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Valuing the Risk of Death from Terrorist Attacks

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Abstract

Regulations designed to increase homeland security often require balancing large costs against highly uncertain benefits. An important component of these benefits is the reduced risk of fatalities from terrorist attacks. While the risk to an individual appears small, the benefits may be large when aggregated over the population. U.S. regulatory agencies have well-established approaches for valuing mortality risks, but address risks that differ in significant respects from those associated with terrorism. The best available estimates of the value of small risk reductions, expressed as the value per statistical life (VSL), average about $6.5 million. However, terrorism-related risks may be perceived as more dreaded and ambiguous, and less controllable and voluntary, than the workplace risks underlying many VSL estimates. These factors may increase the VSL appropriate for terrorism risks, possibly doubling the value.

KEYWORDS: value per statistical life, benefit-cost analysis, homeland security, regulation

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INTRODUCTION

In response to the events of September 11, 2001, the U.S. Department of Homeland Security (DHS) undertook an ambitious regulatory program to protect the U.S. against future attack. Many of these regulations have significant economic costs, requiring careful assessment of the extent to which they result in commensurate benefits.

Averted mortality risks often account for a significant share of the quantifiable benefits of these rules; other benefits include reducing the risks of nonfatal injuries or illnesses, property damage, business disruption, and other adverse effects. The importance of each benefit category will vary depending on the goals of the regulation and the types of attacks addressed.[1] To determine the value of these benefits, Federal agencies generally evaluate each outcome separately then sum the results, taking care to avoid double-counting.

Because it is extremely difficult to predict the effects of alternative policies on the likelihood and consequences of terrorist attacks, DHS often uses breakeven analysis to determine the reduction in attack risk needed for the benefits of each option to equal or exceed its costs. Decisionmakers can then consider whether the change in attack risk is likely to be achieved. This assessment is one of many inputs into policy decisions, which also involve weighing a number of other, often non-quantifiable, impacts. These impacts may include, for example, the regulation's effect on the level of fear and anxiety within society and on civil liberties, as well as the fairness or equity of its requirements.

The value of reducing mortality risks from terrorist attacks is not well studied. While major U.S. regulatory agencies follow well-established approaches for valuing mortality risks, the risks they address differ in significant respects from those addressed by the DHS. Most of the available scholarly research also considers dissimilar risks, focusing largely on job-related accidents and other more common causes, rather than less frequent but potentially catastrophic events such as terrorism. Thus the value of reducing terrorism-related risks must be derived by transferring values from different contexts, adjusting the values to the extent possible to better fit the homeland security context.

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[1] For example, in DHS' analysis of its Western Hemisphere Travel Initiative Rule for International Land Travelers (IEc 2008), mortality risks accounted for 52 percent ($2.7 billion of $5.2 billion) to 66 percent ($2.7 billion of $4.1 billion) of the damages associated with its baseline risk estimate, if valued using an estimate for mortality risks similar to that used by the U.S. Environmental Protection Agency. The remaining quantified damages included nonfatal health risks ($0.1 billion to $1.2 billion) and averted property damages and business disruption ($1.3 billion). These estimates may significantly understate overall damages, however, because the available data focused on insured losses. The effects of the rule on reducing the overall fear and anxiety attributable to terrorism were not quantified.

This article considers how to best accomplish this "benefit transfer." Benefit transfer is frequently used in policy analysis. It involves reviewing the available research to determine its quality and applicability, considering the similarities between the scenarios studied and those addressed by the policies of concern. When applied to mortality risk valuation, benefit transfer often involves two steps: (1) identifying the best available estimates of these values from the research literature; and, (2) determining whether these estimates can be quantitatively adjusted to better fit the regulatory context.

Because of the importance of mortality risks in the overall benefit estimates for DHS rules, these values could significantly affect the relationship between the costs and benefits of alternative policies. Thus developing values tailored to the homeland security context may have important implications for the extent to which varying policies appear cost-beneficial.

The remainder of this introductory section discusses the framework for regulatory analysis in more detail, describes the value per statistical life (VSL) concept, and summarizes current Federal agency practices. The following sections then develop VSL estimates that can be tailored to the homeland security context.

Analytic Framework

Under Executive Order 12866 (Clinton 1993) and U.S. Office of Management and Budget (OMB) guidance (OMB 2003), Federal agencies are required to assess the costs, benefits, and other impacts of economically significant regulations.[2] The core of these assessments is a benefit-cost analysis which compares different policy options, measuring impacts in dollar terms to the extent feasible. Agencies are also required to provide information on outcomes that cannot be quantified or monetized and to explore the uncertainty in the results. While the benefit-cost analysis focuses on estimating net benefits nationally, agencies must also report the distribution of the impacts across key subgroups (e.g., children, small businesses), so that decisionmakers can evaluate the equity of the options as well as their economic efficiency. Decisionmakers weigh numerous other factors, including legal and political considerations, in selecting among the policy options.

The benefit-cost analysis embedded in these assessments is based on the principles of welfare economics, a key premise of which is that each individual is the best judge of his or her own welfare. Thus an individual's willingness to pay (WTP) for a good, service, or other regulatory outcome (which corresponds to his willingness to forgo spending on other goods or services) is used to indicate its

[2] The Obama Administration is currently considering changes to this Executive Order; see: http://www.whitehouse.gov/omb/inforeg_regmatters/.

value.[3] Because conducting new research to estimate WTP requires investing significant time and resources, regulatory analysts generally use results from previously completed studies to estimate the value of reduced mortality risks and other benefits, following the benefit transfer framework introduced above.

