Natural Hazards and Climate Change as Dread Risk

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ABSTRACT

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People judge the risks in their environment not only based on objective measures such as lives lost or dollars spent, but also based on their subjective perceptions of those risks. These perceptions can depend on a number of different characteristics of risk, including: how voluntarily the risk is undertaken, how immediately effects are seen, how known the risks are to scientists and to those exposed to them, how controllable those risks are, how new the risks feel, how catastrophic the effects tend to be, how likely the effects are to be fatal, and how dreaded the risk feels on a gut level. These nine characteristics of risk tend to load onto two orthogonal factors, or risk dimensions: unknown risk, and dread risk. While past research using such a psychometric approach to risk perception has established dread and unknown risk levels, as well as relative risk ratings, for a slate of 30 common technologies and activities (e.g., nuclear power, pesticides, skiing, fire fighting), most of these studies are now over three decades old. Chapter 1 of this dissertation replicates and updates the findings from those original psychometric studies of risk perception, showing that the dread-unknown factor space is still a useful framework for studying risk perceptions, and illustrating some of the ways that risk perceptions for technologies have changed since the 1970s. Chapter 2 applies the same methodology to study people's responses to the risks of natural hazards and climate change. Although the slate of nine risk characteristics used to assess technological risk in Chapter 1 does not apply perfectly to a study of natural hazards on their own, Chapter 2 shows that this framework does work well as a means of assessing the differences in risk perception between natural hazards and climate change–related risks. We find that climate change and sea-level rise are not treated similarly to natural hazards like floods and wildfires; relative to the natural hazards, they fall at the extreme low end of the dread risk dimension, and the extreme high end

of the unknown risk dimension. Chapter 3 goes on to apply the dread-unknown risk framework to directly compare attitudes toward technological risks, natural hazards, and climate-related risks. Nearly all natural hazards rank higher on dread than nearly all of the man-made risks, but the natural hazards tend to cluster near the mean on the unknown-risk dimension while technological risks vary across the full unknown-risk scale. Climate change and sea-level rise, on the other hand, both fall among the highest-unknown items on the list, and lie just below the mean on dread risk. Climate change and sea-level rise continue to show risk profiles that clearly differentiate them from the natural hazards; instead, they more closely resemble the profiles for low-dread, high-uncertainty technologies like pesticides. This characterization of climate change as highly uncertain but relatively non-dread is consistent with theories that link the public's failure to engage on climate-related issues with a lack of vividness or immediacy to the concept of climate change. Since dread risk invokes the affective processing systems that can be more successful than analytical risk estimates at inspiring action, communicators or policymakers who are currently struggling to engage the public on the risks of climate change might find more success by linking these topics to hazards, such as hurricanes and floods, which appear to naturally invoke these desired qualities of dread risk.

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Dedication

To the Gimlet, who valiently raced this dissertation into the world, but fortunately lost.

Chapter 1: Is Safe Enough Still Safe?

An updated psychometric study of perceptions of technological risks and benefits

In everyday life, we engage in activities and interact with technologies that carry some amount of risk of bodily harm. Driving a car could lead to a crash, taking a prescription antibiotic might cause unpleasant side effects, and living near a nuclear power plant could increase the chances of radiation exposure. Different technologies vary both on their probability of causing death or injury and on the benefits they offer to society to make up for those costs—but they vary on many other dimensions as well, and these other dimensions may carry much more weight when it comes to our judgments about how risky different technologies seem or feel. For example, although many more people are killed or injured every year in car crashes than by nuclear power, the latter still often feels more unsafe.

Starr argued for a “revealed preference” approach to risk perception, assuming that the current risk levels for various activities and technologies are “essentially optimum,” and have been reached through society’s weighing of risk and benefit: working harder to reduce the risk for activities deemed too costly, and allowing for greater risk for activities that come with enough benefits to balance the risks. This revealed preference method, in its focus on overall risks and benefits, did not take any other dimensions of risk into account besides overall harm to society.

In their 1978 paper “How Safe is Safe Enough?,” Fischhoff, Slovic, Liechtenstein, Read, and Combs used a psychometric analysis to help explain why different technologies and activities might inspire such different risk reactions. In contrast to Starr’s “revealed preference” stance, Fischhoff et al. instead take the position that risk can vary across many characteristics—How immediately do the effects take place? How many people are affected at once? How controllable do the consequences feel? In this “expressed preference” approach to risk perception, Fischhoff et al. show that perceptions of risk for everyday activities and technologies tend to load onto two orthogonal dimensions, which they called dread risk and unknown risk.

Dread risk appeared to relate to consequences that are likely to be catastrophic, that are certain to be fatal, and that feel dreaded on a gut level. Unknown risks were those that are new, that are undertaken involuntarily, whose consequences are delayed, and which seem not fully known to science or to those exposed (Fischhoff et al., 1978). In later studies, similar sets of characteristics were found to load onto these factors: dread risk encompassing lack of control, catastrophic and fatal effects, a feeling of dread, and an imbalance in the distribution of risks and benefits; and unknown risk being associated with consequences that are unobservable, new, delayed, and unknown to science and the exposed (e.g., Slovic, 1987; Slovic, Fischhoff, & Lichtenstein, 1985, 1986).

Since the 1980s, hundreds of studies have cited the concepts of dread and unknown risk to illuminate risk perception on topics ranging from avian flu (Gstraunthaler & Day, 2008) to genetically modified foods (Gaskell et al., 2004), to financial decisions (Koonce, McAnally, & Mercer, 2005). Other studies have investigated cross-cultural risk perceptions using Fischhoff et al.'s (1978) framework in nations such as Norway, Hungary, and Korea (Cha, 2000; Englander, 1986; Teigen, Brun, & Slovic, 1988). However, little work has shown how perceptions of risks for everyday technologies and activities have changed (or not) over the past three decades, aside from studies looking at relatively specific domains (e.g., a study on food-related hazards by Sparks & Shepherd, 1994).

We therefore have little idea of how risk attitudes have shifted over time. Since the 1980s, the objective risks of many of the 30 items that Fischhoff et al. (1978) studied have in fact changed, as have the media culture and public knowledge about these risks. New technologies have emerged during the intervening decades, bringing new risks to public awareness and likely influencing public opinion about older technologies. Between the emergence of the 24-hour news cycle in the 1980s, the rise in awareness of global terrorism in the United States since 2001, and the information-sharing culture encouraged by social networking, it is reasonable to expect changes between 1978 and today in terms of the

psychological availability of various technological risks, as well as the public's knowledge about and attitudes toward those technologies.

The goal for this study was firstly to replicate and update the findings of Fischhoff et al.'s 1978 study, and to offer a descriptive look at how risk perceptions for a set of 30 activities and technologies have changed over the past several decades. While we did not expect that people today would show the same risk perceptions for those 30 items as people did in the 1970s, we did believe that the expressed preference framework that Fischhoff and colleagues developed would still be effective today to illustrate and partially quantify those perceptions of risk.

In addition to this primary goal of replication and revisiting of this methodology, this study was designed to set the stage for a broader investigation into risk perceptions for some of the most pressing environmental hazards facing society today. After establishing the continued usefulness of the psychometric approach to risk perception in this preliminary study, we will be able to extend the current line of research to include modern risks such as terrorism and cell phones, and—more importantly—to understand how people think differently about risks across various domains, including natural disasters and global climate change. It has been suggested that the lack of an inherent dread quality to climate change may contribute to the public's hesitation to acknowledge the dangers it poses (Weber, 2006); however, it remains to be shown that climate change really inspires less of a dread reaction than other environmental and technological hazards. The current study marks the first step toward a larger body of research that will allow us to assess climate change as a dread risk, as well as to better understand other aspects of the ways that people perceive the risks of environmental and technological hazards in relation to one another.

Method

We matched the design and content of this study as closely as possible to Fischhoff et al. (1978). The primary differences in method between the current version of the study and the original one are in elicitation medium (online vs. on paper) and in participant population (a fairly

representative US sample vs. Oregon League of Women Voters members and their husbands).

Design

Following Fischhoff, et al. (1978), Ps evaluated 30 activities and technologies on multiple dimensions: (1) the technology/activity's perceived benefit [risk] to society; (2) the acceptability of the technology/activity's current level of risk; and (3) its placement on each of nine dimensions of risk. The first part of the study was varied between Ps: some judged only the perceived benefit of each activity or technology, while others judged only the perceived risk. All Ps then answered the same questions in Parts 2 and 3.

The list of 30 activities/technologies for Ps to judge was copied exactly from Fischhoff et al., and can be seen in Table 1. For each task in the study, the order in which the 30 activities/technologies appeared was counterbalanced in a blocked Latin square design: five blocks of six items each were shuffled so that each activity/technology appeared early in the list for some Ps, in the middle of the list for others, and at the end of the list for others. No order effects were detected.

Matching the instructions used by Fischhoff et al. (1978) (hereafter FSLRC78), our Ps were told before they began their evaluations that "This is a difficult, if not impossible, task. Nevertheless, it is not unlike the task you face when you vote on legislation pertaining to nuclear power, handguns, or highway safety. One never has all the relevant information; ambiguities and uncertainties abound, yet some judgment must be made. The present task should be approached in the same spirit."

Tasks

1a. Perceived Benefit. Participants in the *benefits* condition were asked to judge the benefits to society of each of the 30 activities or technologies. For each, Ps were asked to "consider all types of benefits: how many jobs are created, how much money is generated directly or indirectly (e.g., for swimming, consider the manufacture and sale of swimsuits), how much enjoyment is brought to people, how much of a contribution is made to the people's health

and welfare, and so on.” Ps in this condition were instructed to ignore risks:

Do not consider the costs of the risks associated with these activities or technologies. It is true, for example, that swimmers sometimes drown. But evaluating such risks and costs is not your present job. Your job is to assess the gross benefits, not the net benefits which remain after the costs and risks are subtracted out. Remember that a beneficial activity affecting few people will have less gross benefit than a beneficial activity affecting many people. If you need to think of a time period during which the benefits accrue, think of a whole year—the total value to society from each activity or technology during one year.

The wording used for these instructions matched, as closely as possible, the language used by FSLRC78. Some changes were made to better fit the online nature of the task, e.g., asking Ps to click on the name of an activity/technology to place it into a ranked list, rather than moving index card into place to determine the rankings of the 30 items.

Ps were instructed to first “study each activity or technology individually, thinking of all the benefits of each.” Then Ps were asked to place the 30 activities/technologies in order of increasing benefit by clicking on each of the 30 items to move it into their ranked list. Ps could adjust the list until they felt it accurately reflected their judgments of benefit. Once this had been done, Ps were asked to assign a numerical value for the perceived benefits of each item, with the least beneficial (the first item on their list) assigned the value of 10, and other items judged relative to that. Ps were encouraged to take their time on this portion of the task, and given detailed instructions about how to assign values:

If you feel that an item is twice as beneficial as the least beneficial item, assign it a 20. This means that a rating of 12 indicates that the item is 1.2 times as beneficial as the least beneficial item (this means it is 20% more beneficial). A rating of 200 means that the item is 20 times as beneficial as the least beneficial item, to which you assigned a 10. Please take some time on this question, and double-check your ratings to make sure that they are consistent. For example, if one activity is rated a 50 and a second is rated 100, the second

item should seem twice as beneficial as the first. Adjust the numbers until you feel that they are right for you.

1b. Perceived Risk. Participants in the *risks* condition were given very similar instructions to those of the *benefits* Ps, except that they were asked to consider the “the risks of the activities and technologies listed below. Consider the risk of dying as a consequence of this activity or technology. For example, use of electricity carries the risk of electrocution. It also entails risk for miners who produce the coal that generates electricity. Motor vehicles entail risk for drivers, passengers, bicyclists, and pedestrians, etc.” Just as the *benefits* Ps were instructed not to consider risks, the *risks* Ps were instructed that “Your job is to assess the gross risks, not the net risks which remain after the benefits are subtracted out.” As before, the language used in this section was modeled on the task used by FSLRC78.

2. Risk Adjustment Factor. After judging *either* the risks or benefits of the 30 activities and technologies, all Ps were asked to decide for each activity/technology “whether the associated risks are either too high, at an acceptable level, or too low.” As in FSLRC78, Ps were told:

Almost any activity or technology carries some amount of risk, but this is not the ideal risk. Ideally, the risks should be zero. The acceptable level is a level that is “good enough,” where “good enough” means you think that the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity. For example, we can make drugs “safer” by restricting their potency; or cars can be made safer at a cost, by improving their construction or requiring regular safety inspection. We may, or may not, feel restrictions are necessary. If an activity’s present level of risk is acceptable, no special action need be taken to increase its safety. If its riskiness is unacceptably high, serious action, such as legislation to restrict its practice, should be taken. On the other hand, there may be some activities or technologies that you believe are currently safer than the acceptable level of risk. For those activities, the risk of death could be higher than it is now before society would have to take serious action.

For each activity or technology, Ps had to choose among “(a) Could be riskier,” or “(b) It is presently acceptable,” or “(c) Too risky.” If (a) was selected, an additional question would appear on the screen, asking the P to fill in the blank in the statement “It would be acceptable if it were _____ times riskier.” If (c) was selected, the P instead saw the question “To be acceptable, it would have to be _____ times safer.” If (b) was selected, no additional questions would appear, and the P would move on to judging the risks of the next activity or technology. As piloting revealed this task to be taxing, the 30 items in this section appeared in blocks of 6 items on 5 separate pages, allowing Ps to take a short break between blocks if they wished.

3. Characteristics of Risk. In the final section, Ps were asked to judge each technology or activity on each of nine scales representing different characteristics of risk. Each characteristic, measured on a seven-point scale, was assessed for all 30 activities/technologies before moving on to the next characteristic. The order and wording of the nine scales closely matched those used in the original 1978 study:

1. How Voluntary is the Risk? For the activities and technologies listed below, please indicate whether you think people take on the potential risks voluntarily. If for a particular activity some of the risks are voluntarily undertaken and some are not, choose an appropriate rating toward the center of the scale. (1 = voluntary, 7 = involuntary)
2. How Immediate is the Risk? For the activities and technologies listed below, to what extent is the risk of death or injury immediate—or is death or injury likely to occur at some later time? (1 = immediate, 7 = delayed)
3. Knowledge About Risk: For the activities and technologies listed below, to what extent are the risks known precisely by the persons who are exposed to those risks? (1 = known precisely, 7 = not known)
4. Scientific Knowledge About Risk: For the activities and technologies listed below, to what extent are the risks known to science? (1 = known precisely, 7 = not known)
5. Control Over Risk: If you are exposed to the risk of each activity or technology listed

below, to what extent can you, by personal skill or diligence, avoid death or serious injury while engaging in the activity? (1 = uncontrollable, 7 = controllable)

6. Newness of Risk: For the activities and technologies listed below, are the risks new and novel ones, or old and familiar ones? (1 = new, 7 = old)

7. Chronic vs. Catastrophic Risk: For the activities and technologies listed below, is it a risk that kills people one at a time (a chronic risk, meaning the risk is continual over time) or a risk that kills large numbers of people at once (a catastrophic risk)? (1 = chronic, 7 = catastrophic)

8. Common Risk vs. Dread Risk: Is each of the activities and technologies listed below a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for—on the level of a gut reaction? (1 = common, 7 = dread)

9. Severity of Consequences: And finally, when the risk of each activity is realized in the form of a mishap or illness, how likely is it that the consequences will be fatal? (1 = certain not to be fatal, 7 = certain to be fatal)

After completing these three parts of the study, Ps were given the Berlin Numeracy Scale (Cokely et al., 2012), answered basic demographics questions, and received debriefing information. Ps were paid \$3 for participation in the study.

Participants

The 83 participants (Ps) were recruited through Amazon's Mechanical Turk online labor market in August of 2013. Mean completion time for the study was about 90 minutes. We omitted data from any Ps whose answers to test questions indicated that they were clearly not reading instructions: eight Ps were removed from analysis in this way. Of the remaining 75 Ps (36 female, 37 male, 2 unspecified), 42 were randomly assigned to the "benefits" condition, and 33 Ps to the "risks" condition. Ps' mean age was 36.1 ($sd = 12.5$), with 57.5% having earned a bachelor's or associate's degree, 27.4% having earned a high-school diploma, and 15.1% having earned a master's degree or higher. Although these education levels make our sample

fairly representative of the United States population overall,¹ the political beliefs of our Ps skew more liberal than average: 52.1% identify as Democrats, 30.1% identify as Independents, and 16.4% identify as Republicans.

Results & Discussion

Perceived Risk and Benefit

Geometric means of perceived risk and perceived benefit for each of the 30 activities/technologies are shown in Table 1. The range of judgments of perceived benefit and perceived risk in our study is much smaller than in Fischhoff et al., 1978 (FSLRC78): maximum benefits and risks in FSLRC78 were 274 and 250, respectively; here they were 86 and 77 (see Appendix for a table comparing Table 1 between 1978 and the current study). Neither study constricted the range for perceived risk and benefit values, except to specify that the lowest-ranked item for risk (or benefit) should be assigned a value of 10, and that other judgments should be made based on that value. Participants could, therefore, assign to risks and benefits any value between 10 and infinity.

Although our Ps' appear to have used a more limited range of values, the activities/technologies' rank order does not differ significantly between the 1978 results and the current data (for benefits: $p=0.91$, $p<.001$; for risks: $p=0.83$, $p<.001$). That is, across both studies the same activities/technologies in both studies fall in roughly the same order. As a result, we see similar items appearing at both extremes of the perceived benefit scale (lowest benefit: smoking, food coloring, spray cans; highest benefit: electric power, vaccinations, antibiotics) just as the same activities/technologies tend to cluster at each end of the perceived risk ratings (lowest risk: food coloring & preservatives, appliances, vaccinations; highest risk: handguns, nuclear power, smoking).

Table 1. Mean Judgments of Risk and Benefit from 30 Activities and Technologies

¹ as of 2013, 29.5% of US adults over 18 had a high-school diploma, 28% had a bachelor's or associates degree, and 10.2% had a master's degree or higher, per: <https://www.census.gov/hhes/socdemo/education/data/cps/2013/tables.html>

	Activity or technology	Perceived benefit	Perceived risk	Risk Adjustment Factor (geometric mean)		Acceptable level of risk	
		(geometric mean)		Risk Ps	Bene. Ps	Risk Ps	Bene. Ps
1	alcoholic beverages	20	39	1.0	1.0	39.1	39.3
2	bicycles	36	20	1.6	1.1	12.8	17.7
3	commercial aviation	51	34	0.7	0.8	46.4	41.9
4	contraceptives	50	17	1.8	1.5	9.5	11.9
5	electric power	86	33	1.1	1.2	30.6	28.8
6	fire fighting	59	56	1.4	1.6	40.4	35.4
7	food coloring	17	17	3.0	2.8	5.5	6.0
8	food preservatives	41	17	1.1	1.4	15.1	12.2
9	general aviation	41	37	2.5	2.2	14.5	16.4
10	handguns	26	77	1.1	1.0	67.7	73.6
11	HS & college football	22	25	0.9	1.0	27.7	26.1
12	home appliances	42	19	0.9	1.2	22.6	16.3
13	hunting	26	41	1.1	0.9	36.0	43.0
14	large construction	55	38	2.7	1.5	13.9	25.0
15	motorcycles	27	48	1.9	2.0	25.0	23.4
16	motor vehicles	60	50	7.9	4.7	6.3	10.5
17	mountain climbing	21	42	2.3	3.6	18.1	11.8
18	nuclear power	58	64	2.5	2.7	25.5	24.1
19	pesticides	32	31	0.7	1.1	44.5	29.5
20	power mowers	27	30	0.9	1.5	32.1	19.3
21	police work	61	54	12.4	14.7	4.4	3.7
22	prescription antibiotics	62	20	2.3	1.5	8.5	13.0
23	railroads	61	35	0.9	1.1	37.8	33.1
24	skiing	21	29	12.1	7.1	2.4	4.0
25	smoking	13	56	1.0	1.3	59.0	44.6
26	spray cans	18	23	1.8	1.8	12.9	12.7
27	surgery	75	45	3.4	2.6	13.4	17.2
28	swimming	27	22	0.7	0.9	28.9	24.9
29	vaccinations	70	20	1.6	1.9	12.2	10.6
30	X-rays	44	20	0.8	1.1	24.1	18.8
mean of all activities/technologies:		42.4	30.3	1.6	2.7		
Coefficient of Concordance		0.50	0.37	0.28	0.21		

Consistent with FSLRC78, there is no significant relationship in this study between perceived risk and benefit, as shown in Figure 1.

