The relation between cost-benefit analysis and risk acceptance in regulatory decision-making

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Abstract: Risk cannot be avoided completely in modern society. As a society develops, public concerns on reducing risks are elevated, resulting in legislation and executive orders to create agencies that regulate such risks. However, it has been noted that the cost efficiencies of federal regulations are not consistent either within or across regulatory agencies, suggesting a need to establish a solid framework to advance regulatory decision-making in the public interest. In this paper, we utilise cumulative prospect theory (CPT) to investigate risk acceptance reflected in several US federal regulatory policies, specifically in their proposed regulations that address public safety and health issues. Attitudes toward risk are reflected in perceptions of likelihoods and consequences of hazardous events or exposure to hazardous materials. Twenty-two regulations proposed are analysed. The relative standing of risk acceptance reflected in each regulation sheds light on the differences in risk acceptance attitudes.

Keywords: cost-benefit analysis; cumulative prospect theory; CPT; risk acceptance; decision-making; regulations; risk perception.

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1 Introduction

Risk is defined, in general, as the potential for loss to an individual's health or financial well-being from hazardous events or exposure to hazardous materials. Removing the source of risk seldom is possible because the benefits accrued from certain activities containing an element of risk (e.g., commercial aviation) may be substantial; furthermore, eliminating risks from certain hazardous events may be costly and or impractical. Therefore, efforts to manage risks have focused on reducing them to socially acceptable levels rather than removing them entirely. Managing risk has become a primary goal of health and safety-related regulatory decision-making in modern societies, including the USA, for the last four decades (Kaplan and Garrick, 1981; Kraus and Slovic, 1988; Morrall, 1986, 2003). As risk management activities have increased, various regulatory policies have been instituted to prevent excessive governmental spending on implementation and enforcement of regulations and to provide transparency in regulatory decision-making. The US Office of Management and Budget (OMB) has required an impact analysis of each regulation that reduces risk to safety and health to the public since the Reagan Administration. This impact analysis has provided the basis for regulatory decision making (e.g., Morrall, 1986).

In an effort to better understand the governmental regulatory decision process and how it might be improved in the future, databases on the cost-effectiveness of past regulations have been established (Morall, 1986, 2003; Travis et al., 1987; Tengs et al. 1995; Houtven and Cropper, 1996). Analyses of 76 regulatory actions promulgated by the US Federal Government between 1967 and 2001 have revealed significant discrepancies in cost per statistical life saved (Morrall, 1986, 2003). Separate studies have noted similar differences for 500 US life-saving interventions (Tengs et al., 1995), for over 100 federal regulatory decisions regarding cancer risk management (Travis et al., 1987), and for numerous Environmental Protection Agency (EPA) regulations (Houtven and Cropper, 1996). Such differences have numerous sources, among them: the legislation authorising the budget for the agency; political or intangible (non-quantifiable) factors that are weighted arbitrarily; agency statutory requirements; and rule-making and enforcement actions by agency personnel. A better understanding of these differences is an essential step in developing a sound general governmental regulatory decision-making framework for future use. In short, they reflect differences in risk perception and risk acceptance attitudes in the regulatory decision-making process.

In this study, we explore the nature of risk acceptance attitudes implied by federal regulations that are intended to enhance health and safety of the public using a modern decision-theoretic model known as cumulative prospect theory (CPT). We begin with a brief review of CPT, showing that it can model the risk attitude of a decision-maker in a relatively flexible way. CPT subsequently will be used to perform a retrospective analysis of regulatory agency decisions aimed at reducing risk. We will consider regulations concerning risks from diverse causes, ranging from industrial atmospheric pollutants to terrorist attack on a commercial aircraft. Twenty-two regulations promulgated by the following agencies are considered: four by the National Highway Traffic Safety Administration (NHTSA), six by the Occupational Safety and Health Administration (OSHA), three by the Transportation Security Administration (TSA) [including one rule by the Federal Aviation Administration (FAA)], seven by the EPA and two by the Nuclear Regulatory Commission (NRC). The general risk attitude implied in each regulation (and, to some degree, of each agency) can be extracted from these retrospective analyses. We emphasise that the quantitative tools introduced herein do not explain the root causes (mentioned above) of the apparent difference in risk attitudes among regulatory agencies; rather, they simply provide a consistent metric by which their risk mitigation policies can be compared. The results of these analyses will provide perspectives on potential discrepancies in risk acceptance attitudes reflected in the regulations enforced by different agencies and make it possible for them to strive for a more consistent stance toward decision-making.

2 Regulatory decision-making in the presence of uncertainty

2.1 Cost-benefit (C/B) analysis of a regulation

Executive Order 12291 issued by President Reagan on February 17, 1981 stated that *regulatory action shall not be undertaken unless the potential benefits to society from the regulation outweigh the potential costs to society*. This order mandates regulatory impact analyses for major rules[1], which contain descriptions of the potential costs and benefits and their corresponding likelihoods. Since then, cost-benefit (C/B) analysis has served as a framework to aid decision-making of various government agencies.

