicts numbers that has taken place since the early 1990 s owes little to any of the above factors. Here the evidence suggests the main driver of change has been the extraordinary upsurge of activism by the international community that has been directed toward conflict prevention, peacemaking and peacebuilding' (Human Security Report 2005, p.155).

2 We use 'host country' to indicate the place where UN peacekeepers are stationed.

investment. If peace operations are successful in delivering a safe and secure environment, then the mission should laid the foundation for economic development. Without security there is no investment, given the uncertainty of future returns. Deploying peacekeeping forces has also more direct economic effects. Peacekeeping often includes civil engineering projects and provides humanitarian aid. Many services are also supplied locally to the mission, such as administration, accommodation, and transportation. The direct impact ranges from increased local spending to international supply chains. Moreover, a country's level of economic development affects its vulnerability to repeated conflicts. Economic development shapes the opportunity costs of returning to war (Walter 2004; Collier et al. 2009); over time economic growth and development are also the critical determinants of a low risk of a return to civil war (Sambanis 2008).

There are a number of available methods used to analyze the impact of peacekeeping, including accounting procedures (Carnahan et al. 2007), statistical models of individual countries (Mvukiyehe and Samii 2010) or of large *N* cross-sections or panels (Doyle and Sambanis 2000), and case studies (Durch 2006). Smith (2014) discusses the empirical techniques used to estimate the economic costs of war, which is similar to estimating the benefits of peacekeeping. We use the synthetic control method developed by Abadie and Gardeazabal (2003), a systematic way to choose comparison units in comparative case studies, to complement the quantitative studies on the impact of peacekeeping. To evaluate the impact of peacekeeping, we compare conflict-torn countries hosting peace operations with non-treatment groups made up of countries that have had recent conflicts but not peacekeeping missions. Overall, our results suggest that peacekeeping does not significantly affect economic development. Yet, there are several lingering threats to identification, and our results should be interpreted with caution. We begin Section 2 with a short overview of the potential effects of peacekeeping on economic outcomes. Section 3 discusses the counterfactual problem. Section 4 describes the synthetic control method and its main advantages in this study, and Section 5 presents our empirical results. Finally, Section 6 provides concluding remarks.

2. The Economic Impact of Peacekeeping

The economic impact of military interventions on the host economy can be both indirect, through improved security and health-care services—usually provided by affiliated actors such as non-governmental organizations (NGOs)—and direct, from the demand for local goods and services to job training. Four studies on the local economic impact of peacekeeping are offered by Carnahan et al. (2007), Solomon (1999), Mvukiyehe and Samii (2010), and Caruso et al. (2017). A comprehensive survey of peacekeeping economic impacts at both local and regional levels, including trends of how military interventions may develop until 2020, is offered by Tejpar (2009).

The indirect effects are possibly the most substantive. Conflict leads to a dramatic disruption of economic activity at both macroeconomic and microeconomic levels. Some economic consequences include high levels of unemployment, great inequality in the distribution of resources, food insecurity, loss and damage of existing capital and infrastructure, and reduced investment (Blattman and Miguel 2010). Gates et al. (2012) find that war has also detrimental effects on progresses in meeting the UN Millennium Development Goals, such as on the reduction of poverty, hunger, infant mortality, and on access to water and primary education. Whereas less-developed societies recover only a portion of their pre-war performance, the least-developed societies endure the highest costs and fall into lasting poverty traps (Kugler et al. 2013). Peacekeeping operations may have an important place in helping war-torn countries to develop and sustain their own institutions and to revitalize the economy.

In fact, most of the empirical studies suggest that peacekeeping reduces the level of violence and increases the likelihood of peace. Beardsley (2011) finds that peacekeeping limits the spatial and temporal contagion of conflict, and Melander (2009) demonstrates that peacekeeping operations have a preventive effect in reducing the risk of genocides. Costalli (2014) examines the location of UN deployments in the Bosnian civil war, and finds that whereas the UN deployed where the most severe violence took place, peacekeepers had little effect on subsequent violence. According to Elbadawi (2008), UN peacekeeping generally succeeded in maintaining peace up to 5 years after the end of civil wars, although in many instances short-term gains are not sustained in the longer run, particularly after the UN mission ends. We also know that the size of a mission matters, as it influences cooperation between the so-called blue helmets and locals (Ruggeri et al. 2013), violence against civilians, and battle deaths between belligerents (Hultman et al. 2013, 2014). Finally, Bove and Ruggeri (2016) find that not only the size but also the diversity within the peacekeepers are associated with lower levels of hostilities.

