GEOGRAPHIC PROFILING OF LONE WOLF TERRORISTS: THE APPICATION OF ECONOMICS, GAME THEORY AND PROSPECT THEORY

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This paper presents an economic analysis of the choices made by lone wolf terrorists. Using RAND-MIPT data about the fatalities that are inflicted by different attack methods, the paper develops an analysis on a foundation of orthodox utility theory and Markowitz-Tobin approximations. This approach permits a computable opportunity set within a risk-reward or mean-variance framework. Optimal choices can be determined using the Markowitz quadratic programming technique. The framework may provide a useful foundation for an economic perspective on 'offender profiling' applied within a terrorism context. Mapping attack methods into mean-variance space provides a more definitive categorisation of the riskiness of attack methods from the terrorist's perspective and suggests the possibility of identifying the terrorist's revealed risk preference. Inferences about the unknown offender may be drawn that complement other aspects of the investigative process. One of the key challenges of law enforcement is drawing inferences about the offender's location and the location of potential targets. Superimposing a game theoretical payoff matrix over a geographic location where payoffs are partially informed by the terrorist's choices and risk preference may contribute another, economic, perspective to this part of the law enforcement process. Prospect theory may also contribute useful insights into the geographical profiling problem.

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Key words: lone wolf, risk-reward, optimal choice, risk preference, law enforcement, offender profiling, geographic profiling, game theory, payoff matrix, prospect theory.

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I. Introduction

Lone wolf terrorism is terrorism perpetrated by an individual outside of any organisational structure and, strictly speaking, without the assistance of any accomplices. From an economics perspective, this type of behaviour is purposeful or rational individually motivated violent action directed towards the achievement of some end or objective and undertaken under conditions of risk and uncertainty. The actions of the lone wolf terrorist are especially amenable to the application of economic theory within which the individual remains the archetype decision-maker. Such an application should allow us to say something about the opportunity set from which the lone wolf terrorist may choose a terrorist action and allow us to say something about what choices may be more or less likely under different conditions. More than this, though, we should expect to be able to draw inferences from our economic analysis about particular instances of lone wolf terrorism. If these expectations regarding our theoretical framework are met, the economic analysis of terrorist behaviour would be extended in much the same way that the psychological analysis of terrorist behaviour has been extended by offender profiling or, more formally, investigative psychology.

II. Visualising the Terrorist's Opportunities in Terms of Risk and Reward

'Risk' and 'reward' are concepts that everyone can understand, even when more precise economic definitions are appended to their everyday meaning. But they are not easy concepts to visualise when they are encompassed within the long lists of outcomes, utilities and probabilities of full expected utility analysis[1]. These disadvantages must be overcome if the results of economic analysis are to be perceived as more directly useful to the investigative and law enforcement process. One way to bring risk and reward to the forefront of the analysis is to work in terms of the two moments of the distribution of outcomes of a terrorist action: the mean or average outcome and the standard deviation of the outcomes around the mean. The mean or average outcome of a terrorist attack is the number of fatalities[2] that the terrorist can expect to result from the use of a particular attack method. The dispersion of outcomes around the average, measured by standard deviation or variance, reflects the risk that the actual outcome may be quite different from what the terrorist expected[3]. When the payoffs are a quantifiable unit such as fatalities[4] with a calculable average and standard deviation, each attack method can be represented by a single point in risk-reward space. Table 1 presents the mean number of fatalities and the standard deviation of those fatalities[5] for each of the RAND-MIPT attack methods—armed attacks, arson, assassination, hostage-taking, bombing, hijacking, kidnapping and unconventional attacks—for the period 1967 to 2007.

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[1] An extended discussion originally intended to follow the introduction is contained in Appendix 1.

[2] See appendix 1 for a discussion of this point.

[3] Whereas other types of economic decision-makers may only be concerned with downside risk or outcomes below expectations, this need not be the case in the terrorism context. As such, standard deviation around an expected outcome is perhaps a more suitable measure for risk than in some other contexts.

[4] Contrast this with the abstract payoff 'political influence' that is sometimes used in theoretical economic analysis. Another quantifiable payoff is media coverage which can be measured in a number of different ways (see Pohl 2014a and 2014b).

[5] This is computed using data for the period 1967 to 2007.

Table 1

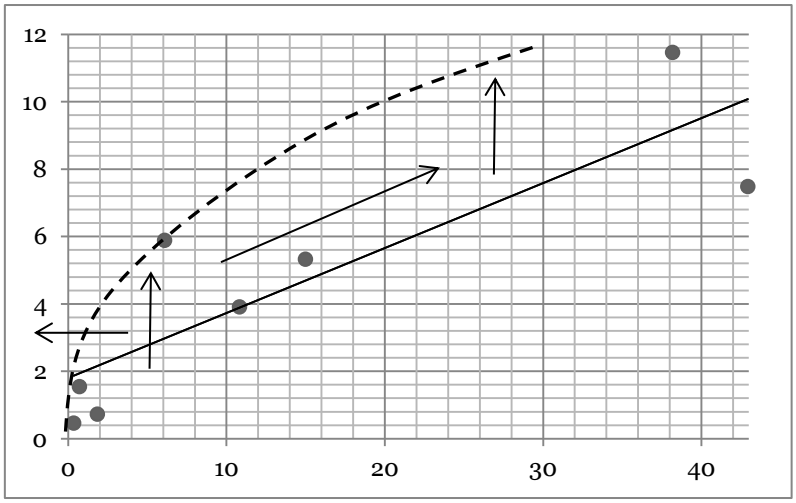
Individual Attack Methods: Fatalities and Variability of Outcomes

Attack Type	Average Fatalities and Injuries Per Attack Per Year	Standard Deviation
Armed Attacks	5.32	15.00
Arson	0.72	1.85
Assassination	1.54	0.71
Hostage	11.46	38.18
Bombing	5.88	6.09
Hijacking	3.91	10.82
Kidnapping	0.46	0.35
Unconventional	7.48	42.94

The generally positive risk-reward trade-off that characterises these attack methods is depicted in Figure 1 where the risk-reward pairs for each of these attack methods are plotted as individual points. The positively sloped trend-line is sketched[6]. The riskiness of different attack methods can be compared. For example, a terrorist who chooses bombing bears a greater risk that the outcomes will be different from what he expected than the terrorist who chooses an arson attack. This is more precise than the 'qualitative' risk assessments that are sometimes found in the literature. This is, however, only part of the picture. A terrorist might not use the same single attack method within or across periods.

