IN Psychological Perspectives on Justice:
Theory and Applications, B. Mellers & J. Baron (eds.)
Cambridge: Cambridge Univ. Press, 1993

#18

14 Fairness of distribution of risks with applications to Antarctica

Ivy E. Broder and L. Robin Keller

In this chapter we consider distributional fairness issues in decision making regarding health, safety, and environmental risks in Antarctica. Alternative safety improvements or operating procedures can result in different risk distributions among different groups of individuals at risk in Antarctica. We describe some of the risk trade-offs involved in balancing safety and environmental concerns. The focus of the chapter is on the insights for modeling fairness gained by examining the potential application of models incorporating fairness to Antarctic policymaking. Illustrative examples of alternative Antarctic policies are used to motivate the discussion of the implications for fairness modeling.

Decision analysts have recently been investigating ways to incorporate equity considerations into preference functions for guiding decision making about policy issues involving substantial risks to humans or the environment. Most of this work has been at the foundational level, with a focus on the mathematical models that can incorporate preferences for equity (see, e.g., Fishburn, 1984; Fishburn & Sarin, 1991; Fishburn & Straffin, 1989; Harvey, 1985a,b; Keller & Sarin, 1988; Keeney, 1980a,b,c; Keeney & Winkler, 1985; and Sarin, 1985 and in this book). This stream of work uses the

term *equity* to refer in general to the *fairness* of the distribution of risks, with or without added information on the distribution of benefits, effort, and so on. Related work by psychologists uses the terms "equality" when outcomes are equally balanced and "equity" when deserved outcomes are balanced with inputs such as effort. (See Harris 1976, 1980, and in this book; Walster, Walster, & Berscheid, 1978.) We hope that this chapter and Sarin (this book) will stimulate fruitful merging of the decision analytic and psychological streams of research on equity. A key purpose of decision analytic equity modeling is to develop models that can be operationalized to aid in choosing between alternative policy options.

A number of features of health, safety, and environmental risks in Antarctica make it interesting as an application arena for examining the equity models that have been proposed. Historically, the primary focus of the U.S. Antarctica Program (USAP) was on the substantial scientific benefits of Antarctica as an international location for important research and exploration. Recently, however, the issues of health, safety, and environmental risks have been receiving increasing attention. In 1988, a detailed report, *Safety in Antarctica*, was prepared by a blue-ribbon panel of experts following a year-long review of the United States' facilities in Antarctica, which are managed by the National Science Foundation (NSF). The report made many procedural and policy recommendations. The U.S. Congress, which directs the funding of the USAP through NSF, has been particularly concerned about the process of managing the safety and environmental risks in Antarctica, mirroring the concerns of the public or at least the concerns of certain interest groups. Attitudes toward catastrophic risks and perceived fairness of risk distributions may play a role in the public concern about Antarctica.

In USAP operations, there are many affected groups with overlapping memberships: military personnel, civilian contractors, scientists, NSF personnel, workers from different countries, tourists, environmental activists, and others. Under alternative regulatory and management policies, different distributions of risks could result among the different groups.

The harsh and remote physical environment in Antarctica, along with limited financial resources, places tight constraints on operations. Severe weather, communication difficulties, and limited availability of medical and other health and safety personnel and resources combine to make Antarctic operations relatively high in health and safety risks. Thus, trade-offs must be made between short-term health and safety risks and long-term environmental risks in Antarctic operations, because NSF must allocate financial and other resources between these short-term and long-term management issues. This chapter is a first attempt to apply methods of decision analysis to risk trade-offs in Antarctica. Although environmental concerns are an important component of the public policy debate, this application of equity models will focus on health and safety risks.