Figure 1. Relationship between perceived risk and perceived benefit. Linear model shows no significant correlation: $y = 33.1 + 0.054x$, $r^2=0.005$, $p= ns$.

Risk-Adjustment Factor

Judgments of whether the risks associated with each activity/technology “could be higher,” “must be lower,” or were “presently acceptable” were used to calculate a risk-adjustment factor (RAF) for each activity/technology for each P. For risks that a P considered too high, the RAF was calculated as the value they entered to finish the statement “must be ___ times safer to be acceptable.” For risks that a P believed could be higher, RAF was calculated as the multiplicative reciprocal of the value that finished the statement “would be acceptable if it

were ____ times higher.” For activities/technologies that Ps judged as “presently acceptable,” RAF was set to 1.0. Thus, RAF values greater than 1.0 indicate that current risk of the activity or technology is too high and must be lowered, and RAF values less than 1.0 mean that the risk could be higher. Table 1 shows the geometric mean RAF for those Ps who had previously judged risks, versus those who had previously judged benefits. The risk-adjustment task was identical for these two groups, and a paired t-test shows that RAF does not differ between the groups ($t(29)=0.82, p>.05$).

Of the 2250 total risk judgments, 7.7% were “could be riskier,” while 66.4% of judgments were “appropriately risky” and 25.8% were “should be safer.” While the proportion of “could be riskier” activities/technologies hasn’t changed substantially since 1978 (Fischhoff et al. found it to be 10%), the values for the other two judgment categories represent a trend toward activities and technologies being judged as less risky since 1978: FSRLC78 found that only 40% of their Ps’ judgments were “appropriately risky,” while 50% were “should be safer.” There may be several reasons for this shift of activities/technologies from “should be safer” to “appropriately risky.” It may be that the status quo for acceptable risk levels has changed: that people now are willing to accept a slightly higher level of risk from technologies or activities than they were three decades ago. It is perhaps more likely, though, that the decrease in “should be safer” judgments is due to the fact that the risks for many of the 30 activities and technologies have indeed decreased over time, due to increased regulation or advances in technology. Smoking rates, for example, have nearly halved since the 1970s, dropping from 34% in 1978 to 19% in 2011 (CDC, 2011b), and although the risk of death among smokers rose precipitously between 1959 and 2010, the death rate attributed to smoking has dropped overall in that time period (USDHHS, 2014). Similarly, although handgun death rates remain higher in the United States than in many other Western nations, the per-capita risk of firearms death has dropped from a peak of 16 per 100,000 in 1975 to 10.4 per 100,000 in 2011 (CDC, 2011a; FICAP, 2011).

We cannot rule out, however, the possibility that the difference in risk judgments

between the two studies stems from the difference in populations. The participants in the original 1978 study were “a generally liberal, environmentally minded group” drawn from a socially aware population (the Oregon League of Women Voters), and it is possible that such a population would set a lower threshold for what risk level constitutes “appropriately risky” vs. “should be safer.”

While FSLRC78 found that the mean perceived risk ratings from the group that judged risk correlated significantly with mean RAF both among Ps who had originally rated benefits and those who had rated risks ($r=0.75$ and $r=0.66$, respectively), we did not see a significant correlation for either group: $r=0.25$ for benefit Ps, $r=0.19$ for risk Ps, both p 's $>.05$. This suggests that our participants did not feel that the higher-risk activities/technologies needed to be reduced proportionally more than the lower-risk activities/technologies. For example, although handguns were ranked as the technology with the highest perceived risk (77), the RAFs for handguns are 1.1 and 1.0, indicating that this high risk level is currently acceptable. Other activities/technologies with RAFs very close to 1 are smoking (perceived risk = 56), hunting (perceived risk = 41), alcohol (perceived risk = 39), and x-rays (perceived risk = 20). This range of risks that are all considered presently acceptable clearly illustrates the lack of correlation between perceived risk and RAF, even if it does not explain the disappearance of this effect since the 1978 study.

Following FSLRC78, a value for “level of acceptable risk” was calculated for each activity/technology by dividing its perceived risk (averaged across the Ps who judged risk) by the risk-adjustment factor (see the final two columns in Table 1). In this way, activities/technologies that were judged as currently too risky have a lower acceptable risk level than the current perceived risk, and activities/technologies that were judged as safer than necessary end up with an acceptable risk that is higher than the current risk. For example, motor vehicles received a risk score of 50 and a RAF of 7.9 from the Ps who judged risks, indicating that the risk would need to be nearly 8 times lower in order to be acceptable. This

results in an acceptable risk score of 6.3, or $(50 \div 7.9)$. On the other hand, pesticides, with their perceived risk of 31 and “could be riskier” RAF of 0.7, indicate an acceptable risk of 44.5, which is higher than the currently judged risk.

Fischhoff et al. (1978) found this acceptable risk level judged by both risk and benefit Ps to correlate positively, if not strongly, with perceived benefit ($r=0.42$ and $r=0.31$, respectively). Given that the current study found no relationship between perceived risk and RAF, it is not surprising that we fail to replicate these correlations with acceptable risk level, given our difference in RAF scores. The acceptable risks did not correlate with perceived benefit among Ps who judged benefits ($r=-.12$, $p=.39$), nor did they among Ps who judged risks ($r=-.19$, $p=.22$). It is slightly surprising that both of these correlations would be negative when the original relationships were found to be positive (although weak), but given that neither relationship is statistically significant, we cannot read much into the apparent direction of the effects.

Inter-Participant Agreement

We find moderate inter-participant agreement for both perceived benefit and perceived risk across all 30 activities/technologies: Kendall's coefficient of concordance is 0.50 for perceived benefit and 0.37 for perceived risk. The agreement among our participants is not as substantial as in FSLRC78 (1978 values: $W_{\text{benefit}}=0.77$, $W_{\text{risk}}=0.50$), but both values are significantly different from zero, $p<.001$. This pattern of lower inter-participant agreement is not surprising, considering the relative diversity of our population compared to the fairly homogeneous group that Fischhoff and colleagues sampled.

The inter-participant agreement for the risk-adjustment factor (RAF) is weaker than for perceived risk and benefit, but still significant: $W=0.28$ among benefit Ps, and $W=0.21$ among risk Ps, $p<.001$. As with perceived risk and perceived benefit, these coefficients of concordance in our nationally representative sample show relatively less agreement than among Fischhoff and colleagues' more homogeneous participant group (their values: $W_{\text{RAFb}}=0.50$, $W_{\text{RAFr}}=0.50$).

Nine Characteristics of Risk

Participants in both conditions judged the 30 activities/technologies on the same nine scales (see Table 2). As in FSLRC78, the scores from the risk and benefit participants for this task do not differ substantially from each other (only one difference, out of the 270, is greater than 1.0; the mean absolute difference across all judgments is 0.31), and so we pooled the data from the two groups for the remaining analyses.

Inter-participant agreement. As with the risk and benefit judgments and risk-adjustment factors, the agreement on the nine risk scales is generally lower than it was among Fischhoff and colleagues' participants, although in each case it is still significantly different from zero. Where the 1978 data show coefficients of concordance mostly between 0.4 and 0.6, here eight out of the nine characteristics see a concordance of $W=0.24$ to $W=0.42$. The notable exception is for the "known to science" characteristic: here the concordance is a very high $W=0.76$, compared to only $W=0.30$ or $W=0.35$ (for benefit and risk Ps, respectively) in Fischhoff and colleagues' data. This may be a reflection of the (perceived or actual) advances in technology in the past three decades, which has led both to a significantly lower mean score on "known to science" (where 1 = "known precisely" and 7 = "not at all known"), and greater interparticipant agreement about which items are better known than others. Interestingly, mean scores on the characteristic of "known to those exposed" have also shifted significantly toward "known precisely" since 1978, but the concordance ($W=0.31$) is substantially lower than that for "known to science," reflecting a perception that on average the public knows more now about these 30 technologies and activities than they did in the 1970s, yet indicating a lack in unanimity over the relative ranking of the 30 items in terms of which are now most precisely known.

This shift in the concordance for this single risk characteristic is striking, and may in fact help to explain the finding that perceived risk is no longer correlated with risk-adjustment factor. Although both knowledge characteristics (known to the exposed, known to science) have significantly lower mean scores today than in 1978 (see Table 2), the ratings for "known to

Table 2. Mean Ratings for Nine Characteristics of Risk.

	voluntariness 1 = voluntary	immediacy 1 = immediate	known to exposed 1 = known precisely	known to science 1 = known precisely	controllability 1 = uncontrollable	newness 1 = new	chronic-catastrophic 1 = chronic	common-dread 1 = common	severity of consequences 1 = certain not to be fatal
alcoholic beverages	1.59	4.89	2.32	2.03	5.62	6.16	2.15	2.06	4.03
bicycles	1.82	3.14	2.22	2.29	5.42	6.42	2.33	1.61	3.42
comm. aviation	2.88	2.36	2.63	2.10	2.68	5.47	6.00	4.49	5.57
contraceptives	1.92	5.27	4.04	2.73	4.90	4.44	2.28	2.28	2.75
electric power	4.24	3.62	3.23	2.26	4.08	5.37	3.65	2.56	3.97
firefighting	2.73	2.11	1.79	2.03	4.10	5.97	3.82	3.56	5.15
food coloring	3.47	5.65	5.04	3.23	4.18	4.07	2.56	2.06	2.60
food preservatives	3.99	5.51	4.73	3.19	4.00	4.34	2.86	2.44	3.04
gen. aviation	2.53	2.35	2.59	2.21	3.41	5.51	5.40	4.19	5.42
handguns	2.76	1.80	1.78	1.97	4.92	5.74	4.04	4.36	5.53
HS & college football	1.78	4.07	3.16	2.86	4.95	4.90	2.39	2.49	3.07
home appliances	2.99	3.84	3.85	2.84	5.03	5.26	2.44	1.78	2.88
hunting	1.73	2.34	1.86	2.27	5.08	6.38	2.60	2.74	4.71
large construction	3.38	3.09	3.03	2.58	4.15	5.42	4.06	2.53	4.49
motorcycles	1.76	2.11	1.85	1.97	4.86	5.67	2.74	2.83	5.14
motor vehicles	3.04	2.23	2.14	2.15	4.41	5.70	4.10	2.56	4.68
mountain climbing	1.61	1.91	1.74	2.19	5.15	6.22	2.88	3.25	5.08
nuclear power	5.08	4.39	3.59	2.47	2.19	3.73	5.97	5.28	5.71
pesticides	4.57	5.23	4.41	2.81	3.30	4.07	3.81	3.67	4.19
power mowers	2.38	2.86	2.92	2.48	5.47	5.23	2.44	2.10	3.43
police work	2.84	2.65	2.32	2.47	3.77	5.89	3.15	3.22	4.74
rx antibiotics	3.78	4.72	4.23	2.44	4.04	4.38	2.44	2.29	3.33
railroads	3.36	2.82	3.10	2.58	3.52	6.12	5.08	2.47	4.81
skiing	1.57	2.12	1.90	2.15	5.08	6.10	2.50	2.24	3.83
smoking	1.66	5.54	1.79	1.86	5.03	5.84	2.36	2.69	5.08
spray cans	2.70	4.65	4.04	2.53	4.68	4.75	2.56	2.01	3.03
surgery	3.99	2.96	2.78	2.30	2.71	4.90	2.28	4.58	4.65
swimming	1.65	2.66	2.32	2.16	5.56	6.48	2.38	1.88	4.06
vaccinations	3.80	5.18	4.27	2.68	3.71	4.34	2.56	2.57	3.28
x-rays	3.86	5.74	3.89	2.32	3.52	4.90	2.01	2.49	3.19
mean	2.85	3.59	2.99	2.40	4.32	5.33	3.19	2.84	4.16
σ	1.00	1.32	0.99	0.34	0.90	0.78	1.13	0.92	0.94
coeff of concordance	0.31	0.42	0.31	0.76	0.24	0.26	0.32	0.28	0.37
mean (1978)	3.24	3.49	3.78	2.98	3.73	4.41	2.50	2.85	4.37
difference in means ^a (2013 - 1978)	-0.39**	0.10	-0.80**	-0.58**	0.59**	0.92**	0.69**	-0.01	-0.21

a: stars indicate significant paired-t-tests at the $\alpha=.01$ level (*) and the $\alpha=.001$ level (**)

science” are nearly all approaching the floor of the rating scale (toward the “known precisely” end). Thus, the consensus today appears to be that, as we would expect, the risks of every one of these 30 activities/technologies are all very well understood by the scientific community. Our Ps’ judgments also indicate a significant shift toward more knowledge of the risks among those exposed to them, and toward risks being assumed more voluntarily than in the past—though there is more variation between activities/technologies for these variables than there is within the “known to science” characteristic. These shifts are consistent with our expectations: over the past three decades, science does indeed know more about the risks of these activities and technologies, as does the general public, and thus those people who are at risk are more likely to have placed themselves knowingly and voluntarily in that situation.

It is also logical that overall, the 30 activities/technologies are seen as both more controllable and less new today than they were several decades ago. The shift that may seem somewhat counterintuitive is the one toward more catastrophic as opposed to chronic risk. Overall, this trend suggests that the risks of these 30 activities/technologies are more likely to affect large numbers of people at once, as opposed to one at a time. It is tempting to guess that increasing population and population density may contribute to this increase in catastrophic risk potential, but to fully understand this shift, it may be necessary to look at the changes for specific activities/technologies. Only five out of the 30 activities/technologies have shifted toward the chronic (lower) end of the 1-7 scale, and only three of those shifts are greater than 1/3 of a point: spray cans (-1.26), pesticides (-0.94), and nuclear power (-0.46). Given increased regulation of aerosol cans and pesticides, and a temporal remove from large-scale nuclear disasters like Chernobyl, a move away from the catastrophic end of the scale seems to make sense. (Note that nuclear power, despite the nearly half-point drop in catastrophic risk, is still considered extremely catastrophic at 5.97 on the 7-point scale.) By contrast, the activities/technologies that have increased the most toward the catastrophic end of the scale are general aviation (+2.0), handguns (+1.94) and mountain climbing and skiing (+1.56 and +1.44,

respectively). As of the fall of 2013, when this study was run, airplane crashes and mass shootings were concepts with high psychological availability, which would contribute to higher perceptions of catastrophic risk (Tversky & Kahneman, 1973). The United States saw vivid examples of these risks in an Asiana Airlines flight crashing short of the runway at San Francisco International airport on July 6, 2013 (Onishi et al., 2013), and a mass shooting on July 26, 2013 in Florida that left 7 people dead. Similarly, the perceptions of catastrophic risk for both skiing and mountain climbing may have increased partly due to the availability of vivid stories from, among other incidents, the April, 2013 Sheep Creek avalanche, which killed 5 people; and the February, 2012 Tunnel Creek avalanche, which killed 3 skiers and was profiled in an extensive and interactive multimedia piece on NYTimes.com in December of 2012.

Correlations among the risk characteristics. As expected, the nine characteristics of risk are highly inter-correlated (see Table 3), in a way similar to FSLRC78: 14 of the 17 pairs that show significant correlations in our current study were also significantly correlated, in the same direction, in the 1978 study. Of the five additional pairs of characteristics that were

Table 3. Pairwise correlations among the 9 risk characteristics. Variable pairs that were correlated (at $\alpha=.001$) in Fischhoff et al.'s 1978 data are underlined here.

	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe
voluntary	<u>0.37</u>	<u>0.64**</u>	<u>0.43</u>	<u>-0.80**</u>	<u>-0.71**</u>	<u>0.39</u>	<u>0.39</u>	-0.02
immediate		<u>0.77**</u>	<u>0.55*</u>	-0.13	<u>-0.69**</u>	-0.34	-0.28	-0.62**
known (exposed)			<u>0.85**</u>	<u>-0.36</u>	<u>-0.86**</u>	-0.09	-0.19	-0.67**
known (science)				<u>-0.18</u>	<u>-0.67**</u>	-0.13	-0.27	-0.67**
controllable					<u>0.53*</u>	<u>-0.63**</u>	<u>-0.70**</u>	-0.33
new						-0.06	<u>-0.19</u>	0.39
chronic							<u>0.68**</u>	0.68**
common								<u>0.75**</u>

* $p<.005$; ** $p<.001$

correlated in 1978 but are not in this current study, all show moderate, though non-significant, correlations in the same direction as in 1978. Even though the correlations in both studies were evaluated at a conservative alpha level of 0.001, we are hesitant to make specific comparisons between the two studies on the basis of such a large number of individual tests. Instead, we will focus the ability of the current data to predict perceived risk, benefit, and acceptable risk.

Relationship of the nine risk characteristics with perceived risk and benefit.

Perceived risk and perceived benefit correlate with many of the nine risk characteristic scores individually, but given the multicollinearity among the nine characteristics, we will not attempt to interpret the individual correlations.² Using a multiple linear regression model, perceived benefit is predicted only by scores on the voluntary scale: for every one-point increase on that seven-point scale, the perceived benefit increases by 15.6 points. In other words, the more involuntary the activity, the greater the perceived benefit. This is a substantial effect, given that the maximum mean benefit score was 86 (for electric power), on a scale where 10 represents the benefit of the lowest-ranked technology or activity (the lowest mean benefit was smoking, coming in at 13). It may seem counterintuitive that involuntary activities carry higher benefits, but this relationship may make more sense when viewed in the opposite direction: the higher the benefit of a risky technology or activity, the more likely may it be imposed upon members of society. While this relationship between voluntariness and perceived benefit was not significant in FSLRC78, it was in the same direction ($r=0.24$).

Several of the risk characteristics predict scores on perceived risk. As with benefits, (in)voluntariness has a positive relationship with perceived risk: for every one-point shift toward involuntary, perceived risk increases by 10.2 points. We also see an effect of newness: for

² Correlation tables are presented in the appendix to this chapter. The differences in the apparent relationship between the four outcome variables and the nine risk characteristics as indicated by the individual correlations, compared to the linear models, is an example of the importance of controlling for the effects of other, correlated predictor variables in situations like this one—relationships that appear to be substantial and significant in the correlation tables are negligible when controlling for the other risk characteristics, and vice versa.

every one-point shift toward an activity or technology being newer, there is a 14.4-point increase in perceived risk. There is a similarly strong effect of controllability, in which a one-point move toward an activity/technology being more controllable is associated with a 14.7-point jump in perceived risk. Although knowledge to science does not predict risk perception, knowledge to the exposed does: a one-point shift toward precise knowledge of an activity/technology's risks predicts a 17.3-point increase in perceived risk. Taken together, these relationships suggest that riskier activities and technologies tend to be more involuntarily undertaken, newer, more controllable, and more precisely known to those exposed to the risk. This profile is consistent with the highest perceived risk scores going to activities and technologies that are typically taken on knowingly: handguns, nuclear power, smoking, fire fighting, police work, and motor vehicles top the rank list of perceived risk.

Table 4. Linear models predicting perceived risk and benefit by scores on the nine risk characteristics. The minimum score for perceived risk and perceived benefit is 10; the maximum mean scores for benefit and risk are 86 and 77, respectively. Note that, for this analysis, scores on the 9 characteristics were mean-centered, so the intercepts represent the perceived risk and benefit score for a technology or activity that is “average” on all nine characteristics.

		perceived benefit (β)	perceived risk (β)
intercept		41.6	35.3
voluntariness	1 = voluntary	15.6*	10.2**
immediacy	1 = immediate	-6.53	1.36
known to exposed	1 = known precisely	-11.7	-17.3*
known to science	1 = known precisely	-24.9	1.81
controllability	1 = uncontrollable	-8.81	14.7***
newness	1 = new	-8.75	-14.4**
chronic-catastrophic	1 = chronic	4.32	2.26
common-dread	1 = common	-8.17	3.07
severity of consequences	1 = certain not fatal	-16.2	7.43
<i>adjusted R²</i>		0.44	0.82

*p<.05; **p<.01; ***p<.001

This linear model of perceived risk does not, therefore, replicate FSLRC78's finding that

perceived risk correlates directly with (only) dread and severity. Although we do see strong individual correlations between these two risk characteristics and perceived risk in the current dataset (see Appendix), these relationships disappear when the other risk characteristics are controlled for. Additionally, the nine risk characteristics do a markedly better job at predicting perceived risk ($r^2=0.82$) than perceived benefit ($r^2=0.44$). This effect is consistent with the finding that in this study, perceptions of risk and benefit are unrelated to each other, and the fact that the nine characteristics were designed to be measures of risk, not of benefit.