Figure 1

The Risk-Reward Trade-Off and Attack Method Combinations



If the lone wolf terrorist can combine attack methods during a period or across periods, the risk-reward trade-off is stretched towards the northwest in risk-reward space to reflect the higher expected outcomes and lower risk of attack method combinations *vis-à-vis* individual attack methods. If we do not take combinations of attack

[6] The risk-reward pairs will not form a perfectly straight line except in equilibrium (see Sharpe 1966). The plot for the 1967 to 2007 period is one snapshot of a dynamic process. Always, however, the generally positive risk-reward trade-off is observed.

methods into account and consider only the relatively linear risk-reward trade-off plotted by individual attack methods, we underestimate the terrorist's payoffs and overestimate the risk that the terrorist bears in undertaking some types of attacks in combination with others. When combinations of attack methods are considered, the risk-reward trade-off becomes the concave shape depicted by the dashed line in Figure 1. This dashed line also represents an 'efficient frontier' for the terrorist's opportunity set beyond which gains in terms of lower risks or increased numbers of expected fatalities are impossible given the current state of affairs describing the terrorism context.

The efficient frontier is computed by the solution of the quadratic programming problem first elaborated by Markowitz (1952):

$$\max E(x_c) = \sum_{i=1}^{n} w_i E(x_i)$$

$$\sigma_c^* = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j p_{ij} \sigma_i \sigma_j}$$

The expected outcome of a combination, $E(x_c)$, is the weighted average of the expected outcomes of each attack method in a combination. The weight, w_i, is the proportion of each attack method in a total combination. For example, a terrorist who undertakes 3 bombings and 3 assassinations assigns a 0.50 to each of these two attack methods and a 0.00 weight to each other method[7]. An optimal combination is found by maximising the expected outcome subject to a given level of risk or standard deviation. The standard deviation of a combination is not a simple weighted average of the individual standard deviations. Because the outcomes of attack methods are imperfectly correlated the correlation, ρ_{ij}, between each pair of attack methods must be considered in determining the riskiness of a combination of attack methods. As a result of applying this method, the optimal combinations of attack methods are identified. Although particular attack methods dominate at different levels of risk—for example, assassination dominates at low levels of risk—other attack methods constitute the optimal combinations across all risk ranges. So, even though a very risk-averse terrorist might choose assassinations or targeted armed attacks, it may be optimal for him to combine this type of attack with a more risky attack method such as bombing even though bombing considered as a single attack method would not normally be selected by a very risk-averse terrorist.

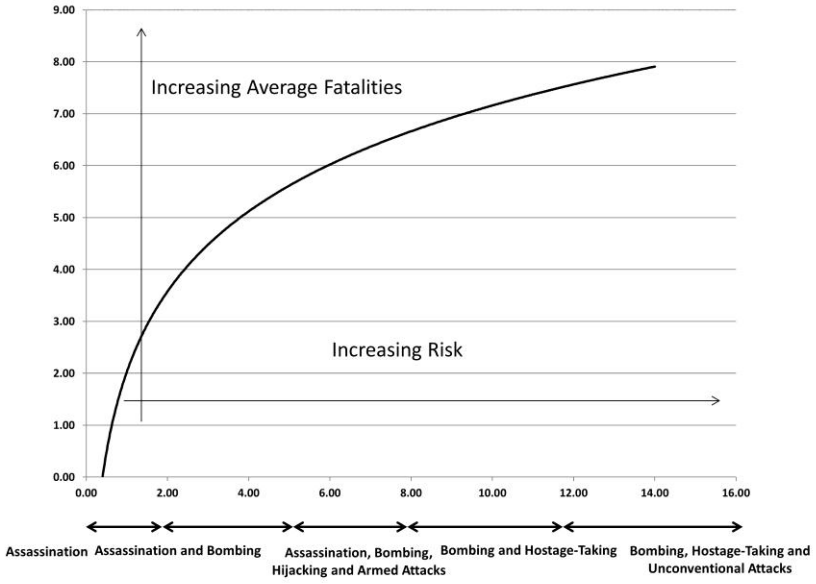
The main constituents of the efficient or optimal attack method combinations across different risk ranges are shown in Figure 2. This diagram was constructed by solving the Markowitz quadratic programming problem at each level of risk to find the optimal combinations of attack methods at increasing levels of standard deviation. The data that forms the foundation for this task is the data presented in Table 1. As expected, the opportunity set for attack method combinations is concave. At very low levels of risk, assassination dominates efficient attack

[7] The weights cannot exceed 1.00 or 100 percent.

method combinations. Gradually, as risk increases, bombing is added to assassination and the pair of attack methods dominate the next highest risk range. As risk increases further, assassination comes to represents a smaller and smaller constituent of an efficient combination as hijacking and armed attacks are added to bombing. At still higher levels of risk, the attack methods with the highest standard deviation emerge as constituents of optimal combinations whilst the less risky attack methods fade out of consideration for a terrorist willing to bear a relatively high possibility that the actual outcome of his attacks will diverge from that which he expected. The riskiest attack method, unconventional attacks, is the category that includes actions such as the 9/11 attacks. Presently, this is the type of innovative attack that would be selected by the risk seeking terrorist who, by definition, always selects the attack method with the highest risk. We now move on to a consideration of how the terrorist may choose from the set of individual attack methods and combinations.