If peacekeeping facilitates the transition from war to peace, then we should observe positive effects on a number of economic variables. Real improvements in security resulting from peacekeeping missions should boost economic activities of the host countries in the short-run, whereas the restoration of law and order should set the stage for long-term development. Caruso et al. (2017) explore the relation between the presence of UN peacekeepers and cereal production in Sudan, where the agricultural sector is adversely affected by conflict. They find that the presence of UN peacekeepers increases the production of crops, thus indicating a positive impact of peacekeeping on the local economy. Furthermore, the security umbrella provided by the peacekeepers encourages non-state actors, such as NGOs, and government development agencies, to direct aid and assistance to the host countries. In fact, many peacekeeping missions start at the same time as development assistance programs.

Peacekeeping operations have also a direct impact on the host country economy through a number of channels. The deployment of peacekeepers affects the housing, retail and service markets, and the labor force. We should expect an upward surge in economic activity as a consequence of the international mission subsistence allowance spent on the local economy, local mission procurements, and wages paid to locally hired staff. Indeed, peace missions often offer a number of job opportunities to locals, and part of the civilians and military wage is spent in the host country.[3] Accordingly, the High-Level Independent Panel on UN Peace Operations (2015, p. 78) claims that peace operations 'can and should strengthen both the economy and national capacities by sourcing their goods and services requirements locally to the extent possible'. Often peacekeepers bring substantial resources into the host country, undertake civil engineering projects such as building schools and hospitals, and provide humanitarian aid including food and medicines. Also, disarmament and

3 Peace operations employ national personnel to fill predominantly administrative tasks (including interpreters) and clerical and support roles. More senior-level positions include mechanics, technicians, and clerical staff in areas such as procurement, inventory, accounting/financing, travel, and personnel (see Tejpar, 2009).

demobilization programs often involve material benefits to ex-combatants, such as farm and building material, transportation, and job training (Fortna 2010).

The relatively large amount of economic resources poured into a developing country may overheat the local market and create a bubble economy. Bove and Gavrilova (2014) explore the effect of North Atlantic Treaty Organization (NATO) military deployment in Afghanistan on the local economy. They find that International Security Assistance Force (ISAF) deployment is associated with an increase in the levels of wages and commodity prices. The literature on the effects of aid on growth in developing countries provides some theoretical foundations on the economic effect of peacekeeping. In the traditional Harrod–Domar model of economic growth and in variants of this model (Easterly 1997), foreign aid closes the domestic savings gap to increase investment or finance imports, leading to higher growth. However, several recent empirical studies have not been able to reproduce this result robustly across different time periods and countries (Tsikata 1998; Easterly 2003; Djankov et al. 2008). In fact, the estimated effectiveness of aid is highly sensitive to the choice of estimator and the set of control variables (Hansen and Tarp 2001). The situation when a country receives a large influx of foreign assistance bears also resemblance to the so-called 'Dutch Disease' phenomenon (Michaely 1981; Corden and Neary 1982; Paus 1995). The inflow of foreign exchange to pay for the extraction of a major natural resource leads to an overall decline in the tradable goods sector of the economy. Demekas et al. (2002) found that although humanitarian aid does reduce long-term capital accumulation, such as in the traditional aid-growth literature, it enhances welfare in the short run, particularly when labor supply is low. Moreover, the reconstruction aid may not result in Dutch Disease, since higher factor productivity in both sectors could offset the contraction of the tradable goods sector.[4] In both strand of the literature, the net effect is not obvious and has to be determined from the data.

The failure to integrate top-down estimates, usually regression based, with the more microeconomic bottom-up estimates, often using accounting methods, compounds the problem of a clear identification of the economic effects of peacekeeping. Carnahan et al. (2007) collected field data from the Chief Financial Officers or Chief Procurement Officers in eight active missions.[5] Data suggest an immediate upsurge in economic activity associated with the restoration of basic security. They also find that the spending from international staff allowances (e.g. purchase of local goods and services), local procurement, and on national staff wages provided a significant stimulus to the local economy. In some cases the local impact made a significant contribution to the gross domestic product (GDP) of the host country. By assuming a Keynesian multiplier of 1.5, in four of the nine missions the local impact was over 6% of GDP, and in two cases it was over 10%. Solomon (1999) estimates the direct, indirect, and induced impact of the United Nations Mission in Haiti (UNMIH) on the Haitian economy. He compares Haiti's situation to a small isolated community in Canada with a military base and uses a similar multiplier to estimate the spin-off effect of the mission, which is estimated to amount to $34 m in 1995–1996, a negligible share of the country GDP. Finally, using survey and administrative data from post-war Liberia, Mvukiyehe and Samii (2010) do not find evidence that deployments were substantial contributors to local social infrastructure and find a negative relationship between

4 The higher demand for domestic goods and services may be met without considerable reallocation of labour and capital, allowing both sectors to expand (Demekas et al., 2002).