The Value per Statistical Life

Most regulations lead to relatively small changes in mortality risks and address scenarios where the individuals who would have died in the absence of the rule cannot be identified in advance.[4] These risks are often expressed as "statistical lives," which involve aggregating small risk changes across many individuals. For example, a 1 in 100,000 risk reduction that affects 100,000 individuals can be expressed as a statistical life (1/100,000 risk x 100,000 individuals = 1 statistical life).

For an individual, the value per statistical life (VSL) is generally estimated by dividing his or her WTP for a small risk change in a defined time period by the size of the change.[5] For example, if an individual is willing to pay $60 for a 1 in 100,000 reduction in his own current-year mortality risk, then his VSL is $6 million ($60 ÷ 1/100,000 = $6 million). Alternatively, the VSL can be understood as aggregating individual WTP across a larger population. If each member of a population of 100,000 is willing to pay $60 on average for a 1 in 100,000 decrease in her risk of dying during the year, the corresponding VSL would be $60 x 100,000 or $6 million.

Thus the VSL represents an individual's willingness to exchange income or wealth for small changes in the likelihood of survival, rather than purchasing other goods or services. Individuals often make decisions that reflect these types of tradeoffs between mortality risk and money or convenience; for example, when deciding what safety features to include when buying a new car, whether to purchase a more expensive house in a safer neighborhood, which types of food to buy, and whether to jay-walk across a busy street.

Economists often estimate the value of mortality risk reductions using revealed preference methods, particularly wage-risk studies (also referred to as compensating wage differential or hedonic wage studies). In these studies, researchers compare earnings across workers in different occupations or industries who face varying levels of on-the-job risks, using statistical methods to

[3] Estimates of willingness to accept (WTA) compensation are also consistent with this framework, but are less often applied due to difficulties in measurement. We reference WTP throughout this article for simplicity. See Freeman (2003) for more information on related theory and methods.
[4] See Hammitt and Treich (2007) for more discussion of identifiable versus statistical lives.
[5] See Hammitt (2000) and Viscusi and Aldy (2003) for more detailed discussion of the theoretical foundation and models underlying the VSL concept.

control for the effects of other factors (such as education or nonfatal job risks) on this relationship.

Alternatively, stated preference methods may be used. These methods involve asking respondents how they would behave in a hypothetical situation, via various types of surveys. For example, respondents might be asked whether they would pay some amount for a treatment that would reduce the risk of incurring a particular illness.

Each method has advantages and limitations. Revealed preference studies rely on actual behavior (which may be more credible than survey responses) but address scenarios that differ in significant respects from those of concern in many analyses. Stated preference studies allow researchers to better tailor the scenario to the risks of concern but are hypothetical.

Numerous studies have used these methods to estimate the VSL. However, most of this research addresses risks that are somewhat dissimilar to those associated with many major regulations. Thus analysts usually apply estimates derived from one scenario (such as job-related accidents) to a somewhat different scenario (such as air pollution or homeland security regulations). This benefit transfer requires careful consideration of the quality of the available research (the data and methods used) and the suitability of the estimates (the extent to which they consider populations and risks similar to those addressed by the regulations). While it may be possible to quantitatively adjust the primary research results to better fit the regulatory scenario, gaps in the available research mean that analysts often must explore the implications of the resulting uncertainties qualitatively.

The values assigned to mortality risk reductions have been contentious in some regulatory settings (Robinson 2007, Viscusi 2009a). These debates in part reflect confusion over basic concepts, resulting from the misleading "value of life" terminology. The VSL does not measure the value of a "life" or an individual's intrinsic worth; rather, it measures how individuals trade-off income (or spending on other goods and services) and small risk changes.

Current Federal Agency Practices

The use of a benefit transfer approach for valuing mortality risks in regulatory analysis is well-established. Agencies typically first review the available research to develop best estimates of the base VSL, often including a central estimate and a distribution of higher and lower values. Because the research literature has been dominated by studies of job-related risks, agencies generally rely on these studies for their base estimates. They next determine whether and how to adjust these estimates to reflect differences between the scenarios studied and their regulatory scenarios. For example, their regulations may address different population subgroups (such as individuals not in the labor force) or different risks (such as deaths from illness rather than from injuries).

While the major regulatory agencies each apply somewhat different VSL estimates, they rely on many of the same underlying studies and make relatively few adjustments to the results. The differences reflect how each agency interprets the available research, rather than tailoring of the estimates to the particular risks they regulate or the affected subpopulations.

Agency practices are governed in part by OMB guidance on the analysis of economically significant regulations (OMB 2003). OMB notes that the available research indicates that the VSL is roughly between $1 million and $10 million (no dollar year reported). While the guidance allows agencies some discretion in selecting VSL estimates that best fit their regulations, ultimately the estimates result from negotiation during OMB's review of the regulations prior to promulgation. Agencies are now coalescing around values at or above the middle of the range identified by OMB, with central VSL estimates ranging from about $5 million to about $8 million in 2008 dollars, based largely on the results of selected meta-analyses and literature reviews.[6]

Historically, the U.S. Environmental Protection Agency (EPA) has been responsible for most of the economically significant health and safety rules that lead to quantifiable mortality risk reductions and has devoted considerable attention to developing valuation methods. EPA derives its base VSL from a review by Viscusi (1992, 1993), which identified 26 potentially suitable values. Inflated to 2008 dollars, the range becomes $0.9 million to $21.9 million, with a mean of $7.8 million.[7] EPA ultimately incorporated this approach into its *Guidelines for Preparing Economic Analysis* (EPA 2000), which it is now updating.[8,9]

In comparison, the U.S. Department of Transportation (DOT) promulgates fewer such rules. Its recommended base VSL estimate is currently $6 million (DOT 2009), with a range of $3.4 to $8.6 million for use in sensitivity analysis (2008 dollars).[10] DOT's base value averages the estimates from four meta-analyses (Miller 2000, Mrozek and Taylor 2002, Viscusi and Aldy 2003, Kochi et

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[6] See Robinson 2007, 2008 for more detailed discussion of current practices. Inflated to 2008 dollars using the Consumer Price Index – All Urban Consumers (http://www.bls.gov).

