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Abstract

Experimental research has a long-established tradition in psychology and sociology, and a more recent but important history as a useful methodology in economics. In this article, we discuss the strengths and weaknesses of experiments as a method for studying terrorism and other national security topics. For example, given the paucity of data on counterterrorism policy decisions by governments, as well as for planning, targeting and selecting methods of attack by terrorist organizers, the experimental approach can substitute for this lack of field data. Experiments can also identify policy counterfactuals that might otherwise be unobservable. Hence, we begin by discussing several theoretical themes in the analysis of terrorism: interdependent security games such as airline screening; the dual nature of pre-emptive versus deterrent counterterrorism policies and the implications of this duality for policy coordination among targeted nations; the resurgence of interest in Colonel Blotto games when properly adjusted to reflect the asymmetric conflict between target governments and terrorist groups; and the relationship between terrorist activity and extreme punishments (or vendettas). The small but emerging literature using experiments to examine these issues is reviewed, paying particular attention to how experimental results can inform theory and policy. Finally, we propose new directions for researchers to explore.

Keywords

conflict experiments, counterterrorism game, interdependent security, terrorism experiments

Introduction

Research on terrorism and national security has significantly increased since the 11 September attack. Researchers in diverse fields have increasingly turned their attention to questions around terrorism and national security. Significant progress has been made, especially in developing models to explain and predict terrorist attacks and in analysis of observational datasets/event studies and survey data. Other articles in this special issue, as well as previous special issues around this topic, attest to the impact of this body of work: for example *Journal of Conflict Resolution* (2000) 44(6), *Defense and Peace Economics* (2003) 14(6), *Journal of Conflict Resolution* (2005) 49(2), *Defense and Peace Economics* (2005) 16(5), and *Journal of Conflict Resolution* (2010) 54(2).

However, information on *national security* decisions – the decisions that countries make in response to terrorist threats – is relatively scarce. Governmental officials are often (understandably) close-lipped about their chosen policies and the reasoning which led to them. This leaves researchers with little ability to test the predictions of models involving national security decisions, to distinguish between competing models or to refine their predictions of countries' reactions in advance of extreme events. We believe that controlled laboratory experiments offer a useful methodology in this context, and

that experiments have the potential to significantly contribute to our studies of terrorism and national security.

Lab experiments are related to, but remain distinct from other types of empirical work, including observational (empirical) research, surveys, and field (or social) experiments. In observational research, a researcher collects and analyses naturally occurring data (e.g. historical observations of attacks, as in Brandt & Sandler, 2010). In survey research, individuals from the population of interest answer questions about their intentions, motivations or behaviors (e.g. the motivations for terrorists to attack, as in Fair & Shepherd, 2006). Finally, field or social experiments involve a comparison of policies by inducing them in different populations or in the same population over different times (e.g. different security procedures at airports). Very few countries or other organizations are comfortable experimenting with anti-terrorism policies, and thus few field experiments have been run in this domain.

In contrast, laboratory experiments use human participants in relatively abstract and artificial settings (the laboratory) which are constructed to capture critical features of theories being tested. Participants are exposed to different treatments

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(policies) and their behavior is compared with the theory's predictions directly, as well as between the different treatments. Experiments can test theories of terrorism and national security and suggest how they might be improved. Experiments can identify unanticipated patterns of behavior, which can then be integrated into our theories and resulting predictions. Furthermore, experiments can test policies which have the potential to improve our national security, but which we cannot test in advance of implementation.

Like any scientific methodology, the experimental methodology has both advantages and disadvantages. Advantages include a high degree of control, the ability to explore counterfactuals, and an ability to replicate. In a laboratory experiment, a theory can be tested directly by controlling for extraneous factors, much as a physics experiment might control air pressure in measuring an atomic reaction. This additional control can be used to construct conditions to separate alternate theories and to test predictions that might not otherwise be identifiable with naturally occurring data. Additionally, experiments can illuminate the counterfactual: what would have happened if a different policy had been implemented. These results can be informative for policymakers as a 'wind tunnel' test in advance of implementation. Furthermore, as laboratory experiments are replicable, other researchers can reproduce the experiment and verify the findings independently.

On the other hand, the data that result from laboratory experiments are (by construction) different from observational data. Just because a theory predicts outcomes in a laboratory experiment, this does not mean it will work in reality. Thus, experiments can provide a middle ground between theoretical work and empirical reality. If a theory works in the lab, it can be further tested in the field. If it does not, either the theory or the experiment (or both) should be refined before further implications are discussed.

This article focuses on economics experiments rather than experiments in psychology, sociology or other related fields. This focus is primarily driven by the expertise and background of the authors. Readers interested in psychology experiments in terrorism might consult work by Jennifer Lerner and colleagues on individuals' reactions to terrorist events and their resulting risk perceptions (Lerner et al., 2003; Fischhoff et al., 2003; Fischhoff et al., 2005; Small, Lerner & Fischhoff, 2006), or by Randy Borum on the psychology of terrorists (Borum, 2004).

Our goal in this article is not to justify the use of the experimental method, nor to describe the specifics of how one might run an experiment (see Kagel & Roth, 1995, and Friedman & Sunder, 1994, for excellent discussions of these topics).¹ Instead, we will highlight four streams of research in national security in which researchers have used

experiments to test theories of national security and use them as exemplars of how experiments can complement theoretical and empirical analysis. We will also outline other areas in which we believe that experiments have the potential to make contributions in this field.

Each of these areas is treated in the subsequent sections. The fifth ensuing section contains our suggestions for other domains in which experiments could be run, and the final section concludes.