5 UNMIK (Kosovo); UNMISET (Timor-Leste); UNAMSIL (Sierra Leone); MONUC (Democratic Republic of Congo); MINUSTAH (Haiti); ONUCI (Côte d'Ivoire); UNMIL (Liberia); and ONUB (Burundi).

peacekeeping deployment locations and NGO contributions to social infrastructure. Nonetheless, they suggest that deployments seem to stimulate local markets and boost employment possibilities and incomes. The differences in findings arise for a variety of reasons, for example because these studies involve different implicit counterfactuals.

3. Counterfactual

There are no agreed criteria for the success of a peacekeeping mission, partly because of the lack of agreement on goals and what would have happened without a deployment (Bove and Smith 2011). In establishing the counterfactual—for example, what would Angola have been like in 2000 had there been no peacekeeping in 1995—many judgments are required about which impact is a consequence of the intervention and which would have occurred anyway without the mission. Benefits that would have occurred without the mission need to be clearly identified to show what outcomes can be attributed to the mission and whether the original objectives were met. However, there is often little information either about precise objectives or about what would have happened had peacekeeping not been undertaken. A peacekeeping mission may coincide with an improvement in security, but it is often difficult to judge whether this improvement would have occurred without the mission. Many studies on the success of peacekeeping try to control for the difficulty of the missions, e.g. whether there was already peace when peacekeepers were deployed or the observed level of violence, but these indicators do not always explain all of the variation in outcomes, and there is still room for unobserved factors to be influencing the difficulty of missions. This may cause bias in the results. The direction and magnitude of the bias will depend on whether peacekeepers and the UN in particular are going to missions that are harder or easier than the observed data suggest. Gilligan and Stedman (2003) and Mullenbach (2005) find that the deployment of peacekeepers is determined by whether the combatants have signed either cease-fires or peace treaties. If there are unobserved factors that make missions easier (e.g. the belligerents' desire for peace) and also make peacekeepers more likely to deploy, the benefit of peacekeepers will have been overestimated.

A quantitative method for generating a hypothetical counterfactual is to look at the outcomes where there has been no treatment, that is a control group. By seeing what happens in countries that are similar but have no peacekeeping missions, the non-treatment group, we could form counterfactuals for those countries that have peacekeeping missions, the treatment group. The experiences of the non-treatment group would form the basis of a hypothetical counterfactual for the treatment group. This matching technique plays important roles in many areas of economics; it was famously used by Becker (1973, 1974) to characterize marriage markets and fully developed as an econometric evaluation estimator by Heckman et al. (1998).

Most often it is applied in settings where the interest is in the average treatment effect for the treated and there is a large reservoir of potential controls (Imbens and Wooldridge 2009). In fact, the selection of comparison units is crucial in determining the success of peacekeeping missions because using inappropriate comparisons may lead to erroneous conclusions. If comparison units are not sufficiently similar to the units representing the case of interest, any difference in outcomes between these two sets of units may be a mere consequence of the disparities in their characteristics (King et al. 1994; Abadie et al. 2015). Gilligan and Sergenti (2008) correct for the nonrandom assignment of peace operations using matching techniques and find that UN interventions after the end of the Cold War are effective in post-civil-conflict scenarios, while interventions when civil wars are still ongoing have no causal effect. Given the matched pairs, the treatment effect within a pair is estimated as the difference in outcomes, and the overall average as the average of the within-pair difference. Yet, the classical Mill's method of difference, upon which the matching method is based, is limited by the presence of unmeasured factors affecting the outcome variables as well as heterogeneity in the effect of observed and unobserved factors. Moreover, given the lack of a large reservoir of controls, that is comparable countries that have no peacekeeping missions, suitable single comparisons often do not exist, leading to some problematic pairwise comparisons. For example Azerbaijan is used as the sole control unit for Croatia, Bosnia, Lebanon, and Tajikistan, while Niger is chosen as the untreated unit to match Tajikistan.

We use the method proposed by Abadie and Gardeazabal (2003) and construct an artificial control group that is more similar to the treatment group in the initial period than any of the control groups on their own. The method weights the units in the control group to construct a synthetic counterfactual that replicates the initial conditions and the outcome potential of the countries of interest before exposure to peacekeeping. This approach does a better job at reproducing the characteristics of intervened countries than any single comparison country alone. In particular, it makes explicit the contribution of each comparison unit to the counterfactual of interest. More importantly, the method corrects for the presence of unmeasured time-varying factors affecting the outcome variables and for the heterogeneity in the effect of both observed and unobserved factors (Abadie et al. 2015). This should mitigate the bias stemming from the omission of important time-varying variables that affect both the evolution of per capita GDP as well as the presence of a peace operation. Bove et al. (2017) examine the relationship between the case study, synthetic control, and large-N panel-data approaches, and provide a range of estimates of the effect of civil war on economic growth.