Figure 2

Attack Method Combinations: Constituents Over Risk Ranges



III. The Choice of Attack Method

Rather than imagine that the terrorist chooses his attack method by an assessment of long lists of outcomes, utility numbers and probabilities, we can imagine that the terrorist chooses his attack method on the basis of an assessment of risk and reward. That is, the terrorist assesses the average outcome and variability of outcomes across different attack methods and chooses the risk-reward pair that he is most comfortable with[8]. If we consider the list of individual attack methods, very risk-averse terrorists will choose an attack method such as

[8] Each attack method is associated with an expected number of fatalities. A utility-maximising terrorist might be thought to choose the attack method with the highest number of expected fatalities and that a preference ordering over the available attack methods will always rank the most devastating attack more highly than less devastating attacks. However, this will *not* be case unless some rather strict conditions, including risk neutrality, are met. The terrorist's risk preference will be an important in shaping his choice. This in turn indicates once more why we need to define and measure the risk of a terrorist action and why we need to do this from the terrorist's point of view.

assassination, arson or kidnapping. Less risk-averse terrorists will choose armed attacks, bombing or hijacking. If they are not very risk-averse at all, hostage-taking or unconventional attacks may be ranked highest by order of preference. If the terrorist is risk-seeking, he will always be observed to choose the attack method with the most variable outcomes. The information that guides the terrorist's choices is contained media reports and other publicly available information. No special information is required. Terrorists can reasonably be expected to know, within a reasonable margin of error, what is the average or usual or common number of fatalities to result from a particular type of attack and to know of some attacks where the outcome has been roughly the same, much less or much more than the average. This is enough to determine a preference ordering over the available attack methods[9].

If a preference ordering over the list of attack methods can be formed on the basis of reward and risk (mean-variance), why did we need to work through the Markowitz approach and consider attack method combinations? Most fundamentally, if the terrorist can combine attack methods we need to know how the risks and rewards for different combinations are distributed. The Markowitz method provides the optimal combinations which, from our perspective, are also the most dangerous attack method combinations. A terrorist who seeks to maximise his utility will choose from this efficient set of opportunities. This analytical approach equates 'rational' in the traditional sense it is used in economic analysis with 'dangerous' or 'lethal'. Although the terrorist may not always choose optimally, even the staunchest critic of economic analysis could not deny the value of knowing what the optimal set consists of. It is not sound to argue that because terrorists do not choose rationally—a belief that probably holds sway within the broader terrorism studies community—that we should not be concerned with the choice set from which a rational terrorist would choose, especially when this choice set contains the most lethal or insidious or dangerous actions. Aside from this important methodological point, there are other important operational reasons for applying the Markowitz approach.

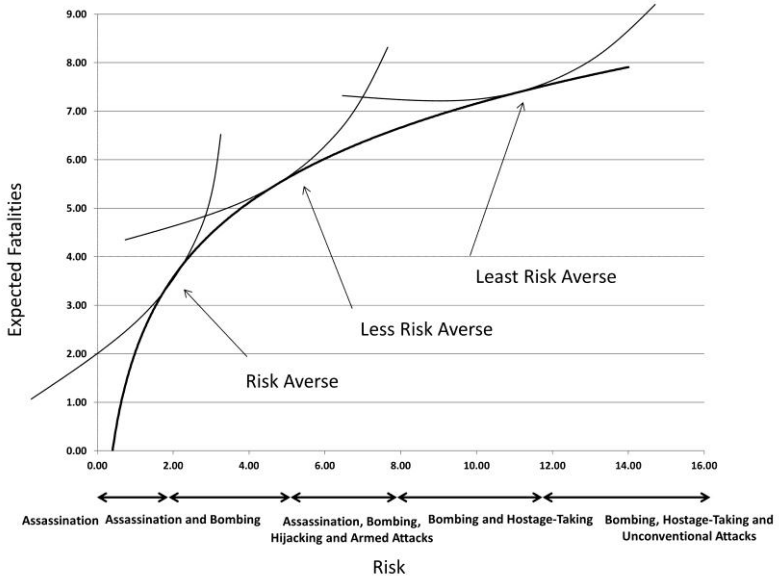
First, when only the single attack methods are considered we conclude that a risk-averse terrorist is most likely to choose assassination, kidnapping or arson. The terrorist then works his way up the scale of risk depending on his risk preference. When combinations are considered, however, we find that arson and kidnapping do not feature prominently in any of the optimal combinations of attack methods and that, somewhat surprisingly, the risk-averse terrorist is found to combine assassination with the more risky attack method of bombing. The same sort of observation is made at the mid-ranges of risk. Here the relatively less risk-averse terrorist combines attack methods from across a large part of the risk spectrum: assassination, bombing, hijacking and armed attacks. And for the much less risk-averse terrorist bombing, combined with the much more risky hostage-taking and unconventional attack methods, remains a constituent of the optimal combination even though it is much less risky than the other two attack methods. The willingness of terrorists with different levels of risk aversion to deploy attack methods that are somewhat unexpected given their risk preferences but are optimal when

[9] Formally, this mean-variance preference ordering will approximate a full expected utility preference ordering. No utility function specification need be chosen. However, the mean-variance preference ordering will be guaranteed to be consistent with the von Neumann-Morgenstern axioms if utility is quadratic *or* if outcomes approximate a normal distribution. The main shortcoming of quadratic utility is the possibility of satiation. This may not be a shortcoming at all when we consider a terrorism context. In any case, quadratic utility approximates a broad class of utility functions.

combined with other attack methods is something that can only emerge clearly when combinations are considered. Figure 3 depicts the choices of attack method combinations that are consistent with different risk preferences. Risk preference is depicted by the slope of the terrorist's indifference curve. This shows formally why different risk preferences are consistent with different choices. The steeply sloped indifference curve of the more risk-averse terrorist can only form a tangent with the optimal choice set in the low risk range. The same holds for the flatter indifference curves of the less risk-averse terrorists.

Figure 3

Attack Method Combinations, Risk Preference and Choice



Second, although a terrorist group can combine attack methods within a single period of time, the lone wolf is constrained. Because he is a lone individual capable of being in only one place at a time, he can only combine attack methods *across* periods of time. The time periods could be arbitrarily short and adjacent to each other. For example, Breivik first placed a bomb at a government building before engaging in an armed attack (shooting spree) a very short time afterwards. Our analysis provides us with the flexibility to consider the type of decision-making displayed by Breivik as the choice of two single attack methods or as the across-period combination of attack methods. If a lone wolf terrorist's attack method combinations emerge across periods, we would be missing something from the analysis if we considered his choices always to be independent choices of single attack methods. This might lead to misleading conclusions and misleading investigative advice during an ongoing investigation of a serial lone wolf terrorist. Imagine a lone wolf who first engages in a bombing attack. This reveals a mid-range level of risk aversion and, as we shall explain later, may lead us to draw particular inferences about the terrorist. If his next attack is a targeted shooting or bombing directed towards an individual—an assassination-type attack—our estimate of his risk aversion must be revised upwards. This is not the same thing as concluding that the terrorist has become more risk-averse between his first and second attacks. Rather, it is the emergence of a clearer picture of his risk preference as he forms his combination of attack methods over time.