Interdependent security games

The area in which the most experimentation has been done involves *interdependent security* games. These games were introduced and theoretically analyzed by Heal & Kunreuther (2005, 2007; Kunreuther & Heal, 2003) in order to capture the decisions facing private firms (like airlines) who were deciding how much screening they should do (e.g. of customers, luggage, etc.). In these games, each firm can pay a cost to engage in a higher level of screening. While this higher level of screening eliminates potential damages from internal causes (e.g. one's own customers or luggage checked into one's own airline), it does not eliminate all potential damages (e.g. from individuals or luggage making connections from other airlines). For example, the downing of Pan Am flight 103 over Lockerbie, Scotland is often attributed to a bomb that was checked into a connecting flight that originated in Malta.

Heal & Kunreuther consider a simplified setting of two airlines, each choosing whether to engage in costly excess screening. If both pay the cost of screening c (invest in protection), the risk is eliminated. Each firm earns Y and pays the cost c . If either airline does not screen, they incur a risk of allowing a bomb onto their plane and bearing cost L . However, because baggage and individuals are transferred between airlines without additional screening, this risk is borne by *both* airlines. Thus, if one airline screens and the other does not, *each* airline faces a probability p of incurring the loss L . If neither airline screens, then each faces the probability p of loss L from their own unscreened cargo and the probability $(1-p)p$ of loss L from the other airline's unscreened cargo. These payoffs are represented in Table I, which depicts a simplified version of the game presented in Heal & Kunreuther (2005).

The theory identifies parameters in which we expect that firms will (and will not) choose to invest in protection. In particular, when c is low ($c < pL$), all firms will screen and when c is high ($c > (1-p)pL$) no firms will screen. However, in this middle range $pL > c > (1-p)pL$, there are two possible equilibria (both invest, and both do not invest), as well as a mixed-strategy equilibrium in which airlines randomize between investing and not investing.

This theory is difficult to test with observational data. In the field, the parameters which would allow us to make predictions are rarely known (although see Kearns & Oritz [2004] for a computational algorithm approach to estimate

¹ Other methodological articles include Binmore (1987, 1999); Plott (1982, 1991a, 1991b, 1994); Roth (1986, 1988, 1991, 1994); Smith (1976, 1989, 1994).

Table I. A simplified interdependent security game from Heal & Kunreuther (2005)

	Screen	No Screen
Screen	Y-c, Y-c	Y-c-pL, Y-pL
No Screen	Y-pL, Y-c-pL	Y-pL-(1-p)pL, Y-pL-(1-p)pL

these parameters). Furthermore, we cannot investigate a number of questions of interest, such as whether and how decisionmakers will coordinate on the high-investment equilibrium or learn to improve their decisions, or whether groups make this decision differently than individuals.

Thus a series of experiments have investigated these questions in the laboratory.² In Hess, Holt & Smith (2007), the authors first run experiments using the basic game finitely repeated. Participants were divided into groups of size four. Nine groups (36 participants) played in the baseline game. Each participant *simultaneously* determined whether they would invest or not invest. Participants then learned what others in their group had done. Based on those decisions, they faced a risk of losing money (or not), which was resolved by a random draw, and they were paid their resulting earnings (in dollars). Each group repeated the decision for 10 rounds (with the same partners). At the end of the experiment, participants were paid their earnings in cash, based on the decisions they and their counterparts made.

The experimental parameters were chosen to induce two (competing) equilibria. In the high-security equilibrium, everyone invests in extra protection which reduces the probability of an extreme event. In the low-security equilibrium, no one invests in extra protection. The results of this experiment are somewhat pessimistic. Only 30% of individuals invest in security.

The authors go on to examine this model under sequential rather than simultaneous moves. In this sequential treatment, participants were allowed to view the decisions of other group members as soon as they were submitted, even if they had not yet made their own investment decision. This condition significantly increased the proportion of individuals investing in security to 42%: a decided improvement but still far from an optimistic picture of the ability of firms to solve this problem without government or other intervention.³

Gong, Baron & Kunreuther (2009) also experimentally examine a game of interdependent security. They choose parameters in which there is a unique equilibrium in which neither

of the parties invests in additional protection, and compare decisions made by individuals with those made by groups. In the individual case, two individuals made their decisions simultaneously. In the group case, three individuals within a group made a collective decision, and two groups' decisions were compared to yield the outcome.

As in Hess et al., this article finds little evidence that individuals invest in security (although here this behavior is the sole equilibrium prediction). In the individual treatment only 22% of the decisions involved investing. When decisions were made by a group, the situation improved: 52% of decisions involved investing in higher levels of security, moving the outcome away from the equilibrium closer to the social optimum.

In a third article, Kunreuther et al. (2009) ask about the impact of information on decisions. Their experiment again uses parameters with one low-security equilibrium. Each individual makes 10 simultaneous decisions with the same partner. They then re-shuffle the partners and play another 10 rounds, continuing with this procedure until the time runs out. They compare behavior when participants receive full feedback after each round (they know the decision their partner chose) or when they receive partial feedback after each round (they know the outcome, but not their partner's decision).

This study again finds relatively low levels of investment in security, ranging from 25% to 38%, depending on the particular parameters used. There is no significant difference based on the type of feedback offered.