The C/B ratio is often used to measure relative efficiency of available alternatives and to evaluate the impact of a specific risk-mitigating regulation. In the calculation of a C/B ratio as a part of a regulatory impact analysis, the cost term is defined by all the costs that are incurred to develop, implement, and maintain the safety level required by that regulation. The benefit term is defined by all the beneficial effects of the regulation, including fatalities avoided and reduced direct and indirect economic losses attributable to the increased safety provided by the regulation. Thus, the C/B ratio is defined as:

$$\frac{C}{B} = \frac{C_i}{C_d \cdot \left(p_0 - p_1\right)} \tag{1}$$

in which C_i is the cost of implementing the regulation, C_d is the potential loss that can be avoided by implementing the regulation, and p_0 and p_1 are, respectively, the probabilities of the potential loss without and with the implementation of the regulation. For regulations that deal with public health and safety, the potential loss is determined from the loss to the total population exposed to the hazard of concern while the probability of the potential loss is determined from the mortality rates due to the risk among the population. Fatalities, moderate, and minor injuries can be considered in the mortality rate calculation (NHTSA, 1984). Measures such as cost per life saved, opportunity cost of statistical life saved, and cost per life-year saved have been used in past studies to evaluate cost-efficiencies of past regulations.

2.2 *CPT: modelling risk acceptance attitude*

While C/B analysis has been broadly accepted and utilised as a norm of rational decision making in various contexts, it has been criticised for its simplified economic valuation of risk (von Neumann and Morgenstern, 1953; Arrow, 1971; Tversky and Kahneman, 1992; Viscusi, 1992; Slovic, 2000). Furthermore, it does not incorporate the diverse risk attitudes of decision makers (Keeney and Raiffa, 1976; Quiggin, 1982; Tversky and Kahneman, 1992; Sunstein, 2003; Lofstedt, 2003), which can be essential in some decision contexts, including those that involve public health and safety. From a quantitative view, risk involves a convolution of likelihood and consequences within a particular context. The risk attitude of a decision maker is reflected in his/her perceptions or preferences for the possible outcomes from a hazard which, in turn, create a tendency to overstate or understate a confronted risk, through biases in estimating its likelihood or its consequences (deaths or injury, and economic losses). If a decision-maker is risk-averse, he/she overestimates a risk; conversely, if a decision-maker is risk-accepting, he/she underestimates the risk. Finally, if a decision-maker neither overestimates nor underestimates a risk, he/she is regarded as risk-neutral. The attitude of each decision-maker toward a risk changes depending on the context of the risk assessment, including familiarity of the hazard or risk, the characteristics of potential losses, and the social position of the decision-maker. In general, individuals and small groups tend to be risk-averse toward a risk with potentially catastrophic events, while large groups such as government agencies or large corporations are risk-neutral decision-makers. Risk-accepting attitudes are often apparent when a decision-maker is not fully aware of potential consequences of a risk or is constrained by the resources that are available for mitigation, and must manage the risk with limited resources.

While C/B (and expected cost) analysis presumes that risk can be entirely monetised, there are certain situations, particularly involving low-probability, high-consequence events, where this is not the case. Some advanced decision models have been introduced to better depict actual decision-making by incorporating risk attitudes in such situations (Quiggin, 1982; Tversky and Kahneman, 1992; von Neumann and Morgenstern, 1953). Risk attitudes are incorporated by quantitative measures of desirability that reflect a distinct value system of each decision-maker. A value system can be represented by nonlinear functions that assign values to probability of occurrence and consequence of a potentially hazardous event. The utility function (von Neumann and Morgenstern, 1953) is a well-known example. The utility function is an increasing function of wealth, in which the marginal increase in utility varies over the range of wealth. The function is convex, concave and linear for risk-averse, risk-accepting and risk-neutral stances, respectively. While a decision-maker's perception of a risk must be reflected solely by the utility function in utility theory, his/her value system can be decomposed further in CPT through a value function, $V(C)$, and probability weighting function, $w(p)$, which represent values assigned to event consequence (C) and weights assigned to event likelihood (p), respectively. This separation of hazard likelihood and consequences is consistent with the observation (Tversky and Kahneman, 1992) that the likelihoods of low-probability, high-consequence events tend to be overstated by many decision-makers, particularly when limited information is available; this overstatement is reflected in $w(p)$. Furthermore, the value function consists of two separate parts, one for gains and the other for losses, each of which is an increasing function of consequences. By using two separate functions for gains and losses, behaviours such as loss aversion can be handled with more flexibility than in utility theory, which vests attitudes toward risk solely in the utility function (Tversky and Kahnemann, 1992). Further details on the utility, value, and probability weighting functions are provided elsewhere (Keeney and Raiffa, 1976; Tversky and Kahneman, 1992; von Neumann and Morgenstern, 1953; Prelec, 1998; Ang and Tang, 1984; Cha and Ellingwood, 2012).

2.3 Quantification of risk acceptance attitude evidenced by a regulation

The nature of the risk attitude reflected in a regulation that limits the risk exposure of a population and mandates mitigation of the risk can be investigated in the framework of cumulative prospective theory (Cha and Ellingwood, 2013). Suppose that a regulation's C/B ratio is determined by monetising both the implementation costs and the risk mitigation benefits. If the C/B ratio of the regulation is greater than 1, it implies that the potential benefits of the regulation to society are judged not to outweigh its potential costs. If the regulation is, in fact, finalised despite its cost-inefficiency, it is considered that the perceived potential benefits of the regulation to society outweigh its *perceived* potential costs in the regulatory agency's value system. However, if the C/B ratio of the regulation is less than 1, the regulation should be easily justified. Thus, if the regulation is rejected, it would imply that the potential benefits are not perceived greater than the potential cost. The *perceived C/B ratio* of a regulation can be represented by a value function, $V(C)$, and a probability weighting function, $w(p)$:

$$\left(\frac{C}{B}\right)_p = \frac{\left(1 - V\left(C_i\right)\right)}{\left(1 - V\left(C_d\right)\right) \cdot \left(w\left(p_0\right) - w\left(p_1\right)\right)} \tag{2}$$