[7] Values taken from EPA (2000) and inflated from 1997 to 2008 by the authors, with no adjustment for changes in real income over time.

[8] From 2004 through 2008, EPA relied on VSL estimates based on recent meta-analyses in its assessments of air pollution regulations (e.g., EPA 2006a), while continuing to follow the 2000 guidance in its analyses of drinking water and other regulations. EPA has now discontinued this practice, and relies solely on the approach described in its 2000 guidance.

[9] See http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/homepage.

[10] Personal communication, Peter Belenky (DOT), January 15, 2010.

al. 2006) and one wage-risk study (Viscusi 2004), adjusted for both inflation and real income growth over time.

The Food and Drug Administration (FDA) also periodically issues economically significant rules that include quantified estimates of mortality risk reductions. FDA has not developed formal guidance, but cites several literature reviews and meta-analyses as the sources of its estimates. In the past, it has generally relied on a base VSL of $5 million and/or $6.5 million, without specifying a dollar year (e.g., FDA 2007); future analyses are likely to include updated values. Other agencies develop relatively few such rules and usually follow valuation approaches similar to those described above.

These agencies each adjust their base values quantitatively for only a few differences between the scenarios studied and the scenarios addressed by their rules. These adjustments reflect changes in real income over time, any time lags between changes in exposure and changes in mortality incidence, and costs paid by third parties (such as insured medical costs). Each agency uses somewhat different approaches to implement these adjustments.

Agencies generally do not adjust their VSL estimates for differences across population subgroups, despite evidence that individuals' WTP for their own risk reductions varies depending on characteristics such as income and age. U.S. government agencies currently use the same VSL for all affected individuals, viewing this approach as promoting equitable treatment and equal protection for different groups in policy decisions.

ESTIMATES FOR HOMELAND SECURITY RULES

The approaches used by other Federal agencies are not entirely appropriate for homeland security rules for two reasons. First, they address different types of risks, in some cases affecting different subpopulations. Second, they do not yet fully incorporate the most recent research and expert panel advice. Thus in this section, we first review the homeland security regulatory context then evaluate the available VSL research. We follow the standard benefit transfer framework, first developing base estimates and then considering how they can be adjusted to better fit the regulatory context.

The Regulatory Context

Using the benefit transfer approach for homeland security regulations requires first understanding the context in which the values will be applied. Homeland security rules vary in the types of protection they provide: some focus on particular types of attacks or targets, while others focus more broadly on preventing terrorists or terrorist weapons from entering the United States.[11] For example, recent rules have addressed the documentation required for international travelers and shipments.

When a DHS initiative is expected to result in an economically significant regulation, the agency is required (by government-wide guidance) to assess the benefits, costs, and other impacts of alternative approaches (Clinton 1993, OMB 2003). As noted earlier, because it is difficult to predict the effects of different policies on the likelihood of attack, DHS often performs breakeven analyses rather than calculating the net benefits of the options. These breakeven analyses estimate the decrease in attack risk needed for the benefits of each option to equal or exceed its costs; decisionmakers can then consider whether the decrease is likely to be achieved.

In DHS regulatory analyses, the characteristics of the averted attacks are usually explored using case studies and expert judgment. Review of these studies (see Robinson 2008) suggests that deaths may disproportionately occur among working-age adults in many cases. In addition, terrorism-related mortality risks may often result from immediate trauma or exposure to fast-acting toxins. However, subpopulations other than working-age adults will also be affected, and some types of attacks (e.g., involving chemical, biological, radioactive, or nuclear contaminants) will lead to lingering illnesses that are ultimately fatal in addition to more immediate deaths.

Thus in applying the benefit transfer framework, we assume that the deaths averted by homeland security rules would most likely occur during or shortly after the attack, and that working-age individuals may be disproportionately affected. We also consider how the value of mortality risk reductions might change if different population subgroups are affected or if the deaths result from various types of illnesses rather than traumatic injury.

Base VSL

As discussed above, Federal agencies rely in part on recent meta-analyses as the basis of their VSL estimates, although the particular analyses cited vary. Meta-analyses synthesize the findings from several independent studies and examine the variation in the results. The key VSL analyses cited by the agencies are listed in Table 1. Federal agencies differ in which estimates they select from each meta-analysis.

[11] Detailed information on these rules as well as the supporting analyses is available at www.regulations.gov.

Table 1: Key VSL Meta-Analyses

Meta-Analysis	Studies Included (publication dates)[a]	Best VSL Estimate[b]	
		As Reported (dollar year)[c]	Inflated to 2008 dollars[d]
Miller (2000)	~30 U.S. wage-risk studies (1974-1990)	$3.7 million (1995 dollars)	$5.2 million
Mrozek and Taylor (2002)	~25 U.S. wage-risk studies (1974-1995)	$1.5 million to $2.5 million (1998 dollars)	$2.0 million to $3.3 million
Viscusi and Aldy (2003)	~30 U.S. wage-risk studies (1974-2000)	$5.5 million to $7.6 million (2000 dollars)	$6.9 million to $9.5 million
Kochi, Hubbell and Kramer (2006)	~30 U.S wage-risk studies (1974-2002)	$8.9 million (2000 dollars)	$11.1 million

Notes:
a. Number of studies varies across model specifications. Count reflects subset of studies used to develop estimates in subsequent column. Miller (2000) and Kochi et al. (2006) also include contingent valuation studies in some models.
b. Estimates from U.S. studies only; each meta-analysis also includes other countries.
c. Mean or median U.S. estimate(s), highlighted by authors in abstract or discussion of alternative models.
d. Adjusted for inflation using the Consumer Price Index - All Urban Consumers. Not adjusted for real income growth.