Relationship of the nine risk characteristics with RAF and acceptable risk. We see very little relationship between risk-adjustment factor (RAF) and any of the nine risk characteristics. There is a small but significant effect of controllability, such that a one-point shift toward more controllable risk is associated with a 3.11-point increase in risk-adjustment factor. In other words, the more controllable the activity's risk, the more people believe it must be reduced. This relationship suggests that our Ps are likely making their RAF judgments in part based on how feasible that adjustment might be.

While we found an effect only of controllability, FSLRC78 found that RAF correlated moderately with voluntariness and catastrophic risk, and substantially with dread risk and severity, but not with controllability. This discrepancy is consistent with other indications that RAF is the measure that has changed the most notably between 1978 and now. The proportion of activities/technologies that our Ps judged as needing to be made safer was only about half as large as the same judgment made by participants in Fischhoff, et al.'s study (26% vs. 50%), so it should not be surprising that the relationship between RAF and the nine risk characteristics has changed as well.

Acceptable risk is predicted by scores on several of the risk characteristics. One-point increases in involuntariness and delayed (as opposed to immediate) risk correspond, respectively, to increases of 10.8 and 7.92 points on acceptable risk. The biggest contributor to acceptable risk is controllability: a one-point increase on this scale predicts a 24-point jump in

acceptable risk level. Slightly more difficult to interpret is the effect of the common-dread scale. A one-point shift toward more dread risk is associated with a 19.5-point increase in acceptable risk. Taken together, this model suggests that risks are more acceptable if they are involuntary or delayed, and even more so if they are controllable or dread.

Table 5. Linear models predicting risk-adjustment factor (RAF) and acceptable risk (perceived risk divided by RAF) by scores on the nine risk characteristics. Note that for this analysis scores on the 9 characteristics were mean-centered, so the intercepts represent the RAF and acceptable risk for a technology or activity that is “average” on all nine characteristics.

		RAF (β)	acceptable risk (β)	acceptable risk (β)
intercept		2.34	24.2	-18.2
voluntariness	1 = voluntary	-0.86	10.8*	-1.85
immediacy	1 = immediate	-0.85	7.92*	7.12*
known to exposed	1 = known precisely	-2.86	0.76	20.6
known to science	1 = known precisely	4.17	-9.90	-9.29
controllability	1 = uncontrollable	-3.11*	24.0**	9.06
newness	1 = new	-2.51	15.8	32.2**
chronic-catastrophic	1 = chronic	-1.38	8.60	5.72
common-dread	1 = common	-2.34	19.5*	17.0*
severity of consequences	1 = certain not fatal	1.32	-6.41	-12.8
perceived benefit				0.01
perceived risk				1.08**
<i>adjusted R²</i>		0.07	0.41	0.60

*p<.05; **p<.01; ***p<.001

Factor analysis of the 9 risk characteristics. We ran a principal components factor analysis to see whether our participants’ responses on the nine scales loaded onto the same two factors that Fischhoff and colleagues called “Technological Risk” and “Severity” (FSLCR 1978), and that in subsequent studies have also at times been called “Unknown Risk” and “Dread Risk,” respectively (Slovic, 1987). Following Fischhoff et al., we computed the factor analysis on the pooled data (risk and benefits groups, combined), and did not find any improvements in interpretability by applying a varimax rotation. As Tables 6 and 7 show, the

unrotated factor loadings and communality scores for the nine characteristics are reasonably similar to the 1978 results.

Table 6. Factor Loadings for the nine risk characteristics for the current study.

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance
Factor 1	0.64	0.83	0.98	0.85	-0.34	-0.88	-0.18	-0.20	-0.70	4.23	0.47
Factor 2	0.65	-0.18	0.03	-0.10	-0.88	-0.31	0.85	0.90	0.67	3.31	0.37
commonality	0.83	0.71	0.96	0.74	0.90	0.87	0.75	0.85	0.94		

Table 7. Factor Loadings for the nine risk characteristics from Fischhoff et al., 1978.

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance
Factor 1	0.89	0.70	0.88	0.88	-0.83	-0.87	0.62	0.67	0.11	5.30	0.59
Factor 2	0.03	-0.45	-0.39	-0.28	-0.24	0.14	0.55	0.6	0.91	1.91	0.21
commonality	0.79	0.69	0.93	0.86	0.75	0.78	0.69	0.81	0.84		

Table 8. Changes in factor loadings between the current study and those from Fischhoff et al., 1978. Positive values indicate a loading that has increased (or shifted from negative to positive) from 1978 to the present study; negative values indicate a loading that has decreased (or shifted from positive to negative).

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe
Factor 1	-0.25	0.13	0.10	-0.03	0.49	-0.01	-0.80	-0.87	-0.81
Factor 2	0.62	0.27	0.42	0.18	-0.64	-0.45	0.30	0.30	-0.24

In the current study, the two orthogonal factors together account for 84% of the variance, and the two-factor solution appears sufficient to explain the correlations among the variables (a third factor explains only an additional 6% of the variance). Although a direct comparison of the two PCAs would require sample sizes much larger than used in either the 1978 study or the current study, it does look qualitatively as if the current study has captured the same or very similar factors. One notable difference between the two factor analyses is the relative strength of loadings of the two factors: whereas in the original study Factor 1 (technological/unknown risk) accounted for nearly three times as much of the variance as Factor 2 (severity/dread risk), here the division is more even: Factor 1 explains 47%, while Factor 2 explains 37%. This greater balance of the explanatory power of the two factors makes sense: as technology has advanced in the past three decades, perhaps an increase (actual or perceived) in scientific and public knowledge about the risks has led to decreased impact of the unknown factor, while the 24-hour news cycle may have contributed to an increased influence in the dread factor.

Here, Factor 1 appears to capture delayed consequences, lack of knowledge (of the exposed and of science), newness, non-fatal consequences, and to a lesser extent, involuntariness. As the differences between the factor loadings in Table 8 illustrate, this unknown risk factor is therefore missing the components of chronic (as opposed to catastrophic) risk and dread risk that loaded onto it in FSLRC78, though it now captures the characteristic of severity, which did not load substantially onto unknown risk in 1978. In contrast with the trimming of loadings onto Factor 1, Factor 2 captures more variables in our current study than it did in 1978: catastrophic, dread, and uncontrollable, and to a slightly lesser extent involuntary and fatal. This shift toward substantial loadings for more of the variables on Factor 2 leads to the increase in the proportion of the overall variance that it explains.

Figure 2. Factor space for the 30 activities and technologies.

By using the loadings on each of the two factors of each of the 30 activities and technologies, we can create a risk factor space that allows for visual depiction of the activities/technologies along the axes of Factor 1 (unknown risk) and Factor 2 (dread risk or severity). The placement of the 30 activities/technologies in Figure 2 is somewhat similar to the corresponding figure from Fischhoff and colleagues' paper (1978, Figure 7). Although the sample sizes of this study and the original do not give us enough power to compare the two factor analyses quantitatively, there do appear to be a few noticeable shifts between the two.

Some items, such as surgery and contraceptives, have not moved very much at all within the factor space in the past decades. The most dramatic difference between 1978 and today is nuclear power's drop on the unknown axis: it has moved from being a notable outlier on both factors to ranking only 10th out of the 30 items on unknown risk. Figure 3 highlights this movement in the factor space for nuclear power, as well as some other notable shifts for some of the other activities and technologies. Pesticides and spray cans have also moved down in unknown risk since 1978, which may illustrate the public's growing comfort with both technologies; regulation of pesticide use and labeling for food products was tightened dramatically by Congress in 1996 ("The Food Quality Protection Act ", 1996), and the 1987 Montreal Protocol led to international regulation of chlorofluorocarbons (CFCs), causing spray cans to become much less environmentally harmful and in fact leading to a drop in the atmospheric chlorine levels starting in 1998 (Nangle, 1989; UN, 2010).

In contrast to pesticides and spray cans, vaccinations and high-school and college football have each increased markedly in both dread and unknown risk, and it is not hard to imagine why. With the recent increase in public attention to the prevalence of concussions in football, the public likely does now know much more clearly just how much is currently *unknown* about the long-term health risks associated with head trauma (Delaney, Lacroix, Leclerc, & Johnston, 2002). Vaccines, on the other hand, have certainly increased in both safety and effectiveness since 1978—but although science has come to an overwhelming consensus, the public conversation remains dominated by many loud (if uninformed) voices questioning the wisdom of vaccination. A look at the two risk characteristics related to knowledge nicely illustrates this gap, with the rating of vaccinations as “known to science” leaning toward “known precisely” at 2.68, but the rating for “known to those exposed” a much more ambivalent 4.27. In general, items tend to be rated as more precisely known to science than to the exposed, indicating (likely accurate) belief that the public has a less comprehensive understanding of the risks of these technologies than does the scientific community. For vaccines, however, this gap

between the ratings on “known to science” and on “known to the exposed” is larger than for any other technology—there is a substantial difference of 1.59 between “science” and “the exposed” for vaccines, while the mean difference between these two characteristics across all technologies is only 0.80.

Figure 3. Movements of selected items in the dread-unknown factor space between FSLRC78 (grey dots) and the current study (black dots). As we do not have sufficient power in this study to analyze these shifts quantitatively, they should be considered as rough qualitative estimates.

Other items have dropped considerably on the dread axis: although all of the transportation-related technologies have come down on both dread and unknown, commercial aviation has shifted the farthest. Again, this change is consistent with actual trends over the past decades. Despite several memorable crashes in recent years, the number of aviation accidents and deaths have both steadily declined since the 1970s, even while passenger load has grown dramatically (Tolan, Patterson, & Johnson, 2014). So while commercial aviation still ranks second highest on the dread factor, it is no longer quite the outlier it was in 1978.

Figure 4 shows the mean scores on each of the nine risk characteristics for vaccinations, compared with three other technologies: nuclear power (which is more dread/severe but slightly less unknown), food preservatives (which, like vaccinations, fall at the mean of the dread/severe axis, but rate as somewhat more unknown than vaccinations), and pesticides (which are about even with vaccinations on the unknown axis, but considered substantially more dread/severe). While vaccinations and food preservatives share a very similar profile across the nine characteristics, the difference between the two technologies on the unknown factor can be seen in the higher scores for vaccinations on immediate-delayed, uncontrollable-controllable, and both known-unknown characteristics. Similarly, we can see the components of the dread/severe factor in the differences between vaccinations and pesticides: the latter is more involuntary, catastrophic, dread, and certain to be fatal.

Figure 4 (next page). Mean ratings across all nine characteristics for vaccinations, compared with nuclear power (top), food preservatives (middle), and pesticides (bottom). The distances between vaccinations and nuclear power in the dread-risk factor space is underscored by the two items' very different profiles across the nine risk characteristics. Although vaccinations fall a similar distance from food preservatives and pesticides in the dread-unknown factor space, these risk profiles show them to be more closely similar to preservatives.

Multivariate Determination of Acceptable Risk Levels

Following Fischhoff and colleagues' successful attempt to predict acceptable risk levels using perceived benefit along with Factor 1 and Factor 2, we tested a model that predicts scores of acceptable risk on the 30 activities and technologies as a function of our factors of unknown risk and dread risk. We find that the two factors together do a moderately good job of predicting acceptable risk level ($F(27)=4.81$, $p=.017$, $R^2=0.21$), though adding perceived benefit to the model does not add any additional predictive power (see Table 8). The two factors do a better job at predicting perceived risk ($F(27)=22.8$, $p<.001$, $R^2=0.60$), but again, adding perceived benefit as a predictor does not improve the model.

Table 8. Linear models predicting acceptable risk and perceived risk as a function of the two risk factors.

	acceptable risk (β)	perceived risk (β)	acceptable risk (β)	perceived risk (β)
intercept	24.2	35.3	28.4	39.6
Factor 1 (unknown)	-3.15*	-4.48***	-2.97*	-4.30***
Factor 2 (dread)	2.56	4.36***	3.11	4.92***
perceived benefit	-	-	-0.10	-0.10
adjusted R^2	0.21	0.60	0.19	0.59

* $p<.05$; ** $p<.01$; *** $p<.001$

Perceived benefit does not add to these models' predictive power, but the model of perceived risk quite nicely shows the relationship between the two factors in terms of their influence on risk perception. While increases on Factor 1 (toward more unknown) lead to *lower* perception of risk, equivalent increases on Factor 2 (toward higher dread) are associated with the same magnitude of change in perceived risk, but toward *higher* risk. In other words, the more known and the more dread a risk is, the higher the perceived risk. This relationship allows us to consider the risk space in Figure 2 as having perceived risk increase roughly from the upper left quadrant to the lower right, as in Figure 5.

Figure 5. Factor space from Figure 2 with point size determined by mean perceived risk for each of the 30 activities/technologies. Though the activity/technology labels have been removed to make the point size gradient more visible, the activities/technologies locations are the same as in Figure 2.

Conclusions

We were able to successfully replicate Fischhoff et al.'s 1978 results in many areas, starting with the finding that relative risk perceptions for the 30 activities and technologies have stayed remarkably consistent across several decades: the rank ordering of the 30 items in terms

of their perceived risk and benefit has not changed since 1978. We also replicate the lack of any direct relationship between perceived risk and perceived benefit, echoing Fischhoff et al.'s support for an “expressed preferences” approach to risk attitudes, rather than Starr’s “revealed preferences” assumption that society naturally reaches a balance between risk and benefit (1969). Additionally, the nine characteristics of risk investigated by Fischhoff et al. continue to reduce to two dimensions, dread risk and unknown risk, that together explain a great deal of the variance across the nine characteristics. Although perceived benefit is unrelated to either of these factors, perceived risk is predicted by both factors, such that technologies or activities that are highest on dread and are most well known tend to receive the highest risk scores.

Notable changes since 1978 include the fact that risks for these 30 activities and technologies appear to have become more acceptable overall—likely because the actual risks of many of these items have in fact decreased over the past three decades. The application of the nine studied risk characteristics has also changed slightly over time: the dread risk dimension appears to capture the characteristics of voluntariness and controllability, which it did not before. This dimension also now explains more of the variance than it did in the original study, while the unknown risk dimension explains slightly less of the variance. In these respects, the current study’s risk dimensions look more similar to those found in later studies by the same researchers (Slovic et al., 1985), where the dread risk factor did include the characteristics “uncontrollable” and “involuntary.”

While this study meets its goal of investigating the current state of risk perception for 30 activities and technologies, one of its limitations is that comparisons made between the current results and those from the original 1978 paper must in most cases be limited to qualitative or speculative statements. Neither the current nor the original study have large enough samples to allow for a quantitative comparison. And for the qualitative shifts described above—for example, the dramatic drop of nuclear power on the dimension of unknown risk—this study alone cannot definitively explain *why* such changes have occurred. For many of these shifts we can identify

matching trends in external factors such as regulation or death rates, but to show causal connections between these trends is beyond the reach of this study.

It should also be noted that all of the trends and conclusions reported here are based on aggregate data. This approach to the analysis of risk perception has its drawbacks, among them the loss of variation and detail that an individual-level analysis could provide, and likely a falsely elevated assumption of consistency of risk judgments within the same individual (Marris, Langford, Saunderson, & O'Riordan, 1997). But keeping in mind these limitations on the conclusions we can draw here, there is also a benefit from getting a broad look at many activities and technologies across a range of risk characteristics—not to mention the advantages of matching Fischhoff et al.'s 1978 methods as closely as possible for the purposes of replicating and updating their findings. This aggregate view also fits with the wider goals of the current line of research, which include investigation into risk perceptions for recently emerging technologies, as well as for environmental dangers like natural hazards and climate change. Having established in this study that the psychometric paradigm remains reliable and relevant for investigating the types of technologies and activities it was designed to assess, we can now move forward in extending its use into environmental hazards.

Chapter 2: Placing Natural Hazards and Climate Change into the Dread-Unknown Risk Space

The psychometric approach to studying risk perception, pioneered by Paul Slovic and Baruch Fischhoff in the 1970s and 80s (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978; Slovic, 1987), has had great impact on our understanding of how people react differently to the risks and benefits of various technologies and human activities. But while this approach inspired many replications and follow-up studies (e.g., Gaskell et al., 2004; Gstraunthaler & Day, 2008; Slovic, Fischhoff, & Lichtenstein, 1986), few have moved beyond the domain of technological risk to study how environmental risks such as climate change and natural hazards are perceived (recent exceptions, which incorporated mathematical and engineering risk into estimates of perceived risk, as well as slightly changing the definition of dread risk, are Corotis & Hammel, 2010; Hurley, 2011).

Given the steady increases over time in both numbers of natural hazard events and damage done by those hazards (MunichRe, 2012), a clearer understanding of how different environmental dangers are perceived could contribute a great deal to the hazard mitigation field. It seems reasonable to assume that people don't think about and prepare for earthquakes in the same way that they do for winter storm events, but in order to make specific recommendations about how to present hazard information differently for the two phenomena, quantitative measures are needed.

The psychometric framework developed by Fischhoff et al. (1978) allows for items to be placed in a risk space defined by two dimensions: dread risk, and unknown risk. Recent work has shown that these methods are still reliable today and can be implemented online with relative ease (Fox-Glassman & Weber, in preparation-a). In Study 1 of this chapter, we test this methodology on 20 natural hazards to show the risk ratings and locations in the dread-unknown factor space for these hazards, relative to each other. In Study 2, we examine risk attitudes toward climate change and sea-level rise alongside the same 20 natural hazards.

Study 1

We first apply the psychometric risk paradigm of Fischhoff et al. (1978) to 20 natural hazards (see Table 1 for full list). We expect that the risk space for this set of items will look somewhat different than it did for the technologies and activities studied previously (Fox-Glassman & Weber, in preparation-a), since some of the risk characteristics that make up the dread and unknown risk dimensions are either less relevant, or less variable, when applied to natural disasters. However, the idea of rating hazards along the dread dimension has good face validity, and we expected to see our studied hazards cover a wide range in dread, with climate-related hazard (e.g., dust storms and heat waves) ranking low on dread, due in part to their slow time courses and lack of some of the vivid elements that would contribute to high psychological availability (Tversky & Kahneman, 1973). In contrast, we anticipated high dread scores for high-energy geophysical hazards such as earthquakes and volcanoes, which are relatively rare, but tend to happen relatively suddenly, receive extensive media coverage, and otherwise rate high on availability and the kind of vividness and emotional qualities that might make them feel more frightening within the “risks as feelings” framework (Lerner, Gonzalez, Small, & Fischhoff, 2003; Slovic, Finucane, Peters, & MacGregor, 2004).

Method

Participants

The 89 participants (Ps) were recruited and run through Columbia’s Student Participant Pool in November of 2013. Mean completion time was about 90 minutes, and student participants were awarded course credit for their time. We omitted data from nine Ps whose answers clearly indicated that they had ignored instructions, leaving 80 Ps for analysis. The mean age for these student participants was 21 years ($SD=4.08$), and based on answers to questions about personal experience with the 20 natural hazards studied, 75% of Ps had experienced between 3 and 7 different hazards (mean = 5.31 hazards). The least-experienced hazards were landslides and mudslides (1 P reported experiencing each), followed by

volcanoes (2) and avalanches (2). The most commonly experienced hazards were hurricanes (41), heat waves (42), and fog (51).

Design

This study used largely the same methodology employed by Fox-Glassman & Weber (in preparation-a) in their study of 30 technologies and activities which, in turn was closely modeled on Fischhoff et al. (1978),, to assess risk perceptions for 20 natural hazards (see Table 1).

Minor edits were made to help the language to fit hazards rather than activities and technologies; primarily, these changes consisted only of changing mentions of “technologies” to “natural hazards.” Additionally, the *perceived benefits* condition used in the prior study was omitted in this study, since asking about benefits made sense for technologies and activities, but is not appropriate for natural hazards. The most substantive change from Study 1 was to add a new task to the beginning of the study. Before ranking the 20 hazards, Ps were asked to consider each one individually, and to “list one or two of the primary risks that, in your opinion, each hazard poses to humans.” This task was added to help ensure that Ps had considered each of the items before beginning to rank them.