A final article returns to the parameter set of Hess et al. in which two equilibria exist, a high-security and a low-security outcome (Shafran, 2008). This experiment tests a policy of subsidizing the additional investment in security. They compare symmetric subsidies (everyone who invests receives one) and asymmetric subsidies (only some who invest receive subsidies). Participants are arranged into groups of five to seven players and play repeatedly with the same group. As predicted, when investment decisions are subsidized, individuals are significantly more likely to engage in them. With symmetric subsidies, 63% of decisions involved investing in the protective action. With asymmetric subsidies, 83% of decisions involved investing in the protective action (although the subsidies were sufficiently high that almost half of these involved free investments).

These four articles provide useful examples of how experiments can test theories and policies in national security. Hess et al. and Shafran explore situations in which there are multiple equilibria and contribute to the understanding of conditions under which firms will coordinate on the high-security outcome. Hess et al. demonstrate the importance of real-time communication in inducing coordination. Shafran identifies and tests a potential policy that might be considered to solve the coordination problem. Gong et al. and Kunreuther et al. explore situations in which there is one equilibrium (to not invest). Kunreuther et al. demonstrate that feedback does not influence choices in this setting. Gong et al. show that decisions made by a group involve higher levels of investment than decisions made by individuals.

² These articles predominantly focus on the playing of pure strategy equilibria. Whether subjects play mixed strategy equilibria in the lab (and how to measure this behavior) is a subject of much debate in the experimental community. See O'Neill (1987) and the response by Brown & Rosenthal (1990), and more recently, see Palacios-Huerta & Volij (2008) and the response by Levitt, List & Reiley (2010).

³ A second experiment, not discussed here due to space constraints, compares situations in which risks are symmetric or asymmetric across firms.

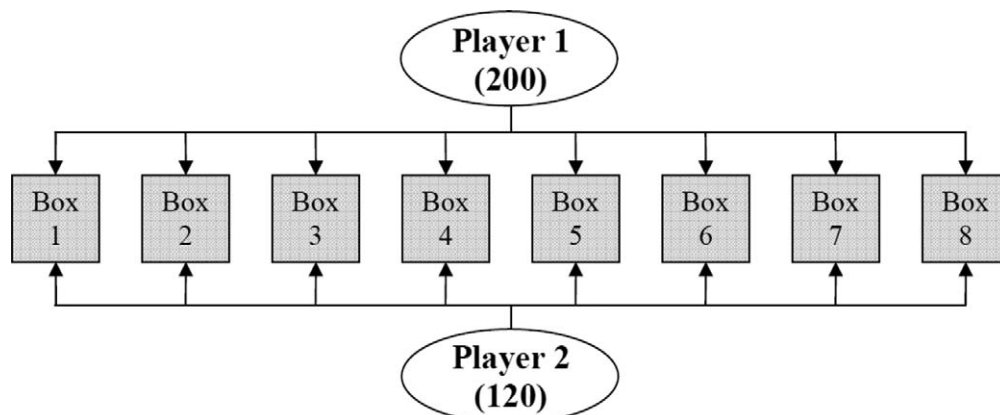


Figure 1. Blotto game from Chowdhury, Kovenock & Sheremeta (2009)

These experiments demonstrate conditions under which individuals or firms might under-invest in security, relative to the social optimum. They provide a first estimate of the likely effectiveness of considered policies like subsidies and help us to estimate a cost–benefit analysis of competing policies (asymmetric subsidies are cheaper and more effective than symmetric subsidies). In these ways, experiments can contribute to our understanding of security measures in settings of interdependent security.

Colonel Blotto

A second setting of experiments in security involves attack/defend games. One game which has been extensively theoretically studied is the Colonel Blotto game. In these games, players have a fixed number of resources (e.g. troops) which they can allocate to attacking (or defending) a particular target (e.g. battlefield). Players simultaneously decide how to allocate their resources between targets.⁴ In general, the side which allocates the most resources to a given target ‘wins’ it, while the other side(s) lose. Sometimes the payoff to each side depends on the proportion of targets won (see e.g. Roberson, 2006). In other variations, one target is chosen at random, and the side which has allocated the most resources to that target wins the entire game (see e.g. Hart, 2008). These games were developed for military strategy but also have applications for other settings of resource allocation (e.g. lobbying and campaigning by political parties, research and development expenditures among firms, advertising competition).

The Colonel Blotto game was introduced and analyzed by Borel (1921), but terrorism activity and recent events have rekindled an interest in attacker–defender games. Imagine a

terrorist target (like the USA) having a limited number of resources it can allocate to defend against multiple terrorist attacks. Similarly, terrorist organizations can allocate their resources among multiple targets, either coordinating their attack on one target or distributing their attacks across multiple targets (e.g. World Trade Center, Pentagon, and other national symbols). Thus, while Colonel Blotto games are somewhat outdated as a description of country-to-country warfare, they are excellent descriptions of terrorist-to-country attacking and defending activities.

Chowdhury, Kovenock & Sheremeta (2009) experimentally test behavior in a Blotto setting. In their experiment, one player acts as the attacker and another as the defender. Each player has resources to allocate to eight possible locations, as shown in Figure 1 from their article.

The players are asymmetric; the defender (player 1) has more resources available to allocate than the attacker (120 versus 200), capturing the inherent asymmetries between large target countries and small attacking terrorist organizations.

Each individual makes an allocation decision, learns the outcome (winning or losing for each location), and then makes a new decision in each of 15 rounds. The experiment compares an auction treatment (where the side with the most resources allocated to each position wins it) and a lottery treatment (where the probability of winning the location is the ratio of one side’s allocation to the total allocated there) and compares a partners design (where the individual keeps the same partner for all 15 rounds) and a strangers design (where the partner changes after each round).