4. Empirical Strategy

Consider $i = 0, 1, 2, \ldots, G$ countries that have experienced a civil war at time T_0, with $1 < T_0 < T$, and a peace operation occurring in country 0. Then, denote by $D_{0t} = 1$ the treatment status, that is peacekeeping. The treatment effect for country 0 at time t on the outcome of interest Y_{0t}, that is per capita GDP, is defined as follows:

$$\alpha_{0t} = E[Y_{0t}|D_{0t} = 1] - E[Y_{0t}|D_{0t} = 0] \qquad \text{for } t = T_0 + 1, \ldots, T. \tag{1}$$

The potential outcome for the post-treatment period in the absence of the treatment is estimated as a weighted average of periods $t = T_0 + 1, \ldots, T$ outcomes in the $i = 1, 2, \ldots, G$ control groups,

$$E[Y_{0t}|D_{0t} = 0] = \sum_{i=1}^{G} \lambda_i \bar{Y}_{it}, \tag{2}$$

where $\bar{Y}_{it}$ is a generic linear combination of pretreatment outcomes, and λ_i are weights, satisfying $\Sigma_{i=1}^{G} \lambda_i = 1$ and $\lambda_i \geq 0$, to prevent extrapolation outside the support of the data. The weights are chosen to make the weighted control country resemble the treatment country prior to the treatment. That is, the estimation problem amounts to choosing the vector of weights that minimizes the difference between the treated country, and the λ-weighted average of the control countries over the period in which none of them had been exposed to the treatment, that is:

$$\left\| \begin{array}{c} Y_{0t} - \sum_{i=1}^{G} \lambda_i \bar{Y}_{it} \\ \vdots \\ Y_{0T_0} - \sum_{i=1}^{G} \lambda_i \bar{Y}_{iT_0} \end{array} \right\|,$$

where $\|\|$ denotes a measure of distance. To determine the weights, we use all pre-intervention outcomes, as well as information on human capital, investment, and geographic characteristics (Barro and Sala-I-Martin 2003). In fact, as in Abadie and Gardeazabal (2003), we use an algorithm that minimizes the distance in terms of pretreatment outcomes. Specifically, let X_1 be the $(k \times 1)$ vector of pre-intervention outcomes for the treated country, and X_0 be the $(k \times i)$ matrix that includes the same variables for the unaffected countries; also, let V be a $(k \times k)$ diagonal matrix with nonnegative entries measuring the relative importance of each predictor. Conditional on V, the optimal vector of weights, $\Lambda^*(V) = (\lambda_1, \ldots, \lambda_G)'$, must solve

$$\min(X_1 - X_0\Lambda(V))'V(X_1 - X_0\Lambda(V)) \tag{3}$$

subject to $\lambda_i \geq 0$ and $\Sigma_{i=1}^{G} \lambda_i = 1$. The vector of weights $\Lambda^*(V)$ defines the combination of untreated control countries which best resemble countries hosting peacekeeping in economic growth before the intervention. We then select V such that the mean squared prediction error of pretreatment outcomes is minimized, that is:

$$\frac{1}{T_0} \sum_{t \leq T_0} \left(Y_t - \sum_{i=1}^{G} \lambda_i^* Y_{it} \right)^2. \tag{4}$$

When the number of pre-intervention periods in the data is large, as in our case, matching on pre-intervention outcomes helps control for the unobserved factors affecting the outcome of interest. Once it has been established that the unit representing the case of interest and the synthetic control unit has similar behavior over extended periods of time prior to the peace mission, a discrepancy in the real per capita GDP following the peace mission is interpreted as produced by peacekeeping itself.

The idea is that the future path of the synthetic control group, consisting of the λ-weighted average of all the control groups, mimics the path that would have been observed in the treatment group in the absence of the treatment.