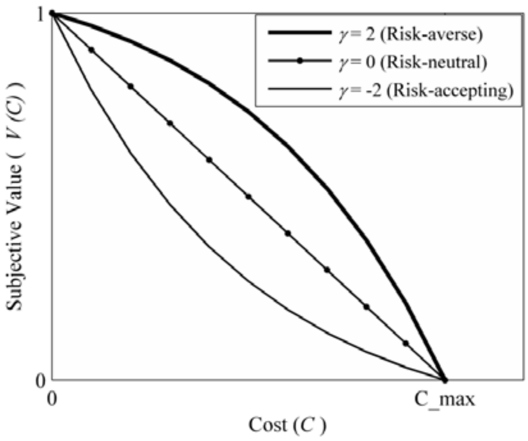
The *perceived C/B* ratio is proportional to both $(1 - V(C_i))/(1 - V(C_d))$ and $1/(w(p_0) - w(p_1))$, both of which vary depending on the nature and the degree of risk attitude; both terms decrease as the degree of risk aversion/acceptance reflected in the functions increases/decreases. Thus, the nature and the degree of risk attitude encapsulated in a regulation can be investigated by identifying the value and the probability weighting functions that make the *perceived C/B* ratio equal to unity. Note that the *perceived C/B ratio* is developed from CPT; it is not the *monetary C/B ratio* represented by equation (1).

In this study, only one value function will be adopted since a regulatory agency, unlike a private-sector business, is confronted only with losses (entirely negative consequences). This value function in a normalised form is (Keeney and Raiffa, 1976; Cha and Ellingwood, 2012):

$$V(C) = \frac{1}{1-e^{-\gamma}} \cdot \left(1 - e^{-\gamma \frac{C_{\max}-C}{C_{\max}}}\right) \quad (3)$$

where cost $C \geq 0$ and $C_{\max}$ is the maximum possible value of a potential loss. The parameter γ governs the convexity of the value function, which is directly related to the nature and the degree of risk attitude and thus is denoted the risk-aversion parameter. The value of γ indicates the nature of the risk attitude associated with the decision-maker's values; γ is positive, negative and zero for risk-averse, accepting and neutral attitudes, respectively. As shown in Figure 1, the convexity of the value function becomes more distinct as γ increases from 0, implying more risk-aversion. Similarly, the concavity of the value function becomes more apparent as γ decreases from 0, implying a higher degree of risk-acceptance.

Figure 1 Typical value functions representing risk-averse, neutral and accepting attitudes



A typical probability weighting function for rank-ordered and one-sided consequences is (Tversky and Kahneman, 1992; Prelec, 1998).

$$w(p) = \exp^{-\alpha(-\ln p)^{\varphi}} \quad (4)$$

where p is a cumulative probability and the parameters α and φ determine, respectively, the convexity and the characteristic inverse-S shape of $w(p)$. Although the parameters α and φ together govern the overall shape of the probability weighting function and are related to the risk attitude that is associate with the function, we fix the value of α at 1 and use only φ as the risk-aversion parameter in equation (4) for simplicity. The parameter φ is chosen instead of α because probability weighting functions have been reported to be inverse-s shaped from controlled, hypothetical decision experiments (Tversky and Kahneman, 1992; Prelec, 1998). The characteristic inverse-S shape of the function becomes more pronounced as the value of the parameter φ decreases from 1 as shown in Figure 2, implying that additional risk-aversion is being encapsulated by the function. Conversely, the function becomes more S-shaped as the value of the parameter φ increases from 1, implying more risk-acceptance.

Figure 2 Typical probability weighting functions representing risk-averse, neutral and accepting attitudes

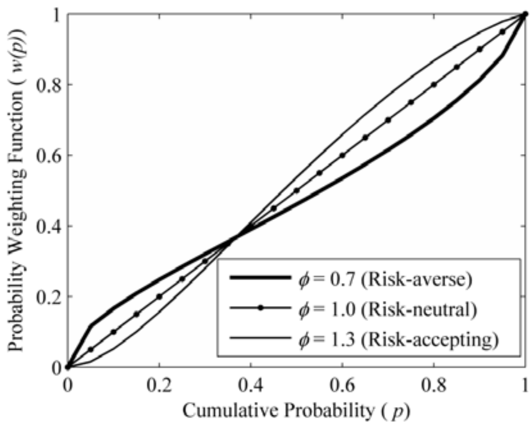
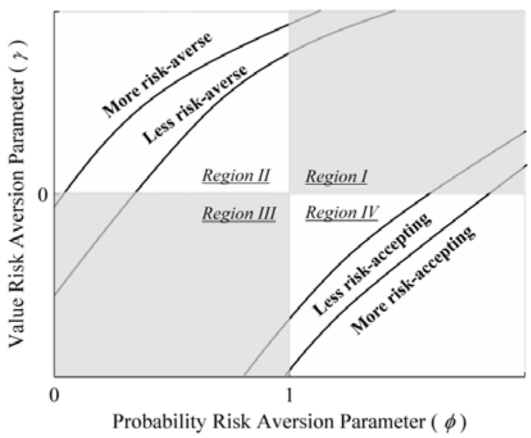