The equilibrium prediction of this game involves the wealthier player (the defender) spreading resources evenly across the targets, while the poorer player (the attacker) uses a strategy which randomly targets a subset of locations and concentrates resources there. Randomization is taken to be consistent with terrorists rationally creating an aura of uncertainty about their actions. The results of the experiment provide surprising support for the equilibrium predictions of the theory in both the auction and lottery versions of the game.

⁴ A related literature exists on hide-and-seek games (where one party hides a valuable item or person while the other attempts to find it) that provide models of locating training camps or military bases that can be tested (see Crawford & Iriberri [2007] for a discussion of these games and some of the laboratory experiments that have been run to test their predictions).

Table II. Global security game from Arce & Sandler (2005)

	Pre-empt	Status quo	Deter
Pre-empt	$2B-c, 2B-c$	$B-c, B$	$B-c-C, B+b-C$
Status quo	$B, B-c$	0,0	$-C, b-C$
Deter	$B+b-C, B-c-C$	$b-C, -C$	Nash $b-2C, b-2C$

However, the experiments also uncover an interesting pattern of behavior. Attackers do not randomize over targets as predicted but instead exhibit serial autocorrelation in their allocation choices.⁵ It is as if participants 'stick to' their strategies intertemporally, even though they should be re-randomizing in each period. This effect is equally strong when they are paired with the same counterpart (partners) as when they are re-matched each round (strangers), suggesting the behavior is caused by an internal bias rather than by expectations of bias on the part of one's counterpart.

This article thus demonstrates both the success and failure of a theory in the laboratory. On the one hand, in the cross-section, the theory's predictions are supported. On the other hand, in the time series, individual decisionmaking appears biased in a way that may be exploitable by a defending nation. This experiment also illustrates a potential contribution of experiments: identifying an empirical regularity which was not theoretically predicted.

Global security games

A third area in which modeling work has been extremely impactful involves global security games. First introduced by Sandler & Lapan (1988), these games have been extensively explored in follow-up work, including Sandler (2003), Sandler & Arce (2003), Arce & Sandler (2005), Sandler & Siqueira (2006), Siqueira & Sandler (2007), and Sandler & Siqueira (2009).

In these games, countries can invest resources in one of three activities. First, they can keep the status quo and invest in productive activities which increase their GDP but have no impact on the likelihood or severity of a terrorist attack. If each of two countries chooses this option, we normalize their earnings to zero. Second, they can pre-empt, that is, invest in attacking the terrorists directly. In this case, they incur a cost c , and each country (themselves included) receives benefit B . These activities reduce the likelihood of a terrorist attack but

have a positive externality on other countries, as terrorists are less able to attack anyone. Finally, they can deter an attack, that is, invest in protective measures for their own population. This yields a benefit to them of b , but imposes a cost on either country of C , as terrorists are likely to simply choose another target, be it a different target nation or the targeting of a nation's citizens on foreign soil (as is often the case for US citizens). These payoffs are captured in Table II, from Arce & Sandler (2005).

Equilibrium predictions again depend on parameterizations. The most interesting (and most-studied) case involves $2B > c > B$ and $2C > b > C$. This parameterization captures fundamental externalities associated with counterterror policies that have been shown to be robust across myriad alternative formulations. Specifically, the 2×2 box highlighted in the upper left of Table II is the Prisoner's Dilemma associated with the voluntary provision of public goods because pre-emption is akin to public benefit for target nations. Alternatively, the 2×2 game in bold in the lower right of Table II is akin to the Prisoner's Dilemma as Tragedy of the Commons because policies such as the hardening of targets do not eliminate terrorists' activities, but direct them elsewhere. The authors call the combined scenario PD². The dominant strategy equilibrium of this game is when both countries deter, leading to the worse of all possible joint outcomes.⁶

Two experimental articles have attempted to test these models. In Colombier et al. (2009), four participants in a group each have resources which can be invested in these three possible activities. Based on their investments and the investments of their partners, they face a residual risk of attack and associated loss of income. Parameters are set such that there is a unique equilibrium of investing only in their own protection. Each group makes the decision 80 times, receiving feedback after each round about the decisions of others and the outcomes. The results are consistent with the theoretical predictions of free-riding on another country's policy of pre-emption. On average, individuals invest only 11% of their resources toward pre-emption, and that percentage significantly decreases over the course of the game.

A second set of treatments adds the possibility of reward or punishment. After observing each individual's contribution, participants can reward (or punish) their counterparts at a cost to themselves. Results indicate that adding this option significantly improves global cooperation. Groups with the ability to reward contribute on average 55% of their resources toward pre-emption, while groups with the ability to punish contribute on average 36%. Both are significantly larger than baseline contributions of 11%.

⁵ This result is similar to those found in the literature on mixed strategy equilibrium play, referenced above.

⁶ Empirical evidence that partially supports this phenomenon is given in Sandler, Arce & Enders (2009) and a way to mitigate deterrence through policies that leverage network effects is examined in Sandler, Arce & Enders (2010). See also Brockner (1993).

Interestingly, while both rewards and sanctions increase contribution, sanctions are used only rarely (only 15% of people ever sanction others) while rewards are used frequently (58% of people reward others). One possible reason for this pattern is that sanctions are doubly costly; they cost the punisher and the punished, while rewards cost the rewarder but benefit the target.