These estimates are roughly equivalent to the $1 million to $10 million range described in OMB's 2003 guidance. The differing results stem largely from the analytic approaches used. For example, Mrozek and Taylor (2002) adjust the individual study estimates to reflect the use of statistical controls for inter-industry variability and other factors, while Kochi, Hubbell, and Kramer (2006) combine the estimates using an empirical Bayes approach rather than regression analysis.

The studies included in these analyses rely on relatively old data and often do not adhere to currently accepted best practices. In particular, in 1992, the U.S. Bureau of Labor Statistics (BLS) began conducting the Census of Fatal Occupational Injuries (CFOI) to address some of the limitations of the older risk data; most of the studies included in the meta-analyses were completed before these data became available. In addition, the model specifications used in VSL studies have improved over time as a result of on-going research on potential confounding factors and related issues.

The approaches employed in the meta-analyses themselves have also been criticized. An expert workgroup convened by the EPA noted that, whereas meta-analysis is a reasonable tool for analysis of the VSL literature, the existing meta-analyses all suffer from weaknesses in execution that preclude relying on any of them as a source of a final VSL estimate (EPA 2006b). Building on that report, an EPA Science Advisory Board panel indicated that researchers should establish criteria for selecting well-executed studies that are applicable to the population of concern (Cropper et al. 2007). Both panels recommended improvements in the statistical techniques used and in the reporting of the data, methods, and results.

Given these concerns, we reviewed more recently completed individual studies to determine their suitability for use in homeland security regulatory analyses (see Robinson 2008). We considered both the similarities in the populations and risks addressed and the study quality.

As discussed earlier, deaths from terrorist acts may disproportionately occur among working-age adults. Thus the U.S. wage-risk studies come closest to addressing the population most at risk, particularly those that include both blue and white collar workers. In addition, both job-related deaths and deaths from terrorist attacks are often likely to occur relatively quickly, without significant delay between the event and the resulting death.[12] As described later, information from other studies may be used to adjust these estimates for differing scenarios; e.g., those involving lingering illnesses.

Of the recent wage-risk studies, we found that Viscusi (2004) provides an appropriate foundation for developing base VSL estimates for homeland security rules. This study focuses specifically on developing improved VSL estimates, using wage-risk data and model specifications that incorporate several enhancements over earlier research. The study addresses problems related to how the job risk variable was defined in earlier studies, and relies on more recent 1992-1997 CFOI data on job-related risks and 1997 Current Population Survey (CPS) data on wages. Rather than solely considering risks by industry or by occupation, it considers the combined effects of both industry and occupation. In addition, the model specifications better capture the effects of nonfatal job-related risks and the workers' compensation replacement rate. For the full sample, controlling for nonfatal risks and workers' compensation, Viscusi's best estimate is a mean VSL of $4.7 million (1997 dollars). Supplementary analysis indicates that the 95 percent confidence interval is $3.7 million to $5.9 million.[13]

Thus, based on the quality and applicability considerations discussed above, we rely on the Viscusi (2004) study to develop base VSL estimates for homeland security regulatory analyses. When inflated to 2008 dollars, this estimate increases to $6.3 million (prior to adjustment for real income growth), distributed normally with a 95 percent confidence interval of $5.0 million to $7.9 million. While based on newer data and improved methods, this central estimate is within the range of estimates now used by other Federal agencies, with a narrower confidence interval.

[12] The best available stated preference studies do not address more comparable populations and risks. For example, Corso et al. (2001) consider auto safety; Alberini et al. (2004) focus on all-cause mortality risk that could be reduced by purchasing an unspecified product; and Cameron and DeShazo (2009) assess profiles that combine different types of morbidity and mortality, in most cases addressing fatal illnesses rather than injuries.

[13] Analysis conducted by J. Aldy and reported in Robinson (2008).

Adjustments for Income, Age, and Illness-Related Deaths

The second step in transferring VSL estimates to the homeland security regulatory context involves determining whether to adjust the estimates to reflect differences between the populations and risks studied and those affected by the regulations. We first discuss three key differences that are important in many regulatory contexts: income, age, and illness-related deaths.[14] The following section then discusses issues of particular importance in the homeland security context: qualitative risk attributes and ambiguity. For ease of presentation, we discuss each difference individually; however, they are often inter-related.

Income adjustments: Empirically, the effect of income on the VSL is clear: as income increases, WTP for risk reduction increases. This effect can be measured across different individuals or groups as well as throughout the population over time. However, using different VSL estimates for individuals with different incomes is controversial, raising concerns about the equitable treatment or equal protection of richer and poorer segments of the population in policy analysis. As a result, Federal agencies generally use population averages rather than estimates that vary across subgroups, adjusting only for population-wide changes in real income over time.

This longitudinal adjustment requires estimates of the income elasticity of the VSL (the percent change in the VSL associated with a 1.0 percent change in income) as well as the change in real income, and is separate from any adjustment for inflation. Because our base VSL estimate is taken from a wage-risk study, we rely on income elasticity estimates from a recent meta-analysis of such studies, Viscusi and Aldy (2003).