IV. Drawing Inferences from Attack Method Choice

The idea that it is possible to draw inferences about an offender, especially a serial offender[10], is the cornerstone of 'offender profiling'. Offender profiling was developed by agents working out of the FBI Behavioural Science Unit during the 1970s. During the early years, offender profiling was characterised by a 'criminal investigative approach' which combined the evidence collected at the crime scene with the investigator's knowledge to draw inferences about the type of offender that may have committed the crime. Gradually, formal expression was given to the framework used to generate inferences about the unknown offender. This framework is called the organised/disorganised typology. The organised/disorganised typology, developed from interviews with offenders, suggests that the organised offender leaves behind an organised crime scene and vice versa (Douglas et al. 1986)[11]. Furthermore, inferences can be drawn about the type of person who may have committed the crime because his organised or disorganised nature is consistent across his criminal and non-criminal activities. It is possible to say, therefore, that an offender who leaves an organised crime scene is an organised offender and, by inference, an organised person. Being an organised person, he will lead an organised life. He will be more likely to have a skilled job. He will be more likely to be socially adept with stable relationships with family and friends and so on (Canter et al. 2004, pp.293-294). In this way, a picture of the offender is constructed on the basis of the nature of the crime scene.

The organised/disorganised typology is essentially a list of crime scene features that can be used in conjunction with what is known about the nature of the crime scene to assign the unknown offender to either the organised or disorganised category and, from there, to build a profile of the type of person that may have committed the crime. A major part of the research program that constitutes the emerging discipline of investigative psychology is the development of the theoretical and empirical foundations for the organised/disorganised typology and its alternatives. This development has been led by Canter (1989, 1994, 2004)[12]. Although investigative psychology is now much more far-reaching in terms of what it tries to contribute to the investigative process, the development of typologies that can be used to categorise offenders on the basis of evidence left at the crime scene remains a fundamental part of the research program. A 'statistical approach' has come to dominate the older 'criminal investigative approach' as researchers try to look for structure and patterns between crime scene evidence and offender characteristics using multivariate and spatial analysis and assess the results within the well-established methodological frameworks of the social and psychological sciences (Alison et al. 2010). However, despite significant theoretical and empirical problems[13] the organised/disorganised typology remains by far the most routinely used typology in practice (Snook et al. 2008, p.1259).

[10] The offender profiling of terrorists has been a relatively recent development. See LaFree and Dugan (2004), Rausch and LaFree (2007), Agnew (2010) and Phillips and Pohl (2012).

[11] An organised crime scene might display evidence of planning, the victim is likely to have been restrained, the victim is likely to have been approached verbally (rather than surprised from behind), the weapon would have been taken to and from the crime scene and evidence such as blood, semen and fingerprints will be absent (Canter et al. 2004).

[12] These references represent only a fraction of the work produced by Canter and his co-researchers. See Canter and Youngs (2009), for example. This is the first comprehensive textbook produced in the field of investigative psychology.

[13] See Canter et al. (2004) and Phillips (2013).

If relatively simple typologies are used to categorise offenders and provide the foundation for the drawing of inferences about the type of person that may have committed a crime, it should be possible to use the economic models that describe criminal and terrorist behaviour and the empirical investigations guided by these models to make a contribution to the investigative process. In doing so, one significant weakness that characterises the offender profiling process might be overcome. This weakness is the reliance on qualitative assessments of the risk that the offender bears. For example, Douglas et al. (1986, p.411) describes the way in which the profiling process assesses the risk that the offender bears as follows:

> Data on victim risk integrates with information on offender risk, or the risk the offender was taking to commit the crime. For example, abducting a victim at noon from a busy street is high risk. Thus, a low-risk victim snatched under high-risk circumstances generates ideas about the offender, such as personal stresses he is operating under, his beliefs that he will not be apprehended, or the excitement he needs in the commission of the crime, or his emotional maturity.

An abduction staged at noon on a busy street is high risk. Presumably, the same abduction staged at night in a deserted alley is lower risk. But is a shooting at noon on a busy street higher risk than the abduction at noon on the same street? Is there more or less chance of an outcome different from the expected outcome when one attack method is chosen over the other? Even if we allow that all types of attack may be more risky during the daytime on a busy street, how do we distinguish between the risk of the different types of attacks undertaken at the same time or location? Furthermore, a choice that may appear to indicate that the offender is very risk averse may be followed by a subsequent choice that appears to indicate that the offender is not very risk averse[14]. A qualitative assessment of this sort of behaviour would probably conclude that the offender is some blend of risk aversion and is sometimes bolder than at other times. But if the offender's choices gradually form a combination over time, an accurate assessment of the offender's risk preference can be obtained by measuring the risk of the chosen combination. Rather than oscillating between degrees of risk aversion, the offender's choices are likely to be found to be consistent with a particular level of risk aversion.

Defining risk as the possible divergence of the actual outcome from that which was expected and measuring this possible divergence by standard deviation or variance allows a picture of the offender's risk preference to be developed in a manner that overcomes a number of the problems inherent in purely qualitative assessments of risk. The lone wolf terrorist who strikes once and remains unidentified and 'at large' initiates the investigative process. Part of this process may involve the application of investigative psychology and offender profiling with the aim of building a picture of the type of person that may have undertaken the attack. Economic analysis—investigative economics—may contribute to building this picture of the offender. An assessment of the offender's risk preference or at least an assessment of the risk that he took in committing the offense is a key part of the profiling process. As we have explained, if the different choices that the terrorist makes can be placed or mapped into a risk-reward space in a manner that precisely delineates the relative possibility that the actual outcome of a particular type of attack will be different from that which was expected, the terrorist's choice of attack method reveals something about his preference for risk. If the terrorist strikes a second time, something more is revealed about his risk preference.

[14] Within our terrorism attack method context, this might be a choice of assassination followed by a choice of bombing.

