Terrorism, Lightning and Falling Furniture

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ABSTRACT

From time to time, opinion pieces appear in the media that point out that the risk of being harmed by terrorism is very low. This much is true, at least from an actuarial perspective. These opinion pieces are often accompanied by lists of other, usually absurd, ways that a person is more likely to die, including being struck by lightning or crushed by falling furniture. When asked, people do state a likelihood of being harmed by terrorism that is much greater than the actuarial odds. But risk perception is complex and to many people the actuarial odds of being killed by terrorism versus being killed by falling furniture do not adequately reflect the differences in the nature of risks from these two things. A discussion about risk perception and terrorism cannot start and end with the conclusion that people simply overestimate the risk. To do so would be to overlook the nuances of risk perception and decision-making under conditions of risk and uncertainty. An understanding of the complex ways in which risk perceptions are shaped is essential for those who would seek to accurately characterise, compare and regulate risks in the terrorism context.

Introduction

The Royal Statistical Society 2017 International Statistic of the Year: 69.
This is the annual number of Americans killed, on average, by lawnmowers - compared to two Americans killed annually, on average, by immigrant Jihadist terrorists.[1]

An internet search for "how likely am I to be killed by terrorism", yields a mixture of statistics and insurance websites[2] and blogs[3] along with opinion pieces from major media outlets[4] that provide some answers to this question. The answers are actuarial estimates of the odds calculated by dividing the number of people killed by terrorism during some period of time by the number of people in the relevant population (country, region or city). For example, in 2017 in the United Kingdom, the actuarial odds of being killed by terrorism were 1-in-2,000,000 or 0.00005 percent while at the same time in France the odds were 1-in-267,206 or 0.0004 percent (Andrews 2017).[5] Following the 9/11 attacks, the actuarial odds of being killed by terrorism in the United States reached an all-time high of approximately 0.001 percent or, if we only consider New

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[1] Royal Statistical Society (2017).
[2] For example, the Insurance Information Institute's (2017), Facts + Statistics = Mortality Risk.
[3] For example, Muggah's (2017) blog entry published by the World Economic Forum or Jetter & Stadelman's (2017) blog entry published by The Conversation.
[4] For example, Andrews (2017) writing for *Forbes Magazine* and Shaver (2015) writing for *The Washington Post*.
[5] The populations of the two countries being approximately equal.

York City, the odds in 2001 that a citizen of that city would be killed by terrorism were 0.0375 percent. Though quite different from time to time and place-to-place, they are all very small numbers.[6]

In contrast to these small odds, people place 'terrorism' near the top of 'most dreaded risks' (Slovic & Peters 2006) and, when asked, they state a very high probability of being harmed by terrorism. Goodwin et al. (2005) asked people,[7] 'How probable do you think a terror attack on Britain is, on a scale of 0% (not at all) to 100% (extremely likely)?' They also asked, 'How likely is this attack to directly threaten you or your family, on a scale of 0% (not at all) to 100% (extremely likely)?' Two separate groups of people were asked these questions. The first group of 100 people worked in central London and perceived the likelihood of there being a terrorist attack to be 66 per cent while the likelihood that an attack would represent a direct threat to them or their families was perceived to be 34 per cent. The second group of 240 people included a mixture of students attending universities in London and Oxford. About 50 of these were from central London while others lived in suburban London and Oxford. Their responses to the two questions were 46 per cent and 20 per cent.[8]

The discrepancy between the actuarial odds and people's subjective probability assessments in the terrorism context has produced numerous pieces, some published by outlets such as *Forbes Magazine* and *The Washington Post*, whose authors appear to be trying to calm readers' fears not only by pointing out the small likelihood of being killed by terrorism but also by highlighting how the small probability of being killed by terrorism compares to other causes of death that most people pay little attention to, either because they are too absurd, like a lawnmower accident, or too mundane, like a car accident. Andrews (2017) lists 'falling off a ladder', 'falling out of bed' and 'stumbling down the stairs' as three more likely causes of death than terrorism. Shaver's (2015) example is 'crushed by falling televisions and furniture', while Jetter & Stadelmann (2017) opt for 'drowning in your own bathtub'.

That such statistics have amusement value cannot be denied. But from the perspective of more serious authors who are concerned about exaggerated risk assessments introducing the burden of unnecessary costs onto society (for example, Sunstein 2003), comparisons of the actuarial odds of different causes of death trivialise what is a very complex problem. For instance, "To many people, statements such as, 'the annual risk from living near a nuclear power plant is equivalent to the risk of riding an extra three miles in an automobile', give inadequate consideration to the important differences in the nature of the risks from these two technologies. In short, 'riskiness' means more to people than expected number of fatalities" (Slovic 1987, p.285).[9]

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[6] In this paper, we do not debate the appropriateness of using actuarial odds as a measure of risk. Consider, though, that the odds of being killed in a car accident (1-in-583) are greater than the odds of being killed in a motorcycle accident (1-in-846). This is because many more people die in car accidents (Insurance Information Institute 2017). Despite this, most people probably perceive motorcycle riding to be riskier than driving a car. And it is difficult to argue that they are wrong. It is also the case that the actuarial odds have no "logically necessary implications for acceptability of risk" (Slovic 1987, p.285, Fischoff et al. 1981).