Viscusi and Aldy experiment with several approaches for estimating income elasticity, using data from over 40 wage-risk studies conducted in the U.S. and other countries. They find mean elasticity estimates that suggest that, for each 1.0 percent change in real income, the VSL is expected to increase by 0.46 to 0.61 percent, considerably less than proportionate to income.

Our preferred elasticity estimates are those provided by the model that controls for the largest number of variables and includes an adjustment for outliers that may distort the results. This model (Viscusi and Aldy's Model 6) provides elasticities at the low end of the overall range, resulting in conservative estimates of the relationship between income and the VSL. The elasticity estimates from this preferred model are normally distributed, with a mean of 0.47 and a 95 percent confidence interval ranging from 0.15 to 0.78. We apply this

[14] Given the substantial uncertainty in estimates of the likelihood of death from terrorist attack, we do not discuss the effects of the size of the risk reduction, which are described in Hammitt (2000), Hammitt and Treich (2007), and Viscusi and Aldy (2003).

elasticity estimate to data on changes in real income over time, relying on CPS earnings data since it is the source employed in Viscusi (2004).

Using these data to adjust the base VSL estimates for real income growth as well as inflation leads to a central estimate (in 2008 dollars) of $6.5 million, with a range of $5.1 million to $8.2 million.[15] This range can be used for simple sensitivity analysis. To assess uncertainty using probabilistic analysis, the base VSL estimates, the elasticity estimates, and the estimates of real income growth can be entered as separate distributions.[16]

Age adjustments: The effect of age on the VSL has been an important research topic in recent years, particularly in the environmental economics literature, as well as a source of controversy. EPA's air pollution rules often disproportionately affect elderly individuals, whose life expectancies are shorter than those of the younger (working-age) individuals addressed in most VSL studies. As a result, there has been substantial debate over whether lower VSL estimates should be used to reflect the smaller number of expected life years remaining, portrayed by critics as a "senior discount."[17]

There are two dominant approaches for making these adjustments. The first is to adjust the VSL for the age of the affected individual, reflecting how WTP for small annual reductions in mortality risks varies by age. The second involves calculating the value per year of life extension (the value per statistical life year, VSLY), then multiplying it by the predicted (discounted) years of increased life expectancy associated with the regulation. The VSLY is most commonly derived by dividing the selected VSL estimate by the expected number of discounted life years remaining for the average individual studied. This approach assumes that the value of each year is constant, using discounting to reflect time preferences.

However, the relationship between age and the VSL or VSLY is not likely to be constant. Hammitt (2007) notes that there is little theoretical basis for assuming that these values increase, decrease, or remain the same at different ages. Aldy and Viscusi (2007) examine the results from revealed preference (primarily wage-risk) studies, and conclude that the VSL and VSLY follow inverted U-shaped patterns, increasing with age in early adulthood, peaking in middle age, and then declining at varying rates. These studies only include

[15] This range was calculated by adjusting the 95 percent confidence interval VSL estimates for income growth using the mean elasticity of 0.47 in all cases. It does not apply the low (or high) elasticity estimates, because combining low or high end estimates for both the base VSL and income elasticity will lead to an income-adjusted estimate that is more extreme than the bounds of a 95 percent confidence interval.

[16] In uncertainty analysis, the normal distribution for the VSL estimates should be truncated at zero because values below zero are implausible. The distribution for income elasticity should also be truncated at zero.

[17] See Robinson (2007) for more discussion of the senior discount controversy.

working-age individuals, while stated preference studies allow researchers to focus on other age groups. However, Krupnick (2007) finds that the results of stated preference studies are inconsistent. Some do not find statistically significant relationships between age and the VSL, while others find that the VSL decreases among older individuals in varying patterns and amounts.

Recently, an EPA advisory panel (Cropper et al. 2007) reviewed related research and concluded that the empirical evidence is not sufficiently robust to support application of a VSL that varies with age, and that the application of a constant VSLY is not justified. A National Academy of Sciences panel (NAS 2008) came to a similar conclusion, noting the need for more research.

Valuing children's risks presents several difficult problems that have not yet been fully addressed (see, for example, Dockins et al. 2002, EPA 2003). The number of related studies is increasing and they generally suggest that reducing risks to children is valued more highly than reductions for adults, perhaps by a factor of two.[18] However, this literature has not yet been thoroughly evaluated.

Given the complexities of these issues and the status of related research, Federal agencies generally apply the same VSL to both children and adults of all ages. This avoidance of age adjustments reflects concerns about the equity of such adjustments as well as the research evidence. However, age-related differences may be of less concern for homeland security rules than in the environmental context, because homeland security rules are less likely to disproportionately reduce the risks faced by very old or very young individuals. A key question is whether the VSL estimated from a wage-risk study of working-age individuals will be biased if applied to a population that also includes some younger and older individuals, given that the VSL may be larger for the former and somewhat smaller for the latter group. The net effect will depend on the proportion of the affected population that falls into each age group as well as the magnitude of the age-related change in the VSL.

Adjustments for deaths from illness: The available VSL estimates rely largely on studies of trauma-related deaths, which differ in significant physical respects from deaths due to illnesses such as those associated with chemical, biological, radiological or nuclear threats. For some illnesses (especially cancers), there may be a time lag between the occurrence of the source or cause of the risk (e.g., exposure to a contaminant) and the onset of symptoms, as well as a period of morbidity prior to death. Death is more immediate for most fatal injuries.