We use a fairly standard set of economic growth predictors, such as per capita capital stock, human capital index, altitude, mean distance to the nearest coastline, the percentage of land in geographical tropics, an indicator of soil suitability, percentage of population affected by malaria in 1982, and the number of civilian casualties caused by civil war. We also include the lags of per capita GDP. Using all outcome lags as separate predictors improves the pretreatment fit of the dependent variable and should help mitigating the endogeneity stemming from omitted variable bias. Yet, it also makes most of the remaining predictors less relevant, that is they are assigned a small weight, but the choice of predictor variables remains a controversial issue (Bove et al. 2017). The real per capita GDP, capital stock, and the human capital index are taken from the Penn World Table data set (version 9.0). Country geography data are from Gallup et al. (1999), and information on malaria is from Gallup and Sachs (2001). Information on peace operations is from the UN Department of Peacekeeping Operations.[6] Finally, data on civil wars and casualties are taken from the Uppsala Conflict Data Program (UCDP)/Peace Research Institute Oslo (PRIO) Armed Conflict data set, although information on battle deaths is not available for some countries in the donor pool. Accordingly, a civil war is defined as a conflict between a government and a non-governmental party, where the use of armed forces between the two parties results in at least 25 battle-related deaths in one calendar year. We consider a 20-year time window so as to have 10-year pre-peacekeeping data to calibrate the synthetic and 10-year post-peacekeeping to forecast the long-run effect of peacekeeping. The synthetic control method requires a number of comparative units, but it is sometimes difficult to find unexposed units at war that approximate the most relevant characteristics of the countries exposed to peacekeeping during exactly the same period. Therefore, we include donor countries which have been at war in the period considered, although not necessarily for the same number of years, that is there may not be a perfect overlapping in terms of war duration between the treated and untreated units when, for example, one of the unexposed unit ceases to be at war during the peacekeeping deployment in the country of interest. We report in the online appendix the weights of each control country in the synthetic case studies as well as comparisons of pretreatment characteristics between synthetic and actual case study.

One question is whether the estimated effects are statistically significant. This is quite important, since large sample inferential techniques are not appropriate for comparative case studies with a small number of treated and control units (Abadie et al. 2010). The synthetic control method enables us to conduct falsification exercises, the so-called 'placebo studies', an alternative mode of quantitative inference. This mode is based on the premise that the confidence that a particular synthetic control estimate reflects the actual impact of peacekeeping would be undermined if we obtained estimated impacts of similar or greater magnitudes in cases where the intervention did not take place. The idea is to apply the synthetic method to every potential control in our sample to assess whether the estimated effects for the country affected by peacekeeping is large relative to the distribution of the effects estimated for countries chosen at random and not exposed to the intervention.

5. Case Study Selection

A distinctive feature of the synthetic control method is the possibility to select *ad hoc* case studies to examine the economic consequences of peacekeeping in civil wars. As a preliminary step, we identify a pool of feasible experiments that meet the following conditions: (i) the treated country hosted a peace operations at the earliest in 2004, as we focus on 10-year post-operation window[7]; (ii) there exists a sufficient set of countries with civil wars that do not host peacekeeping in the 20-year time window to provide a pool of similar countries; and (iii) in case of subsequent peace operations, we select the first one in chronological order.

6 http://www.un.org/en/peacekeeping/documents/operationslist.pdf

7 With the exception of the Chad and Sudan, where we only have 7 and 9 years post-civil war, respectively.

Of the range of missions covered by the definition of peacekeeping, not all operations are alike. Fortna (2010) provides a useful classification. Although there is a widely shared consensus that the use of civilian police missions and observers are needed in crisis management and human security, comparing them with 'full scale' multidimensional peacekeeping missions may be problematic. As missions differ in scope and mandate, we exclude purely observers missions (e.g. UN Observer Mission in Georgia) and civilian police missions, for example UN Civilian Police Mission in Haiti), and focus only on operations with a military component, as they are expected to have a more meaningful direct and indirect effect on economic development.[8]

By meeting the above conditions, we end up with 11 case studies.[9] In the next section we therefore present results for the remaining 11 cases.

6. Results

Our results are reported in Figures 1 and 2. Figure 1 is on the effect of peacekeeping on per capita GDP. The solid line shows the evolution of per capita GDP in the treated unit, the dotted line represents the counterfactual, and the gray area indicates the actual duration of peacekeeping. Furthermore, we add for each country the number of civilian casualties every year, taken from the UCDP/PRIO Armed Conflict data set, to measure the intensity of war. Our analysis focuses on Angola, Cambodia, Central African Republic, Chad, Democratic Republic of Congo (DRC), Ethiopia, Haiti, Ivory Coast, Namibia, Rwanda, and Sudan. As explained above, we construct the synthetic of, for example, Angola as the convex combinations of countries in the donor pool that most closely resemble Angola in terms of pre-intervention values of economic development. The treated countries and the synthetic control behave similarly in most part of the sample, with few notable exceptions; in fact, the per capita GDP in the synthetic Cambodia and Chad does not closely track the trajectory of this variable in the treated units for the entire pre-intervention period. This is because there is no combination of civil war countries in our sample that can efficiently reproduce the time series of the per capita GDP in Cambodia and Chad during the pre-intervention periods. In all the remaining cases, the synthetic provides a sensible approximation to the per capita GDP that would have been achieved in the host countries in the post-intervention period in the absence of peacekeeping.