Figure 3 Typical risk-equivalent curves representing risk-averse and accepting attitudes



The relationships between the parameters γ and φ and the risk attitude that is associated with the value and the probability weighting functions allow us to quantify a risk attitude. Therefore, the risk attitude reflected in a regulation will be quantified by the values of parameters γ and φ that makes the *perceived C/B ratio* equal to 1. Previous studies (Cha and Ellingwood, 2012, 2013, 2014) have found that the analysis of a decision (regulation) does not yield a unique pair of the risk-aversion parameters; instead, pairs of (γ, φ) are identified. A curve formed by those pairs of (γ, φ) identified for a decision is denoted the *risk-equivalent* curve, in the sense that every point on the curve represents a similar risk attitude that leads to the same decision. The nature of the risk attitude that is associated with a risk-equivalent curve is indicated by the *location* of the curve, as shown in Figure 3. Every point in the region defined by $\{\gamma > 0\} \cap \{0 < \varphi < 1\}$ (region II) characterises a risk-averse attitude and thus *any* curve that lies in this region reflects a risk-averse attitude. In contrast, a risk-accepting attitude is reflected by a risk-equivalent curve that lies in the region defined by $\{\gamma \leq 0\} \cap \{\varphi \geq 1\}$ (region IV). In regions I and III, one of the parameters represents a risk-accepting attitude while the other represents a risk-averse attitude at the same time; since this is not a plausible value system for a decision-maker, regions I and III are considered infeasible. The degree of risk-attitude is then reflected by the relative location of the risk-equivalent curve. A risk-equivalent curve lies further from $(\varphi, \gamma) = (1, 0)$ if the risk-aversion or risk-acceptance associated with the curve increases, as shown in Figure 3.

The apparent risk perceptions embedded in 22 regulations promulgated by five federal regulatory agencies are examined in the following section using the methodology described above. As noted previously, CPT provides a consistent metric by which these apparent risk perceptions can be compared, but does not explain the root causes of the apparent differences. It is assumed that these attitudes are time-invariant, which causes the dependence of regulatory action on the political climate to be neglected. Additional data must be gathered and analysed to determine the dependence of these attitudes on time.

3 Risk perceptions reflected in federal regulation

A retrospective analysis of 22 proposed, final or rejected federal rules by five agencies of the US Government, for which comprehensive information on risks, benefits, and costs was available, was conducted utilising the methodology introduced in Section 2. The agencies were the NHTSA, OSHA, TSA, EPA and NRC.

3.1 National highway traffic safety administration

The NHTSA is an agency of the US Department of Transportation, which was established by the Highway Safety Act of 1970 to carry out safety programs previously administered by the National Highway Safety Bureau (NHTSA, 2006). It has proposed and issued numerous rules under titles 23 and 49 of the US code. Four NHTSA rules are analysed to understand the nature of attitude toward the risk of a driver or occupants losing their lives in a motor vehicle accident. The four rules deal with: (N1) steering column protection (1967), (N2) side door structure improvements (1970), (N3) fuel system integrity (1975) and (N4) passive restraints/belts (1984). The total exposed population, initial annual risk, risk reduction attributable to each rule and cost of implementing the requirements of each rule, and the impact analysis report of each rule have been provided previously (Morrall, 1986; NHTSA, 1981, 1982, 1983, 1984), as summarised in Table 1. The annual cost per life saved was reported to be \$0.1, \$1.3, \$0.3 and \$0.3 million (measured in 1984 US dollars) for rules (N1)–(N4), respectively and the corresponding non-dimensional monetary C/B ratio[2] is determined from equation (1) as 0.035, 0.448, 0.103 and 0.103, respectively. C/B ratios that are less than 1 imply risk-accepting attitudes.

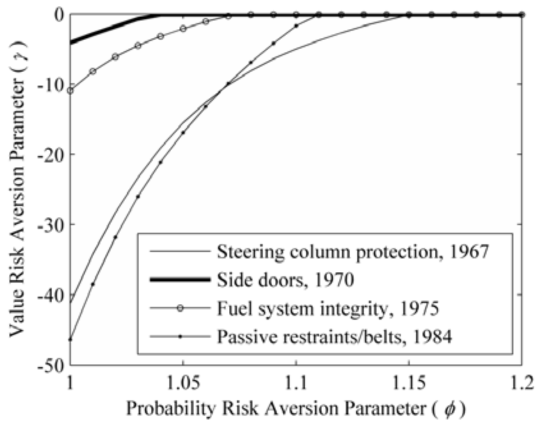
Table 1 Cost and risk reduction benefit of federal regulations*