[7] Before the 2005 London bombing attacks.

[8] An estimate of approximately 20 per cent was also recorded in a study by Lerner et al. (2003). Most studies of this type were completed during the 2000s. Having established that people's perceptions of terrorism risk are high compared to the actuarial odds, research has moved on to explore the reasons for this and its implications (see Braithwaite (2013) for a summary of these studies.

[9] The problems with comparing the risk of death by lawnmower with the risk of death by terrorism are discussed by Ritchie (2018) in a blog entry published by Our World in Data.

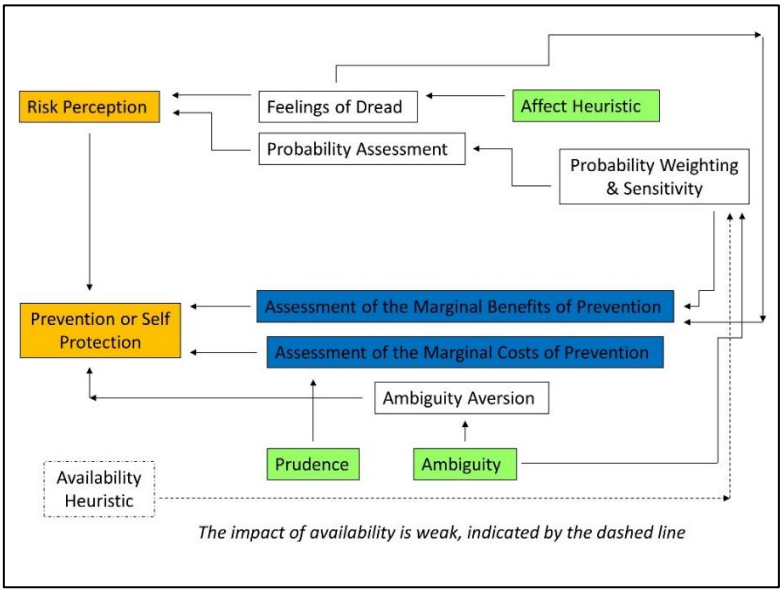
Although targeted information campaigns might enable people to better assess their chances of being harmed by terrorism, we shall see that subjective probability is just one of many factors that determine how a risk is perceived (Sjöberg 2000, p.2). And in any case, policy initiatives designed to lower the public's assessment of terrorism risk would seem to be inconsistent with the publication of terrorism threat levels that advertise a threat as 'highly likely' or 'probable' or that there is a 'severe risk' of attack.[10] If it is true that exaggerated perceptions of the risk of terrorism introduce unnecessary social costs or simply diminish people's welfare by making them feel bad, researchers and policymakers interested in 'characterising, comparing and regulating' risks (Slovic 1987, p.285) must be sensitive to the nuances of risk perception in a terrorism context. Drawing on the latest research in decision theory, as well as classic contributions, our objective is to follow the course taken in other fields, especially medicine and risk communication,[11] and introduce readers in terrorism studies to some of the most important developments in the theory of risk perception.

This is still, even after forty years of research, a field in which there are many interconnected findings with strands that are difficult to separate. What is more, the rate of publication of relevant results has increased over the past few years. This presented us with the challenge of keeping the narrative from splintering in many directions. Our two central concepts are risk perception and prevention (self-protection). Risk perception influences prevention; but just because people perceive a risk to be high, it does not follow that they will do something to protect themselves from it. The matter is rather more complex than that. To help organise some of the complex relationships, Figure 1 presents a conceptual map that shows how the ideas discussed in this paper are connected together.

Of the many factors that have been found to shape risk perception, 'dread' appears to be one of the most important. In Figure 1, these feelings of dread are shown to flow directly into risk perception. Feelings of dread are influenced by the 'affect heuristic', which may operate through graphic media reporting about terrorism. People's subjective probability assessments also shape risk perception. Probability assessments are influenced by the availability heuristic, though to a relatively minor extent, as well as the non-linear ways in which people tend to weight probabilities. People will tend to overweight the chance of a rare event such as being harmed by terrorism. This tendency will be observed even when people know and fully understand the actuarial odds. As mentioned, just because people perceive a risk to be high, it does not follow that they will take steps aimed at prevention or self-protection. Probability weighting not only affects risk perception, it also influences prevention by influencing its perceived marginal benefits. Two other psychological factors, prudence and ambiguity aversion, also influence prevention but these factors operate primarily through their influence on the perceived marginal costs of self-protection. The remainder of this paper separates these interconnections and sets forth an explanation of how they work.