A second article explores global security games in a different setting. Cadigan & Schmitt (2010) allowed participants to engage in activities with either positive or negative spillover effects (externalities). Participants were arranged into groups of three and made eight decisions with new partners. One experimental treatment involved negative externalities (e.g. resources would be spent on defense), another involved positive externalities (e.g. resources would be spent on attacking), and a final treatment involved a baseline setting of no externalities. As predicted, expenditures were significantly lower in the presence of positive externalities than none. Expenditures were directionally higher in the presence of negative externalities than none, but this result was not statistically significant.

Both these articles test and support the predictions of the theories of global security games. Individuals engage in under-spending on security in the presence of positive externalities and (directionally) over-spending on security in the presence of negative externalities. However, these experiments can also tell us about mechanisms to meliorate these effects. The ability (and willingness) of nations to punish and reward those who are doing their part in the fight against terror may increase the provision of resources toward this global public good. Rewards are somewhat more effective than punishments in the lab, but they are also used more frequently, thus further work needs to be done to determine the causality of this relationship. Additional work is also needed to explore whether this finding translates into the field, where rewards and punishments are difficult to provide and enforce.

Punishment/vendettas

A final area which is linked to terrorism has to do with punishment and vendettas. A series of articles explores the question of when individuals choose to punish free-riders (or reward contributors) in public goods settings (see e.g. Fehr & Gächter, 2000, 2002; Sefton, Shupp & Walker, 2007; Nikiforakis, 2008; and Nikiforakis & Normann, 2008). However, a more recent article looks at *punishment cycles*, that is, how punishment for a transgression can inspire counter-punishment which can inspire counter-counter-punishment, etc.

In Abbink & Hermann (2009), participants in the experiment are arranged into two groups of four players each with identical endowments. In each round, each player can reduce the payoff of each member of the other group at a small cost to himself. The game is repeated for ten rounds. In a second treatment, each individual who engages in punishment is entered into a lottery in order to win a small prize. Since punishment costs resources, the equilibrium prediction is that no

punishment should be observed. Even (and especially) if others are punishing, the benefit from punishing is less than the cost. However, the authors find that individuals punish. In the baseline experiment, about 13% of individuals choose to punish, while in the prize condition, the punishment rate is 41%. In particular, the authors find a significant correlation of punishing among the different groups. Punishment by one group is responded to by a high frequency of punishment by the other group.

This article thus demonstrates how a lab experiment in an abstract setting with student participants can be used to model real-world forces like revenge and vendettas. Emotions experienced in the lab, while not as strong or long-lasting as those in the field, are strong enough to induce the kinds of punishment and counter-punishment behaviors we observe in terrorists. Future research can investigate mechanisms to meliorate these cycles.

Potential future work⁷

These four streams of research explore decisionmaking in terrorism and national security from multiple angles. Within each stream, further work can clearly be done. In interdependent security games, more work needs to be done on exploring possible policy solutions that might induce firms or organizations to invest in security. These solutions might be examined both in cases of multiple equilibria (tipping) and in cases where there exists a unique equilibrium of non-investment.⁸ Of course, regulatory solutions are always an option. Governments can simply require that firms invest in security. However, this might result in excess investment – investment in security when the underlying cost structure counterindicates such an investment.

More market-based policies might attempt to internalize the externality inherent in the security investment, in order to move investment decisions closer to optimal, and could be tested in the lab. For example, subsidies or tax breaks for investments (symmetric or asymmetric), favored status bidding on contracts for firms that invest, or cost-sharing between firms on screening equipment and staff could be explored to evaluate their likely impact. Mechanisms that have been identified to internalize externalities in other settings theoretically and tested experimentally (e.g. Groves & Ledyard, 1977, as tested in Chen & Plott, 1996) might also be considered.

Additional research could investigate the mixed strategy equilibria predicted by many parameterizations of these games. The mixed strategy equilibrium calls for each firm to randomly choose whether to invest or not invest in screening. But an

⁷ Special thanks to Todd Sandler for suggesting many of the ideas presented in this section.

⁸ In this sense, the interdependent security games share much in common with the deterrence game that is nested in Arce & Sandler's (2005) PD².

alternative formalization might involve screening only a randomly selected proportion of bags. Presumably, this formalization would involve some fixed cost and some variable cost based on the proportion of bags screened. Understanding how this option changes the game, the predicted equilibria, and whether individuals are more (or less) likely to choose it than either of the pure strategies (screening none or screening all), would be a useful next step in the research.

In Colonel Blotto games, a number of experiments suggest themselves. Current work is exploring behavior when the targets are valued differently by the attacker and defender, when multiple attackers or defenders need to coordinate their strategies, and when the decisionmakers are responsible not only for their own outcomes but for the outcomes of others (Arce et al. 2010).

Other research might explore behavior when some targets are inherently weaker or stronger than others. Perhaps it is easier to defend more centralized cities with few entry/exit points than other, more decentralized, cities. Thus resources spent on defense might be more effective for some locations, while more must be spent on an attack in order to be successful. This factor might interact with the asymmetric value of the target – for example, an easy-to-defend site might be worth less to the defender than a hard-to-defend one. Future work can identify and test equilibrium predictions under this kind of asymmetry. In particular, it is an open question as to how well policymakers and their constituents understand Dresher's (1961) classic, 'no-soft-spot' principle, where the defender distributes defensive resources in a pecking order in which high-value or highly vulnerable assets are protected first, leaving some targets unprotected. Will accountability, learning, or experience affect a policymaker's willingness to leave some targets undefended, particularly if a terrorist's success leads to a change in cabinet (e.g. Siqueira & Sandler, 2007; Gassebner, Jong-A-Pin & Mireau, 2008; Arce, Kovenock & Roberson, 2010)? Furthermore, recent theory in this setting also examines the endogenous decision to reveal information about target protection (e.g. Zhuang & Bier, 2007; Bernhardt & Polborn, 2010) which could also be profitably explored in the lab.