Regulations	*Initial annual risk*	*Exposed population (M)*	*Risk reduction (%)*	*Implementation cost (millions of 2009 $)*
(N1) steering column protection, 1967	7.7 in 10^5	141	12	268
(N2) side doors, 1970	3.6 in 10^5	95	14	1,288
(N3) fuel system integrity, 1975	4.9 in 10^6	193	42	248
(N4) passive restraints/belts, 1984	9.1 in 10^5	45	45	1.2
(O1) hazard communication, 1983	4.0 in 10^5	25	20	743
(O2) servicing wheel rims, 1984	1.4 in 10^5	0.23	70	2.4
(O3) grain dust, 1987	2.1 in 10^4	0.027	70	23.1
(O4) asbestos, 1972	3.9 in 10^4	1.2	83	6,050
(O5) ethylene oxide, 1984	4.4 in 10^5	0.068	94	1,487
(O6) asbestos, 1986	6.7 in 10^5	1.2	90	13,774
(T1) federal air marshal, 2003	3.1 in 10^7	290	5	1,145
(T2) federal flight deck officers, 2003	3.1 in 10^7	290	23	21
(F1) hardened cockpit doors, 2002	3.1 in 10^7	290	68	46.6
(E1) benzene/fugitive emissions, 1982	1.5 in 10^8	30	69	1.2
(E2) arsenic/glass manufacturing plants, 1986	3.3 in 10^8	12	83	7.0
(E3) benzene/storage vessels, 1989	8.4 in 10^{10}	85	44	0.22
(E4) benzene/coke by-product recovery plants, 1989	1.0 in 10^7	20	98	32.9
(E5) radionuclides/DOE facilities, 1989	1.1 in 10^9	64	44	2.6
(E6) radionuclides/elemental phosphorous, 1984	4.5 in 10^9	13	71	6.0
(E7) benzene/maleic anhydride, 1984	2.9 in 10^9	10	14	1.3
(Nu1) anticipated transient without scram (ATWS), 1984	5.5 in 10^8	155	99	358
(Nu2) station blackout, 1988	9.1 in 10^7	155	76	366

Note: *Rules that are regulated by other agencies, (O1)~(Nu2), will be introduced successively in following sections.

The degrees of risk-acceptance reflected in regulations N1–N4 are quantified using the risk-aversion parameters γ and φ in the value and probability weighting functions defined in equations (3) and (4). The pairs of risk-aversion parameters that represent a risk attitude that is associated with each regulation are determined by searching for a value of γ at which the *perceived C/B* ratio [calculated from equation (2)] reaches at 1, as φ is fixed at a value increasing from 1. Risk-equivalent curves that are formed by the pairs (φ, γ) so obtained are shown in Figure 4. All four curves lie in region IV (cf. Figure 3), confirming the risk-accepting attitudes associated with these four regulations. Note that the curves present the highest possible risk acceptance associated with the regulations. In other words, a risk-averse decision-maker also could have adopted the rules because of cost efficiency; however, a decision-maker with risk tolerance higher than the obtained level would have rejected the rules. For each risk-equivalent curve, the value of γ increases as φ increases because as more risk-acceptance is encapsulated by the probability weighting function, less is encapsulated by the value function. The relative location of the risk-equivalent curves from the risk-neutral position, $(\varphi, \gamma) = (1, 0)$, indicates that the regulation concerning (N2) side door structure improvements is least risk-accepting, followed by (N3) fuel system integrity, and (N1) steering column protection and (N4) passive restraints/belts. However, the risk-acceptance reflected in the regulations (N1) and (N4) could not be uniquely rank-ordered. Regulation (N4) reflects more risk-acceptance than regulation (N1) based on the value of γ at $\varphi = 1$ while the regulation (N1) reflects more risk-acceptance than the other based on the value of φ at $\gamma = 0$. This problem in rank-ordering of degrees of risk-acceptance associated with the regulations N1–N4 suggests that the monetary C/B ratio, by itself, may not reflect risk acceptance accurately and that other factors, alluded to in the introduction, may play an important role in decision-making.

Figure 4 Risk-acceptance attitude defined by risk-equivalent pairs (γ, φ) reflected in regulations issued by NHTSA



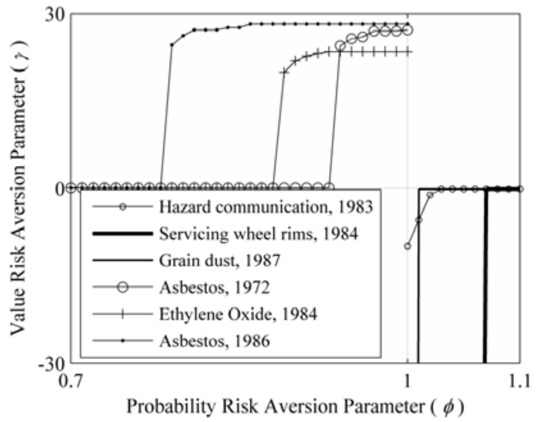
3.2 Occupational safety and health administration

The OSHA was created by the Occupational Safety and Health Act of 1970 as a part of the US Department of Labour to prevent workers from being killed or seriously harmed due to a potentially hazardous working environment (OSHA, 2011, 2013). Since then, OSHA has set and enforced standards under title 29, United States code. Six rules that were issued by the OSHA were examined: (O1) hazard communication (1983), (O2) servicing wheel rims of large trucks, trailers, buses, and off-road construction equipment[3] (1984), (O3) grain dust (1987), (O4) asbestos (1972), (O5) ethylene oxide (1984) and (O6) asbestos (1986). The first three rules concern workplace safety while the remaining three concern latent cancer risks from inhaling toxic materials. All six rules were identified from Morrall's study (1986), which reported that the annual costs per life saved were \$1.8, \$0.5, \$2.8, \$7.4, \$25.6 and \$89.3 million (in 1984 US dollars) for rules

(O1)~(O6), respectively. Further information required to assess the underlying risk attitude embodied in these rules is provided in (OSHA, 1988, 1998, 1992, 2003, 2005) and is summarised in Table 1.