Work on this chapter was done while both authors were serving as program directors at the National Science Foundation; Keller was with the Decision, Risk, and Management Science Program and Broder was with the Economics Program. As part of our National Science Foundation service, we participated on an NSF task force on health and safety in Antarctica. We thank Deh-I Hsiung and Gary Staffo of the NSF's U.S. Antarctica Program for their help in supplying background information on Antarctica. We also appreciate helpful comments on an earlier version of the manuscript by volume editor Barbara Mellers, Colin Camerer, and Richard Harris. Broder also thanks American University for providing sabbatical support. Keller's work on equity has been partly supported (prior to joining NSF) under NSF grant SES-8721423 to Duke University from the Decision, Risk, and Management Science Program. The views expressed in this chapter are entirely the authors' and do not necessarily reflect the views of the National Science Foundation.

Background on Antarctica

The continent of Antarctica contains 10% of the world's land mass (approximately the size of the United States and Mexico combined) and 70% of its fresh water. In addition to the scientific stations of 24 countries, Antarctica is home to 33 million seals, 75 million penguins, 80 million seabirds, 700 million tons of krill, and half a million whales. The USAP runs three year-round stations as well as remote field operations and refueling facilities during the austral summer (late October through late January). McMurdo is the largest of the three stations in both the number of personnel (about 1,150 during the November peak) and the number of structures (about 100). Projects are also carried out or supported from ships (*Research Vehicle (R/V) Polar Duke* or icebreakers). The South Pole Station is at an elevation of 9,500 feet and is built on ice and snow. The peak personnel load is about 100 people, with only about 15 to 20 who stay the entire winter. There are only about a dozen buildings at the site, which is supplied by ski-equipped aircraft during the austral summer. Palmer Station is the smallest of the three permanent stations, with a peak of about 40 people during the summer and a correspondingly small number of structures. It is accessible by ship year-round.

Health and safety risks

The cruel and distant environment of Antarctica poses some obvious risks to the people who work in and visit the area. Between 1946 and 1987, there were 29 incidents involving fatalities of U.S. Antarctic personnel, resulting in 52 deaths. There have also been more than 300 fatalities among tourists in the area during the past dozen years.

Air safety. Air operations pose the single most significant risk to workers and tourists alike in Antarctica. Since 1946, there have been 10 fatal airplane accidents involving USAP personnel, which led to 32 deaths. The largest single accident was in 1966, when 6 people died after an aircraft crashed during a landing approach. More recently, this risk appears to have been reduced, there having been only one fatal crash since 1969. It occurred in late 1987, when two people on a salvage mission died after a crash during a landing approach. However, a far greater number of tourists have died as a result of airplane crashes – in fact, all of the tourist fatalities mentioned were the result of airplane crashes. Quite recently, another catastrophic incident occurred when a tourist expedition bound for Antarctica crashed in Chile on February 14, 1991, with a loss of 19 lives (*Washington Post*, 1991).

Several factors have been identified as leading to a possible reduction in the risk of airline travel: more modern radar equipment, landing on "blue ice" areas, increased training requirements, additional airline operation resources, increased air refueling capability and modernization of the aircraft fleet. Increased air operations are necessary to reduce the risks in other arenas of Antarctica's operations. Therefore, the risk of air operations plays a central role in the overall risk levels in Antarctica, as well as the distribution of those risks among different groups of people.

Health and medical care. The difficult environmental conditions in Antarctica pose physical and mental health risks to personnel. Suggestions of ways to reduce health risks among U.S. personnel include increasing the number and training of medical staff, regular inspections and upgrading of medical facilities, blood storage, expanded survival training, improved materials for clothing, better preassignment psychological screening, substance abuse instruction, and increased recreational facilities. A more physically and mentally fit community would make fewer mistakes, lowering the risks of field operations.

Communications. When remote scientific field parties are in operation, they are completely reliant on high-frequency radio for communication with their home stations. Sometimes, these parties travel as far as a thousand miles away. All distant operations are required to check in on a daily basis, and search and rescue operations will automatically begin if a communication is missed. However, atmospheric disruptions occur and there are frequent equipment breakdowns. Better equipment maintenance and equipment modernization could lead to improved communications networks with remote field parties. This would reduce the risks to such operations, as rescue teams could be deployed more quickly.