Until recently, there was little research that directly addressed the effects of these time lags on the VSL, and for many years EPA and others have used simple discounting to account for this effect. For example, if a pollution reduction occurs in the current year but a portion of the risk reduction occurs five years

[18] See, for example, Liu et al. (2000), Dickie and Messman (2004), and Hammitt and Haninger (2010). One exception is Jenkins et al. (2001) which estimates a higher VSL for adults.

later, then EPA would discount the VSL to reflect the five-year delay, using the same rate as applied elsewhere in the analysis.[19] Recent studies support the use of discounted values for delayed impacts (e.g., Viscusi and Aldy 2003, Hammitt and Liu 2004, Alberini et al. 2006, Van Houtven et al. 2008), although the estimates of the amount (or rate) of the discount over time vary.

In addition, deaths from illness may be preceded by a period of morbidity that is generally absent when death results from injury. Because of limitations in the available valuation research, an EPA expert panel (Cropper et al. 2001) suggested adding the costs of medical treatment to the VSL as a lower bound estimate of the value of averting this morbidity. However, these costs are not a measure of WTP. Perhaps most importantly, they exclude the value of avoiding pain and suffering and other quality of life impacts. Newer studies, such as Cameron and DeShazo (2009), Adamowicz et al. (2009), and Hammitt and Haninger (2010), address the combined effects of morbidity and mortality and may ultimately provide an improved approach for valuing the risks of illness-related deaths.

Whether adjustments for the differences between lingering illness and more immediate deaths are relevant to the analysis of homeland security regulations will depend on the types of deaths averted. For example, a rule that focuses on reducing exposures to cancer-causing substances or radiation may involve significant latency and/or illness prior to death, while a rule focused on reducing explosions or release of fast-acting toxins would more likely prevent immediate deaths. As needed, the research discussed above can be used either to develop quantitative adjustment factors tailored to the specific health effects or to support qualitative discussion of the implications of these differences.

Effects of Risk Perception, Tolerance, and Ambiguity

Perhaps the most significant difference between the risks addressed in the VSL literature and those associated with homeland security rules relates to how individuals perceive, or feel about, different hazards. Most VSL research focuses on relatively common risks (particularly workplace or motor vehicle accidents) which may be viewed as more controllable, voluntary, and familiar, and less feared, than infrequent but potentially catastrophic terrorist acts.[20] In addition, to the extent that experts disagree on the likelihood of attack, this ambiguity will affect how the risks are perceived.

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[19] OMB (2003) generally requires that regulatory analyses report the results using discount rates of both three percent and seven percent and also report the undiscounted values.

[20] The most common job-related risk results from transportation accidents (43 percent, U.S. Bureau of Labor Statistics 2007); several valuation studies also address motor vehicle accidents directly.

Unlike the risk characteristics discussed earlier, which have physical manifestations (morbidity, latency), these perceptions are primarily psychological. They may lead individuals to rank risks of the same expected magnitude (e.g., 1 in 100,000) and same outcome (e.g., immediate death) differently when they stem from different causes. Slovic (1987) notes that individuals are more likely to want to see a risk reduced through regulation if it is dreaded (involving "perceived lack of control, dread, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits") or unknown ("hazards judged to be unobservable, unknown, new, and delayed in their manifestation of harm" (Slovic 1987, p. 283).

In addition to affecting preferences for government intervention, these perceptions affect how the public responds to risk information. The link between risk perception and risk communication has been explored extensively. In contrast, relatively few studies quantify the effects of risk perceptions on monetary values.[21] The Appendix lists the key features of 15 selected studies, all of which use stated preference methods and were conducted in the U.S. or other high income countries. Eight of these studies consider trade-offs between risks of different types, providing adjustment factors that can be applied to valuation studies, while the remaining seven studies directly elicit monetary values.

Below, we briefly review these studies and discuss their implications. In this discussion, we focus on the effects of risk perception and ambiguity on the valuation of mortality risks. More generally, the increased fear and anxiety within society may be one of the most important consequences of terrorist attacks. However, the level of this more generalized fear may not be proportional to magnitude of the mortality risks, and would be most appropriately addressed separately in the analysis.

Qualitative risk characteristics: Of the 15 studies summarized in the Appendix, 12 address how different risks are perceived. Six address risks to oneself or one's household, one addresses risks to the community, and five address risk-reducing policies. Most consider risks that are more common than terrorist acts, including various types of transportation-related accidents (auto, rail, air); disasters of different types and magnitudes (fires, explosions, nuclear power); and illnesses associated with different causes (air pollution, drinking water contamination, pesticides in food). Only one (Viscusi 2009b) addresses terrorism.

The authors' featured estimates in several cases suggest no difference in the values placed on different risk scenarios, with most studies suggesting factors

[21] While we discuss these perceptions separately, they are often related to other population and risk characteristics. For example, studies that compare injuries to illnesses may confound the effects of differences in physical manifestation with differences in risk perception.

less than 2.0.[22] Only two studies result in significantly higher ratios: the Chilton et al. (2006) estimates for fires in public places and rail accidents, and the Itaoka et al. (2006) estimates for nuclear power generation.

These types of studies face several methodological challenges and many were developed to experiment with alternative approaches. Several test an approach using a small group of respondents rather than focusing on representative national samples. For example, Jones-Lee and Loomes (1995), Chilton et al. (2002), and Chilton et al. (2006) each ask respondents to discuss the task in a small group, then to complete the questionnaire individually. Such testing is necessary in part because several studies have found problems with how the scenarios are interpreted. There is often a fine balance between providing enough information to ensure that the respondents understand the task and providing so much information that they are overwhelmed. In addition, respondents may ignore or reject information if it conflicts with their prior beliefs.