All Ps completed the same four tasks, further described below, in the same order: (1) descriptions of the risks, (2) perceived risk judgments, (3) assignment of risk adjustment factors, and (4) assessment of the nine risk characteristics. Since no order effects were detected in previous uses of this paradigm, the order of the hazards listed in this study was not counterbalanced systematically; wherever feasible based on the structure of each task, the list of hazards was presented in randomly shuffled order.

After completing these four parts of the study, Ps were given the Berlin Numeracy Scale (including the 3-question Cognitive Reflection Task), and basic demographic questions. They then indicated whether they had personally experienced any of the 20 natural hazards listed in the study, or whether they had close friends or family members who had experienced them. Ps were debriefed and awarded extra credit toward their introductory Psychology course grade in

return for their participation in the study.

Results

Perceived Risk

Geometric means of perceived risk were calculated for each of the 20 items (see Table 1). The hazards with the lowest perceived risk tend to be weather-related: fog, dust storms, lightning, and hailstorms; those with the highest perceived risk include both high-energy weather-related hazards (hurricanes and tornadoes) and geophysical hazards (tsunamis, earthquakes, and volcanoes). The average perceived risk across all 20 hazards is 54.7, which is significantly higher than the average perceived risk for the 30 activities and technologies (35.3) used in (Fox-Glassman & Weber, in preparation-a). $t(24)=2.4$, $p=.025$

Table 1. Mean judgments of risk from 20 natural hazards.

	hazard	Perceived risk	Risk- Adjustment Factor	Acceptable level of risk
1	avalanches	54.6	1.3	43.2
2	blizzards	45.3	1.0	45.5
3	droughts	48.6	1.5	31.8
4	dust storms	20.8	0.8	25.9
5	earthquakes	100.7	3.5	29.0
6	flash floods	56.6	1.2	45.6
7	floods	59.7	1.4	43.6
8	fog	11.6	0.5	25.1
9	hailstorms	26.4	0.7	39.5
10	heat waves	28.2	1.0	27.0
11	hurricanes	110.2	3.5	31.7
12	ice storms	35.0	1.0	35.1
13	landslides	41.9	1.2	35.8
14	lightning	23.8	0.6	41.8
15	mudslides	40.0	1.1	37.7
16	sinkholes	30.2	0.9	34.5
17	tornadoes	92.3	2.2	42.9
18	tsunami	143.5	5.5	26.1
19	volcanoes	72.3	1.8	39.2
20	wildfires	51.4	2.1	24.4
mean (sd) of all items:		54.7 (33.9)	1.6 (1.24)	35.3 (7.3)
Coefficient of Concordance		.50	.30	

Risk-Adjustment Factor

Participants' judgments of whether the risks associated with each hazard "could be higher," "must be lower," or were "presently acceptable" were used to calculate a risk-adjustment factor (RAF) for each hazard for each P. For risks that a P considered too high, the RAF was calculated as the value they entered to finish the statement "must be ____ times safer to be acceptable." For risks that a P believed could be higher, RAF was calculated as the reciprocal of the value that finished the statement "would be acceptable if it were ____ times higher." For activities/technologies that Ps judged as "presently acceptable," RAF was set to 1.0. Thus, RAF values greater than 1.0 mean that current risk of the hazard is too high and must be lowered, and RAF values less than 1.0 mean that the risk could be higher.

Of the 1600 total risk-adjustment judgments for the 20 natural hazards, 27.8% indicated that the current risk of the hazard was considered too high and "should be safer," 56.6% were "presently acceptable," and 15.6% allowed that the hazard "could be riskier." As expected, perceived risk and risk-adjustment factor are strongly positively correlated, such that the higher the perception of risk for a hazard, the more Ps would like that risk to be reduced $r=0.95$, $p<.001$. The hazards whose mean RAF was lower than 1.0 ("could be riskier") were fog, lightning, hailstorms, dust storms, and sinkholes, which make up five of the six lowest-ranked hazards for perceived risk. The sixth, heat waves, has a mean RAF of 1.0 ("presently acceptable"), as do ice storms and blizzards. The remaining 12 hazards all show mean RAFs greater than 1.0, indicating an average attitude that their risks must be reduced in order to be acceptable. The three hazards that Ps ranked highest in perceived risk—earthquakes, hurricanes, and tsunamis—all have RAFs substantially higher than the rest: earthquakes and hurricanes, with RAFs of 3.5, fall 1.5 standard deviations above the mean RAF score, while tsunamis' RAF of 5.5 is 3.1 standard deviation above the mean.

A value for "level of acceptable risk" was calculated for each activity and technology by

dividing the perceived risk by the risk-adjustment factor (Table 1). The hazards with the highest levels of acceptable risk are flash floods, blizzards, and floods; those with the lowest acceptable risk levels are wildfires, fog, and dust storms. There was no relationship between acceptable risk levels and experience with these hazards ($r=-0.14$, *ns*).

Interparticipant Agreement

For both perceived risk and risk-adjustment factor, we find reasonable levels of interparticipant agreement. Kendall's coefficient of concordance, which measures agreement among Ps in their rank ordering of the 20 hazards, is a fairly strong 0.50 for perceived risk, and a moderate 0.30 for risk-adjustment factor.

Nine Characteristics of Risk

Participants in Study 1 judged each natural hazard on the same nine risk scales developed in Fischhoff et al. (1978) and used by Fox-Glassman & Weber (in preparation-a). During debriefing, some Ps reported ambivalence about using the “newness” scale, saying that all 20 items feel fairly old—and indeed, the mean score on newness is a quite high 5.13 (7 = old), with a very low variance ($SD=0.43$). This response makes sense, as the natural processes that cause these hazards all pre-date human society, even though the risk each poses to humans has varied over time, depending on the location and the vulnerability of human settlements. The 20 hazards were also rated consistently near the bottom of the “known to science” scale: mean = 2.42 (1 = known precisely, 7 = unknown), and with even less variance ($SD=0.24$), likely also a reflection of how long humans have lived alongside these hazards.

Correlations among the risk characteristics. As seen in other applications of this psychometric risk assessment paradigm that examined health and safety risks (Fischhoff et al., 1978; Fox-Glassman & Weber, in preparation-a), the nine characteristics of risk are highly intercorrelated (see Table 3). The pattern of correlations does, however, look quite different to that seen in Fox-Glassman & Weber's study of technologies and activities. Ten pairs of characteristics that were strongly correlated for technologies/activities show no significant

Table 2. Mean Ratings for Nine Characteristics of Risk.

	voluntariness	immediacy	known to exposed	known to science	controllability	newness	chronic-catastrophic	common-dread	severity of consequences
	1 = voluntary	1 = immediate	1 = known precisely	1 = known precisely	1 = un-controllable	1 = new	1 = chronic	1 = common	1 = certain not to be fatal
avalanches	4.18	1.83	3.03	2.37	2.48	4.93	5.15	5.04	5.15
blizzards	4.07	3.72	2.83	2.16	4.67	5.56	3.81	2.41	3.26
droughts	5.47	5.71	3.76	2.39	3.83	5.71	3.15	3.50	3.72
dust storms	4.28	4.13	4.25	2.75	4.99	4.87	3.00	2.72	2.54
earthquakes	5.37	2.01	2.61	2.21	2.41	5.24	6.07	5.20	5.24
flash floods	5.07	2.20	3.76	2.39	3.05	4.8	5.11	4.12	4.22
floods	4.16	2.91	2.93	2.19	3.92	5.64	4.27	3.65	3.77
fog	3.45	4.17	3.84	2.73	6.29	5.28	2.11	1.19	1.86
hailstorms	4.38	3.32	3.89	2.49	5.01	4.85	3.09	2.42	2.69
heat waves	4.43	4.36	4.21	2.61	5.33	4.87	2.92	2.31	3.15
hurricanes	5.01	2.14	2.47	2.17	3.6	5.21	5.78	5.31	5.23
ice storms	4.38	3.34	3.67	2.47	4.68	5.12	3.51	2.73	2.95
landslides	4.97	2.42	4.13	2.43	2.73	4.8	4.97	4.34	4.36
lightning	4.66	2.03	3.64	2.48	3.81	5.89	2.80	2.59	4.15
mudslides	4.91	2.55	4.16	2.55	2.84	4.97	4.50	4.22	4.09
sinkholes	5.00	2.45	4.73	2.97	3.04	4.11	4.00	4.27	4.43
tornadoes	4.95	1.59	2.47	1.95	3.19	5.45	5.64	5.16	5.31
tsunami	5.88	1.59	2.73	2.17	1.92	4.65	6.59	6.59	6.27
volcanoes	4.32	2.92	3.36	2.32	2.87	5.65	5.49	5.69	5.3
wildfires	4.66	2.91	3.32	2.6	3.57	4.92	4.18	3.99	4.22
mean	4.68	2.92	3.49	2.42	3.71	5.13	4.31	3.87	4.10
σ	0.57	1.07	0.67	0.24	1.14	0.43	1.26	1.39	1.13
coeff of concordance	.09	.32	.17	.07	.30	.06	.32	.39	.39

relationships in this current study of hazards. Notably among these is the characteristic of newness, which the previous study of technologies and activities correlated with every other characteristic except severity; here, it correlates strongly and negatively with severity (such that the older a hazard is, the more certain it is not to be fatal), as well as chronic/catastrophic (the newer, the more catastrophic) and common/dread (the newer, the more dread). Conversely,

nine pairs of characteristics that are significantly correlated in this hazards study were not related in the earlier technologies study. Four of these pairs include the chronic/catastrophic characteristic, and two others include the common/dread characteristic. It seems, therefore, that while the newness scale is slightly more relevant for rating technologies and activities than it is for hazards, the chronic/catastrophic and common/dread scales produce more variability, and interrelate to the other scales more tightly, for ratings of natural hazards than for technologies. These two shifts are consistent with the dread-risk factor now having greater explanatory power than the unknown-risk factor, as discussed in the factor analysis section, below.

Table 3. Correlations among the 9 risk characteristics. Variable pairs that were correlated (at $\alpha=.001$) in Fox-Glassman & Weber (in preparation-a) are underlined here.

	immediacy (1 = immediate)	knowledge to exposed (1 = known precisely)	knowledge to science (1 = known precisely)	controllability (1 = uncontrollable)	newness (1 = new)	chronic/catastrophic (1 = chronic)	common/dread (1 = common)	severity (1 = certain not to be fatal)
voluntary	-0.33	<u>-0.17</u>	-0.28	<u>-0.71**</u>	<u>-0.23</u>	0.59*	0.66*	0.67*
immediate		<u>0.43</u>	<u>0.37</u>	0.70**	<u>0.21</u>	-0.73**	-0.66*	<u>-0.73**</u>
known (exposed)			<u>0.88**</u>	0.32	<u>-0.46</u>	-0.62*	-0.49	<u>-0.55</u>
known (science)				0.38	<u>-0.52</u>	-0.63*	-0.49	<u>-0.54</u>
controllable					<u>0.17</u>	<u>-0.85**</u>	<u>-0.91**</u>	-0.91**
new						-0.13	-0.16	-0.05
chronic							<u>0.95**</u>	<u>0.91**</u>
common								<u>0.96**</u>

* $p<.005$; ** $p<.001$

Relationship of the nine risk characteristics with perceived risk, RAF, and acceptable risk. In a multiple linear regression model (see Table 4), perceived risk is predicted by scores on voluntariness, knowledge of the exposed, and controllability: moving one point on the scale toward more involuntary risk is associated with a 22.7-point jump in perceived risk; sliding one point toward a hazard's risk being known more precisely by those exposed to it is

associated with a 21.9-point increase in perceived risk, and raising the controllability of a hazard's risk by one point is associated with a 16.9-point increase in perceived risk. In other words, the more involuntary, precisely known, and controllable the risks posed by a hazard are, the higher they are perceived to be, and these three characteristics do a very good job of predicting the risk (adjusted $R^2=0.95$).

The linear model predicting risk-adjustment factor looks similar to that for perceived risk, which makes sense considering the close correlation between perceived risk and RAF. The more involuntary and precisely known the risks are, the more people want them to be reduced: RAF goes up by 1.27 for every one-point shift toward involuntary, and it increases by 1.4 for every one-point shift toward known precisely to the exposed. Interestingly, acceptable risk—which is calculated by dividing perceived risk by the adjustment factor—is predicted instead by voluntariness and knowledge to *science*, but not knowledge to the exposed. For every one-point

Table 4. Linear models predicting perceived risk, RAF, and acceptable risk by scores on the nine risk characteristics. Note that for this analysis scores on the 9 characteristics were mean-centered, so the intercepts represent the perceived risk and benefit for a technology or activity that is “average” on all nine characteristics.

		perceived risk (β)	RAF	acceptable risk
intercept		54.7	1.63	35.3
voluntariness	1 = voluntary	22.7**	1.27**	-8.9*
immediacy	1 = immediate	0.34	0.10	-2.2
known to exposed	1 = known precisely	-21.9**	-1.4**	9.2
known to science	1 = known precisely	10.8	2.5	-47.3**
controllability	1 = uncontrollable	16.9**	0.68	-6.8
newness	1 = new	-0.33	-0.11	-3.2
chronic-catastrophic	1 = chronic	10.8	0.45	-5.0
common-dread	1 = common	11.6	0.32	-1.7
severity of consequences	1 = certain not fatal	2.9	0.11	0.47
adjusted R^2		.95	.83	.52

* $p<.05$; ** $p<.01$

move toward a hazard's risk being involuntary, there is a 8.9-point *drop* in acceptable risk, while a one-point move toward a hazard being known precisely to science leads to a 47.3-point *increase* in acceptable risk. Thus, it seems that as long as people are putting themselves in a hazard's path of their own accord, and as long as the risks involved are understood by science, it is considered acceptable for the risk to remain high.

Factor analysis of the 9 risk characteristics. As expected, a principal components analysis shows somewhat similar, though not identical, factor loadings as seen for the activities and technologies from Fox-Glassman & Weber's study (in preparation-a). The two orthogonal factors together account for 83% of the variance for the nine variables overall, and the two-factor solution appears to sufficiently explain the correlations among the variables (adding a third factor explains only an additional 8% of the variance).

The main difference between this study's factor loadings and those from the previous study of technologies and activities is that here the dread risk factor explains much more of the variance in the ratings of the nine risk characteristics than the unknown risk factor does. This shift makes sense, given the ways that the nine risk scales were used for natural hazards: characteristics that in previous studies have loaded strongly onto the unknown factor, such as newness and knowledge to the exposed and to science, show very little variation across the 20 hazards. These characteristics still contribute to the unknown risk factor, but others that previously loaded onto this factor, such as immediacy and voluntariness, now appear to load more strongly onto the dread risk factor. In fact, dread risk now includes components of nearly all of the nine characteristics to some extent, with the strongest loadings coming from the characteristics that made up the dread factor in previous studies: chronic-catastrophic, dread, severity, and controllability. Only newness seems to have no relationship with the dread factor for natural hazards. Because the dread factor in this study includes more components than the dread factors seen in previous studies, we will refer to it here as the hazard-dread factor.

Table 5. Factor Loadings for the nine risk characteristics

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance accounted for
Factor 1 (unknown)	0.34	-0.15	0.68	0.68	-0.28	-0.89	0.04	0.16	0.08	1.96	0.22
Factor 2 (hazard- dread)	0.68	-0.76	-0.65	-0.66	-0.90	-0.04	0.96	0.95	0.97	5.49	0.61
commonality	0.58	0.61	0.88	0.90	0.89	0.79	0.93	0.93	0.94		

Table 6. Factor Loadings for the nine risk characteristics for 30 technologies & activities (from Fox-Glassman & Weber, in preparation-a)

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance accounted for
Factor 1 (unknown)	0.64	0.83	0.98	0.85	-0.34	-0.88	-0.18	-0.20	-0.70	4.23	0.47
Factor 2 (dread)	0.65	-0.18	0.03	-0.10	-0.88	-0.31	0.85	0.90	0.67	3.31	0.37
commonality	0.83	0.71	0.96	0.74	0.90	0.87	0.75	0.85	0.94		

By mapping the psychological risk dimensions of each hazard onto a two-dimensional dread and unknown risk factor space, we can visually compare perceptions of the 20 hazards. As expected, the natural hazards show a wide spread on the hazard-dread dimension, with fog, the lowest-ranked item in terms of risk, at the low extreme on this scale as well. Weather-related hazards make up the rest of the low-dread space, with the notable exception of hurricanes and tornadoes, which both rate as relatively high on the hazard-dread dimension. It is interesting, and perhaps slightly surprising, that tsunamis score so much higher on the hazard-dread factor than do earthquakes (which are the cause of most large tsunamis, and which offer humans less

forewarning than the tsunamis that they trigger). We were also somewhat surprised that volcanoes fell so much lower on hazard-dread than earthquakes, hurricanes, and tornadoes; the idea of molten rock seems at face value to be a high dread concept, and in terms of energy release, volcanic eruptions are more powerful than most earthquakes and virtually any hurricane. However, volcanic eruptions are both less frequent and less likely to affect human populations than earthquakes, tsunamis, and hurricanes, so based on the characteristics of risk that contribute to the hazard-dread factor, the placement of volcanoes does make sense.

Figure 1. Factor space for the 20 natural hazards.

The 20 hazards cluster closer to the mean on the unknown factor scale, with sinkholes being the sole high-unknown exception, and in the other direction blizzards marking the slightly more known extreme. Considering the consistency of participants' ratings of the various hazards on the risk characteristics that load most strongly onto the unknown factor—newness, known to science, and known to the exposed—it is not surprising that the hazards would score similarly on this factor. The extreme position of sinkholes comes from its rating as the most new of the hazards, as well as being the most unknown to science and most unknown to the exposed.

Multivariate Determination of Acceptable Risk Levels

When attempting to predict perceived risk and risk-adjustment factor (RAF) for each hazard using its scores on the two factors, we again see that the hazard-dread factor has notably more explanatory power than the unknown factor. While acceptable risk is not significantly predicted by either of the two factors, hazard-dread significantly predicts both

Table 7. Linear models predicting perceived risk as a function of the two risk factors and exposure to hazards.

	perceived risk (β)	perceived risk (β)
intercept	54.7	50.7
Factor 1 (unknown)	-3.95	-4.00
Factor 2 (hazard-dread)	12.58***	13.2***
experience		0.20
adjusted R^2	0.81	0.80

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 8. Linear models predicting risk-adjustment factor (RAF) as a function of the two risk factors and exposure to hazards.

	RAF (β)	RAF (β)
intercept	1.63	1.58
Factor 1 (unknown)	-0.028	-0.029
Factor 2 (hazard-dread)	0.405***	0.413***
experience		0.003
adjusted R^2	0.58	0.55

* $p < .05$; ** $p < .01$; *** $p < .001$

perceived risk ($p < .001$, $R^2 = .81$) and RAF ($p < .001$, $R^2 = .58$). Neither of these models is improved by adding the effect of personal experience with hazards (see Tables 7 and 8).

Unlike in Fox-Glassman & Weber's study of 30 technologies and activities, where perceived risk increased with higher scores on dread and decreased with higher scores on the unknown factor, here we see no effect of the unknown factor and only an effect of dread. This relationship can be seen in Figure 2 as a simple trend toward larger point size (greater perceived risk) moving to the right in the factor space.

Figure 2. Factor space from Figure 1 with point size determined by mean perceived risk for each of the 20 items.

Study 2

Where would climate change and sea-level rise each fall in relation to the natural hazards mapped out in Study 1? Although both of these risks very likely have a significant anthropogenic component (IPCC, 2014), their effects tend to manifest in ways that look similar to many of the natural hazards: climate change may influence weather extremes and storms, and its effect of sea-level rise is mostly relevant to people in its contribution to flood events. There may therefore be a simultaneous perception that climate change and sea-level rise are both consequences of human actions as well as naturally driven processes. This tension leads to two possible predictions about where the two items might fall in the dread-unknown risk space. If, as some studies have suggested, climate change is perceived to be analogous to natural hazards like floods or weather events, they would likely cluster near those hazards in the risk space: somewhere at or below the middle of the dread axis, and close to the middle of the unknown axis (e.g., Lorenzoni, Leiserowitz, de Franca Doria, Poortinga, & Pidgeon, 2006).