[10] The language differs across jurisdictions. In the UK, the threat levels refer to likelihood. In Australia, the threat levels refer to attacks being probable and in the US, the threat levels refer to risk.
[11] For example, Peters et al. (2006) and van der Pligt (1998).

Figure 1: Conceptual Map: Risk Perception and Prevention



Heuristics and Risk Perception

As technology, among other things, became more complex during the 1970s and 1980s, a discipline called 'risk assessment' developed to provide specialist assessments—identification, characterisation and quantification—of risk. It was soon recognised that the conclusions of expert assessors were often at odds with those of 'ordinary' people. That is, risk assessments diverged from risk perceptions (Slovic 1987, p.280). For example, when asked to rank in order of riskiness a set of 30 different activities and technologies, non-experts ranked nuclear power first and vaccinations last.[12] They also ranked mountain climbing 15th; just behind spray cans (14th) and hunting (13th). In contrast, the experts assessed nuclear power as being only the 20th most risky activity of technology, ranking motor vehicles first. Vaccinations were ranked 25th. The experts ranked mountain climbing 29th, spray cans 26th and hunting 23rd (Slovic 1987, p.281). According to the expert assessments, skiing is the least risky activity (non-experts ranked skiing 21st). Although the rankings are similar for some activities, there are also big discrepancies.

One explanation for the overestimation of the odds of being killed by terrorism is that, like deadly shark attacks,[13] there is a social amplification of likelihoods through intense media reporting (Combs & Slovic 1979, Koné & Mullet 1994, Freudenburg et al. 1996, Wahlberg & Sjöberg 2000). This amplification activates people's use of an availability heuristic that, in turn, leads to biased perceptions of risk. In decision theory, the dominant though not unchallenged research program that explores the effect of phenomena such as availability on decision-making is called 'heuristics and biases'. Originating with Tversky & Kahneman (1974), 'heuristics and biases' represents a body of evidence that suggests that people apply rules of thumb called heuristics[14] in making decisions, especially decisions that involve chance or probability. While this allows people to make very fast decisions, it comes at the cost of introducing biases.

[12] By 2006, 'terrorism' ranked 1st (Slovic & Peters 2006, p.323).
[13] For research on risk perception, social costs and ecology see Lennox et al. (2018, p.283), Carter & Linnell (2016) and Gallagher (2016).
[14] Shedler & Manis (1986, p.26) define a heuristic as "…a strategy that people use in making inferences; it is a shortcut that takes the place of an exhaustive approach to the problem at hand".

One of the most widely researched heuristics is 'availability'. The availability heuristic refers to the influence that the number (availability) of examples that people can call to mind has on their subjective probabilities (Tversky & Kahneman 1973).[15] When terrorist attacks are frequent, contemporary and people know about them, a behavioural expectation that would be drawn from Tversky & Kahneman's research program would be that people on average would overestimate the risk to their personal safety because they can easily recall many examples of attacks where people were harmed. This seems to be quite a powerful explanation. However, in many ways, an availability-based explanation for exaggerated risk perception in a terrorism context is characterised by the same narrowness that afflicts the comparison of people's probability estimates with the actuarial odds.

The availability heuristic is a *cognitive* strategy that people use to simplify or quicken the process of making inferences. It seems, however, that *feelings* may matter even more than cognition, particularly in certain contexts. Fischhoff et al. (1978), Fischhoff et al. (1982) and Slovic (1987) found that people's cognitive-based assessments of the odds (subjective probabilities) are only one of the factors that determine risk perception. The list of other factors[16] that play a role in risk perception includes the degree to which the outcome is (Slovic 1987, p.282):

1. Dreaded;
2. Controllable;
3. Globally catastrophic.

And whether the consequences are:

1. Known;
2. Fatal;
3. Equitable;
4. Individual.

The role of feelings, especially feelings of dread, was identified early as a key factor in the determination of public risk perceptions (Fischhoff et al. 1978). Being killed by terrorism is highly dreaded compared to being killed by falling furniture. While availability is a cognitive heuristic, 'affect' is a feelings-based heuristic. 'Affect' refers to the influence of current emotions or feelings on decision-making.[17] While media reports may contribute to availability, the impact of the media on risk perception may operate more potently through affect. Vivid pictures of terrorism and its outcomes have been found to heighten people's dread and, in turn, influence their perceptions of risk (Fahmy et al. 2006, Rubaltelli et al. 2018). If people

[15] In the literature there is also a slightly different definition or interpretation of availability that stresses the 'ease' with which examples can be called to mind, not the number.
[16] The full list of factors is called the psychometric model. Although the model contains more than 20 factors, it can explain just 20 percent of the variation in risk perception (Sjöberg 2000, p.8).
[17] "Humans perceive and act on risk in two fundamental ways. Risk as feelings refers to individuals' instinctive and intuitive reactions to danger. Risk as analysis brings logic, reason, and scientific deliberation to bear on risk management. Reliance on risk as feelings is described as the affect heuristic" (Slovic & Peters, 2006, p.322).