In some cases, respondents may consider risk attributes not explicitly discussed in the survey, as illustrated by several studies that explore the dread associated with fatal cancers. While Magat et al. (1996) find that the median respondent is indifferent between fatalities from lymphoma and from auto accidents, this indifference may reflect consideration of latency, which was not explicitly discussed in the survey but may counterbalance the effects of any dread associated with these cancers. A more recent survey conducted by Van Houtven et al. (2008) clearly addresses both cancer morbidity and latency, and finds that the combined effects of these physical attributes and dread lead to cancer values up to three times greater than the value of auto accidents. Adamowicz et al. (2009) find that the value of reducing cancer risks is generally slightly lower than for microbial risks (although the differences are often statistically insignificant), noting that this might in part reflect how respondents interpreted characteristics implicit in the scenarios. The results of other studies are inconsistent. Hammitt and Liu (2004) find that reducing the risk of cancer is valued more highly than reducing the risk of similar noncancer effects, suggesting that dread increases the cancer values. In contrast, Hammitt and Haninger (2010) find similar values for mortality risks from cancers and noncancers as well as auto accidents.

In another study, Jones-Lee and Loomes (1995) compare events that differ in magnitude, but find little evidence of a scale premium. They suggest that, in the case of rare catastrophic events, aversion to ambiguity (discussed in more detail below) may be counterbalanced by doubts about whether programs can be designed to effectively avert such risks.

Several researchers find that the magnitude of the risk reduction may not have been fully understood. While WTP should increase when the risk increment

[22] Some of the scenarios considered in Subramanian and Cropper (2000) and in Van Houtven et al. (2008) lead to ratios between 2.0 and 3.0, but most estimates are below 2.0.

increases, respondents in many studies made little adjustment to their reported WTP. For example, Itaoka et al. (2006) find a large difference in WTP per expected fatality when comparing risks from a nuclear accident and from on-going fossil fuel generation, which appears to reflect insensitivity to the likelihood that such disasters might occur. Carlsson et al. (2004) find that some individuals appear to respond to their perceived risk levels rather than to the actual risks presented in the survey, while Chilton et al. (2006) find that some respondents appear to use heuristics (or simple decision rules) that lead to irrational responses.

Whether risks to oneself or risk-reducing policies are considered may also affect the results, but the magnitude of this effect may vary depending on the attributes of the scenario. For example, Subramanian and Cropper (2000) explicitly consider the trade-offs between different environmental and public health interventions.[23] They ask respondents to rate the programs in terms of selected psychological attributes, and find that these risk perceptions influence program choice by differing amounts.

Only one study (Viscusi 2009b) addresses homeland security. Viscusi asks respondents to evaluate trade-offs between the risks of terrorism or natural disasters and the risk of traffic fatalities. The terrorism scenario is framed by first reminding respondents of the number of deaths from the 9/11 attacks. The survey then asks them to choose among two policies, where both have the same costs but save differing numbers of lives – in one case from terrorist attacks and in the other from traffic accidents. (The approach is similar for natural disasters.) The results are ratios rather than monetary values.

Viscusi finds that the values placed on terrorism deaths are approximately equal to those placed on traffic-related deaths, and that these values are about twice those for natural disasters. His detailed exploration of the results suggests that they are consistent with several tests of rationality. It is unclear, however, whether these results would be the same if the survey was anchored in a discussion of a broader range of terrorism risks (beyond the 9/11 attacks). In addition, more work is needed to understand why some studies of risks that appear to be less feared than terrorist attacks (such air pollution) lead to higher ratios than does this study.

The results from these studies are summarized in the Appendix. In general, they do not provide definitive evidence regarding the effects of risk perceptions on the VSL for homeland security risks, due to both methodological limitations and differences in the populations and scenarios addressed. In particular, as discussed above, many rely on small, non-representative samples,

[23] The programs include: smoking education vs. air pollution control; colon cancer screening vs. drinking water pollution control; dual airbags in autos vs. auto emission controls; pneumonia vaccine vs. air pollution control; home radon control vs. workplace smoking ban; and home radon control vs. pesticide ban on fruit.

provide evidence that respondents did not fully understand the scenarios, and address scenarios that are dissimilar to homeland security risks.

Some (most importantly, Viscusi 2009b) suggest that there may be no difference between the values placed on reducing homeland security mortality risks and more commonplace risks such as those associated with motor vehicle accidents. Eliminating the studies that result in unusually large ratios (due most likely to responses that are inconsistent with the magnitude of risk reductions, as in Chilton et al. 2006 and Itaoka et al. 2006), the highest ratios appear to be around a factor of two. In combination, these studies indicate the need for more research.

Ambiguous risk information: One issue not explored in the Viscusi (2009b) study is the extent to which risk ambiguity affects valuation.[24] Because terrorist acts occur infrequently and perpetrators act strategically, it is very difficult to estimate the likelihood of future occurrences. Thus the values that individuals place on averting related mortality risks may in part reflect their aversion to the ambiguity of the risk.

The final three studies in the Appendix address this ambiguity, generally suggesting that WTP increases when ambiguity increases.[25] Viscusi et al. (1991) find that respondents are adverse to ambiguity, measured as the difference between two risk estimates. Shogren (2005) assesses the impact of ambiguous probabilities on WTP to decrease the likelihood of food-borne illness. He finds that mean WTP estimates are usually higher for the ambiguous risk scenario. Riddel and Shaw (2006) explore individual willingness to accept compensation for incurring the risks associated with nuclear waste transport and find that it rises as ambiguity increases. These studies suggest that ambiguity may increase values by a factor of two or less, implying that the VSL could be somewhat higher for terrorism risks than for less ambiguous risks.