C/B ratios for the six rules are determined from equation (1) as 0.619, 0.171, 0.970, 2.54, 8.82 and 30.8, which suggest risk-accepting attitudes toward workplace safety and risk-averse attitudes toward latent cancer risk due to involuntary exposure to toxic materials. For each rule, a risk-equivalent curve is obtained similarly as in Section 3.1 and is plotted in Figure 5. The rules are found to be more risk-averse based on the value of γ at $\varphi = 1$ in the following order: (O6), (O4) and (O5), (O1) and (O3), and (O2). The risk-equivalent curves that are associated with rules (O1)–(O3) lie in region IV, which represents a risk-accepting attitude. In contrast, the curves associate with rules (O4)–(O6), lie in the region II that represents a risk-averse attitude. The attitude toward risk of cancer from exposure to asbestos is the most risk-averse of all hazards, as reflected in regulations (O4) and (O6).

Figure 5 Risk-acceptance attitude defined by risk-equivalent pairs (γ, φ) reflected in regulations issued by the OSHA

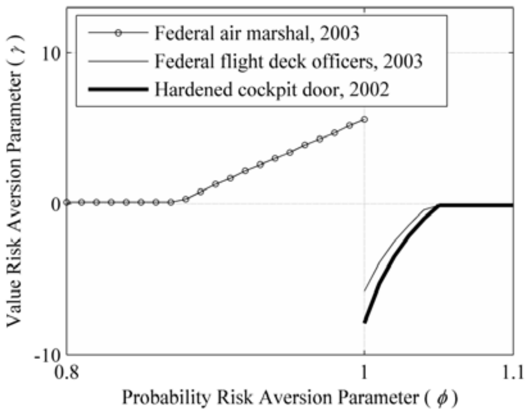


3.3 Transportation security administration

The TSA is an agency of the US Department of Homeland Security which was created by Aviation and Transportation Security Act of 2001 following September 11, 2001. With the mission of ensuring the freedom of movement for people and commerce, the TSA strives to reinforce the security of US transportation systems (TSA, 2013). Transportation security regulations are codified in title 49 of the United States code, chapter XII, parts 1500 through 1699. In this section, two security programs that are administered by the TSA are analysed with respect to attitudes toward security risks to airport systems from terrorist attacks: (T1) federal air marshal program (2003), and (T2) federal flight deck officers program (2003). In addition to these two rules, a third rule (F1) requiring hardened cockpit doors on domestic and foreign airlines serving the United States (2002), which was issued by the FAA, is analysed to compare the regulations issued by two federal agencies to address the same risk issue. Information on the costs and risk reduction benefits of the programs has been provided in earlier studies (Wilson and Thomson, 2005; GAO, 2009; Stewart and Mueller, 2013) (see Table 1).

The monetary C/B ratios for programs (T1), (T2) and (F1) are 42.5, 0.169 and 0.127, respectively, implying a combination of risk-accepting and risk-averse attitudes toward aviation security. Figure 6 shows the risk-equivalent curves that are associated with the three programs. The federal flight deck officer program (T2) represents a case of risk-acceptance while the federal air marshal program (T1) represents a case of risk-aversion. However, the two programs of the TSA are found to be less risk-accepting than the FAA's hardened cockpit doors program (F1). This may be attributable to the fact that the TSA was established to regulate aviation security risk immediately following a catastrophic security failure while the FAA has been regulating aviation risks for several decades. The cost-inefficiency of the federal air marshal program (T1) has been noted in previous studies (GAO, 2009; Stewart and Mueller, 2013). However, the risk-equivalent curve that is associated with program (T1) in Figure 6 is located under and to the right of the curves associated with the health rules of the OSHA in Figure 5 (cf. Figure 9), which implies lower risk-aversion for program (T1) than for programs (O4)–(O6).

Figure 6 Risk-acceptance attitude defined by risk-equivalent pairs (γ, φ) reflected in regulations by the TSA

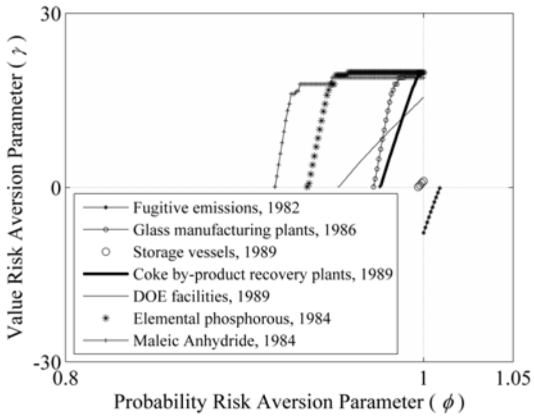


3.4 Environmental protection agency

The EPA was created by Executive Order in 1970 (EPA, 1970), following heightened concern about environmental pollution. With the mission of protecting human health and the environment, the agency has been writing and enforcing regulations found in title 40 of the United States code as well as researching and monitoring activities that might increase environmental risks to the public. In this section, seven regulations that have been proposed by the EPA to mitigate risks to the public health from various environmental pollutants are examined. The regulations concern: (E1) benzene/fugitive[4] emissions (1982), (E2) arsenic/glass manufacturing plants (1986), (E3) benzene/storage vessels (1989), (E4) benzene/coke by-product recovery plants (1989), (E5) radionuclides/DOE facilities (1989), (E6) radionuclides/elemental phosphorous (1984) and (E7) benzene/maleic anhydride (1984). Among these seven regulations, the first five were finalised and the last two were rejected following public comment. Information on cost efficiencies of the seven regulations and the corresponding risk levels have been provided (Morrall, 1986; Travis et al., 1987; Tengs et al., 1995; Houtven and Cropper, 1996; EPA, 1982, 1984a, 1984b, 1986, 1989).