use the affect heuristic in a terrorism context, the result is a feelings-based reaction to the danger rather than a deliberate analysis of the data. People judge the threat of terrorism by what they think about it *and* how they feel about it (Slovic & Peters 2006). Because the consequences of terrorism (i.e. a particularly violent death that may come with little warning and cause great distress to one's family) carries strong affective meaning, the probability of the event carries comparatively little weight in the decision-making process. In short, it is not the odds but the dread[18] that has the upper hand in shaping people's risk perceptions in the terrorism context.

Even so, it is not the case that people should be made to feel some degree of shame for having relied upon a heuristic to make a decision. In the literature, including in popular books like Kahneman's (2011) *Thinking: Fast and Slow*, the decisions that people make are compared against some benchmark or other, usually unfavourably. It is telling that Kahneman and Tversky's research program is called 'heuristics *and biases*'. The rival 'fast and frugal' research program, led by Gerd Gigerenzer,[19] criticises many of its key propositions (Shah & Oppenheimer 2008), especially the conclusion that the use of heuristics always delivers second-best results vis-à-vis optimisation. Under certain circumstances, heuristics are all that a person can rely upon. This is the case for many aspects of life and it is this point that Gigerenzer has tried to stress throughout much of his work.[20] When we say, therefore, that the use of an affect heuristic may lead to exaggerated risk perceptions, it should not carry with it a negative connotation about the accuracy of human decision-making versus optimisation rules, especially in contexts where optimisation rules cannot be applied.

Probability Weighting and Prevention

Below are two equations. The first is the equation for expected utility, EU. The second is the equation for prospect value, V:

$$EU = \sum u(x_i)(p_i)$$

$$V = \sum v(\Delta x_i)\, \pi(p_i)$$

In both equations, the outcomes are denoted by *x*. The outcomes are what could happen. They can be good or bad. They can be few in number or very many.[21] Both theories are explanations of how people rank and choose from among the possibilities. They are inherently similar in principle but there are two fundamental

[18] Dread is different from fear and has different neurological effects. The difference may be expressed as follows. A person experiences dread while sitting in the dentist's waiting room. He experiences fear as the drill comes towards his mouth (Kellerman 2014). To say, then, that people dread the consequences of terrorism is different from saying that they fear terrorism or are afraid of it.

[19] Among the many research papers produced by Gigerenzer and his team, see Gigerenzer (1991, 1996, 2002, 2004, 2007, 2008), Gigerenzer & Edwards (2003), Gigerenzer & Engel (2006), Gigerenzer & Goldstein (1996), Gigerenzer & Hoffrage (1995) and Gigerenzer et al. (1999)

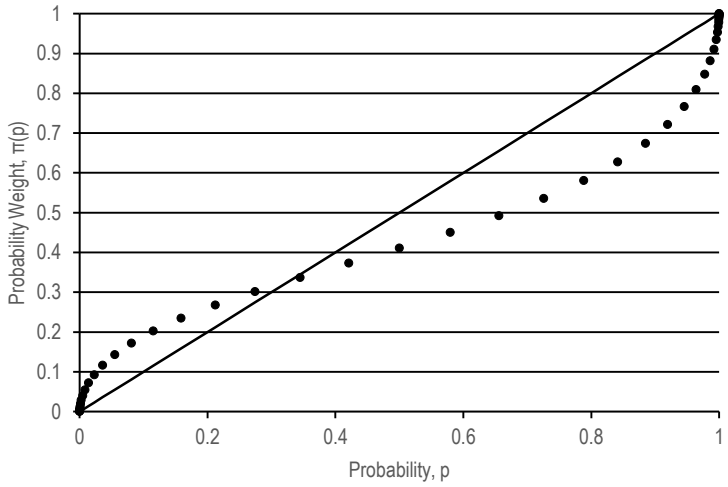
[20] See especially, Gigerenzer (2008) and Gigerenzer & Brighton (2009).

[21] That is, the subscript *i* might be just two or it could be 50 or any other number depending on the context and the possible outcomes that characterise it.

differences between expected utility theory and prospect theory revealed in these two equations.[22] The first is that prospect theory refers to changes in x (Δx) relative to a reference point rather than absolute values as expected utility theory does. Second, whereas in expected utility theory the utility of an outcome, $u(x_i)$, is weighted by its probability of occurrence, p_i, in prospect theory the relative value of an outcome, $v(\Delta x_i)$, is not weighted by the probability of occurrence but by a transformed or weighted probability where the weight is denoted by π. The most prominent feature of the weighting function is its non-linearity.