If, however, climate change and sea-level rise are considered more like anthropogenic hazards by people who are thinking about these items' scores on the various risk characteristics, they might be located far higher on the unknown axis and lower on the dread axis—much like the newer and more controversial technologies (e.g., food preservatives, spray cans) were in Fischhoff et al.'s original study on technologies (1978). This second prediction is more in line with the predictions of Weber (2006), who suggested the absence of inherently dread qualities in people's mental models of climate change as one factor that has contributed to the lack of public concern and action on climate-related issues, relative to the severity of the potential consequences of climate change.

Method

Participants

The 108 participants (Ps) were recruited and run through Amazon's Mechanical Turk in April of 2014. Mean completion time was about 90 minutes. We omitted data from 17 Ps who

dropped out in the middle of the study, or whose answers clearly indicated that they had ignored instructions, leaving 91 Ps for analysis. Mean age was 34.7 years ($SD=9.5$), and 75% of Ps had experienced between 2 and 8 of the 20 natural hazards (mean = 5.29). Although this sample is much older than the student participants used in Study 1, the exposure of the two groups is very similar, at least in terms of mean number of hazards personally experienced. Numbers of Ps having experienced each hazard ranges from zero (tsunamis and volcanoes) to 43 (blizzards), 49 (heat waves), and 55 (fog).

Of the Ps who reported their education, 39% had completed a high-school diploma, 36% had completed a bachelor's degree, 20% had completed associates' degrees, and 5% had master's degrees. Politically, our sample skews left, with 50% identifying as liberal, 31% identifying as Independent, and 13% identifying as conservative.

Design

This study used the same methodology as Study 1 (see above), adding two additional items to the list of 20 natural hazards: climate change, and sea-level rise. As in Study 1, the order of the 22 items was presented randomly whenever feasible; in Part 3 (assignment of the risk-adjustment factors), climate change was presented as the 12th item (part of the third block of items), and sea-level rise was presented as the 19th item (part of the fourth block of items).

Results

Perceived Risk & Risk-Adjustment Factor

Geometric means of perceived risk and perceived benefit were calculated for each of the 22 items (see Table 9). As in Study 1, the hazards with the lowest perceived risk are all common weather events: fog, dust storms, hailstorms, and heat waves; those with the highest perceived risk also match the highest-risk hazards in Study 1: tsunamis, hurricanes, tornadoes, earthquakes, and volcanoes. The average perceived risk across the 20 natural hazards is 40.9, which is significantly lower than the average perceived risk (54.7) for the 20 hazards assessed in Study 1, $t(19)=4.12$, $p<.001$. This difference may be due to the fact that Study 1's participants

were young college students and Study 2 used a more nationally representative (albeit online) sample. But while average perceived risk is higher here, the relative risk rankings for the 20 hazards used in both Study 1 and Study 2 have not changed, $\rho=0.95$, $p<.001$.

Sea-level rise and climate change are the 6th and 10th-lowest items in terms of perceived risk. Although these hazards rank so low on risk, scores on the risk-adjustment factor (RAF) tell a slightly different story. Climate change and sea-level rise rank 6th and 7th highest on RAF, which leaves their acceptable level of risk as the two lowest out of all 22 items. So although our Ps do not indicate belief that these two environmental hazards are all that risky, they do indicate that the risks for both should be reduced down to levels lower than any other hazard on the list.

Table 9. Mean judgments of risk from 20 natural hazards, climate change, and sea-level rise.

hazard		Perceived risk	Risk-Adjustment Factor	Acceptable level of risk
1	avalanches	40.2	1.2	34.4
2	blizzards	33.2	1.3	26.2
3	climate change	31.2	2.2	14.2
4	droughts	27.2	1.5	18.2
5	dust storms	17.2	1.0	17.1
6	earthquakes	67.4	2.9	23.2
7	flash floods	44.8	1.4	32.1
8	floods	43.0	1.3	32.3
9	fog	11.9	0.7	17.4
10	hailstorms	21.7	0.9	24.2
11	heat waves	24.7	1.1	22.9
12	hurricanes	74.6	2.6	28.6
13	ice storms	29.7	1.0	30.0
14	landslides	34.9	1.2	28.1
15	lightning	25.0	0.7	37.3
16	mudslides	35.9	1.3	28.5
17	sea-level rise	26.0	1.8	14.2
18	sinkholes	27.3	1.2	22.7
19	tornadoes	73.0	3.2	22.8
20	tsunamis	83.8	5.6	15.1
21	volcanoes	54.2	1.5	36.9
22	wildfires	48.0	2.2	21.4
mean (sd) of all items:		39.8 (19.3)	1.7 (1.1)	24.9 (7.0)
Coefficient of Concordance		0.71	0.18	

Risk-adjustment factor was calculated the same way as in Study 1, such that RAF values greater than 1.0 mean that current risk of the hazard is too high and must be lowered, and RAF values less than 1.0 mean that the risk could be higher.

Of the 2002 total risk-adjustment judgments, 24.7% indicated that the current risk was considered too high and “should be safer,” 67.0% were “presently acceptable,” and 8.3% allowed that the hazard “could be riskier.” These proportions are similar to those seen in Study 1, though show a slight increase in “presently acceptable” ratings, and a corresponding decrease in “could be riskier.”

As in Study 1, perceived risk and risk-adjustment factor are strongly positively correlated, such that the higher the perception of risk for a hazard, the more Ps would like that risk to be reduced $r=0.84$, $p<.001$. In keeping with Study 2’s tendency to show slightly less risk tolerance than Study 1, fewer hazards here received RAF scores below 1.0: only hailstorms, fog, and lightning were considered, on average, to be acceptable even if the risk were slightly higher. This trend toward slightly lower perceived risks and lower RAF scores could be driven by the relative nature of risk: if people do have a “finite pool of worry,” as has been suggested (Hansen, Marx, & Weber, 2004), then the inclusion of two additional items on the list in Study 2 could have reduced the perceived risk for each individual item. However, as the total perceived risk across the 20 items in Study 1 is substantially higher ($pr_{total}=1093$) than for the 22 items in Study 2 ($pr_{total}=875$), it seems unlikely that the difference in perceived risk and RAF scores is due merely to the relative nature of risk perception; it is more likely a factor of variation across the two different participant populations.

As before, the highest RAF scores (indicating items most in need of having their risks reduced) are tsunamis, tornadoes, earthquakes, and hurricanes. There is no correlation between mean RAF score for a particular hazard and the frequency with which our Ps have experienced it ($r=-0.13$, ns); nor is there a correlation between experience and perceived risk

($r=-0.18$, *ns*).

Interparticipant Agreement

Study 2 shows higher interparticipant agreement on perceived risk than Study 1. Here, Kendalls' coefficient of concordance is a strong $W=0.71$, compared to $W=0.50$ in Study 1. On risk-adjustment factor, however, Study 2 shows less concordance: concordance is down to $W=0.18$, from $W=0.30$ in Study 1. So while Study 2's slightly more diverse participant group is more closely aligned on rankings of the 22 hazards for perceived risk, they diverge quite a bit from each other in terms of which hazards' risk most need to be reduced. One possible explanation for this pattern of results is to assume that the greater geographical spread of Ps in Study 2 has given them more experience with particular hazards that might cause them to be more divided with regard to which hazards are most worthy of mitigation efforts. Studies on flood risk have shown that greater experience tends to lead to higher risk perception increased concern, and greater support for mitigation for floods (Lawrence, Quade, & Becker, 2014; Spence, Poortinga, Butler, & Pidgeon, 2011); if this is true for other hazards as well, then a more diverse slate of hazard experience could well lead to more diverse opinions about mitigation priorities. However, despite the age differences between the samples in Studies 1 and 2, the actual experience of the 20 hazards looks quite similar between the groups.

Nine Characteristics of Risk

Participants in Study 2 judged each natural hazard on the same nine risk scales used in Study 1. One notable difference to Ps' use of these scales here compared to in Study 1 is the more extreme values for the "new" characteristic. The addition of two obviously newer items (namely climate change and sea-level rise) appears to have resulted in all of the natural hazards receiving higher (older) ratings in contrast—here, the natural hazards range from 4.63 to 6.52 on newness with 10 of the values above 6.0, while in Study 1 values ranged from 4.11 to 5.89. Here, climate change (2.02) and sea-level rise (2.22) have taken up the space at the other

extreme of the scale. This scale usage is consistent with a common conclusion of risk-perception studies: that risk is relative (Elke U Weber, 2004), and underscores the need, when comparing risk perception of hazards, technologies, and activities, to make such comparisons only within—not across—studies.

Table 10. Mean Ratings for Nine Characteristics of Risk.

	voluntariness	immediacy	known to exposed	known to science	controllability	newness	chronic-catastrophic	common-dread	severity of consequences
	1 = voluntary	1 = immediate	1 = known precisely	1 = known precisely	1 = un-controllable	1 = new	1 = chronic	1 = common	1 = certain not to be fatal
avalanches	4.29	2.02	2.98	2.23	3.22	6.21	4.72	4.49	5.13
blizzards	4.70	3.66	2.72	2.08	4.71	4.63	4.30	2.71	3.34
climate change	4.34	5.39	4.70	3.38	3.83	2.02	2.58	3.38	3.13
droughts	5.79	5.46	3.66	2.20	4.06	6.18	3.03	3.17	3.58
dust storms	5.00	3.94	4.11	2.54	4.54	5.12	3.37	2.64	2.42
earthquakes	5.38	1.93	2.93	2.18	2.70	5.63	6.25	5.17	4.33
flash floods	5.41	2.12	3.18	2.27	2.98	6.13	5.11	4.04	4.49
floods	4.53	2.88	2.99	2.11	3.91	6.48	4.72	3.60	3.85
fog	4.39	3.87	3.20	2.08	5.08	6.47	2.75	1.52	1.82
hailstorms	5.59	3.11	3.53	2.03	4.46	5.43	3.83	2.46	2.60
heat waves	5.06	4.14	3.39	2.08	4.62	5.91	3.25	2.22	3.54
hurricanes	4.63	2.11	2.44	1.82	3.62	6.48	6.07	4.78	4.19
ice storms	5.07	3.51	3.18	2.01	4.54	5.47	3.97	2.65	3.03
landslides	4.88	2.37	3.63	2.44	3.11	6.14	4.84	4.01	4.62
lightning	5.28	1.91	3.20	2.12	3.38	5.68	2.74	2.87	4.57
mudslides	5.24	2.40	3.50	2.42	3.13	6.12	4.92	3.75	4.29
sea level rise	4.42	5.90	4.17	3.17	4.08	2.22	2.64	3.52	2.97
sinkholes	5.69	2.34	4.26	2.76	2.74	5.08	3.88	4.06	4.17
tornadoes	5.38	1.62	2.68	1.99	3.16	6.51	6.11	5.26	4.48
tsunami	5.51	1.58	2.96	1.97	2.58	5.92	5.46	5.91	4.24
volcanoes	4.54	2.40	2.91	2.18	3.39	6.52	5.76	5.17	4.61
wildfires	4.89	2.78	2.83	2.09	4.38	5.26	4.70	3.99	3.49
mean	5.00	3.07	3.33	2.28	3.74	5.53	4.32	3.70	3.77
σ	0.45	1.22	0.55	0.37	0.71	1.17	1.15	1.08	0.81
coeff of concordance	.07	.41	.12	.09	.17	.55	.31	.31	.26

Correlations among the risk characteristics. As in Study 1, the nine characteristics of risk are highly intercorrelated (see Table 11). The overall pattern of correlations looks quite similar to that in Study 1, with the primary exception that newness, which previously correlated with no other risk characteristics, now shows a negative relationship with immediacy, and knowledge to the exposed and to science. The return of newness as a variable that actually seems to vary can probably be explained by the inclusion of climate change and sea-level rise on the list of items. Whereas in Study 1 participants reported difficulty rating newness, since all 20 hazards seemed equally old, the addition of two environmental hazards that have only recently gained public attention seems to have made this variable easier to interpret for Study 2's participants.

Table 11. Correlations among the 9 risk characteristics. Variable pairs that were correlated (at $\alpha=.001$) in Study 1 are underlined here.

	immediacy (1 = immediate)	knowledge to exposed (1 = known precisely)	knowledge to science (1 = known precisely)	controllability (1 = uncontrollable)	newness (1 = new)	chronic/catastrophic (1 = chronic)	common/dread (1 = common)	severity (1 = certain not to be fatal)
voluntary	-0.27	0.03	-0.25	<u>-0.35</u>	0.28	<u>0.13</u>	<u>0.13</u>	0.16
immediate		0.62*	0.56	<u>0.64*</u>	-0.66**	<u>-0.76**</u>	<u>-0.59*</u>	<u>-0.68**</u>
known (exposed)			<u>0.87*</u>	0.08	-0.68**	<u>-0.68**</u>	-0.35	-0.37
known (science)				-0.07	-0.82**	<u>-0.49</u>	-0.10	-0.17
controllable					-0.20	<u>-0.58*</u>	<u>-0.82**</u>	<u>-0.83**</u>
new						0.54	0.20	0.39
chronic							<u>0.80**</u>	<u>0.62*</u>
common								<u>0.74**</u>

* $p<.005$; ** $p<.001$

Relationship of the nine risk characteristics with perceived risk, RAF, and acceptable risk. In a multiple linear regression model (see Table 12), perceived risk is

predicted only by scores on the common/dread characteristic, such that a 1-point move toward the dread end of the scale predicts an 11.84-point increase in perceived risk. The linear model predicting risk-adjustment factor looks similar: both dread and severity of consequences predict RAF, such that a 1-point increase in dread predicts a 1.13-point increase in RAF, and a 1-point increase in severity of consequences predicts a 0.93-point decrease in RAF. Taken together, these relationships suggest that our Ps believe that very high-dread hazards should have their riskiness decreased, but that hazards that are more likely to be fatal can still be acceptable even at slightly higher levels of riskiness. In line with this explanation, we see that acceptable risk is predicted only by severity of consequences, such that a 1-point increase in severity (toward “certain to be fatal”) is associated with an 8.89-point increase in acceptable level of risk. In other words, the more likely a hazard is to have fatal consequences, the higher we are willing to leave the risk. This model represents a slightly more resigned attitude than that seen in Study 1.

Table 12. Linear models predicting perceived risk, RAF, and acceptable risk by scores on the nine risk characteristics. Note that for this analysis scores on the 9 characteristics were mean-centered, so the intercepts represent the perceived risk and benefit for a technology or activity that is “average” on all nine characteristics.

		perceived risk (β)	RAF (β)	acceptable risk (β)
intercept		39.8	1.71	24.9
voluntariness	1 = voluntary	-4.97	-0.26	-3.67
immediacy	1 = immediate	3.39	0.23	-1.70
known to exposed	1 = known precisely	-2.12	0.27	1.67
known to science	1 = known precisely	-34.3	-3.11	-3.63
controllability	1 = uncontrollable	-11.3	-1.01	1.58
newness	1 = new	-5.68	-0.49	-0.33
chronic-catastrophic	1 = chronic	3.61	-0.28	2.14
common-dread	1 = common	11.84**	1.13**	-5.71
severity of consequences	1 = certain not fatal	-5.66	-0.93*	8.89**
<i>adjusted R²</i>		0.91	0.76	0.62

*p<.05; **p<.01

Factor analysis of the 9 risk characteristics. The principal components analysis for Study 2 looks similar to that of Study 1 (see Table 13). Some factor loadings have changed slightly, with the unknown factor now taking on a bit more of the total loading, closer to the way it has appeared in studies of risky technologies and activities (Fox-Glassman & Weber, in preparation-a). Still, the unknown factor is composed primarily of the two knowledge characteristics (known to the exposed, known to science), as well as newness, uncontrollability, and dread. As in Study 1, the dread factor comprises loadings from nearly all of the risk characteristics, but is loaded especially strongly by immediacy, catastrophic potential, newness, dread, and severity.

Table 13. Factor Loadings for the nine risk characteristics for Study 2.

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance accounted for
Factor 1 (unknown)	0.06	0.01	0.55	0.75	-0.69	-0.52	0.05	0.52	0.43	2.07	0.23
Factor 2 (hazard- dread)	0.30	-0.90	-0.73	-0.63	-0.69	0.72	0.89	0.76	0.78	4.83	0.54
commonality	0.09	0.82	0.84	0.96	0.95	0.79	0.80	0.84	0.80		

As for Study 1, we can use the two factor scores for each hazard to map the dread-unknown factor space (see Figure 3). We again see sinkholes stand out among the other 19 natural hazards as the most unknown, although here the lowest-unknown score falls to fog, rather than blizzards. The rest of the natural hazards cluster quite similarly to their placement in Study 1's factor space; what is notable here is the position of climate change and sea-level rise in comparison to the natural hazards. Both of these new items are rated as lower dread than any natural hazard, and they both fall at the high extreme of the unknown scale. From this depiction of the factor space, it appears that climate change and sea-level rise are considered quite differently from the majority of the natural hazards.

Figure 3. Factor space for the 20 natural hazards

To gain greater insight into the differences in perception of these global-climate-related hazards, compared to the geophysical- and weather-related hazards that are considered more dreaded and less unknown, we can compare these items' ratings across all nine risk characteristics. From Figure 4, we can see that the profiles for climate-change and sea-level rise are very similar to each other, differing only slightly where sea-level rise is considered more immediate, more dread, and more likely to be fatal. As Figure 4a shows, these manmade

(a)

(b)

Figure 4 (previous page). Profiles on the nine risk characteristics for climate change and sea-level rise, compared with (a) two high-energy hazards (hurricanes and earthquakes), and (b) two weather-related hazards (floods, and heat waves).

hazards are have entirely different profiles from geophysical hazards like earthquakes, which is perhaps not surprising. But even hurricanes, a high-energy hazard that has been linked to both climate change and global sea-level (climate change may be contributing to the formation of Atlantic hurricanes; and the primary danger from hurricanes, storm surge, will worsen as sea levels rise), show an entirely different profile across the nine risk characteristics. Figure 4b compares the two outliers to floods and heat waves: two hazards that, as more closely climate-related and less sudden in onset as hurricanes and earthquakes, might be expected to track closer to climate change and sea-level rise. Indeed, the hazards in Figure 4b all look more similar to each other than those in 4a, but even still, it is clear that climate change and sea-level rise are easily distinguishable from heat waves, and distinct enough from floods to place them in their own category of hazard.

Multivariate Determination of Acceptable Risk Levels

As in Study 1, a linear model predicting perceived risk using the dread and unknown factors only shows a significant effect of dread: each 1-point increase on the dread scale is associated with a 6.92-point increase in perceived risk (see Table 14). We see similar, though weaker, effects of the dread factor on RAF and acceptable risk, such that an increase of one point on the dread scale predicts a risk-adjustment factor 0.22 points higher, and an acceptable risk that is 1.71 points higher (see Tables 15 and 16).

While addition of experience does not improve the model for acceptable risk, it does make a difference for RAF and perceived risk. Experience does not have a direct effect on RAF or perceived risk but controlling for how often each hazard is experienced slightly strengthens the effect of dread risk on RAF (see Table 15), and almost doubles the effect of the dread factor on perceived risk, from $\beta=6.92$ to $\beta=11.66$. So while the commonness of exposure to each

particular hazard does not have any effect on perceived risk, these results do suggest that it is important to measure and control for experience in future studies.

Table 14. Linear models predicting perceived risk as a function of the two risk factors and exposure to hazards.

	perceived risk (β)	perceived risk (β)
intercept	39.8	36.0
Factor 1 (unknown)	2.60	-4.65
Factor 2 (dread)	6.92***	11.66***
experience		-0.07
adjusted R ²	0.63	0.81

*p<.05; **p<.01; ***p<.001

Table 15. Linear models predicting risk-adjustment factor (RAF) as a function of the two risk factors and exposure to hazards.

	RAF (β)	RAF (β)
intercept	1.71	1.53
Factor 1 (unknown)	0.23	-0.15
Factor 2 (dread)	0.22*	0.46**
experience		-0.004
adjusted R ²	0.22	0.35

*p<.05; **p<.01; ***p<.001

Table 16. Linear models predicting acceptable risk as a function of the two risk factors and exposure to hazards.