Note that the estimation of the effect of peacekeeping on per capita GDP is the difference between per capita GDP in the host country and its synthetic version after the deployment. In fact, in virtually all cases, slightly before or immediately after the year of the deployment, the two lines begin to diverge. Yet, the impact is somewhat heterogeneous. Angola, Haiti, and Sudan seem to have benefited from peacekeeping, and the discrepancy between the two lines suggests a positive effect during the deployment. In Central African Republic, Chad, DRC, Ethiopia, Ivory Coast, Namibia, and Rwanda, the impact of the mission appears negative. In most of these cases, however, the reasons might be found in

8 In fact, in addition to the traditional roles played by most peace operations, i.e. monitor and ensure compliance with ceasefire, provide security—most of these operations today perform tasks such as human rights monitoring, police reform, institution building, and economic rehabilitation.

9 We were not able however to find reliable synthetic controls for the following five cases: ONUB-2004 in Burundi; UNIFIL-1978 in Lebanon; UNOMIL-1993 in Liberia; ONUMOZ-1992 in Mozambique; and UNAMIL-1999 in Sierra Leone.

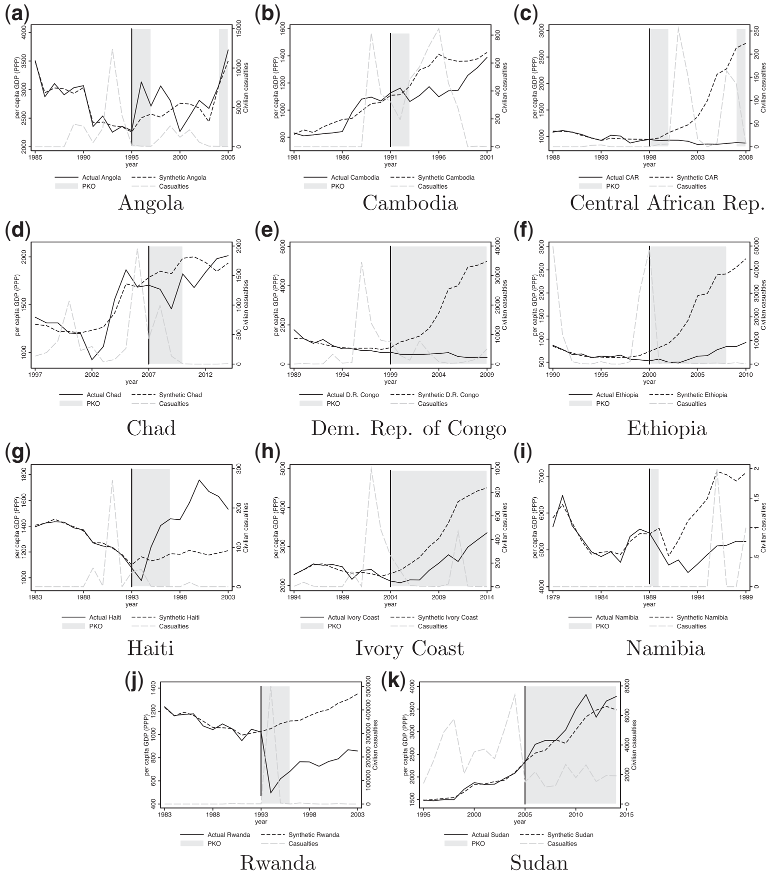

Figure 1. Per capita GDP for Angola, Cambodia, Central African Republic, Chad, DRC, Ethiopia, Haiti, Ivory Coast, Namibia, Rwanda, and Sudan.

the unabated intensity of conflict even after the deployment of peacekeepers, as in the case of Cambodia, or in the periodic post-intervention cycles of violence, like in Central African Republic. In other words, in many operations peacekeeping is not followed by the expected decrease in violence, and therefore the operation is less likely to have a tangible effect on economic development. In some of these cases, like in Namibia, the negative difference between the two series continues to grow until the end of the sample period.