Tverksy & Kahneman's (1992) experiments had revealed that people would tend to weight a relatively rare event by some amount more than its probability. If an event has a true probability of 0.10, a decision-maker will accord it a decision weight of, say, 0.18 even if he perfectly understands the implications of the true probability. At the other end of the distribution, a decision-maker will accord decision weights that are less than their probability of occurrence. Again, even though probabilities might be assessed incorrectly in most practical situations, probability weighting will be observed even when the decision-maker fully understands the true odds of something occurring (Barberis 2013a & 2013b). This sort of behaviour implies an inverse S-shaped probability weighting function reflecting a tendency to overweight less likely outcomes and underweight more likely outcomes. This is depicted in Figure 2. The 45-degree line depicts the linear weighting scheme that would prevail under expected utility theory.

Figure 2: The (Inverse) *S*-Shaped Probability Weighting Function[23]



A number of recent studies have been concerned with the impact of probability weighting on risk perceptions and the preventative measures that people take (or do not take) in order to reduce their risks. Building on two classic papers in economics by Arrow (1963) and Ehrlich & Becker (1972), Baillon et al. (2018) analyse the prevention (or self-protection) efforts of prospect theory decision-makers vis-à-vis

[22] There are others besides these that are not obvious from the two equations presented but which reside elsewhere in the structure of the two theories.

[23] This figure shows probability increasing along the horizontal axis and the way in which decision weights change as it does so. At first, the weights are higher than the probabilities (low probability outcomes are overweighted). Then the weights gradually fall below the probabilities (high probability outcomes are underweighted). We have drawn the inflection point where probability equals 0.50 but some research suggests that inflection might be observed between probabilities of 0.30 and 0.40 (see Prelec 1998).

expected utility decision-makers. The question they seek to answer is the inverse of ours. Whereas Baillon et al. (2018) are interested in how probability weighting leads people to direct less effort than they should to preventative measures (in the context of health risks), we want to know how probability weighting might lead people to direct too much effort towards preventative measures in the context of terrorism. The key to building a probability weighting explanation for either of these questions lies in the relative size of the 'sensitive' and 'insensitive' regions of the probability weighting function.

In the terrorism context, a preventative measure[24] reduces the probability of experiencing the worst possible outcomes (death or injury). Short of remaining at home and never venturing out, no preventative measure can completely eliminate the risk. Because the risk cannot be completely eliminated, a person must compare different risky situations to determine the value of prevention (Baillon et al. 2018, p.4).[25] In making a choice, the decision-maker balances the marginal benefits and marginal costs of prevention and take preventative steps up until the point at which the marginal cost (time, trouble, money, forgone enjoyment etc.) is equal to the marginal benefit (sense of safety, sense of control etc.). The expected utility decision-maker will not make systematic errors in assessing these marginal benefits and marginal costs. He or she will decide upon the optimal level of prevention. Other types of decision-makers will err systematically. One source of systematic error is probability weighting which will tend to lead to a level of prevention that diverges from the optimal level. In some cases, it will be too low. In other cases, it will be too high.

The probability weighting function in Figure 2 has two reference points, zero and one. During the decision-making process, attention is drawn to these reference points and people show diminishing sensitivity to outcomes with probabilities further and further away from either zero or one (i.e. towards the centre). This middle part of the probability weighting function might be called an 'insensitivity region' and the two ends taken together might be called the 'sensitivity region'.[26] Within the insensitivity region, people's assessments of the marginal benefits and marginal costs of prevention are not much affected by probability weighting. Outside of it, they are. Interestingly, probability weighting acts predominantly upon the marginal benefits of prevention, leaving marginal costs more or less unaffected (Baillon et al. 2018, p.9). This is because marginal benefits are less tangible and more the product of the decision-maker's thoughts and feelings (safety, control) while marginal costs are much more tangible and objective (extra time, extra money).

For very low probabilities, the marginal benefit of prevention is overvalued because there is an over-estimation of the reduction in the probability of the bad outcome that accompanies prevention (Baillon et al. 2018, p.8). In simple terms, because the two ends of the probability weighting function are

[24] We are dealing here with measures that people might take themselves, such as cancelling travel, rather than measures that might be put in place by the government, such as more rigorous baggage inspections at airports.
[25] Even if the risk were zero and 'no prevention' was optimal, probability weighting would lead to over-prevention efforts. If the risk of being harmed by an act of terrorism were so great that maximum prevention was optimal, probability weighting would lead to under-prevention (see Baillon et al. 2018, p.4).
[26] l'Haridon & Vieider (2018) studied the risk preferences of people from thirty different countries to determine the typical size of the insensitivity region of the probability weighting function. There is a fairly marked similarity across most countries and the global average is an insensitivity region between 0.0769 and 0.8443.