Environmental risks

Human activity produces many by-products that must be disposed of. The very existence of a scientific mission necessarily has an effect on the environment of Antarctica. Any venture produces solid waste, such as scrap metal, chemicals, batteries, combustibles (including paper and wood products, oils, experimental animal carcasses, plastics, and rubber products) and liquid waste (such as human waste, garbage and laundry effluents, and photographic liquids), and other debris. Given the frigid temperatures, almost nothing is degradable and the accumulation of debris is thought to be unsightly. Waste will remain if it is not hauled away to the United States (retrograded). Sewage and other liquid waste is discharged into McMurdo Sound after treatment, and some combustible materials are burned, which discharges pollutants into the air. Antarctica's land and water areas are enormous, with a corresponding absorptive capacity. So, it is unknown what the risks to the environment might be and the corresponding impact on USAP personnel or the natural habitat of wildlife, although a simple modeling exercise done by NSF suggests that the air quality meets or far exceeds U.S. National Ambient Air Quality Standards (see draft *Supplemental Environmental Impact Statement*, 1990, sec. 5.2.1.2.).

Balancing environmental and health and safety risks

It should be clear from the discussion so far in this section that there is a trade-off between reducing the health and safety risks to the people who live and visit Antarctica and reducing the risks to the environment of Antarctica. The solution to reducing many of the health and safety risks cited involves increasing the personnel at the NSF stations, increasing the safety of aircraft operations, building more facilities, and so on. But with the additional activity would come additional waste products. On the other side of the coin, Congress has reacted to increased pressure from environmentalists to attend to the problems in Antarctica.

One option for decreasing environmental impacts is to streamline personnel, which could lead to increased health and safety risks for workers and tourists alike. Having fewer medical personnel would increase the risk of fatality in medical emergencies (such as the onset of a heart attack, stroke, or other life-threatening illness among workers and visitors). Having fewer flights into and out of the region would result in a smaller total risk of death from an airline crash and lower environmental impacts, but would lead to a greater risk to health and safety from more limited supplies. Having fewer search and rescue team personnel, safety, recreation, or communication specialists could also jeopardize the safety of workers and tourists, as described earlier. Assuming that the scientific mission requires a minimum number of individuals to support the experimentation and observations that are conducted in Antarctica, the reduction in personnel would necessarily come from support staff.

Trade-offs also occur when a resource allocation decision is made about risks in Antarctica. In this case, Congress actually made such a decision when it made its fiscal year 1990 appropriation: Of an estimated $8.21 million for Antarctica's health and environmental programs, $5 million was specifically allocated to the environment. The majority of the funds spent on the environment were targeted to wastewater and solid waste management, clean-up of old research sites, and the purchase of additional fuel tanks and hoses to lower the risk of fuel spills.

Tourists

In 1989 approximately 3,000 tourists visited Antarctica, generating about $1.3 billion for the travel industry, with projections of further annual increases in those numbers. Arrival to the area is by air (military and commercial) and by sea. Costs for these visits range from $1,500 for three days to $70,000 for a seven-week cross country ski trip to the South Pole (Bly, 1989; Slater & Basch, 1991). This price range suggests that the typical tourist to Antarctica is from a high-income household and certainly adventurous. Chile was the first country (and at this point still the only one) to open a hotel on the continent, at its Teniente Marsh Station.

Most tourists expect to be able to visit the scientific station of their country. There is great variation in the degree of "welcome" received at the installations of different countries, with the United States being among the less receptive. Although a traveler's code suggesting appropriate behavior toward wildlife and the environment has been developed and distributed to tour companies, there is anxiety among NSF officials as well as environmentalists about a potential explosion in tourism in the area: NSF is concerned about its role in any potential emergency rescue operation and environmentalists worry about the disruption to wildlife and the environment.