From the attack method choice, inferences can be drawn about the lone wolf terrorist's risk preference. Inferences also can be drawn about the lone wolf terrorist's preferences for risk from the emergence of a combination of attack methods over time. The lone wolf's choices allow us to place him somewhere in the risk-reward space of Figures 1 and 2. This is the primary contribution that economic analysis can make to the profiling process. Although these conclusions about the offender's risk preference may prove to be quite valuable 'standalone' complements to existing profiling techniques, there is also a possibility that additional inferences about the unknown offender may be drawn from within the economic framework that we have described. One possibility that immediately follows from inferences about risk preference is the implications of relative and absolute risk aversion for the lone wolf's actions. Within economic theory more generally, although the evidence is still inconclusive, it is usually assumed that people are characterised by constant relative risk aversion (CRRA) and decreasing absolute risk aversion (DARA)[15].

When the relative and absolute risk aversion concepts are applied to the lone wolf terrorist, it is possible to make statements about his expected behaviour over time *as fatalities accumulate*. CRRA implies that the lone wolf terrorist would keep the proportions of his higher risk activities to lower risk activities constant as his payoffs or fatalities accumulate over time. As such, once we are sure that the picture of his revealed risk aversion is more or less complete it might be concluded that there will be no substantial shifts one way or the other along the risk spectrum even as successes or failures mount. DARA refers to the total amount of resources that the terrorist allocates to risky activities versus 'safe' activities. If we assume that the lone wolf terrorist can divide his total resources between deploying risky attack methods and engaging in 'safe' or zero-risk legitimate activities such as writing and distributing a manifesto, DARA implies that he will allocate more time to deploying attack methods as his payoffs accumulate. That is, if the terrorist is dividing his time between safe legitimate activities and risky illegitimate activities there will be a noticeable shift towards the latter as his payoffs accumulate. This effect may be more pronounced the more risk-averse the lone wolf happens to be.

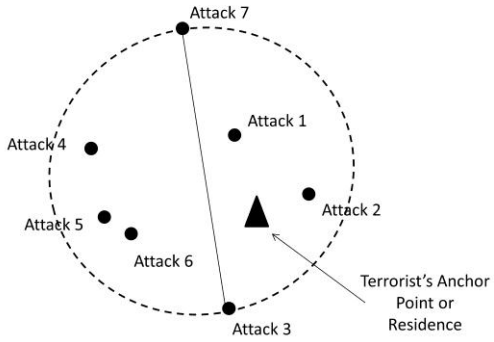
CRRA and DARA are not the only possibilities. Quadratic utility, which has a special place in the mean-variance analysis we discussed earlier, implies that both relative and absolute risk aversion are *increasing*. IRRA implies that the lone wolf terrorist will increase the proportion of lower risk activities to higher risk activities as his payoffs accumulate over time. If the lone wolf terrorist divides his time between terrorism and relatively safe legitimate activities, IARA implies that he will allocate less time to terrorism as the fatalities attributed to him accumulate. When both relative and absolute risk aversion are increasing, we would expect the lone wolf to demonstrate more risk-averse behaviour as his successes mount. He will use more of the attack methods that are characterised by more certain outcomes—attack methods where the possible divergence between the actual and expected outcomes is lower—and perhaps engage less in terrorism overall. Once more, this behaviour may be more pronounced the more risk-averse the lone wolf terrorist. At least in principle economic analysis can say something about the type of behaviour investigators might expect of the terrorist over time as successes or failures accumulate.

[15] This would be consistent with a log utility function.

Another inference that investigative psychologists and profilers attempt to draw relates to the home-base or 'anchor point' of the offender. Inferences about where the offender lives are drawn from the locational distribution of the offender's crime sites. This process is called *geographic profiling*. This process might provide investigative advice pertaining to where the offender may next offend and where he might reside relative to the location of his offenses. Law enforcement may use this advice to pre-empt future attacks, concentrate police patrols and short-list potential suspects. It 'works'[16] by using a combination of spatial analysis or purely geometric calculations and what is known about offenders' cognitive processes or the psychology of place (see Canter and Shalev 2000; O'Leary 2009). Despite the development of at least several different relatively sophisticated algorithms that are used to identify likely anchor-points, one of the simplest methods remains one of the best supported. This is Canter and Gregory's (1994) 'circle hypothesis' where the investigator simply identifies the two crime locations that are furthest apart and use the line that connects them as the diameter of a circle. The offender's home is hypothesised to be within the circumscribed area (Canter and Youngs 2008, p.9). As it turns out, a significant proportion of offenders are found to have their residence 'inside of the circle'.

Figure 4

The Circle Hypothesis (Adapted to Terrorism Context)



In most of the papers that he has written on the subject Canter notes the relevance of both risk and opportunities to the offender's decision of location and identifies location choice as having a risk management dimension. However, the qualitative risk assessments characteristic of investigative psychology and offender profiling figure prominently in shaping Canter's conclusions and, ultimately, limit the extent to which the process of geographical profiling can move beyond a purely geometrical calculation to incorporate a richer consideration of the offender's cognitive processes. For instance, Canter (2003) argues that the offender will weigh the risks of offending close to home or further away. Being close to home carries a risk of being recognised whereas a more distant location carries risks associated with travel to and within relatively unfamiliar territory. Broadly, the risk

[16] Like the other parts of investigative psychology, there is considerable controversy and debate over whether the method actually works.

seeker operates further from home while the risk averter operates closer to home. Dynamically, with each new offense, the offender re-weighs these risks in a manner that incorporates his latest activities. Canter and Shalev (2000) suggest that each new offense changes the 'ecology of risk' in a geographical area and shapes the offender's choice of the next crime location. If he has offended once or a few times in an area, he may move to another area to avoid being recognised, stopped or questioned. Although we could simply give risk assessments developed with the help of economic analysis to the investigative psychologists and allow them to draw their own conclusions, our approach provides a different perspective on some of the things that Canter and his colleagues have to say.