In global security games, experiments can again focus on policy solutions to the free-rider problem. Here regulatory solutions are not as reasonable (since the actors are different countries), but policies like cost-sharing for pre-emption might be effective. Arce & Sandler (2005) show efficiency implications for these types of policies, which could also be tested.

A second article generalizes the pre-empt/deter decision when countries have interests both at home and abroad (Sandler & Siqueira, 2006). They find that countries with limited international interests will overdeter, while those with significant international interests will underdeter. This prediction, and extensions of their model, could be similarly tested.

Other experiments might investigate the baseline model with different variations. For example, consider the situation where a country that is highly targeted (e.g. the USA) or has

a lower cost of pre-emption has an incentive to take pre-emptive action while other targets (e.g. the EU) do not (as in Sandler & Siqueira, 2006). These parameters lead to asymmetric equilibria, which could be tested in the lab.

In vendetta and punishment settings, experiments might explore what can be done to reduce or eliminate punishment cycles. While some work in psychology has investigated this question (e.g. Keysar et al., 2008), more work could clearly be done. Apologies, restitution, or foreign aid might be significantly cheaper and more effective ways to break a cycle of punishment than all-out war, although the impacts of these behaviors on the likelihood of future attackers would also need to be measured.

Finally, there are a variety of theories that have not yet been tested experimentally but could be.

For example, one set of theories involves the policy of negotiating for hostages. Sandler, Tschirhart & Cauley (1983) provide a model of negotiation for hostages between terrorists and governments which could be tested in the lab. In their model, for example, the effectiveness of a no-negotiating strategy depends on the risk attitudes of the terrorists; it is effective with risk-preferring terrorist groups but not for risk-averse terrorist groups. The lab could explore whether participants would appropriately update their beliefs about their counterpart's 'type' on the basis of their actions and choose the appropriate strategy. Lapan & Sandler (1988) present a related theory in which governments choose a level of deterrence in advance of an attack, and identify the resulting time-inconsistent strategy that governments must play – committing in advance to not negotiate, but regretting that choice once an important hostage is acquired. Will individuals uphold their ex-ante claims of 'no negotiation' policies, or cave to existing pressures? Will those decisions be reflected in future attack decisions of their opponents?

A second set of theories involve the signaling between terrorists and governments. In Lapan & Sandler (1993), governments use the behavior of terrorist groups to infer their strengths and make subsequent decisions about whether to resist or capitulate. Of course, terrorists have an incentive to misrepresent their strength by (partially) pooling with stronger groups. Will participants do this, and will defenders anticipate and discount this strategy?

Sandler & Arce (2003) provide a testable model of a government bargaining with terrorist groups with moderate and hardline members. The equilibrium of this model again predicts pooling; moderates mimic hardliners in order to obtain larger concessions and this leads to an adverse selection of hard-liners subsequent to bargaining. The pooling phenomenon again appears in Arce & Sandler (2010) whereby terrorists' 'spectacular' attacks are shown to be a pooling outcome when the government is uncertain as to whether terrorists seek outcome goals such as political concessions or procedural goals such as increasing their pool of recruits in response to a government overreaction to the spectacular. Experiments can guide our understanding by

exploring conditions under which spectaculars occur and how these actions are interpreted.

Another line of research sets governments and terrorist organizations in competition for grassroots support (Siqueira & Sandler, 2006). Depending on the parameter values, governments or terrorist organizations are better off taking the initiative in generating support. These endogenous timing predictions could also be tested in the lab.

In sum, there are numerous possibilities for using experiments to test theories of terrorism. Some build on the four areas we have reviewed here, but others identify other theories that have not yet been tested, or even strategic situations that have not yet been modeled using game-theoretic tools, but which clearly could be.

Conclusion

The goal of this article has been to identify a role for experiments in studying terrorism and national security questions. We described four domains in which experiments are already being run and identified more where they might be considered.

Experiments can accomplish objectives that other forms of analysis cannot. They can offer clean tests of theories by constructing situations in which the assumptions of the theories are all met, and observing the outcome. They can identify where theories predict well (e.g. free-riding in global security games) and where they need to be enriched to capture behavioral regularities that might be exploitable (e.g. intertemporal correlation in Blotto games). They can resolve questions that theory cannot resolve (e.g. the impact of individual versus group decision-making). They can suggest and test policies that can improve behavior (e.g. reducing cycles of punishment).

Every methodology has limitations, and experiments are no exception. Experiments excel at testing theories, but other methods such as surveys, interviews, and focus groups are better for collecting the primary data around which the theory is constructed. Experiments are useful for testing our models of where a group will attack, but econometric analysis of observational data is better for explaining and predicting when an attack will occur. Although it represents a relatively new field, we believe that experiments are an important addition to the researcher's toolbox and can complement other methodologies in advancing our understanding of terrorist and national security decisions.