The monetary C/B ratios for the seven regulations are calculated to be 0.64, 3.56, 1.21, 2.82, 13.5, 24.2 and 54.2, respectively; note that the C/B ratios were relatively high for the two regulations that were not finalised. The risk-equivalent curves that represent the risk attitudes associated with these seven regulations are plotted in Figure 7. The locations of the curves indicate a broad range of risk attitudes, ranging from risk-averse to risk-accepting; in particular, regulations (E2), (E3), (E4), (E5), (E6) and (E7) typify risk-aversion, while regulation (E1) typifies risk-acceptance. Note that the two rejected rules (E6) and (E7) are located furthest from (φ, γ) = (1, 0) in region II of Figure 3, suggesting that the two rules are associated with a level of risk-aversion which simply could not be justified by the EPA. The relative location of the remaining rules implies less risk-aversion with regard to exposure to benzene than toward exposure to radionuclides or arsenic. The risk-aversion toward radionuclides and arsenic cannot be clearly rank-ordered since the risk-equivalent curves associated with (E2) and (E5) are not completely separated.

Figure 7 Risk-acceptance attitude defined by risk-equivalent pairs (γ, φ) reflected in regulations by the EPA

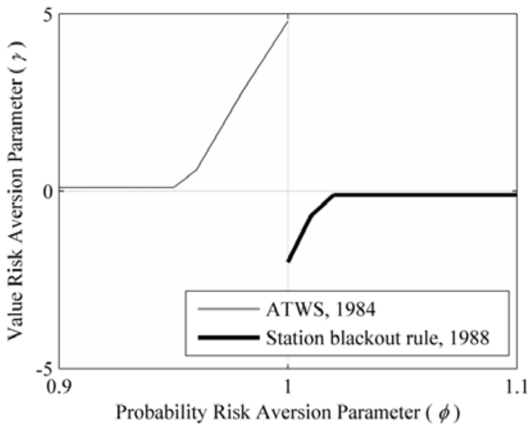


3.5 Nuclear regulatory commission

The NRC is an independent agency created by the Energy Reorganisation Act of 1974 to ensure the safe civilian use of radioactive materials while protecting people and the environment (NRC, 2013). The NRC regulations are codified in title 10 of the United States code. Two major rules of the NRC regulating operation of nuclear power plants are studied: (Nu1) anticipated transient without scram rule (1984) and (Nu2) station blackout rule (1988). Information on the costs, initial risks, exposed populations and risk reduction benefits associated with these rules are provided in NRC's regulatory impact analyses (NRC, 2003a, 2003b; OMB, 2005).

The monetary C/B ratios for these two rules are calculated as 7.04 and 0.568, suggesting apparent risk-averse and risk-accepting attitudes associated with the (Nu1) ATWS rule and the (Nu2) station blackout rule, respectively. The risk-equivalent curves formed by those pairs that are associated with the two rules are shown in Figure 8. Each curve is plotted separately; the (Nu1) lies in the region of risk-aversion (II) and the (Nu2) lies in region of risk-acceptance (IV). It is interesting to note that the attitudes embedded in these two rules exhibit degrees of risk-aversion and risk acceptance that are close to being risk-neutral.

Figure 8 Risk-acceptance attitude defined by risk-equivalent pairs (γ, φ) reflected in regulations by the NRC



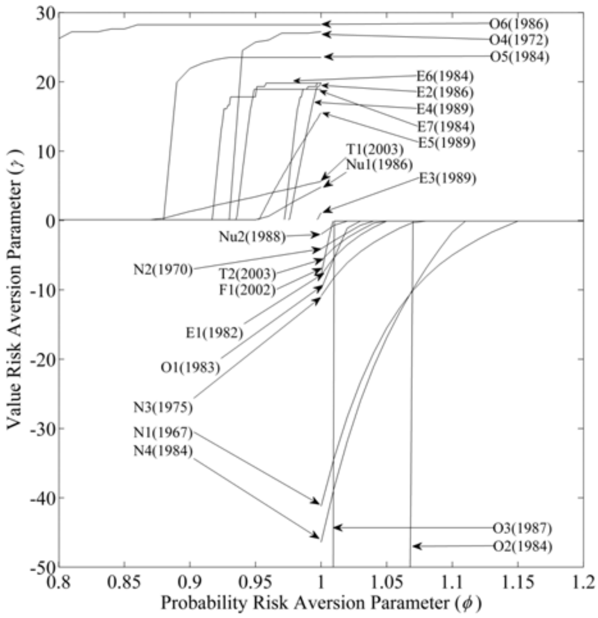
3.6 A comparison of risk acceptance attitudes reflected in selected federal regulations