	RAF (β)	RAF (β)
intercept	24.9	25.5
Factor 1 (unknown)	-0.84	-0.59
Factor 2 (dread)	1.71*	1.40
experience		-0.014
adjusted R ²	0.25	-0.05

*p<.05; **p<.01; ***p<.001

Conclusions

Study 1 tested the usefulness of the nine risk characteristics used in Fischhoff et al.'s (1978) framework for assessing risk perceptions for natural hazards. We found that these nine characteristics aren't perhaps the most useful set for examining natural hazards compared to other hazards. The characteristic of newness, for example, makes little sense in this context, and the unknown factor lacks the explanatory and predictive power that it shows in studies of activities and technologies. For studying natural hazards alone, some other measures of risk perception that were used subsequently by Slovic and his colleagues (1987), such as number of people affected per year, may be more relevant. With hazards, there is also an important question of lead time, or how long the population has between the first warning of an impending disaster and its arrival; this characteristic may play as important a role in risk perception for hazards as catastrophic potential or dread. Spatial uncertainty is another characteristic that may be more relevant for natural hazards than for human-made technologies: a devastating earthquake could occur anywhere in California, but hurricanes only pose very serious risk to populations living near the coast.

While we believe these considerations are important for future studies of natural hazards alone, the purpose of Study 1 was to test how hazards behave in the 9-characteristic risk framework that has been established as a way of understanding human perceptions of the risks of other types of potential dangers, like technologies and activities. With Study 1 confirming that this framework is useable—if not ideal—for examining natural hazards, in Study 2 we were able to show that there is a marked difference between the way that people consider natural hazards and climate change. The risk profiles for climate change and sea-level rise look almost identical to each other, but quite different from the natural hazards studied here, even those that, like hurricanes, heat waves, and floods, have causal connections or physical similarities to the climate-related items.

The next step to better understanding how humans understand both natural hazards and

climate change in the greater context of everyday dangers is to compare them directly. Studies 1 and 2 have demonstrated the efficacy of using Fischhoff et al.'s (1978) framework to compare these dangers to each other; the next step is to place both natural hazards and climate change into the context of the technologies and activities that were examined in Fischhoff and colleagues' original study and revisited in Fox-Glassman & Weber's recent replication (in preparation-a).

Chapter 3: Climate Change as a (not-so) Dread Risk

There are many ways to quantify the perceptions of risk that people have for activities, technologies, and hazards in their environment. One particularly useful framework for measuring and examining risk is the psychometric approach, which considers risk perception for an environmental hazard to be driven by reactions to a variety of different characteristics of the hazard, in addition to merely the number of people likely to be harmed or the economic losses caused by that hazard (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978; Slovic, Fischhoff, & Lichtenstein, 1986). Originally used to examine attitudes toward the risks and benefits of various technologies and everyday activities (such as nuclear power, pesticides, skiing, and air travel), this “expressed preferences” framework indicated that several different characteristics of risk (such as how controllable, voluntary, and catastrophic each risk is) tend to load onto two orthogonal factors: those of dread risk, and unknown risk.

Recent work has replicated and updated the original studies using this psychometric paradigm (Fox-Glassman & Weber, in preparation-a), and extended the paradigm into the domain of natural hazards and climate change (Fox-Glassman & Weber, in preparation-b). Taken separately, these results can illuminate some aspects of risk perception for technologies and for natural hazards, but given the relative nature of risk (Weber, 2004), the findings within the two domains cannot be directly compared. This study seeks to compare perceptions of risk—especially on the dread risk factor—for natural and manmade hazards relative to each other. It also examines the placement of two environmental hazards that have anthropogenic components but natural manifestations, climate change and sea-level rise, within this technology-hazard factor space.

Based on the results of the recent studies by Fox-Glassman & Weber (in preparation), we hypothesized that the natural hazards would not merely fall into the well-established technology risk space as if overlaid on a transparency, with some hazards falling at the extreme

high end of the dread scale and others at the low end. Instead, we expected that the strong dread characteristics of the natural hazards would provide those items with high-dread placements in the risk space and crowd the technologies and activities toward the lower-dread end of the scale.

While past work has shown that climate change and sea-level rise rank lower on dread and higher on the unknown factor than any of the natural hazards, and do not share similar risk profiles even with the hazards to which they are causally related (Fox-Glassman & Weber, in preparation-b), we did not have strong predictions about where these two items would rank compared with manmade technologies and activities. Although lower in dread than the natural hazards, might climate change and sea-level rise still outrank many manmade hazards on the dread dimension? Or would they remain very low in dread even when compared to technologies like food preservatives and bicycles? And finally, do climate change and sea-level rise show risk profiles that are as dissimilar to the manmade hazards as to the natural ones?

Method

Design

The procedures in this study were based closely on those used by Fischhoff et al. in their psychometric study of risk perception for everyday technologies and activities (1978). Participants first ranked a list of 30 items that included 12 of the same activities and technologies from the 1978 study, five new technologies, 11 natural hazards, climate change, and sea-level rise. They then judged the risk associated with each item on an open-ended scale that set the risk for their lowest-ranked item at a value of 10. The next section of the study asked Ps to judge whether the current risks from each item are unacceptably high, are presently acceptable, or could be higher; for answers of the former or the latter, Ps were prompted to judge how much lower the risk must be made, or how much higher the risk could be and still be acceptable—these values allow us to compute a “risk-adjustment factor.” Finally, Ps rated each of the 30 items on each of nine characteristics of risk, such as how controllable the risk is, or

how known the risk is to science.

The 30 items were chosen to represent the full extent of the dread-unknown risk space as set out in prior studies. The 12 technologies from Fischhoff et al. (1978) include three from each of the four quadrants of the dread-unknown space; the 11 natural hazards were selected similarly from Fox-Glassman & Weber's (in preparation) study examining risk perception for natural hazards relative to each other. Four of the five new items—cell phones, GMO foods, plastic food containers, and terrorism—were chosen for their relevance to modern society, and sharks were included because of their status as a quintessentially dreaded danger, yet one that poses very little actual risk to humans.

All participants saw the same stimuli, with the 30 items presented in a randomly shuffled order, except for one between-subjects difference: half of Ps ($N=42$) saw “climate change” as one of the items, while the other half ($N=49$) saw that same item listed as “global warming.” Recent work looking at the effects of local temperature deviations on beliefs about climate change showed no effect of terminology (“climate change” vs. “global warming”) on belief or concern about the phenomenon (Zaval, Keenan, Johnson, & Weber, 2014). However, based on work that has shown that “global warming” evokes more vivid mental imagery among some respondents (Schuldt & Roh, 2014), and the fact that psychological availability and emotional content can often contribute more strongly to risk perceptions than rational calculations (Lerner, Gonzalez, Small, & Fischhoff, 2003; Slovic, Finucane, Peters, & MacGregor, 2004), we hypothesized that “global warming” might evoke a more vivid response, leading to higher perceptions of dread risk than would the more scientific term “climate change.”

Participants

The 91 participants (Ps) were recruited and run through Amazon's Mechanical Turk in May of 2014. Mean completion time was about 90 minutes; mean age was 31.9 years ($SD=10.5$), and 75% of Ps had experienced between 2 and 9 of the 11 natural hazards included in this study (mean = 5.75).

Thirty percent of participants had completed a high-school diploma; 42% had completed a bachelor's degree, 20% had completed associates' degrees, 7% had master's degrees, and 1% had earned a professional degree. Politically, our sample skews left, with 49% identifying as liberal, 36% identifying as Independent, and 11% identifying as conservative.

Results

Perceived Risk & Risk-Adjustment Factor

Geometric means of the perceived risk for each of the 30 items were calculated separately for those Ps who saw the term "climate change" (CC) than for those who saw the term "global warming" (GW). The mean perceived risk is higher for GW (48.8) than for CC (36.1), but more striking is the fact that Ps who saw GW gave higher risk ratings for nearly every item. (The geometric mean for 28 of the items is higher in the GW condition by an average of 9.75 points on a scale where the lowest-risk item is assigned a 10, $t(29)=6.08$, $p<.001$.) This global difference in risk ratings is surprising, given that risk is typically judged relatively, such that a higher risk rating on one item should cause all of the others to decrease slightly (Hansen, Marx, & Weber, 2004). Despite the systematically higher risk ratings in the GW condition, the relative rankings of the 30 items remain very similar between the two conditions, with a rank-order correlation of $r(28)=0.96$, $p<.001$.

Although perceived risk differs between the groups who saw CC as opposed to GW, there is no difference between these groups on risk-adjustment factor (RAF): $t(29)=1.2$, $p=.235$.

Within each group, both for ratings of perceived risk and for RAF, there is extremely high interparticipant agreement. Kendall's coefficient of concordance for perceived risk is 0.92 and 0.90 for the CC and GW groups, respectively; the concordance for RAF is 0.92 and 0.88, respectively. These values indicate strong agreement among participants in the relative rankings of the 30 items in terms of both their level of risk, and the need (or lack thereof) for their risks to be reduced. The fact that the concordance is higher than for previous studies that used the same methodology and similar sample populations to study more homogeneous sets

of risk items (e.g., Fischhoff et al. 1978, Fox-Glassman & Weber, in preparation) suggests that participants might find it easier to rank risks from different domains relative to each other than to make fine distinctions within one domain. Although we do not have any qualitative responses from participants to support this explanation, it is notable that nine of the 11 natural hazards fall above the median for perceived risk; if hazards in general are considered higher risk than technologies in general, that could help explain why participants' risk ratings fall more closely in line with one another's.

With scores from the GW and CC groups pooled, the highest-risk items are handguns, tsunamis, terrorism, hurricanes, and smoking; the lowest-ranked items are plastic food containers, bicycles, cell phones, vaccinations, and food preservatives. Climate change/global warming ranks 14th highest in perceived risk, with sea-level rise close behind in 16th place. Although these two global-climate-related items sit squarely near the median for perceived risk, a high risk-adjustment factor places climate change/global warming as the fourth-lowest acceptable risk—only terrorism, GMO foods, and smoking are given lower acceptable risk levels than climate change. Sea-level rise has a slightly lower risk-adjustment factor, leaving its acceptable risk about twice as large as that of climate change, and placing it as the 10th lowest level of acceptable risk.

Perceived risk and RAF are highly correlated within both the GW and CC groups: $r_{GW}=0.79, p<.001$; $r_{CC}=0.67, p<.001$. In both cases, this relationship makes sense: the higher the perceived risk, the more Ps indicated that they believe the risk should be reduced.

Table 1. Mean judgments of risk for the 30 natural items, divided by participants who saw “climate change” (CC) and those who saw “global warming” (GW).

		Perceived risk		Risk Adjustment Factor (geometric mean)		Acceptable level of risk	
item		CC	GW	CC	GW	CC	GW
1	air travel	22.4	33.4	1.12	1.16	19.9	28.9
2	bicycles	14.8	19.7	0.86	0.85	17.3	23.1
3	electric power	17.7	23.0	0.93	1.18	19.0	19.5
4	food preservatives	20.1	17.9	2.36	1.37	8.5	13.1
5	football	20.7	23.8	1.27	1.48	16.2	16.1
6	handguns	67.4	83.1	6.29	7.84	10.7	10.6
7	motor vehicles	47.4	56.5	3.31	2.33	14.3	24.3
8	nuclear power	40.4	45.7	3.1	4.28	13.0	10.7
9	pesticides	26.8	33.3	1.63	1.7	16.5	19.7
10	skiing	19.9	25.1	1.09	1.11	18.3	22.5
11	smoking	57.4	72.6	13.37	17.69	4.3	4.1
12	vaccinations	18.5	16.6	1.06	0.73	17.6	22.6
13	blizzards	37.2	48.9	1.77	1.31	21.0	37.4
14	dust storms	28.5	28.7	1.55	0.87	18.3	33.1
15	earthquakes	53.3	69.5	3.91	3.33	13.7	20.9
16	floods	47.8	55.8	3.72	3.41	12.9	16.4
17	fog	18.1	23.3	0.87	1.1	20.7	21.3
18	hurricanes	53.5	78.4	5.71	4.09	9.4	19.2
19	landslides	45.5	55.5	3.41	2.63	13.3	21.1
20	sinkholes	30.9	37.5	1.93	1.79	16.0	21.0
21	tsunamis	58.5	79.9	6.62	6.42	8.8	12.5
22	volcanoes	39.2	61.1	2.29	1.72	17.1	35.5
23	wildfires	44.6	61.9	4.07	3.22	10.9	19.3
24	clim. change/global warming	36.1	48.8	5.26	6.53	6.9	7.5
25	sea-level rise	26.9	34.0	1.68	2.48	16.0	13.7
26	sharks	21.1	27.9	1.29	1.27	16.4	22.0
27	plastic food containers	15.5	15.9	1.34	1.13	11.6	14.1
28	cell phones	15.5	19.3	1.07	0.92	14.6	21.1
29	GMO foods	21.0	23.9	2.2	5.69	9.5	4.2
30	terrorism	49.1	87.4	5.75	14.17	8.5	6.2
mean:		33.86	43.61	3.03	3.46	14.04	18.71
Coefficient of Concordance		0.92	0.90	0.92	0.88		

Nine Characteristics of Risk

Participants rated each of the 30 items on the nine characteristics of risk (see Table 2) used by past psychometric studies of risk perception (e.g., Fischhoff et al. 1978, Fox-Glassman & Weber in preparation, Slovic 1987). The scores on these risk characteristics do not appear to

Table 2. Mean Ratings for Nine Characteristics of Risk.

	voluntariness 1 = voluntary	immediacy 1 = immediate	known to exposed 1 = known precisely	known to science 1 = known precisely	controllability 1 = un-controllable	newness 1 = new	chronic-catastrophic 1 = chronic	common-dread 1 = common	severity of consequences 1 = certain not to be fatal
air travel	1.73	1.79	2.16	2.12	3.83	4.46	5.10	3.16	4.91
bicycles	1.63	2.22	2.13	2.10	5.80	5.21	1.88	1.49	2.90
electric power	3.43	3.09	3.10	1.94	4.58	4.76	2.69	1.76	3.60
food preservatives	3.13	6.09	4.62	3.24	4.45	3.07	2.07	1.96	2.84
football	1.37	3.56	2.79	2.52	5.79	3.84	2.11	1.88	2.71
handguns	2.52	1.60	1.70	1.81	4.38	5.03	3.32	4.02	5.51
motor vehicles	1.86	1.86	1.83	1.82	4.90	4.70	3.06	2.02	4.44
nuclear power	4.28	4.40	3.38	2.15	2.96	3.71	4.90	4.27	4.98
pesticides	3.84	5.38	4.43	2.66	4.11	3.70	2.76	2.54	3.28
skiing	1.29	1.93	2.01	2.11	6.05	5.25	2.09	1.82	3.19
smoking	1.42	5.81	1.62	1.44	5.82	5.11	2.11	2.67	5.24
vaccinations	2.19	4.84	3.83	2.49	4.67	3.39	2.35	2.17	2.79
blizzards	6.23	2.21	2.53	1.79	2.72	6.58	5.85	4.64	4.49
dust storms	6.28	2.82	3.04	2.06	2.78	6.44	4.89	4.09	3.75
earthquakes	6.39	1.76	2.27	1.93	2.17	6.73	6.55	5.72	5.17
floods	6.24	1.91	2.39	1.83	2.53	6.64	6.43	5.05	4.99
fog	5.99	2.76	3.06	2.08	3.44	6.39	3.55	2.27	3.17
hurricanes	6.20	1.91	2.13	1.76	2.55	6.70	6.47	5.54	5.34
landslides	6.11	1.84	2.47	1.94	2.20	6.66	6.20	4.96	5.03
sinkholes	6.26	2.18	2.93	2.18	2.37	5.99	5.14	4.32	4.45
tsunamis	6.39	1.78	2.27	1.78	2.02	6.44	6.67	6.02	5.98
volcanoes	5.92	1.93	2.20	1.64	1.93	6.63	6.47	5.33	5.67
wildfires	5.93	1.99	2.29	1.89	2.61	6.45	5.84	5.12	4.82
CC / GW	5.21	5.94	4.21	2.80	2.88	2.94	4.29	3.84	3.80
sea-level rise	5.83	5.16	4.14	2.44	2.69	3.99	4.38	3.54	3.57
sharks	4.29	1.79	2.13	1.79	3.88	6.38	2.45	4.81	4.85
plastic food containers	2.20	6.02	4.53	3.14	4.99	2.94	2.20	1.75	2.40
cell phones	1.69	5.53	4.19	3.01	5.30	2.34	1.98	1.62	2.57
GMO foods	3.29	5.98	5.24	3.69	4.35	2.05	2.40	2.73	2.81
terrorism	5.88	1.99	2.93	2.98	2.11	3.96	5.74	6.51	5.81
mean	4.17	3.27	2.95	2.24	3.69	4.95	4.06	3.59	4.17
σ	1.93	1.67	0.98	0.54	1.30	1.48	1.73	1.52	1.09
coeff of concordance	0.62	0.55	0.29	0.17	0.39	0.54	0.53	0.48	0.43

differ systematically between the global-warming and climate-change groups: the mean difference across all nine risk characteristics and 30 items is 0.029 ($SD=0.31$) on a 7-point scale, with a median difference of 0.015. For the climate-change/global-warming item itself, the highest difference between the two conditions is 0.47, on the “newness” characteristic, with a mean difference across the nine characteristics of 0.001. Based on the similarity between the two groups’ ratings on the risk characteristics, and following Fischhoff et al. (1978), which used a similar between-subjects design, we pooled the two groups’ data for the remaining analyses.

Relationship of the nine risk characteristics with perceived risk, RAF, and acceptable risk. In a multiple linear regression model, perceived risk is predicted by voluntariness, controllability, catastrophic potential, and severity of consequences, such that perceived risk increases by: 11.9 points for every 1-point move toward involuntary, 21.7 points for every 1-point move toward controllable, 6.92 points for every 1-point move toward catastrophic, and 18.0 points for every 1-point move toward consequences being fatal. These relationships are all fairly straightforward, except perhaps the contribution of controllability, which might seem counterintuitive. However, this effect of controllability on perceived risk is similar to that seen in Fox-Glassman & Weber’s study of technologies and activities (in preparation), and likely reflects that fact that society has made a greater effort to find ways to control higher-risk technologies or hazards.

This study finds risk-adjustment factor (RAF) to be very effectively predicted by scores on several of the risk characteristics. A linear model predicting RAF by the nine risk characteristics suggests that people are more likely to judge that risks must be reduced for items that are involuntary, delayed, known precisely to the exposed, unknown to science, controllable, new, and certain to be fatal. It is slightly surprising that the two knowledge-based risk characteristics predict RAF changes in the opposite direction—precise knowledge by the exposed predicts lower RAF scores (indicating less adjustment needed), while precise knowledge by science predicts the same magnitude of change on RAF in a positive direction

(indicating more adjustment needed). It may be tempting to conclude from this pattern that people believe that good scientific understanding of a risk supports a collective effort toward its reduction, while awareness about that same risk among the public should lead to individuals taking action to remove themselves from exposure to the danger. However, given the fact that these two knowledge characteristics tend to track consistently in the same direction in previous studies using this same framework (Fischhoff et al., 1978, Fox-Glassman & Weber, in preparation, Slovic 1987), we are cautious about such an interpretation.

Acceptable risk, like perceived risk, is predicted by voluntariness, controllability, and severity of consequences (though unlike perceived risk, it is not predicted by scores on catastrophic potential). The model predicts that acceptable risk should increase by: 5.23 points for every 1-point increase in voluntariness; 8.04 points for every 1-point move toward uncontrollability, and 6.49 points for every 1-point move toward non-fatal consequences. This suggests that the most acceptable risks are those that are undertaken voluntarily, that are

Table 3. Linear models predicting perceived risk, RAF, and acceptable risk by scores on the nine risk characteristics. Note that for this analysis scores on the 9 characteristics were mean-centered, so the intercepts represent the perceived risk and benefit for a technology or activity that is “average” on all nine characteristics.

		perceived risk (β)	RAF (β)	acceptable risk (β)
intercept		38.7	3.19	16.2
voluntariness	1 = voluntary	11.9**	2.69***	-5.23**
immediacy	1 = immediate	2.18	2.04***	-2.36
known to exposed	1 = known precisely	-7.88	-4.57***	4.34
known to science	1 = known precisely	5.21	4.72**	-9.23
controllability	1 = uncontrollable	21.7*	4.58**	-8.04*
newness	1 = new	-7.15	-0.98**	2.46
chronic-catastrophic	1 = chronic	6.92*	0.28	-0.35
common-dread	1 = common	-0.57	-0.64	0.27
severity of consequences	1 = certain not fatal	18.0**	3.74***	-6.49*
<i>adjusted R²</i>		0.83	0.89	0.66

*p<.05; **p<.01

uncontrollable, and that are not likely to be fatal. As with perceived risk, the contribution of controllability may not seem intuitive, but this relationship between acceptable risk and uncontrollability may illustrate an acceptance of forces that we cannot change in our environment.