In sum, the results of these 15 studies vary. Their findings are of interest in part because they test different approaches for measuring the effects of risk perceptions and ambiguity on the value of mortality risks, suggesting many avenues for further investigation. While some indicate that these risk characteristics may have little effect on the resulting values, others suggest that the effects could be noticeable – indicating that the value of reducing mortality

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[24] Johansson-Stenman (2008) discusses the theoretical relationship between risk perception and WTP, addressing terrorism and other policies and including the effects of fear. He concludes that, when individuals overestimate risk, theory suggests that the effect on WTP is ambiguous.

[25] In his seminal work on this topic, Ellsberg (1961) notes that ambiguity depends on the amount, type, reliability, and unanimity of information on probabilities and the resulting degree of confidence one has in the data. He indicates that many people prefer payments that they will receive with certainty to those that are uncertain, even when the uncertain outcome has a higher expected value.

risks associated with terrorist attacks could be higher than the value of the risk reductions commonly studied, perhaps by a factor of two at most.

CONCLUSIONS AND IMPLICATIONS

While several Federal agencies have developed well-established approaches for valuing mortality risk reductions in their regulatory analyses, those approaches may not be entirely appropriate for homeland security rules. They address different types of risks, in some cases affecting different populations, and do not fully incorporate the most recent research and expert panel advice.

Our review of the available research results in two key findings. First, we develop an updated VSL estimate based on newer studies that appears applicable to a number of regulatory contexts in addition to homeland security. Second, we find that reductions in mortality risks from terrorist acts may be valued more highly than suggested by this estimate, given the qualitative attributes of the risks and their ambiguity. Additional research is needed to more precisely estimate this increment and to determine whether it is large enough to noticeably affect the relationship between the costs and benefits of alternative policies, potentially supporting more costly regulations.

Federal agencies currently use central VSL estimates that range from about $5 million to about $8 million, with low and high end values that vary significantly by agency. Our updated review results in a base value that is within this range. We recommend a central VSL of $6.5 million in 2008 dollars (adjusted for inflation and real income growth), normally distributed with a 95 percent confidence interval of $5.1 million to $8.2 million. This estimate is based on a recent "best practices" study of individuals' willingness to exchange income for reductions in the risk of death from job-related injuries, and can be adjusted to address deaths that result instead from lingering illness.

The available studies indicate substantial uncertainty regarding the extent to which individual WTP may be significantly higher when risks result from terrorist acts rather than workplace accidents. Some studies suggest that more feared and ambiguous risks may be valued as much as twice as high as more common and predictable risks, while others suggest smaller differences. Thus our central estimate of $6.5 million might understate the value of these risks, but the degree of understatement is uncertain. Given the importance of these estimates in regulatory analysis, further research could significantly improve the usefulness of the results for decisionmaking.

APPENDIX: RISK PERCEPTION, TOLERANCE, AND AMBIGUITY

Study	Population (responses)	Findings
Own Risks		
Magat et al. (1996)[a]	N. Carolina (727)	No difference between auto fatalities and fatal lymphoma
Hammitt and Liu (2004)	Taiwan (1,248)	Cancers valued one-third more than noncancers; air pollution risks valued twice drinking water risks.
Carlsson et al. (2004)	Sweden (996)	Risk reductions valued twice as high for air travel as for taxi travel.
Chilton et al. (2006)[a]	U.K. (145)	Dread factor ranges from 0.8 to 1.9 (compared to pedestrian accidents) for: accidents to automobile drivers/passengers, pedestrians, and at home; fires at home; drowning, hazardous production plant accidents and murder. Factor increases for fires in public places (5.8) and rail accidents (8.7).
Van Houtven et al. (2008)[a]	U.S. (1,010)	Cancers valued up to three times higher than auto accident risks.
Hammitt and Haninger (2010)	U.S. (2,018)	Similar values for cancers and non-cancers (from pesticides on foods) and for auto accidents.
Community Risks		
Itaoka et al. (2006)	Japan (1,513)	Fatalities from nuclear power disasters valued 60 times higher than from routine fossil fuel generation.
Risk-Reducing Policies		
Jones-Lee and Loomes (1995)[a]	U.K.(225)	No differences due to scale. Rail-related risks valued 50 percent higher than road-related risks.
Subramanian and Cropper (2000)[a]	U.S. (1,013)	100 percent change in blame, ease of avoidance, seriousness, personal impact, program effectiveness, appropriateness of intervention, fairness of funding, or the time lag led to a 5 to 150 percent change in value
Chilton et al. (2002)[a]	U.K.(254)	Value of preventing deaths from rail accidents and fires at most 20 percent higher than for road accidents.
Adamowicz et al. (2009)	Canada (1,219)	Microbial risks valued one-third more than cancers (generally statistically insignificant).
Viscusi (2009b)[a]	U.S. (1,108)	Traffic deaths valued similarly to terrorism, each valued at twice natural disaster deaths.
Risk Ambiguity		
Viscusi et al. (1991)[a]	N. Carolina (646)	For risk of auto fatalities vs. fatal lymphoma or nonfatal nerve disease, greater ambiguity increases values by a small amount.
Shogren (2005)	NR	For food-borne illness, ambiguity increases values by a factor of about 1.3 to 2 (generally not statistically significant).
Riddel and Shaw (2006)	Nevada (NR)	For nuclear waste transport, increasing ambiguity by a factor of 2 increases values by about 75 percent.
Notes: NR = not reported. a. Survey elicited rates of trade-off between different risk levels or number of deaths, not monetary values.		

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