Rwanda is an exceptional case. The country experienced a sharp decline in per capita GDP, while its synthetic continued a moderate upward trend. This does not however imply that the drop in the GDP was caused by the deployment of peacekeepers but rather indicates that we need to look into the typology, size, and background of the operation. Rwanda is clearly an outlier for the enormous number of civilians killed during the civil war. At the same time, the operation received much attention for the limitations of its rules of engagement. In a similar vein, the operation in Namibia focused narrowly on monitoring the peace process and elections as opposed to multidimensional approaches, which include capacity-building functions such as the rehabilitation of essential infrastructure and assistance in economic reconstruction and development, such as in Cambodia or Haiti.

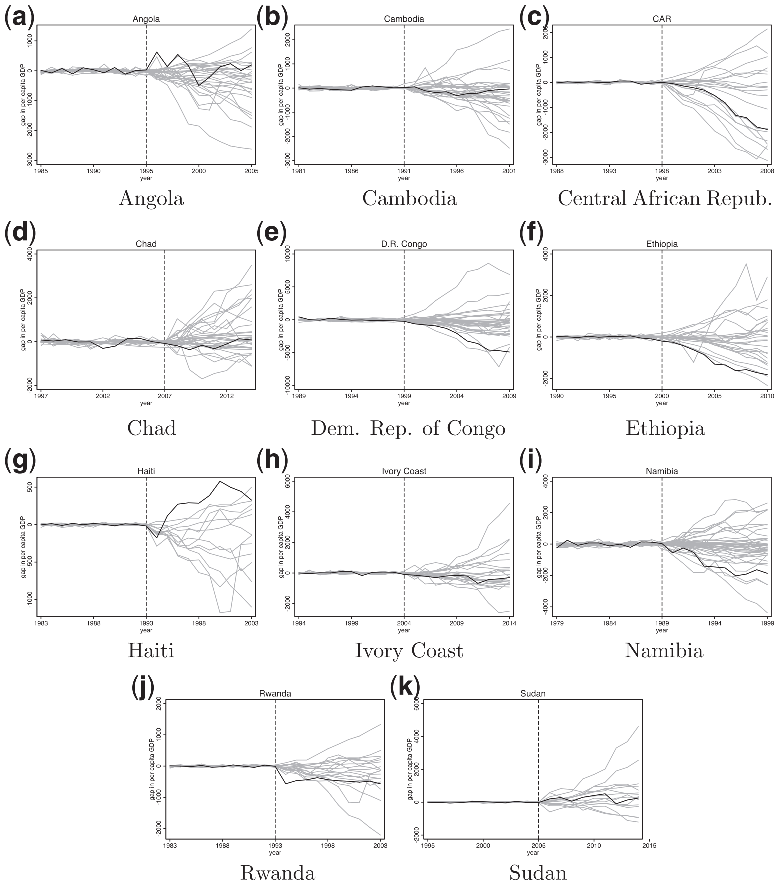

Figure 2. Placebo Gaps in per capita GDP for Angola, Cambodia, Central African Republic, Chad, DRC, Ethiopia, Haiti, Ivory Coast, Namibia, Rwanda, and Sudan [excludes countries with pre-intervention Mean Squared Prediction Error (MSPE) 1.5 times higher than treated's].

Moreover, the timing of the deployment is crucial as peacekeeping missions can be deployed before a potential war or during or after an actual war. Take the DRC. In 1999 the UN authorized a force of nearly 6000 troops, the United Nations Organization Mission in the Democratic Republic of the Congo, known by the French acronym, MONUC, to monitor the cease-fire. However, since its deployment, heavy fighting continued between rebels and government forces and between Rwandan and Ugandan forces. Only in 2002 Rwanda and the DRC signed a peace deal known as the Pretoria Accord, which however did not stop a subsequent wave of violence and insecurity throughout the country. Moreover, the diverging time series between the synthetic and the real DRC during the period just prior to the peacekeeping intervention (1992–1999) originates from unprecedented levels of violence and conflict in the region.

To evaluate the significance of our estimates, we check how often we obtain results of this magnitude if we choose states at random for the study instead of peacekeeping host countries. We run placebo studies by applying the synthetic control method to all countries in our sample. If the synthetic control had failed to fit per capita GDP for the real host country in the years before the peacekeeping intervention, we would have interpreted that much of the post-intervention gap between the real and the synthetic country was also artificially created by a lack of fit, rather than by the effect of intervention. Similarly, placebo runs with poor fit prior to the intervention do not provide information to measure the relative rarity of estimating a large post-intervention gap for a country that was well fitted prior to intervention. Figure 2 shows placebo runs while leaving out countries with a MSPE greater than one and half the MSPE of the treated country. The gray lines represent the gap associated with each of the runs of the test, that is the gap in per capita GDP between each country in the donor pool and its respective synthetic version. The superimposed black line denotes the gap estimated for the real host countries (e.g. Angola). We use conventional test levels and consider the effect of peacekeeping insignificant when more than 10% of the permutations are either above or almost identical with the baseline effect in the treated countries in the short run.[10] As the figure makes apparent, the placebo creates gaps of magnitude similar to the ones estimated for most of the peacekeeping host countries, with the exception of Angola, Haiti, Ethiopia, and Rwanda. Recall that in Angola and Haiti, peacekeeping had a positive effect on the GDP, whereas in Ethiopia and Rwanda, the effect was negative. We cannot reject the null hypothesis of no treatment effect of peacekeeping on per capita GDP for the remaining countries.