steep[27] while the middle part is relatively flat, any prevention measure that operates at either end of the distribution will, in the mind of the decision-maker, result in a more than commensurate decline in risk. Unlike the expected utility decision-maker, the prospect theory decision-maker is working with miss-estimated, overvalued marginal benefits. However, whether the decision-maker will choose to implement the prevention measure still depends on whether the overvalued marginal benefit exceeds the marginal cost. Obviously, we are more likely to observe prevention occurring in cases where the marginal costs are low. As such, in a terrorism context we expect that people would be more inclined to implement small preventions such as avoiding peak hour travel rather than large preventions such as cancelling overseas travel that they have already paid for. The available evidence appears to be consistent with this conclusion. For example, in 2004 only 2 per cent of people said they had changed their overseas travel plans because of terrorism (Goodwin et al. 2005, p.402). By contrast, 22 percent of Belgians said that they avoided public transport following a series of attacks in 2015 and 38 percent said that they avoided participating in mass public events (Crijns, Cauberghe & Hudders 2017, p.226). These are low cost preventions.

Ambiguity and Prevention

Ambiguity is different to risk.[28] Just as they are averse to risk, people are also averse to ambiguity. Interest in ambiguity aversion traces its origins to Ellsberg's (1961) thought experiments involving situations with vague probabilities. Like the Allais paradox, the Ellsberg paradox is cast in terms of a choice between gambles involving the drawing of a particular coloured ball from an urn. Imagine, then, that an urn contains 90 balls where 30 are known to be red but the remainder are some unknown mixture of blue and white. In a first round choice, the gambler can choose from two gambles:

Round One

(1) Receive a prize of $100 if a red ball is drawn; or

(2) Receive a prize of $100 if a blue ball is drawn.

In a second round choice, after having selected either (1) or (2) in the first round, the gambler is asked to choose from a second pair of gambles:

Round Two

(3) Receive a prize of $100 if either a red ball or a white ball is drawn; or

(4) Receive a prize of $100 if either a blue ball or a white ball is drawn.

In experiments, people are observed to make so-called 'Ellsberg choices', which diverge from the predictions of orthodox economic theory. From the first pair of gambles in round one, people usually

[27] The steeper the ends of the probability weighting function, the more pronounced the effect. The degree of curvature depends on the values for the parameters of the probability weighting function. These are determined by fitting the function to data, usually gathered experimentally. For discussion on the determination of the shape of the probability weighting function, see Wu & Gonzalez (1996) and Gonzalez & Wu (1999).

[28] Risk involves clear probabilities while ambiguity involves vague probabilities (Trautmann et al. 2008, p.225).

choose (1) indicating that they believe that drawing a red ball is more likely than drawing a blue ball. From the second pair, they usually choose (4) indicating now the opposite, that drawing a blue ball is more likely than drawing a red ball. If the decision-maker thinks that red is more likely than blue in round one, then she should also think that 'red and white' is more likely than 'blue and white' in round two. Choosing otherwise is called an Ellsberg choice.

In some parts of the economics literature, Ellsberg choices have been described as rational responses to ambiguity (Epstein & Le Breton 1993). Even if those Ellsberg choices are inconsistent with expected utility theory, the inconsistency is said to be due to the vagueness of the probabilities. In a terrorism context, if we were to follow such a line of reasoning we would conclude that the ambiguity that the public confronts in trying to decide what their response to a terrorist attack will be is so great that they err on the side of caution, which comes across as an overestimation of risk but is really a rational response to the vagueness of the situation.[29] Starting out from this rational interpretation of Ellsberg choices, there have been developed a number of very interesting insights into the more subtle ways in which ambiguity shapes prevention.

Primarily, ambiguity means that the decision-maker cannot narrow down the likelihood of possible outcomes. Like in the example of the urns, it is impossible to tell just what the likelihood of drawing a blue or a white ball happens to be, though the chance of drawing either in gamble (4) is clearly 2/3. The more ambiguous the context, the more difficult this becomes. Imagine that a single black ball is added to each urn. The prizes listed above stand but, in addition, there is the stipulation that if the black ball is drawn, a penalty of $1000 is imposed on the player. Also, imagine that the only other thing that is known is that the number of red balls is less than the combined number of blue and white balls. It could be that there is just one ball of each colour. This is a worst-case scenario because, if true, the probability of drawing the black ball is 25 percent. The decision-maker faces considerable ambiguity. He would pay some amount to receive more information or to have more blue balls, red balls or white balls added to the urns or, even better, to have the black ball removed. Such costly steps are analogous to prevention or self-protection and they result in a contraction of the distribution of the possible outcomes. This will always be valuable to an ambiguity averse decision-maker. The question is whether the marginal benefit of such a prevention exceeds its marginal cost.