General trends in risk-acceptance attitudes reflected in the regulations reviewed herein can be compared by considering the relative location of the risk-equivalent curves that are associated with the rules that are promulgated by each agency. The risk-equivalent curves that were identified for the 22 regulations in the previous sections are plotted together in Figure 9. The shapes of the risk-equivalent curves are convex regardless of the region in which each curve lies. The convexity is more pronounced in the region of risk-aversity where the value of γ becomes almost constant as the value of φ changes, implying that utility theory might provide a viable decision model in this region and eliminate some of the difficulties in establishing the probability weighting function used in CPT. It is interesting to note that the risk attitudes in these regulations exhibit a broad range of risk acceptance, at least when analysed using the *perceived C/B* ratio derived from the CPT model. Half of the rules analysed in this study represented potential of risk-accepting attitudes, among which four rules represented high levels of risk-acceptance with values of γ lower than –30. In contrast, the remaining half represents minor or moderate risk-aversion, with the values of γ not exceeding 30. Among the 22 rules, the OSHA rules concerning (O6) asbestos and (O2) servicing wheel rims were identified as rules that are associated with the highest level of risk aversion and risk-acceptance, respectively. The rules issued by the EPA ranked as the second most risk-averse, followed by those issued by the TSA, NRC and NHTSA. In general, we conclude that rules concerning risks to public health tend to be characterised by a higher level of risk-aversion than the rules concerning risks to public safety. This distinct hierarchy of risk-acceptance independently confirms the results of an earlier study by Slovic et al.

(1980) on the perception of risk: people tend to overestimate an involuntary and uncontrollable risk more than a risk that is taken voluntarily by the exposed person who believes that he/she can control the risk with his/her training or capability.

A closer look at the relative location of risk-equivalent curves in Figure 9 suggests discrepancies in risk attitudes reflected in the rules of different agencies toward similar types of risk. For example, the curves associated with the OSHA's health rules (O4)~(O6) are located further from (φ, γ) = (1, 0) than the curves associated with the EPA's rules, indicating that the EPA is less risk-averse toward the possible exposures to industrial pollutants than the OSHA. Similarly, the NRC's rule to limit exposure to radioactive materials during the operation of a nuclear power plant apparently is less risk-averse than the EPA's rule toward radionuclide exposure.

Figure 9 Risk-acceptance attitudes reflected in regulations by different agencies



4 Summary and conclusions

The retrospective analysis presented in this study represents an attempt to understand regulatory decision-making concerning public health and safety in the light of risk perceptions and attitudes reflected in the rules promulgated by several US Federal regulatory agencies. Twenty-two regulations that were proposed by five federal administrative agencies – NHTSA, OSHA, TSA, EPA and NRC – were analysed. This analysis revealed that the rules represented a mixture of risk-accepting and risk-averse stances, showing an inconsistency in the regulations promulgated by these agencies. An ordinal ranking of risk-acceptance in rule-making suggests that it tends to be higher in agencies concerned with risks that are undertaken voluntarily and where the risk can be socialised than in those agencies concerned with health and safety risks.

The results of this study can be used to inform and advance federal agency regulatory decision-making. The risk attitudes reflected in past regulations can be used as a benchmark in analysing the efficiency of future regulations in meeting the statutory responsibilities of the agencies that issue them. Furthermore, the set of risk attitudes uncovered in this study provides a glimpse into current status regulatory rule-making with regard to risks to public health and safety, which can provide a benchmark for new or existing agencies that do not have prior experience or databases in developing their own risk-informed decision frameworks. It can be especially useful for regulating risks in which the level of uncertainty is high and many dimensions are not easily measured. For example, the importance of considering risk aversion for climate change policy has been noted (Nordhaus, 2011; Pindyck, 2011; Weitzman, 2011). It should be noted that the values for risk aversion parameters depend upon an assigned value of a statistical life (OMB, 2003, 2010). Thus, the values of the risk-equivalent parameters and curves should only be considered as a *relative* measure of risk attitude. Regulatory decision-making is a complex process that is influenced by numerous factors beyond risk acceptance attitudes. In this study, the parameters for risk acceptance attitude in the CPT model represent all those factors (politics, statutory requirements, etc.) inclusively; further studies should be conducted to deconstruct their components.

The nature of risk attitudes apparent in 22 federal regulations was assumed to be independent of time within and across the five regulatory agencies. A study of more diverse sets of regulations that deal with the same risk and are issued by the same agency in different years (or in different political administrations), would be desirable to study further historical changes in risk attitude in the regulatory process and the sensitivity of these attitudes to political considerations. In any event, the wide range of evident risk-acceptance attitudes, regardless of underlying cause, indicates a need for a sound framework to guide future regulatory decisions.

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Notes

1 Major rule means any regulation that is likely to result in

a an annual impact on the economy of $100 million or more

b a major increase in costs or prices for consumers, individual industries, federal, state, or local government agencies, or geographic regions

c significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of US-based enterprises to compete with foreign-based enterprises in domestic or export markets (Executive Order 12291).

2 Value of an avoided fatality (value of statistical life) is assumed at $6M in this study (US DOT, 2009). Further discussion of the theory and practice of calculating VSL are provided in OMB Circular A-4, which concludes that a substantial body of the studies of VSL indicate a value that varies from $1 million to $10 million per statistical life (OMB, 2003, 2010).

3 A sudden release of the pressurised air contained in a large wheel during service can hurl an employee across the shop or propel the wheel rim into a worker (OSHA, 1998).

4 The EPA defines 'fugitive emissions' as "those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening" (EPA, 1999).