Relation of Home to the First Attack

Risk preference implies no *a priori* reason for a lone wolf terrorist's first attack to be located in any particular location relative to his place of residence. If a lone wolf terrorist plans to deploy an attack method in a manner that reflects the ways in which the attack method has been used in previous attacks then he will expect the average outcome and some chance of divergence. His choice will be based on this risk-reward assessment[17]. If he lives in an 'average' area he might offend close to home simply because it is easier but it is not possible to conclude *a priori* that the outcomes associated with the use of a particular attack method are more variable closer or further away from the terrorist's place of residence. The conclusion that it is more risky to offend further away from home contains an implicit assumption to the effect that expected risks and rewards depend upon geographical considerations. This is true only with reference to 'typicalness' of the terrorist's residential location which is of course unknown to the investigator.

Relation of the Second Attack to the First

Once the lone wolf offends he changes the ecology of risk as Canter and others suggest. People in the area might become more alert and a law enforcement presence might be enhanced. This is likely to increase the variability of the outcomes associated with the use of a particular attack method. This in turn has implications for what the terrorist will choose to do next. The risk-averse terrorist must move to a different location to rebalance the risk-reward trade-off for his preferred attack method. Therefore, if his first attack was close to home, he will move further away. The less risk-averse terrorist, however, may choose to strike again in the same general area. This inference can be linked to the initial assessment of the terrorist's risk preference based on his attack method choice. As we know, a targeted assassination-type of attack will probably be perpetrated by a more risk-averse terrorist. As such, we would expect this terrorist's second attack to be perpetrated at a reasonable distance from the first. Furthermore, if he is IRRA his attacks might take place further and further away. Conversely, a less targeted armed attack, where victims are randomly selected, will probably be perpetrated by a less risk-averse

[17] The investigative psychology literature equates victims with opportunities. This leads to the conclusion that the offender cannot possibly have a complete picture of the distribution of opportunities (Canter and Shalev 2000). This approach is therefore liable to underestimate the degree of 'rationality' that an offender can bring to his task. If we recognise that the terrorist's opportunities are his attack methods rather than his victims—each attack method or combination being an opportunity to accumulate some number of victims—we are less liable to underestimate what he knows about the possible outcomes of his attacks and less liable to underestimate the logic that he may apply to his choices. In a 'typical' geographical location or area, an armed attack or a bombing or a targeted assassination-type of attack or arson have fairly well-established average outcomes and outcome variability.

terrorist. As such, we would expect this terrorist's second attack to be relatively close by to his first. Although risk preference does not have any *a priori* implications for the location of a lone wolf's attacks to his place of residence it does, as we have just seen, have implications for his future attacks relative to his previous attacks. Importantly, whereas Canter and his colleagues assume that there is something risk-seeking about operating further away from home, the opposite may be true.

Attack Method Combination and Geographical Location

Combining attack methods, which may appear at first to be switching between attack methods, is something that the investigative psychologists do not appear to consider. This is understandable given the nature of the criminal activity they have mainly been focussed on. For the lone wolf terrorist, however, switching between attack methods is not out of the question. Indeed, he must switch occasionally if he is forming a combination over time. What is interesting, however, is that (1) the variability of the outcomes of one type of attack may not be directly affected by the deployment of another type of attack method; and (2) the act of combination itself reduces the variability confronting the offender. Therefore, geographical dispersion may be somewhat compressed even for the very risk-averse terrorist by the terrorist's ability to diversify. The act of combining attack methods is an additional factor that is relevant to assessing the interaction between the terrorist's choices and the ecology of risk that describes the terrorist's environment.

Economic analysis can complement the investigative process in important ways. Placing the terrorist's attack methods into risk-reward framework and identifying the economic logic of attack method combinations allows the revealed risk preference of the lone wolf terrorist to be guessed at in a reasonably structured way. Further inferences about the lone wolf that flow from the initial guess about his risk preference may include the ways in which the terrorist may escalate or decrease his involvement in terrorism as his payoffs accumulate. With regards to geographical profiling, the revealed risk preference of the lone wolf terrorist might also form the foundation for inferences regarding the location of his future attacks to his past attacks. As economic analysis has done in various contexts before, it adds to its substantive contributions the clarification of certain points of logic that have historically been applied to a problem. In the final section, we sketch two more ways in which economic analysis may contribute further to the geographical profiling problem.

V. Geographical Profiling, Game Theory and Prospect Theory

Canter stresses the need for two things that must be incorporated into geographical profiling: (1) dynamics and strategy, broadly speaking; and (2) the cognitive biases of the offender. Economic analysis and behavioural economics are well positioned to provide some of the necessary foundations and material by the application of game theory and prospect theory to the problem. This section provides some glimpses into what the application might look like and some of the insights that might be possible. This section develops two images. The first casts the 'city block' or 'grid map' as a game matrix (Figure 5). The second casts the location of the offender's first attack as a reference point about which an S-shaped utility function is positioned (Figure 6). The types of game structures that might be applied here are numerous. This paper stresses the application of game theory to this type of geographical problem and leaves most of the working out of specific games for future research.