Ambiguity can shape the assessment of marginal benefits and marginal costs in two ways. First, ambiguity can operate through the agency of ambiguity aversion. Higher ambiguity aversion will tend to increase prevention efforts. This result is due to Snow (2011). In bad states, such as in the worst-case scenario we just mentioned, expected utility is very low. When expected utility is low, any increase in expected utility has a relatively high marginal value (Snow 2011, p.29). The more averse to ambiguity the decision-maker is, the more weight he places on the worst-case scenario (Baillon et al. 2018, p.17) where expected utility is lowest and where increases in expected utility have the highest marginal value. Therefore, the more averse to ambiguity the decision-maker is, the more he perceives the marginal benefits of prevention to outweigh the marginal costs. In a terrorism context, ambiguity aversion can be expected to lead to an increase prevention efforts as ambiguity increases and vice versa.

[29] Al-Najjar & Weinstein (2009) review the large amount of literature that this debate has produced.

Second, ambiguity also operates on the assessment of marginal benefits and marginal costs through the agency of probability weighting and here we find that ambiguity can work against prevention. This might seem surprising until one realises that ambiguity makes it more difficult, perhaps even impossible, to assign likelihoods to different outcomes. It might not even be clear what the possible outcomes are. If likelihoods cannot be assigned, they cannot be overweighted or underweighted. Marginal benefits and marginal costs cannot be easily assessed and compared because their impact on reducing the odds of experiencing a bad outcome cannot be gauged. Probability weighting has less agency in the presence of ambiguity (Baillon et al. 2018, pp.16-17). Counterintuitively, this tends to decrease prevention as ambiguity increases. As ambiguity decreases and the likelihoods can begin to be assigned, probability weighting gains strength and leads to increases in prevention.

To see how these effects might manifest themselves in the terrorism context consider the terrorist attack event and its aftermath. In the first instance, the terrorist attack is likely a net contributor to ambiguity. In the days that follow the attack, more information becomes available about the attackers, their allegiances, motives and networks. The investigation that follows the attack decreases ambiguity.[30] If the decision-maker is averse to ambiguity, the decision to self-protect following an ambiguity-creating terrorist attack turns on the relative strength of his ambiguity aversion and his probability sensitivity. These factors could offset each other. When ambiguity decreases with the ensuing investigation, the positive influence that ambiguity aversion has on the assessment of the marginal benefits of prevention dissipates and the decision to prevent turns on the relative strength of the decision-maker's sensitivity to probabilities. As ambiguity decreases and it becomes possible to assign likelihoods to outcomes, probability weighting leads to an overvaluation of the marginal benefits of prevention. It seems, then, that ambiguity can both increase and decrease prevention depending on the relative strength of ambiguity aversion and probability weighting. Prevention can increase following a terrorist attack, though it might be offset somewhat by probability sensitivity. Prevention can also increase during the ensuing investigation even though the investigation decreases ambiguity. Talk of subjective probabilities vis-à-vis the actuarial odds is somewhat pointless in a context that can be submerged by waves of ambiguity because, at times, the actuarial odds of being harmed by terrorism may not even exist.

Prudence and Prevention

Although the technical material is better left to one side,[31] in orthodox economic theory each type of decision-maker who can be formed from the basic building blocks of expected utility—utility functions and the von Neumann & Morgenstern (1947) axioms that hold everything in place—will have some type of risk aversion and will be prudent to some degree (perhaps to a zero degree). Risk aversion is measured by the Arrow-Pratt measures for absolute and relative risk aversion, which involve taking ratios of first and second derivatives of the utility function. The strength of the decision-maker's prudence, which could be

[30] The reader who believes that the structure of information is otherwise, can simply reverse the following reasoning. That is, if terrorism contains information that reduces ambiguity while the investigation that follows makes things less clear, then the marginal benefits of prevention increase with the terrorist attack and decrease with the investigation that follows.

[31] Gollier & Kimball (2018a & 2018b) work through these in detail.

zero for a completely imprudent decision-maker, is shaped by the third derivative of the utility function. This is worked out formally by Kimball (1990, p.53) who defines prudence as the 'propensity to prepare and forearm in the face of uncertainty'.[32] Prudence is distinct from risk aversion which, Kimball (1990, p.55) notes, is how much a person dislikes uncertainty and would turn away from it if possible (also see Bleichrodt & van Bruggen 2018, p.2).

The effect of prudence on economic behaviour is still very much the subject of ongoing research (for example, see Franke et al. 2018 and Heinrich & Mayrhofer 2018). What is clear so far is that prudence, as the definition suggests, leads people to take precautions to forearm themselves against downside risks that they might face in the future. The economics literature tends to deal with financial decisions revolving around wealth and insurance. In this context, prudent people accumulate wealth or precautionary savings to forearm themselves against potential future downside risks. This actually reduces the level of prevention because they are directing more resources to precautionary savings and away from costly prevention now. This is another rather surprising and counter-intuitive conclusion (see Eeckhoudt & Gollier 2005). What is the analogous behaviour in the terrorism context?