Factor Analysis of the 9 Risk Characteristics

A principle-components factor analysis provides a two-factor solution that fits the data quite well, with the two factors together explaining 88% of the variance (see Table 4). As in previous studies using this study design and analysis, applying a varimax rotation does not provide any improvement in interpretability, and so the results shown here are unrotated factor loadings. Here, the factor that corresponds roughly to the “unknown risk” factor identified by Fischhoff et al. (1978) appears to represent risks that are unknown to the exposed, unknown to science, uncontrollable, and involuntary. The primary differences between the unknown factor in this study and that in Fischhoff and colleagues’ original psychometric study of risk perception are a relatively smaller loading of the “immediate/delayed” characteristic, and an overall smaller proportion of the variance explained by the unknown factor overall. Fox-Glassman & Weber (in preparation) found a similar decrease in impact of the unknown factor in a direct replication of Fischhoff et al.’s 1978 study, and concluded that the risks for many of the 30 technologies and activities studied in those two papers have indeed become more known, controllable, and voluntary over the intervening decades, leaving the unknown factor with less variance to contend with.

The dread factor appears to have compensated for the decrease in the impact of the unknown factor, as here nearly every one of the risk characteristics loads quite strongly it. Here, the dread factor represents risks that are involuntary, immediate, known to the exposed and to science, uncontrollable, old, catastrophic, dreaded, and certain to be fatal.

Table 4. Factor Loadings for the nine risk characteristics

	voluntary	immediate	known (exposed)	known (science)	controllable	new	chronic	common	severe	λ (loadings)	proportion of variance accounted for
Factor 1 (unknown)	0.57	0.41	0.72	0.59	-0.60	-0.30	0.36	0.36	-0.05	2.08	0.23
Factor 2 (dread)	0.75	-0.78	-0.67	-0.72	-0.79	0.87	0.89	0.88	0.87	5.83	0.65
commonality	0.89	0.79	0.97	0.87	0.98	0.84	0.92	0.90	0.76		

The scores for each of the 30 items on each of the two factors can be mapped onto a two-dimensional factor space to help visualize the differences in the way people perceive the risk of various technologies, activities, and hazards. As Figure 1 illustrates, nearly all of the natural hazards rank more highly on the dread factor than any other item, with only sinkholes, dust storms, and fog falling below terrorism, the highest-dread of the man-made items. All of the natural hazards tend to cluster closely to the origin on the unknown axis, a distribution that is consistent with the findings of Fox-Glassman & Weber (in preparation), which showed that the unknown factor captures very little variance when applied solely to natural hazards.

Of the newly added items, the three technologies (GMO foods, plastic food containers, and cell phones) appear to be considered similarly to the old technological item of food preservatives: they rank among the lowest-dread items on the list, and all occupy the more unknown half of the factor space. GMO foods represent the most unknown of the 30 items, while cell phones rank much closer to the median rating on the unknown scale.

The other two new items, terrorism and sharks, fall at the other extreme of the dread scale: terrorism is considered more unknown and more dread than any other manmade item on the list, while sharks appear to be classified similarly to air travel and handguns, being moderately dread and fairly well known. Interestingly, the item that consistently represented the high-dread, high-unknown outlier in previous studies, nuclear power (Fischhoff et al, 1978, Fox-

Figure 1. Factor space for the perception of climate change and natural hazards in the context of common technologies and activities.

Glassman & Weber, in preparation, Slovic 1987), is here considered hardly more dread than the average item, and only moderately unknown. Consistent with previous studies showing that risk for an item is typically considered relative to its context (Hansen et al., 2004; Lichtenstein, Slovic, Fischhoff, Layman, & Combs, 1978; Slovic et al., 1986), adding several natural hazards, plus the highly available, very dreaded item of terrorism, appears to have driven nuclear power far down in terms of relative dread.

As seen in Fox-Glassman & Weber's examination of the relative risk perception for

climate change relative to natural hazards, here climate change/global warming and sea-level rise both fall much lower on the dread axis and higher on the unknown axis than any natural hazard. Among the technologies and activities, these two items fall in about the middle of the pack in terms of dread risk: they are both lower on dread than terrorism, handguns, air travel, nuclear power, and smoking, but higher on dread than food preservatives, pesticides, vaccinations, and recreational activities like bicycling, skiing, and football. On the unknown axis, on the other hand, climate change and sea-level rise sit among the most unknown items, trailing only GMO foods and, in the case of sea-level rise, also terrorism.

To get a better sense for what the location of climate change and sea-level rise in the risk factor space might mean, we can examine these items' profiles across the nine risk characteristics, and compare them with the profiles of other items. Figure 2a shows a marked difference between the two climate-related items and two natural hazards that are thought to be at least partially linked to climate change: floods and wildfires. Although the four items share similar ratings on the voluntary and controllable characteristics, climate change and sea-level rise both clearly deviate from the two natural hazards on the other seven characteristics.

Figure 2b shows that climate change and sea-level rise also have quite different profiles than the two items that share their high rank on the unknown factor: GMO foods and terrorism. This makes sense considering the relative strengths of loading of the two factors—most of nine risk characteristics load more strongly onto the dread factor than the unknown, so climate change can deviate from GMO foods and terrorism on many of the characteristics yet still share a similar rating on the unknown factor. If anything, it appears from the risk profile that the closeness of climate change and terrorism on the unknown factor is coincidental, while the similarity between risk perceptions for climate change and GMO foods may be more systematic (though still clearly distinct).

The technological risk items that appear to track most closely with climate change and sea-level rise are nuclear power and, to a lesser extent, pesticides (see Figure 2c). This pattern

suggests that the way people currently think about these two global-climate-related issues is much closer to the way we consider manmade risks like nuclear power than the way we think about natural processes like floods and wildfires—even though these natural hazards have much stronger causal connections with climate change than nuclear power does.

Figure 2 (next 3 pages). Profiles on the nine risk characteristics for climate change and sea-level rise, comparing them with (a) two natural hazards, (b) two new risk items, and (c) two more well-established technologies.

Figure 2 (a)

Figure 2 (b)

Figure 2 (c)

Multivariate Determination of Acceptable Risk Levels

While neither risk-adjustment factor nor acceptable level of risk is predicted by scores on the two risk factors, there is a relationship between perceived risk and the dread factor. In a linear model predicting perceived risk by scores on the dread and unknown factors, perceived risk increases by 5.49 points for every one-point jump on the dread scale ($p < .001$, adjusted $r^2 = 0.48$). This result is consistent with the trend toward recent psychometric studies of risk perception finding less of a contribution of the unknown factor (Fox-Glassman & Weber, in preparation a & b), and it suggests that any leverage in influencing people's perceptions of environmental risks—whether those risks arise from natural hazards or human-developed technologies—must come by influencing the level of dread risk associated with those items.

Conclusions

The primary purpose of this study was descriptive: to illustrate the differences in risk perception for several different types of potential environmental dangers that have previously not been examined side-by-side. Consistent with a lack of strong public support for measures to mitigate the effects of climate change, we find that global warming and sea-level rise are not considered among the highest-risk items from our list of 30—climate change is outranked on perceived risk by 13 other hazards and technologies, and sea-level rise falls even lower on the list of risks. Despite the perception among our subject population that climate change/global warming does not feel as risky as terrorism or handguns, we nevertheless see an attitude that the current level of climate-change risk is unacceptably high. The high risk-adjustment factor for climate change/global warming may indicate an awareness that even though we have not yet seen many deaths attributable to climate change, action must be taken to mitigate the risk going forward.

Placing both manmade and natural hazards in the same risk factor space allows us to examine people's relative perception for different types of environmental dangers. As expected,

the natural hazards cluster on the high-dread end of the dread-risk axis, eclipsing nearly all other items in the list. The only manmade threat that rivals natural hazards is terrorism, which has supplanted nuclear power as the high-dread, high-unknown outlier in the factor space. This shift makes intuitive sense: while nuclear power was a controversial, highly available topic in the 1970s and 1980s, today's news cycle is much more dominated by reports on terrorist groups and their attacks.

Although global climate change has also gotten a great deal of press in the past several years, global warming/climate change and sea-level rise fall at the very low end of the dread scale. This finding is consistent with the lack of urgency with which many US citizens view these hazards. Taken together with the fact that only the dread risk dimension (and not the unknown dimension) predicts perceived risk, the perception of climate change in this study is in line with the “risks as feelings” system of risk perception (Loewenstein, Weber, Hsee, & Welch, 2001, Slovic 2004). Despite our participants' rational awareness that the risks of sea-level rise and climate change need to be reduced, their intuitive ratings of these items indicate little of the vividness and feelings of danger that appear to come naturally when we think of environmental hazards like hurricanes and wildfires. Indeed, the profiles of climate change and sea-level rise across the nine risk characteristics indicate that people are thinking about them along much the same lines as they consider the manmade hazards of nuclear power or pesticides.

While this study limited its aspirations to the descriptive domain, its findings have promise for future prescriptive applications. Further work will be needed to test whether it is possible to use the relationship between dread and perceived risk to influence people's relative risk perceptions for climate change—for example, it may be possible to hitch the concept of sea-level rise to its causally linked, but much more dread, cousins like floods and wildfires, in order to increase climate change's dread-risk potential and help motivate action toward mitigation.

Chapter 4: Discussion & Conclusions

The primary purpose of the body of research described in the last three chapters was to better understand current attitudes toward risks of all types: technological, recreational, natural, and climate-related. To that end, we began by establishing the continuing validity and reliability of the results of the pioneering psychometric studies of perceived risk, designed and conducted by Fischhoff, Slovic, Liechtenstein, Read, and Combs in 1978.

The studies described in Chapter 1 laid a methodological foundation for this dissertation by showing not only that there is continued evidence for the hypotheses of the psychometric psychological risk dimension paradigm, but that it yields very similar results when implemented online using a sample of respondents recruited through Amazon's Mechanical Turk. The second set of studies, discussed in Chapter 2, tested whether the nine risk psychological risk dimensions identified by Fischhoff, et al. were useful measures in the context of natural hazards and climate change. Those studies indicated that although the psychometric risk perception study design does still work in the natural hazards space, some of those characteristics—primarily newness of the risk—are less relevant to a study of natural hazards on their own. However, the results of Study 2 that compared natural hazards with climate change and sea level rise, suggested that those two environmental risks are perceived quite differently from any of the natural hazards. Indeed, the study described in Chapter 3 compared risk perceptions of climate change and sea-level-rise with both natural and man-made risks, and found them to be most closely aligned with the latter. Throughout the studies in all three chapters, one clear trend was the predominance of the dread risk factor over the unknown risk factor: it explains more of the variance in the factor analyses of each risk domain and is a consistently stronger predictor of risk perception and acceptable risk level than the unknown factor is.

This final chapter will discuss the implications of the findings described in the earlier empirical chapters of this dissertation, both in terms of the practical conclusions they point to

with regard to the design of future studies and the real-world applications of their results, and in terms of the theoretical conclusions we can draw about the nature of dread risk: its potential cognitive mechanisms and its connection to current theory.

Practical Implications of This Work

In the Lab

It is striking to note just how replicable the original results of Fischhoff, et al. (1978) remain, even nearly four decades later. The results described in Chapter 1 include plenty of small deviations from those original 1978 results, of course, but the conclusions of both studies align closely, and even some of the more major differences between the two (e.g., the movement of nuclear power toward a lower value of dread risk and a much lower value of unknown risk as the technology has become safer and more common; the jump in unknown risk for high-school and college football mirroring an increased awareness that concussions are likely more dangerous than has been previously assumed) appear to illustrate actual trends in science and public perception over the last few decades.

The replicability of the results of the original implementation of a psychometric approach to perceived risk is all the more impressive when we consider the differences in methods used and populations sampled across the various studies. Fischhoff et al. (1978) used a pen-and-paper survey filled out by members of the Oregon League of Women Voters and their spouses: a population that is limited in terms of geography, age, and political affiliation. The replication described in Chapter 1 drew from a more diverse sample in terms of geography and age, though this Mechanical Turk (MTurk) population does tend to skew more politically liberal than the general United States population. Similar consistency in results was found in Chapter 2, between an MTurk population and a sample of Columbia University undergraduate students. This inter-sample reliability underscores the potential usefulness of this methodology in future studies seeking to compare the risk perceptions and attitudes of diverse populations.

While the current studies offer support for the replicability and reliability of the psychometric approach to risk perception developed by Fischhoff et al., they also highlight the limitations of this approach in its current form. Chief among those limitations is the selection of the nine risk characteristics. Chapter 2 shows that the current list of risk characteristics is likely not fully capturing the constructs of unknown and dread risk for studies of environmental hazards that go beyond technologies and human activities. For example, every natural hazard is rated nearly the same on “newness,” which makes that characteristic both confusing to participants, and of little use to researchers.

There are several candidates for risk characteristics that may be more relevant to a study that seeks to look solely at natural hazards. One characteristic that varies across different hazards and could very easily influence the perception of their risk is lead time. Some hazards, like earthquakes, can be forecast in very general terms (e.g., “there is a 60% chance of a magnitude 6.7 earthquake occurring in Southern California in the next 30 years) but offer essentially no warning once the event has begun; others, like hurricanes, come with several days’ warning. This difference in the perceived “suddenness” of a hazard’s onset may well contribute to a sense of risk and of dread. Similarly, the physical visibility of the hazard as it approaches (either in time or in space) may contribute to perceptions of risk. Wildfires and hurricanes, once they have begun, are easily seen both on satellite images and looming on the horizon, whereas debris flows and flash floods are essentially invisible until the moment they threaten a community. As discussed in Chapter 2, natural hazards can also be compared along the dimension of how much energy they dissipate over a certain amount of time—i.e., how “violent” the disaster event appears. Volcanoes and earthquakes tend to release huge amounts of energy over relatively short time periods, while droughts or sea-level rise manifest their effects gradually over long time courses. Any or all of these additional characteristics of natural hazard risk and their effect on risk magnitude perceptions and acceptability could be valuable to

assess in future studies; these other characteristics may load onto the existing dread risk factor, but they may also comprise a distinct risk factor that is unique to natural hazards.

In the Field

This dissertation also has implications for real-world applications of risk perception research. The dread risk factor consistently predicts risk perception for environmental risks better than the unknown risk factor does, a fact that could help those trying to improve mitigation, preparedness, evacuation rates, and other real-world behaviors. Although a great deal of effort has gone into attempting to make hazards like climate change feel more certain and more known to the public, the results of this body of work suggest that a more effective way of influencing the public's perception of the risks of climate change would be to focus on the dread risk factor, rather than the unknown factor.

Another entry point for more effective risk communication is the connection between climate change and increased frequency or intensity of natural hazards. Although climate change and sea-level rise both appear to have a low inherent value of dread risk, both of these hazards can be legitimately connected with some of the natural disasters that invoke high levels of dread risk. For example, the public might be more receptive to discussions of the dangers of climate change if messaging is focused on the effects that climate change may have on heat wave frequency or hurricane severity (Coumou & Rahmstorf, 2012).

Theoretical Implications of This Work

The Centrality of Dread Risk

In the current slate of studies, the dread risk factor consistently captured more variance in risk perceptions than the unknown risk factor, and dread risk in nearly every case does a better job of predicting perceived risk, risk-adjustment factor, and acceptable risk level than does unknown risk (or any other variable, including experience). This centrality of the dread risk factor is one of the notable differences between the replication study in Chapter 1 and the 1978 Fischhoff et al. study that found uncertainty (=unknown risk?) to be the stronger of the two risk

factors. As discussed in Chapter 1, one reason for dread risk eclipsing unknown risk may simply be that more is known today about environmental risks than was known four decades ago: the risks for the items studied really are less unknown at an absolute level than they once were. However, the consistent strength of the dread risk factor across every study discussed in the preceding chapters points to the importance of dread in its own right, and the potential value in better understanding the mechanisms that underlie it.

Cognitive Mechanisms Behind Dread Risk

One theoretical question that these results bring up is what exactly determines feelings of dread? As defined by the factor analysis, dread is a construct that encompasses involuntariness, immediacy, uncontrollability, catastrophic effects, and fatal consequences. But what factors influence the intuitive feeling of dread (which these studies attempt to measure using the common-dread risk characteristic, which is explained to participants as a risk “that people have great dread for—on the level of a gut reaction”)?

Construal level theory would suggest that the consequences of an environmental risk would seem more immediate, and be the least discounted, the more concrete they are (Trope & Liberman, 2010). This theory could help explain why the natural hazards tend to capture so much more dread risk than some of the technological hazards like food preservatives or pesticides: the consequences of even the least dread natural hazard are still more concrete—more easily imaginable, more vivid—than the effects of most technological hazards. For example, fog is a phenomenon that may not be frightening on a “gut” level, but is nevertheless very easy to picture and is therefore considered more dread than the potential dangers posed by food preservatives, which are abstract: microscopic molecules best pictured as esoteric chemical diagrams.

Other theories in cognitive psychology also support the idea that concreteness or vividness contribute to perceived risk. When making judgments about the frequency of an event, we often rely on the availability heuristic, conflating the probability of an event with the ease with

which examples can be brought to mind (Tversky & Kahneman, 1973). Since the availability of examples is influenced by their vividness (Reyes, Thompson, & Bower, 1980), we would expect that more vivid environmental risks would be more psychologically available, and thus judged as more frequent, and therefore considered more risky.

Taken together, availability and construal level theory could help to explain why hazards like climate change and sea-level rise are rated so low on the dread scale. Climate change is a broad term that encompasses a range of effects: it describes a much more general, less concrete situation than earthquakes or airplane crashes. Similarly, the effects of climate change are hard to imagine in any vivid way—what does a gradual warming of the oceans look like, and how would a two-degree rise in temperature feel? Even the most scientifically specific information about climate change is typically presented in terms of averages across time or space, or ranges in temperature. This abstractness, and lack of vividness of its impacts, would tend to make climate change feel psychologically distant and not particularly available—and therefore not very dread. Further study is needed to confirm whether making climate change more concrete or vivid can in fact influence ratings of dread, but it is suggestive that the slightly more concrete and visualizable concept of sea-level rise was rated as generating more dread than climate change in both studies in which it appeared (see Chapters 2 and 3).

The theory of constructed preference (Lichtenstein & Slovic, 2006) could also prove important for a fuller understanding of the cognitive correlates of dread risk. The consensus in cognitive psychology is that in most cases, preferences and judgments are constructed in real time at the time of decision, rather than being stored and retrieved intact (Weber & Johnson 2006). By this theory, each time a person is asked to make a risk judgment about climate change, he would draw on not only the information in front of him at the moment, but also on memories of past experiences that the question brings up. Availability plays a role here as well: the more available a concept, the more easily it and its associations can be recalled. So if

evidence that climate change poses a real risk is either psychologically unavailable, or otherwise hard to recall, the constructed judgment of level of dread might well be quite low. This hypothesis would also explain why experience with natural hazards appears to play a role in assessment of dread risk: more rich or vivid personal experience, in the form of episodic memory, is one way to enhance accuracy of recall for information (Herbert & Burt, 2004; Tulving, 1985).

One way to test the hypothesis that episodic memory influences dread risk ratings might be very simply to measure reaction times. Presumably, a longer delay in bringing up relevant knowledge and memories about a certain environmental risk would indicate a more laborious recall process. Hazards whose effects are highly available and easy to recall should therefore be rated more quickly on the characteristics of dread risk than those items which are less vivid or for which participants have less familiarity. Of course, such an approach makes assumptions about the cognitive process at work during judgments of risk. One way to gain more insight into that process, and potentially confirm an account of availability driving risk perceptions, would be to use a “think-aloud”-type task. Studies of Query Theory have successfully used an online thought-listing design (essentially, a type-aloud task) to illuminate some of the process behind theories as diverse as the endowment effect and temporal discounting (Johnson, Häubl, & Keinan, 2007; Weber et al., 2007). A similar design to those used in successful Query Theory studies could be employed similarly to investigate the thought process behind risk judgments of the type studied in this dissertation.