Figure 5

Game Matrix as a City Block

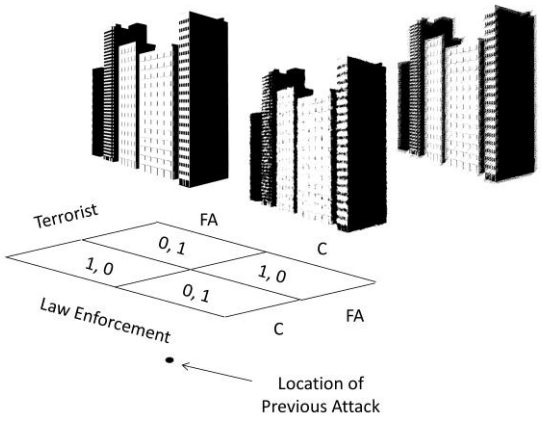


Figure 6

Previous Attack as a Reference Point

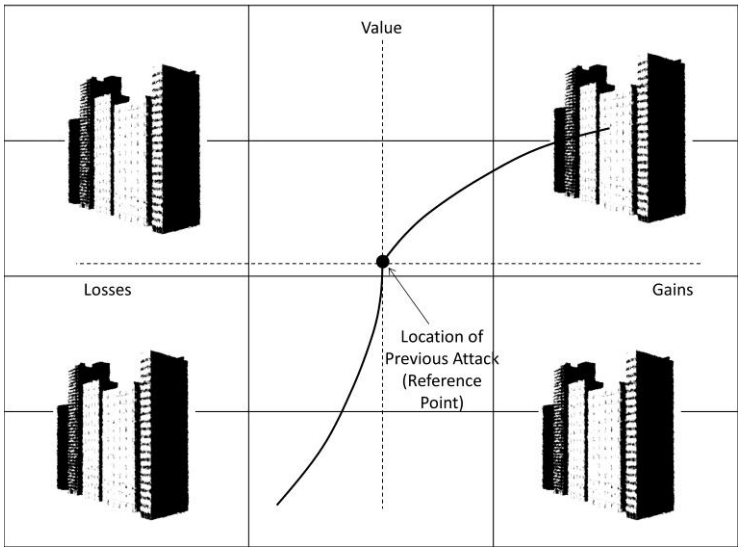


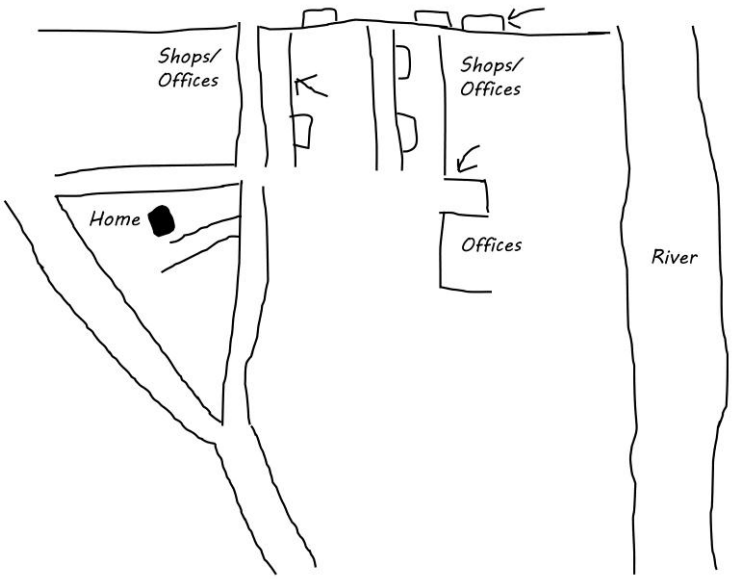
Figure 5 depicts a basic game where the terrorist interacts strategically (and geographically) with law enforcement relative to the location of his previous attack. The 2x2 matrix can be extended (to 3x3, for example) to cover more area. In the illustration 'C' represents 'close' (to the previous attack) and 'FA' represents 'further away'. If the terrorist strikes close to the location of his previous attack while law enforcement positions resources further away, the terrorist obtains a payoff. Similar logic applies to the other possibilities that are depicted. Even this simple game demonstrates the potential application of game theoretical analysis to geographical profiling. The simple zero-sum game depicts the conflict between law enforcement and the lone wolf terrorist in which there is no pure strategy equilibrium. However, equilibrium can be found in the

mixed strategies[18]. Interestingly, one interpretation of this is that there is no equilibrium when the terrorist always chooses 'close' or 'further away' but there is an equilibrium 'somewhere in between'. The game can also be altered slightly to incorporate our previous inferences about risk preference and the terrorist's desire to attack close or further away from his previous attack location. If the terrorist uses a targeted assassination type of attack method for his first attack and we infer that he is likely to be relatively risk averse and likely to attack further away the next time, we might attach a payoff of 2 (rather than 1) to the terrorist when he attacks 'further away' and law enforcement has placed resources 'close'. Although the lone wolf's mixed strategy is the same, in this basic scenario law enforcement should concentrate their resources 'further away' on 2/3 of occasions following the deployment of a lower risk attack method. The results can be much richer with more elaborate games and there is no reason to rule out the delineation of payoffs from empirical analysis.

An important research program within the geographical profiling literature is the examination of offenders' 'mental maps' (sketches) of where they commit their crimes. These are usually interesting for the details that are both included and omitted by the offender himself when drawing a particular geographical area. Sometimes, main roads, canals or waterways form clear boundaries that the offender never crosses. Land-use is also quite prominent in some of these sketches with areas such as parks, fields or waste disposal tips representing 'blank' areas within the area in which the offender is active. That is, he does not even draw them because they do not even figure in his assessment of his surrounds. An (hypothetical) example of this type of 'mental map' is presented in Figure 7. The arrows point to where his crimes were committed. Canter and Hodge (2000) present some authentic examples.

Figure 7

Example of an Offender's Mental Map



[18] A mixed strategy is a probability distribution over the available strategies. For example, the terrorist may attack 'further away' 50% of the time. This is, in fact, his mixed strategy equilibrium for this game.

These types of mental maps suggest that the task of assessing the strategic geography may be less analytically burdensome than one might first think. The geography surrounding the lone wolf's attacks may be bounded by certain land-use and other geographical features that rule out or diminish the relevance of some areas. Even though a city or town or country might be very large, there might be quite limited 'relevant' space for the terrorist to move in. Whereas a payoff matrix or matrices may be thought to spread or branch out in all directions from the location of the first or subsequent attacks in a manner that in analytically intractable, there may be reason to suspect that certain directions are bounded by some geographical characteristic or other. Similarly, other geographical or land-use features may be irrelevant to the terrorist and, in essence, 'blank out' significant pieces of his geography. In this way game theoretical analysis can be informed and sharpened from the study of the offender's psychology of space or place (see Canter 1977).

Before bringing this paper to a close, some words on prospect theory. The decision-making behaviour under risk and uncertainty that prospect theory describes has implications for the study of terrorism (Phillips and Pohl 2014). Figure 6 shows the familiar S-shaped utility function introduced by Kahneman and Tversky (1979). Apart from the reference point, the utility function is not fixed to the geography. As such, a spiral of S-shaped functions about the reference point might be a better depiction. Prospect theory provides a way to incorporate decision-making 'biases' such as loss aversion, diminishing sensitivity, reference point dependence, the tendency to overweight small probabilities and underweight large ones and risk-seeking in the loss domain into the analysis. In Figure 6, the location of the lone wolf's first attack becomes his reference point (reference dependence)[19]. If the lone wolf successfully deploys an attack at the reference point location he becomes risk-averse over the domain of gains and *drifts further away*[20] (risk aversion in the domain of gains). On the other hand, if he is unsuccessful, he becomes risk seeking over the domain of losses and *tries again* (risk seeking in the domain of losses). He stays close when he fails. In either case, if value or utility is linked to the lone wolf's geography by and at the reference point, very distant locations are felt less keenly (diminishing sensitivity).