There are however a number of caveats that we should carefully bear in mind. First, data on civil war and conflict intensity are often very sketchy. It is not always clear when fighting starts or stops and whether a particular case qualifies as a civil war. For example, some data sets on civil wars include a case for the secessionist rebellion in Angola, while others do not. Second, the decision of when and where to deploy peacekeepers and where to send them is not random, that is treated and control units be of different nature. Although the synthetic control method mitigates endogeneity concerns by accommodating for unobservable (and time-varying) confounders, it may still fall short of addressing this selection issue. This might be particularly severe for case study with very high level of violence and conflict, for example the genocide in Rwanda. Interestingly, the direction of this potential bias is not obvious and may actually mitigate a potential positive impact of peacekeeping, when, for example, peacekeepers go to conflicts that are more intractable in a way that has not been accounted for by the synthetic control method. In fact, most of the literature suggests that peacekeepers are sent to more difficult cases, those with characteristics that make peace less likely to last (Fortna 2010). Third, it is sometimes difficult to attribute benefits to a peacekeeping mission when there are development agencies doing work at the same time. It is frequently the case that peacekeeping missions start at the same time as increased developmental assistance; this is because the additional security provided by peacekeeping allows developmental agencies to become more involved. There are cases where peace operations and development programs run side by side, so that causality cannot reasonably be attributed to the UN peacekeeping operation alone. Fourth, the impact of peacekeeping on economic development may encompass a multitude of diverse effects which can possibly balance themselves out (conflict recurrence, aid, and assistance programs to the host countries). Finally, the 10-year window for pre-intervention period to calibrate the synthetic control might not suffice for ruling out the presence of unobserved

10 Abadie et al. (2010) examine whether more than 5% of the fake experiments in the potential controls are above the outcome variable of the treated unit. Given the smaller sample size, we use the 10% level.

factors that could steer the post-treatment trajectories of per capita GDP. Unfortunately the very unstable and uncertain economic situation of the cases considered cannot allow us to rely on longer time series for the pre-operation period.

7. Conclusions

Since the end of the Cold War, UN peacekeeping missions are being increasingly involved in development efforts, often working side by side with humanitarian organizations, NGOs, and aid agencies. Peacekeeping operations have an essential role in bringing about all the conditions for successful reconstruction, including establishing law and judicial systems, rebuilding infrastructure, monitoring human rights, and electoral processes; yet, it is not clear whether they have any effect on the economic rehabilitation of host countries. Previous studies on peacekeeping place too large a weight on the security dimension, neglecting additional positive benefits accruing from the operation, in particular its impact on development outcomes. In fact, peacekeeping missions aim to improve security and, through security, the economic recovery of war-torn countries, which is critical in supporting incentives for peace. Whereas most of previous research has focused on conflict-related outcomes, such as the recurrence of wars, we investigate whether there are development consequences associated to peacekeeping missions.

One of the most challenging area in peace operations is to determine what impact can be attributed to the operation as against other factors. Given the high number of influences that can blur the attribution of causality, there are many obstacles to attributing benefits. Because comparison units are meant to approximate the counterfactual of the case of interest without the intervention, we restrict the donor pool to units with outcomes that are thought to be driven by the same structural process as the unit representing the case of interest and that were not subject to peacekeeping during the sample period of the study. In particular, we use the synthetic control method and make use of a combination of comparison units selected as the weighted average of all potential comparison units that best resembles the characteristics of the case of interest. Our findings suggest that, with few exceptions, peace operations do not appear to have significant positive effects on the economic development of host countries. Yet, our results are exploratory and partial, and it is still unclear whether peacekeeping has the potential to kick-start the local economy, or at least to provide a stimulus. Given the limited number of quantitative works on the economic impact of peacekeeping and the lack of consensus on a number of important empirical questions, additional empirical research in this area is certainly needed.

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Corrigendum

Corrigendum to: Defence Commitment and Deterrence in the Theory of War

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The online version of this article omitted a variable (function) in Section 2.4. This function has now been restored, necessitating some changes to the section. A few, additional clarifications have been added.

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