The Relativity of Risk Perception

The studies described in this dissertation add support to the theory that risk is a concept that can most easily be considered—and therefore, should be studied—in relative terms: risky, compared to what? (Weber, 2004; Weber, Shafir, & Blais, 2004). The researchers who established the psychometric paradigm showed in numerous follow-up studies that both

perceived risk and ratings of dread and unknown risk for a particular item will vary depending on what other items are being rated in the same study (see, e.g., Slovic, Fischhoff, & Lichtenstein, 1985 & 1986; Slovic, 1987). For example, asking about nuclear power in the context of several minor risks will result in much higher risk ratings, and much more dread, than asking about nuclear power alongside nuclear weapons and nuclear waste. The relativity of risk can be seen in the current slate of studies in the extent to which nuclear power loses its status as the high-dread outlier as soon as other high-dread items are added to the study: in Chapter 3, the addition of terrorism and the set of 11 natural hazards has drawn away so much of the available dread from nuclear power that it lies almost at the origin of the risk factor space—a dramatic shift from its placement even in Chapter 1’s direct replication of the Fischhoff et al. (1978) study of technologies and activities.

This shift in nuclear power’s status on the dread scale as a result of adding other, more or more newly alarming risks to the list is also consistent with the idea of the “finite pool of worry” posed by Hansen, Marx, & Weber (2004) and Weber (2006). The finite nature of this “pool” means that increasing a person’s worry about any one concern (e.g., climate change) will necessarily come at the expense of a current concern or concerns (e.g., money troubles). This theory would suggest that the ratings for climate change and sea-level rise might look very different if assessed in a study that did not include any natural hazards at all. Chapter 3’s results show clearly that climate change is considered to hold less dread than natural hazards, but if people’s everyday thoughts do not tend to include most natural hazards, it might be a more ecologically valid question to ask how people think about climate change in the context of just the more common risks (i.e., just technologies and activities). It may well be that when considered alongside everyday technologies like cell phones, pesticides, and GMO foods, but in the absence of natural hazards, climate change could look like a relatively high-dread risk.

Future Directions for this Research

One of the chief weaknesses of the current series of studies is the limited nature of the samples of respondents. Even though results appear to replicate quite well across three diverse subject populations, none is a truly nationally representative sample. Given the potentially controversial nature of some of the environmental risks asked about (climate change, handguns, vaccinations), it seems possible that demographic variables such as political affiliation will influence risk perceptions for certain items. Certainly the affect heuristic would predict that participants who enter the study with more favorable attitudes toward certain items would be likely to rate their risks as lower, and their benefits as higher, than would participants with negative attitudes about those items (Finucane, Alhakami, Slovic, & Johnson, 2000). While none of the studies discussed in the preceding chapters showed any statistically significant effects of political affiliation, a larger follow-up study would have greater power to detect such effects. Such a larger study could also reveal whether people assign climate change different ratings on the dread and unknown scales based on other individual differences, such as membership in one of the “six Americas” demographics categories distinguished by Maibach, Roser-Renouf, and Leiserowitz (2009).

Larger-scale follow-up studies could also help to identify potential cross-cultural variations in risk perception. It seems likely that such differences exist; previous studies using the Domain-Specific Risk-Taking Scale (Blais & Weber, 2006) have identified national differences in risk attitude and risk taking (see, e.g., Breuer, Kollath, Salzmann, & Von Nitzsch, 2013; Johnson, Wilke, & Weber, 2004). A large-scale version of the study described in Chapter 3 could identify national variations in which environmental risks are considered high dread. For example, genetically modified (GMO) foods appear to invoke very little dread in an American population (this item ranks in the bottom three on the dread scale; see Figure 1 in Chapter 3), but in Europe, where GMO products are much more stringently legislated against, they may well rank much higher on dread. But while evidence for this sort of national difference would be informative, it could be equally interesting to identify the types of environmental risks that tend

not to vary across cultures. If, for example, a large-scale study focused on natural hazards found similar patterns of dread risk perception to those in Chapter 2 across several geographic and cultural divides, such a result could indicate that there are fundamental ways that humans think about natural phenomena in their environment.

In addition to testing cultural differences, future studies should also attempt to recruit larger samples in order to get a clearer look at the effects of personal experience on dread risk perception. The results discussed in Chapter 2 indicate that although experience with natural hazards does not appear to directly predict perceived risk, controlling for the effect of experience substantially improves the model predicting perceived risk by scores on the dread factor. Those results suggest that a more complicated relationship exists between experience and risk perception than could be explained by that study alone. Future studies should aim to recruit enough participants so that the construct of natural hazard experience can be assessed more specifically than it was in the two studies described in Chapter 2, where “experience” was calculated by the number of natural hazards experienced, rather than on a hazard-by-hazard basis. With a large enough sample, it should be possible to assess the effects of hazard-specific experience on the perception of risk for some of the more commonly experienced hazards (e.g., hurricanes, blizzards, earthquakes). Such a study could also look into questions of whether experience has an effect on dread via ratings on the “known to the exposed” risk characteristic.

Future studies would also do well to measure reaction times for as many variables as is feasible in the online setup. As discussed above, reaction times for ratings of various environmental risks could serve as a proxy for familiarity with those risks, and could help to get at some of the cognitive mechanisms that underlie the dread risk factor. Studies collecting process data, perhaps in the form of thought listings, could likewise provide some insight into these cognitive and affective mechanisms.

Finally, any studies that are specific to one domain of environmental risk, such as those that look at only natural hazards, will need to first establish which risk characteristics to include

in the factor analysis. As discussed above, the nine risk characteristics that were developed by Fischhoff et al. 1978 and were used throughout the studies that make up this dissertation have been shown to be very useful for assessing technological and recreational risks, and for comparing these types of risks to those posed by natural hazards. However, those nine characteristics fall short when used solely to assess attitudes toward hazards. Before any hazard-specific research can be begun, preliminary work must be done to validate a modified set of risk characteristics for use in such studies. This new slate of characteristics will likely omit “newness” and add several new items, perhaps along the lines of “suddenness,” “visibility,” and “violence,” as discussed above.

As with most empirical research, the studies discussed in the preceding three chapters of this dissertation have raised many more questions than they have answered. The future work suggested here represents the beginning of a much larger investigation into the constructs of dread and unknown risk and their effects on perceptions and acceptability of a broad range of risks, and into understanding how the new knowledge produced here can best be applied in real-world settings.

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Appendix for Chapter 1

Table A1 (next page). Mean ratings for nine characteristics of risk for the current study (columns marked 2013), compared with Fischhoff et al., 1978 (columns marked 1978). The final two columns show the difference in risk-adjustment factor (RAF) and acceptable level of risk ratings between the current study and the 1978 data; for these calculations, responses of the Ps who first rated risks and who first rated benefits have been averaged.

Activity or technology	Perceived benefit		Perceived risk		RAF 2013		RAF 1978		Acc. level of risk 2013		Acc. level of risk 1978		RAF ave. diff (2013-1978)	Acceptable level of risk ave. diff (2013-1978)
	2013	1978	2013	1978	Risk Ps	Bene Ps	Risk Ps	Bene Ps	Risk Ps	Bene Ps	Risk Ps	Bene Ps		
alcoholic beverages	20	41	39	161	1	1	4.7	4.2	39	39	34	38	-3	3
bicycles	36	82	20	65	1.6	1.1	1.6	1.4	13	18	41	46	0	-28
commercial aviation	51	130	34	52	0.7	0.8	1.2	1.4	46	42	43	37	-1	4
contraceptives	50	113	17	50	1.8	1.5	2.1	1.9	10	12	24	26	0	-14
electric power	86	274	33	52	1.1	1.2	1.2	0.9	31	29	43	58	0	-21
fire fighting	59	178	56	92	1.4	1.6	1.2	1	40	35	77	92	0	-47
food coloring	17	16	17	31	3	2.8	2.7	3.4	6	6	11	9	0	-4
food preservatives	41	44	17	36	1.1	1.4	2.6	2.8	15	12	14	13	-1	0
general aviation	41	53	37	114	2.5	2.2	2.3	1.8	15	16	50	63	0	-41
handguns	26	14	77	220	1.1	1	17.1	17.5	68	74	13	13	-16	58
H.S./college football	22	35	25	37	0.9	1	1.8	1.6	28	26	21	23	-1	5
home appliances	42	133	19	25	0.9	1.2	1.1	1	23	16	23	25	0	-5
hunting	26	30	41	82	1.1	0.9	2.9	2.1	36	43	28	39	-2	6
large construction	55	142	38	91	2.7	1.5	2	1.4	14	25	46	65	0	-36
motorcycles	27	29	48	176	1.9	2	5.1	5.5	25	23	35	32	-3	-9
motor vehicles	60	28	50	68	7.9	4.7	7.3	4.9	6	11	34	50	0	-34
mountain climbing	21	52	42	250	2.3	3.6	1.1	0.9	18	12	62	76	2	-54
nuclear power	58	87	64	105	2.5	2.7	32.2	25.9	26	24	8	10	-26	16
pesticides	32	30	31	29	0.7	1.1	10.5	8.5	45	30	10	12	-9	26
power mowers	27	178	30	111	0.9	1.5	1.7	1.3	32	19	17	22	0	6
police work	61	185	54	37	12.4	14.7	2.3	1.3	4	4	48	85	12	-62
prescription rx	62	209	20	30	2.3	1.5	1.4	1.2	9	13	21	25	1	-12
railroads	61	38	35	45	0.9	1.1	1.4	1.1	38	33	26	34	0	5
skiing	21	20	29	189	12.1	7.1	1.1	1	2	4	41	45	9	-40
smoking	13	17	56	73	1	1.3	15.2	15.3	59	45	12	12	-14	40
spray cans	18	164	23	104	1.8	1.8	8.6	6.9	13	13	8	11	-6	3
surgery	75	68	45	52	3.4	2.6	2.2	1.6	13	17	47	65	1	-41
swimming	27	194	22	17	0.7	0.9	1.2	0.9	29	25	43	58	0	-24
vaccinations	70	187	20	247	1.6	1.9	1	0.7	12	11	17	24	1	-9
X-rays	44	156	20	45	0.8	1.1	2.1	1.3	24	19	21	35	-1	-7
mean	42.4	69	30.3	69	1.6	2.7	2.7	2.2						
Coeff. of Concord.	0.5	0.77	0.37	0.5	0.28	0.21	0.5	0.5						

Correlations with perceived risk and benefit. Ratings of perceived risk and benefit correlate with some, but not all, of the nine scales. Perceived benefit correlates strongly ($p < .001$) with voluntariness ($r = .61$), and moderately ($p < .005$) with uncontrollability ($r = .51$). (Note that this positive correlation with “uncontrollable” is equivalent to the negative correlation with “controllable” listed in Table 3. Throughout this section, we will describe correlations as positive, related to the listed endpoint of the scale.) While none of the nine scales showed significant relationships (at the $\alpha = .001$ level) with perceived benefit in Fischhoff and colleagues’ original study, the voluntary and control scales had the strongest correlations, in the same direction as seen here.

For perceived risk, we found significant ($p < .001$) and strong correlations with knowledge of science and of those exposed ($r = .60$ and $r = .61$, respectively), with dread ($r = .60$), and with consequences certain to be fatal ($r = .77$). Here, again, we see more significant relationships than in Fischhoff et al.’s 1978 paper: there, perceived risk was only correlated significantly with dread and consequences certain to be fatal.

Correlations with RAF and acceptable risk. None of the nine characteristics predicts risk-adjustment factor scores, which is not surprising considering our finding that RAF is no longer correlated with perceived risk. For acceptable risk, only the voluntariness characteristic correlates significantly: the more involuntary the risk, the higher the acceptable risk level.

Table A2. Correlations between 9 risk characteristics and perceived risk and benefit.

		perceived benefit	perceived risk
voluntariness	1 = <i>voluntary</i>	0.61**	-0.03
immediacy	1 = <i>immediate</i>	-0.05	-0.48
known to exposed	1 = <i>known precisely</i>	0.22	-0.61**
known to science	1 = <i>known precisely</i>	0.05	-0.60**
controllability	1 = <i>uncontrollable</i>	-0.51*	-0.06
newness	1 = <i>new</i>	-0.27	0.24
chronic-catastrophic	1 = <i>chronic</i>	0.31	0.41
common-dread	1 = <i>common</i>	0.21	0.60**
severity of consequences	1 = <i>certain not fatal</i>	0.04	0.77**

* $p < .005$; ** $p < .001$

Table A3. Correlations between 9 risk characteristics and risk-adjustment factor and acceptable risk.

		RAF	acceptable risk
voluntariness	1 = <i>voluntary</i>	-0.02	0.65**
immediacy	1 = <i>immediate</i>	-0.22	-0.02
known to exposed	1 = <i>known precisely</i>	-0.13	-0.08
known to science	1 = <i>known precisely</i>	-0.29	-0.18
controllability	1 = <i>uncontrollable</i>	-0.24	-0.37
newness	1 = <i>new</i>	-0.08	-0.41
chronic-catastrophic	1 = <i>chronic</i>	-0.05	0.11
common-dread	1 = <i>common</i>	0.15	0.27
severity of consequences	1 = <i>certain not fatal</i>	-0.06	0.28

* $p < .005$; ** $p < .001$

Appendix for Chapter 3

Method

The design of this study was based on the psychometric framework for risk perception first set out Fischhoff et al. (1978). The online version of this task was tested in several prior studies by Fox-Glassman & Weber (in preparation a & b).

Design

Ps evaluated 30 items (activities, technologies, natural hazards, and other environmental hazards) on multiple dimensions: (1) the item's perceived benefit [risk] to society; (2) the acceptability of the item's current level of risk; and (3) its placement on each of nine dimensions of risk. The 30 items were chosen as described in the main paper; the full list can be seen in Table 1. For each task in the study, the 30 items appeared in a randomly generated order.

Ps were given this message before they began their evaluations:

The following surveys will ask you to consider a list of 30 activities, technologies, and hazards that are part of modern life for many people. While some of the 30 items involve potential benefits to society, all of them also come with potential risks. You will be asked to make judgments, in a variety of formats, about these 30 activities, technologies, and hazards. This is a difficult, if not impossible, task. Nevertheless, it is not unlike the task you face when you vote on legislation—one never has all the relevant information; ambiguities and uncertainties abound, yet some judgment must be made. The present task should be approached in the same spirit.

Ps were then asked to list the one or two primary dangers inherent to each item—for example, for hurricanes Ps mentioned dangers like “drowning” or “being hit by wind-blown objects.”

Tasks

1. Perceived Risk. Participants were asked to consider the “the risks of the activities, technologies, and hazards listed below. Consider the risk of death or serious injury as a

consequence of each item. For example, motor vehicles carry the risk of crashes, and a hurricane poses the risk of drowning or being struck by wind-driven objects.” Ps were instructed that:

Your job is to assess the gross risks, not the net risks which remain after the benefits are subtracted out. Do not consider any benefits associated with these items. For example, living near the coast may come with the benefits of increased property values, pleasant weather, or recreation opportunities, but you should not consider these benefits when judging the risk of hurricanes or tsunamis, or other coastal hazards. Your job is to assess the gross risks, not the net risks which remain after the benefits are subtracted out.

Remember that a hazard or technology affecting few people will have less gross risk than one that affects many people. If you need to think of a time period during which the risks accrue, think of a whole year—the total risk to society from each item during one year..

Ps were instructed to first “study each activity or technology individually, thinking of all the risks of each.” Then Ps were asked to place the 30 items in order of increasing risk by clicking on each of the 30 items to move it into their ranked list. Ps could adjust the list until they felt it accurately reflected their judgments of risk. Once this had been done, Ps were asked to assign a numerical value for the perceived risks of each item, with the least risky (the first item on their list) assigned the value of 10, and other items judged relative to that. Ps were encouraged to take their time on this portion of the task, and given detailed instructions about how to assign values:

If you feel that an item is twice as risky as the least beneficial item, assign it a 20. This means that a rating of 12 indicates that the item is 1.2 times as risky as the least risky item (this means it is 20% more risky). A rating of 200 means that the item is 20 times as risky as the least risky item, to which you assigned a 10. Please take some time on this question, and double-check your ratings to make sure that they are consistent. For example, if one activity is rated a 50 and a second is rated 100, the second item should seem twice as risky

as the first. Adjust the numbers until you feel that they are right for you.

2. Risk Adjustment Factor. After judging the risks of the 30 items, all Ps were asked to decide for each item “whether the associated risks are either too high, at an acceptable level, or too low.” Ps were told that:

Almost any activity, technology, or hazard carries some amount of risk, but this is not the ideal risk. Ideally, the risks should be zero. The acceptable level is a level that is “good enough,” where “good enough” means you think that the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity. For example, we can make drugs “safer” by restricting their potency; or cars can be made safer at a cost, by improving their construction or requiring regular safety inspection. We may, or may not, feel restrictions are necessary. If an item’s present level of risk is acceptable, no special action need be taken to increase its safety. If its riskiness is unacceptably high, serious action, such as legislation to restrict its practice, should be taken. On the other hand, there may be some activities or technologies that you believe are currently safer than the acceptable level of risk. For those items, the risk of death could be higher than it is now before society would have to take serious action.

For each item, Ps had to choose among “(a) Could be riskier,” or “(b) It is presently acceptable,” or “(c) Too risky.” If (a) was selected, an additional question would appear on the screen, asking the P to fill in the blank in the statement “It would be acceptable if it were _____ times riskier.” If (c) was selected, the P instead saw the question “To be acceptable, it would have to be _____ times safer.” If (b) was selected, no additional questions would appear, and the P would move on to judging the risks of the next item. As piloting revealed this task to be taxing, the 30 items in this section appeared in blocks of 6 items on 5 separate pages, allowing Ps to take a short break between blocks if they wished.

3. Characteristics of Risk. In the final section, Ps were asked to judge each item on each of nine scales representing different characteristics of risk. Each characteristic, measured on a

seven-point scale, was assessed for all 30 items before moving on to the next characteristic.

The order and wording of the nine scales used closely matched those used in the original 1978 study by Fischhoff et al.:

1. How Voluntary is the Risk? For the items listed below, please indicate whether you think people take on the potential risks voluntarily. If for a particular item some of the risks are voluntarily undertaken and some are not, choose an appropriate rating toward the center of the scale. (1 = voluntary, 7 = involuntary)
2. How Immediate is the Risk? For the items listed below, to what extent is the risk of death or injury immediate—or is death or injury likely to occur at some later time? (1 = immediate, 7 = delayed)
3. Knowledge About Risk: For the items listed below, to what extent are the risks known precisely by the persons who are exposed to those risks? (1 = known precisely, 7 = not known)
4. Scientific Knowledge About Risk: For the items listed below, to what extent are the risks known to science? (1 = known precisely, 7 = not known)
5. Control Over Risk: If you are exposed to the risk of each item listed below, to what extent can you, by personal skill or diligence, avoid death or serious injury while engaging in the activity? (1 = uncontrollable, 7 = controllable)
6. Newness of Risk: For the items listed below, are the risks new and novel ones, or old and familiar ones? (1 = new, 7 = old)
7. Chronic vs. Catastrophic Risk: For the items listed below, is it a risk that kills people one at a time (a chronic risk, meaning the risk is continual over time) or a risk that kills large numbers of people at once (a catastrophic risk)? (1 = chronic, 7 = catastrophic)
8. Common Risk vs. Dread Risk: Is each of the items listed below a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for—on the level of a gut reaction? (1 = common, 7 = dread)

9. Severity of Consequences: And finally, when the risk of each item is realized in the form of a mishap or illness, how likely is it that the consequences will be fatal? (1 = certain not to be fatal, 7 = certain to be fatal)

After completing these three parts of the study, Ps were given the Berlin Numeracy Scale (including the 3-question Cognitive Reflection Task) and a basic demographic survey. They then indicated which of the natural hazards covered in the study they had had personal experience with, and received debriefing information. Ps were paid \$3 for participation in the study.