Appendix 1

The Economist's Treatment of the Opportunity Set

The 'global' opportunity set, G, contains all of the opportunities from which the terrorist may choose. For practical reasons, most studies simplify things by concentrating on a sub-set of opportunities, $g_1 \subset G$, or by partitioning the global opportunity set by the imposition of some overarching categories. For example, Becker (1968) simplifies the opportunity set by confronting his decision-makers with the choice between 'legitimate' and 'illegitimate' activities. Becker's decision-maker chooses from one side or the other of this partition. Although Ehrlich (1973) retains the partition, he allows his decision-makers to choose a combination of legitimate and illegitimate activities. Landes (1978) defines a sub-set of the set of illegitimate activities and confronts his decision-makers with a 'hijack' or 'not hijack' dichotomy. Sandler et al. (1983) partition the global set into 'legal' activities and 'terrorism' and define a 'demands' sub-set in an attempt to model the initial choice

[19] In fact, the location of the first attack might be the lone wolf's reference point even *before* he attacks the first time if another lone wolf terrorist has attacked there, for example. In referencing his actions against a predecessor lone wolf terrorist, he selects a similar or the same location.

[20] Assuming, as before, that the variability of the outcomes of subsequent attacks is increased by the previous attack.

between legitimate behaviour and terrorism and subsequent choices or 'demands' that are made during a negotiation process after a terrorist action has been initiated. Other examples of the legitimate-illegitimate partitioning of the opportunity set are found in Enders and Sandler (2002) and Frey and Luechinger (2003). It is also implicit in recent surveys of the field (for example, Intriligator 2010).

The definition of sub-sets or partitions of G depends on the context and the objectives of the economic analysis. Like Landes (1978), the analysis may be concentrated on a particular type of action and require a partition of G and well-defined sub-set. Like Enders and Sandler (2002) or Frey and Luechinger (2003), the analysis may be more general and simply require a partition of G. Other times, the analytical approach may be guided by what the terrorist wants. According to Abrahms (2006, 2008, 2011) this could be any number of things. It could be grass-roots support. It could be membership or affiliates. It could be media coverage. Or, as Abrahms (2008) settles on, it could be links with other terrorists or 'social solidarity' (Abrahms 2008, p.94). The analysis of each of these possible partitions or sub-sets of the opportunity set promises to provide unique insights into different aspects of terrorist behaviour. However, one possibility that Abrahms does not consider is the possibility that the terrorist or terrorist group wants to inflict fatalities and injuries either as a primary or subsidiary objective[21]. Phillips (2009, 2011, 2013) makes a case for examining terrorist choice when fatalities and injuries is the terrorist's objective. None of the attack methods that terrorists have used have an expected fatality or injury count of zero. When a terrorist uses one of these attack methods he must be expecting to inflict some fatalities and injuries. The suggestion that terrorists aim to inflict fatalities and injuries as a primary objective is supported by the 'brutality contests' groups appear to engage in[22], the words of the terrorists who have stated a desire to 'kill as many people as possible' and, of course, their actions which include the deployment of attack methods in crowded rather than deserted locations. A copycat or imitation process may also surface in the behaviour of some violent offenders. In the case of spree shooters a desire to inflict more harm than a predecessor is often expressed by the perpetrator[23].

The identification of the infliction of fatalities and injuries as a terrorist objective means associating with each illegitimate or terrorist activity an expected number of fatalities and injuries. These opportunities may be categorised in different ways including by attack method, target type or location. For example, when a terrorist chooses a particular target location he chooses from a set of locations that are associated with a different number of expected fatalities. A city street at peak hour is a different opportunity with a different expected outcome than the same street at 2 a.m. Similarly, when a terrorist chooses a particular type of attack method, such as bombing or shooting or arson, he chooses from a set of attack methods that are each associated with a different number of expected fatalities. Although each opportunity could be described as a combination of different factors—attack method, time, target, location and so on—each expected to inflict a particular number of fatalities, the analysis must be guided by the availability of data. The availability of a long data series concerning the number of fatalities inflicted by different attack methods is a compelling reason to start this type of analysis by considering terrorist attack method choice where each attack method is an opportunity to inflict an expected amount of harm

[21] For example, more fatalities may mean more media attention. Whilst media attention is the primary objective, the terrorist obtains it by inflicting fatalities.
[22] See Caruso and Schneider (2013).
[23] See Robertz (2007).

on others. This approach partitions G into legitimate and terrorist actions and concentrates on the sub-set of terrorist actions called 'attack methods'.

The orthodox way to obtain a preference ordering over the attack methods is to apply a full expected utility analysis to the opportunity set. This requires estimates of all possible outcomes from the use of an attack method, the probabilities associated with each outcome and a specification for the terrorist utility function. This is the approach that Landes (1978) used in his study of hijacking. The expected utility of attack method is given by:

$$EU = \sum_{i=1}^{n} u(x_i) Pr_i$$

EU is expected utility, x_i is an outcome of an attack, u is the utility of an outcome and Pr_i is the probability of an outcome. The utility, u, is determined by some specification of the utility function, usually 'logarithmic', 'quadratic', 'power' or 'exponential'[24]. The expected utility of an attack method is the sum of the probability weighted utility of each possible outcome. The terrorist chooses the attack method that has the highest expected utility, though not necessarily the highest expected number of fatalities. The disadvantages of this type of approach include, first, the complex depiction of the opportunity set as long lists or columns of outcomes[25], probabilities and utilities and, second, the depiction of the terrorist as a decision-maker capable of assessing each attack method on the basis of all possible outcomes, utilities and probabilities. Analytical challenges are also present, including the possibility of incorrectly specifying the utility function and the computational burden involved in determining a solution to the preference ordering.

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[24] For example, $u = \ln(x)$, is a common specification of the utility function which attaches a utility number to each outcome according to the natural logarithm of the value of the outcome.

[25] The longer the lists, the more outcomes are possible and, in a sense, the more risk there is that the actual outcome will be different from that which was expected.

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