The most directly relevant strand of research is that which has studied prevention in the context of health risks. Courbage & Rey (2006),[33] using a bivariate utility function to separate 'wealth' and 'health', explored the combined effects of 'dread' (of sickness) and prudence on the level of prevention that an individual chooses. Once more, the outcomes of the decision-making process depend on an assessment of the marginal benefits and marginal costs of prevention. The marginal benefits of prevention in the terrorism context are non-monetary. They include feelings of safety and of being in control. Prevention has marginal costs that can be expressed monetarily; for example, the dollar cost of taking private transportation to work. Courbage & Rey (2006) found that 'dread' increases perceived marginal benefits of prevention, leading to more prevention, while prudence increases the marginal costs of prevention, leading to less prevention.[34] The highest levels of prevention will be found among those people who both have a dread of terrorism and who, it comes as a surprise, are *not* very prudent.

As explained in our discussion of probability weighting, sensitivity to probability influences perceived marginal benefits (Baillon et al. 2018). If we add to this Courbage and Rey's (2006) finding that dread influences the marginal benefits of prevention along with what we just learned about ambiguity, then there are two reinforcing factors that increase the perceived marginal benefits of prevention in a terrorism context: (1) probability weighting and (2) dread. Prudence affects prevention by influencing the other side of the cost-benefit analysis (i.e. by acting on the marginal costs of prevention). The twist in the story is that for prudence to reinforce prevention efforts, it will have to be very low. The effects of prudence on prevention are counterintuitive. If people are generally very prudent, their prudence will increase their marginal costs of prevention now, leading to less prevention and offsetting to some degree prevention that

[32] Our discussion refers to this precise definition of prudence. Thinking in terms of the everyday meaning of prudence will only lead to confusion.
[33] Also see Krieger & Mayrhofer (2016), Felder & Mayrhofer (2017) and Brianti et al. (2018).
[34] This is consistent with Eeckhoudt & Gollier's (2005) conclusion that prudence lowers prevention. A very rough explanation is that prudence encourages precautionary savings. Prevention now costs money and if a person wants to keep on preventing in an uncertain future, he or she will need money going forward. Prudence will encourage a reduction in costly prevention now in order to prepare for costly, uncertain, prevention later. As such, if a person is prudent he or she will prevent less now because prudence increases the perceived marginal costs of prevention.

derives from dread and probability weighting. And vice versa for low levels of prudence. The pertinent question, then, is how prudent *are* people?

The answer is, "Quite." Trautmann & van de Kuilen (2018) reviewed the experimental results and were able to list no fewer than 17 papers, most published in 2016 and 2017, that reported estimates on the prevalence and strength of prudence. The main findings, substantiated across all of these studies, is that prudence is quite strong and most people display it in the strict sense as it is defined within economic theory. The conclusion holds for different geographical areas. The studies reviewed by Trautmann & van de Kuilen (2018) were undertaken in the Netherlands, Canada, Germany, China and the USA. Across multiple studies in these countries, the results are remarkably stable. People are both risk averse and prudent and the degree of prudence is strong. Counterintuitive though it may be, prudence will act to *reduce* the effort and resources that people allocate to prevention. Regardless of how uncertain people are about terrorism, their prudence prompts them to reserve effort and resources against potentially greater uncertainty in the future. We do not see people in general take drastic steps to self-protect following an act of terrorism. Even though their beliefs indicate an exaggerated assessment of the subjective likelihood of terrorism, their actual decisions do not involve radical immediate changes to their behaviour and their plans. Small prevention is what we should expect and that is what we observe.

Concluding Remarks

The inverse S-shaped probability weighting function is one of the most characteristic features of the theory of decision-making under conditions of risk and uncertainty. In the early papers by Tversky & Kahneman, the probability weighting function was drawn with only a slightly bowed shape against the purely linear function of expected utility theory. Now, 40 years later, the curvature at the tail ends of the weighting function, near the reference points of zero and one, is drawn with marked concavity and convexity to reflect the accumulated evidence that people overweight unlikely outcomes and underweight more likely outcomes in a very pronounced way. How judgement and decision-making processes, including probability weighting, shape the assessment of marginal benefits and marginal costs of prevention is the current focus of much of the literature on risk perception and prevention. The results being generated are relevant for many different fields of study, including terrorism studies.

As we have seen, distinguishing the effects of each of the factors that shape the decision-maker's assessment of the marginal benefits and marginal costs of prevention is not a straightforward task. The decision to prevent, which is a separate step that follows judgement or the formation of beliefs, is shaped by the influence of probability weighting, the at-times-counterintuitive influence of ambiguity and the always-counterintuitive influence of prudence. Self-protection in the terrorism context will be observed whenever people perceive the marginal benefits of prevention to exceed the marginal costs. There are several reasons why marginal benefits may be overvalued and why prevention levels may be higher than what is purely optimal. In all cases, however, risk perception is more complex than a simple comparison of the actuarial odds of being killed by terrorism, lightning and falling furniture.

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