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References

- Abbink, Klaus & Benedikt Hermann (2009) Pointless vendettas. Working paper, CBEEES, University of East Anglia, Norwich, UK.
- Arce, Daniel & Todd Sandler (2005) Counterterrorism: A game-theoretic approach. *Journal of Conflict Resolution* 49(2): 183–200.
- Arce, Daniel & Todd Sandler (2010) Terrorist spectaculars: Backlash attacks and the focus of intelligence. *Journal of Conflict Resolution* 54(2): 354–373.
- Arce, Daniel; Rachel Croson, Chetan Dave, Catherine Eckel, Enrique Fatas & Charles Holt (2010) Behavioral insights into national security issues. National Science Foundation Grant (funded), BCS-0905060.
- Arce, Daniel; Dan Kovenock & Brian Roberson (2010) Suicide terrorism and the weakest link. Working paper, Purdue University.
- Berhardt, Dan & Mattias Polborn (2010) Non-convexities and the gains from concealing defenses from committed terrorists. *Economics Letters* 107(1): 52–54.
- Binmore, Kenneth (1987) Experimental economics. *European Economic Review* 31(1–2): 257–264.
- Binmore, Kenneth (1999) Why experiment in economics? *Economic Journal* 109(453): F16–24.
- Borel, Emile (1921) La Theorie du Jeu et les Equations Integrales a Noyau Symetrique. *Comptes Rendus de l'Academie des Sciences* 172: 1304–1308. Transl. Leonard J. Savage (1953) The theory of play and integral equations with skew symmetric kernels. *Econometrica* 21(1): 97–100.
- Borum, Randy (2004) *Psychology of Terrorism*. Tampa, FL: University of South Florida.
- Brandt, Patrick T & Todd Sandler (2010) What do transnational terrorists target? Has it changed? Are we safer? *Journal of Conflict Resolution* 54(2): 214–236.
- Brockner, Joel (1992) The escalation of commitment to a failing course of action: Toward theoretical progress. *Academy of Management Review* 17(1): 39–61.
- Brown, James N & Robert W Rosenthal (1990) Testing the minimax hypothesis: A re-examination of O'Neill's game experiment. *Econometrica* 58(5): 1065–1081.
- Cadigan, John & Pamela M Schmitt (2010) Strategic entry deterrence and terrorism: Theory and experimental evidence. *Public Choice* 143(1–2): 3–22.
- Chen, Yan & Charles R Plott (1996) The Groves-Ledyard mechanism: An experimental study of institutional design. *Journal of Public Economics* 59(3): 335–364.
- Chowdhury, Subhasish; Dan Kovenock & Roman M Sheremeta (2009) An experimental investigation of Colonel Blotto games. Working paper, CESifo Working Paper Series, CESifo Group Munich.
- Colombier, Nathalie; David Masclet, Daniel Mirza & Claude Montmarquette (2009) Global security policies against terrorism and the free riding problem: An experimental approach. Working paper, CIRANO, Montreal, Canada.

- Crawford, Vincent P & Nagore Iriberrri (1007) Fatal attraction: Salience, naivete and sophistication in experimental 'hide-and-seek' games. *American Economic Review* 97(5): 1731–1750.
- Dresher, Melvin (1961) *The Mathematics of Games of Strategy*. Englewood Cliffs, NJ: RAND.
- Fair, C Christine & Bryan Shepherd (2006) Who supports terrorism? Evidence from fourteen muslim countries. *Studies in Conflict and Terrorism* 29(1): 51–74.
- Fehr, Ernst & Simon Gächter (2000) Cooperation and punishment in public goods experiments. *American Economic Review* 90(4): 980–994.
- Fehr, Ernst & Simon Gächter (2002) Altruistic punishment in humans. *Nature* 415: 137–140.
- Fischhoff, Baruch; Roxana M Gonzalez, Deborah A Small & Jennifer S Lerner (2003) Judged terror risk and proximity to the World Trade Center. *Journal of Risk and Uncertainty* 26(2–3): 137–151.
- Fischhoff, Baruch; Roxana M Gonzalez, Jennifer S Lerner & Deborah A Small (2005) Evolving judgments of terror risks: Foresight, hindsight, and emotion. *Journal of Experimental Psychology: Applied* 11(2): 124–139.
- Friedman, Daniel & Sunder Shyam (1994) *Experimental Methods: A Primer for Economists*. Cambridge University Press: New York.
- Gassebner, Martin; Richard Jong-A-Pin & Jochen O Mierau (2008) Terrorism and electoral accountability: One strike, you're out! *Economics Letters* 100(1): 125–129.
- Gong, Min; Jonathan Baron & Howard Kunreuther (2009) Group cooperation under uncertainty. *Journal of Risk and Uncertainty* 39(3): 251–270.
- Groves, Theodore & John Ledyard (1977) Optimal allocation of public goods: A solution to the 'free rider' problem. *Econometrica* 45(4): 783–809.
- Hart, Sergiu (2008) Discrete Colonel Blotto and general lotto games. *International Journal of Game Theory* 36(3–4): 441–460.
- Heal, Geoffrey & Howard Kunreuther (2005) IDS models of airline security. *Journal of Conflict Resolution* 49(2): 201–217.
- Heal, Geoffrey & Howard Kunreuther (2007) Modeling interdependent risks. *Risk Analysis* 27(3): 621–634.
- Hess, Rachel O; Charles A Holt & Angela M Smith (2007) Coordination of strategic responses to security threats: Laboratory evidence. *Experimental Economics* 10(3): 235–250.
- Kagel, John & Alvin Roth (1995) *The Handbook of Experimental Economics*. Princeton, NJ: Princeton University Press.
- Kearns, Michael & Luis Ortiz (2004) Algorithms for interdependent security games. In: Sebastian Thrun, Lawrence Saul & Bernhard Scholkopf (eds) *Advances in Neural Information Processing Systems 16*. Cambridge, MA: MIT Press.
- Keysar, Boaz; Benjamin A Converse, Jiunwen Wang & Nicholas Epley (2008) Reciprocity is not give and take: Asymmetric reciprocity to positive and negative acts. *Psychological Science* 19(12): 1280–1286.
- Kunreuther, Howard & Geoffrey Heal (2003) Interdependent security: The case of identical agents. *Journal of Risk and Uncertainty* 26(2–3): 231–249.
- Kunreuther, Howard; Gabriel Silvasi, Eric T Bradlow & Dylan Small (2009) Bayesian analysis of deterministic and stochastic prisoner's dilemma games. *Judgment and Decision Making* 4(5): 363–384.
- Lapan, Harvey E & Todd Sandler (1988) To bargain or not to bargain: That is the question. *American Economic Review* 78(2): 16–20.
- Lapan, Harvey E & Todd Sandler (1993) Terrorism and signalling. *European Journal of Political Economy* 9: 383–397.
- Lerner, Jennifer S; Roxana M Gonzalez, Deborah A Small & Baruch Fischhoff (2003) Effects of fear and anger on perceived risks of terrorism: A national field experiment. *Psychological Science* 14(2): 144–150.
- Levitt, Steven D; John A List & David H Reiley (2010) What happens in the field stays in the field: Professionals do not play minimax in laboratory experiments. *Econometrica* 78(4): 1413–1434.
- Nikiforakis, Nikos (2008) Punishment and counter-punishment in public goods games: Can we really govern ourselves? *Journal of Public Economics* 92(1–2): 91–112.
- Nikiforakis, Nikos & Hans-Theo Normann (2007) A comparative statics analysis of punishment in public goods experiments. *Experimental Economics* 11(4): 358–369.
- O'Neill, Barry (1987) Nonmetric test of the minimax theory of two-person zerosum games. *Proceedings of the National Academy of Sciences* 84: 2106–2109.
- Palacios-Huerta, Ignacio & Oscar Volij (2008) Experientia docet: Professionals play minimax in laboratory experiments. *Econometrica* 76(1): 71–115.
- Plott, Charles (1982) Industrial organization theory and experimental economics. *Journal of Economic Literature* 20(4): 1485–1527.
- Plott, Charles (1991a) Will economics become an experimental science? *Southern Economic Journal* 57(4): 901–919.
- Plott, Charles (1991b) Economics in 2090: The views of an experimentalist. *Economic Journal* 101(404): 88–93.
- Plott, Charles (1994) Market architectures, institutional landscapes and testbed experiments. *Economic Theory* 4(1): 3–10.
- Roberson, Brian (2006) The Colonel Blotto game. *Economic Theory* 29(1): 1–24.
- Roth, Alvin (1986) Laboratory experimentation in economics. *Economics & Philosophy* 2(2): 245–273.
- Roth, Alvin (1988) Laboratory experimentation in economics: A methodological overview. *Economic Journal* 98(393): 974–1031.
- Roth, Alvin (1991) Game theory as a part of empirical economics. *Economic Journal* 101(404): 107–114.
- Roth, Alvin (1994) Let's keep the con out of experimental econ: A methodological note. *Empirical Economics* 19(2): 279–289.
- Sandler, Todd (2003) Collective action and transnational terrorism. *The World Economy* 26(6): 779–802.
- Sandler, Todd & Daniel Arce (2003) Terrorism and game theory. *Simulation & Gaming* 34(3): 19–37.
- Sandler, Todd & Harvey E Lapan (1988) The calculus of dissent: An analysis of terrorists' choice of targets. *Synthese* 76: 245–261.

- Sandler, Todd & Kevin Siqueira (2006) Global terrorism: Deterrence versus preemption. *Canadian Journal of Economics* 39(4): 1370–1387.
- Sandler, Todd & Kevin Siqueira (2009) Games and terrorism: Recent developments. *Simulation and Gaming* 40(2): 164–192.
- Sandler, Todd; John T Tschirhart & Jon Cauley (1983) A theoretical analysis of transnational terrorism. *American Political Science Review* 77(1): 36–54.
- Sandler, Todd; Daniel Arce & Walter Enders (forthcoming) An evaluation of Interpol's cooperative-based counterterrorism linkages. *Journal of Law and Economics*.
- Sefton, Martin; Robert Shupp & James M Walker (2007) The effect of rewards and sanctions in provision of public goods. *Economic Inquiry* 45(4): 671–690.
- Shafraan, Aric P (2008) Coordination failure and tipping in interdependent security games: Experimental evidence. Working paper, Department of Economics, Cal Poly University, CA.
- Siqueira, Kevin & Todd Sandler (2006) Terrorists versus the government: Strategic interaction, support and sponsorship. *Journal of Conflict Resolution* 50(6): 878–898.
- Siqueira, Kevin & Todd Sandler (2007) Terrorist backlash, terrorism mitigation and policy delegation. *Journal of Public Economics* 91: 1800–1815.
- Small, Deborah A; Jennifer S Lerner & Baruch Fischhoff (2006) Emotion priming and attributions for terrorism: Americans' reactions in a national field experiment. *Political Psychology* 27(2): 289–298.
- Smith, Vernon (1976) Experimental economics: Induced value theory. *American Economic Review* 66(2): 274–279.
- Smith, Vernon (1989) Theory, experiment and economics. *Journal of Economic Perspectives* 3(1): 151–169.
- Smith, Vernon (1994) Economics in the laboratory. *Journal of Economic Perspectives* 8(1): 113–131.
- Zhuang, Jun & Vicki M Bier (2007) Balancing terrorism and natural disasters: Defensive strategy with endogenous attacker effort. *Operations Research* 55(5): 976–991.

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