Equity in safety trade-offs

Worker safety versus environmental impacts

Congress has authorized that the NSF direct a Safety, Environment, and Health (SEH) Initiative with a $150 million budget over a five-year period (*Antarctica Journal of the United States*, 1989; Booth, 1990). In this time of severe fiscal constraints, these expenditures loom large and clearly compete with other domestic programs that address the health and environmental needs in the United States. Despite a potentially large budgetary appropriation, dollar estimates are not available for many of the major or marginal changes considered for the SEH Initiative in Antarctica. Because much of the money allocated so far under the initiative has been spent on studies and surveys, it is not feasible in this chapter for us to quantitatively identify any actual management decisions and analyze potential trade-offs. However, four alternatives were considered in the December 1990 draft *Supplemental Environmental Impact Statement for the USAP* (pp. 3–17). The alternative recommended by the agency involves completing the five-year SEH initiative begun in fiscal year 1990, applying U.S. environmental laws and regulations to the U.S. presence in Antarctica, and consolidating USAP activities leading to a reduction in support personnel in Antarctica. The report suggests that there might be a 20% to 24% support staff reduction at McMurdo Station. Although streamlining of redundant personnel could lead to improved safety and health by allowing other support staff to service a smaller number of people, the current Antarctic health and safety system's reliability may have been enhanced by retaining usually redundant staff for occasional emergency periods. Also, the additional science and support operations during the winter could pose additional safety and health risks: riskier flight operations, more difficult search and rescue operations, more difficult emergency medical evacuations, and so on. Also, a forgone option would be increasing the support staff to lower medical risks, provide more effective rescue operations, better mental health through expanded recreation facilities, and so on.

The obvious equity challenge here involves increased safety and health risks (an increased risk of death) to clearly identified individuals who are operating in a dangerous and harsh environment to provide benefits to society (from scientific research) weighed against the reduced risks of degradation to the environment with unknown (and probably low) benefits that would accrue to a small proportion of the wildlife in Antarctica.

A major oil spill in 1989 provides an example of a catastrophic event in Antarctica. On January 28, 1989, the *Bahia Paraiso*, an Argentine tourist and resupply ship, ran aground and broke up, spilling more than 150,000 gallons of fuel. The ship was leaving Arthur Harbor near Palmer Station after a sightseeing visit on shore for the 81 tourists aboard. Wildlife fatalities and breeding failures followed the spill, and several scientific studies were imperiled by the change in the baseline data that occurred because of it. The costs of the spill included a $2 million cleanup, with financial and labor resources diverted from other missions, and a scientific mission with a team of 15 scientists assigned to continue with studies to determine the environmental impact of the spill (Noblet, 1989).

This background provides a focus for a qualitative discussion of equity and risk trade-offs between the environment and human health and safety. It is possible to lower the risks of a fuel spill in Antarctica by (1) building more safeguards into the storage tanks, and (2) decreasing the fuel supply by having lower reserves or by having fewer people at the stations (and therefore having lower fuel requirements). Any of these alternatives might increase the risk to worker safety and therefore pose an equity issue that would require weighing worker against environmental concerns: Different types of storage tanks would be costly (diverting resources from other programs) and would need to be transported to Antarctica; having lower reserves would jeopardize operations if there were a major catastrophe and a portion of the lower reserves were lost (operations might have to close down completely); and having fewer people at the stations would pose the risks described above.

Tourists versus workers

Consider the following two views on Antarctic tourism:

1. The USAP is supported by the taxpayers of the United States. Most of the tourists visiting Antarctica are U.S. taxpayers. Therefore, tourists have a right to visit Antarctica and the U.S. research stations located there.
2. Science has a very short season in Antarctica. The cost of doing science is very high because of the support, materials, and personnel necessary to conduct research in the remote and harsh environment. Diverting time and resources away from scientific research to mollify tourists could be crippling to the research efforts and detrimental to the fragile environment of Antarctica.

These two views reflect the extreme positions regarding tourism and the USAP. Concerns expressed by influential Americans about their poor treatment at USAP stations have prompted a great deal of discussion of the trade-offs involved in allowing tourists in the area. One of these trade-offs involves the equity issue of potential risk exposures in a voluntary setting. There have been four catastrophic events involving tourists in the past dozen years: the crash of an Air New Zealand plane in 1979, killing 279 people; a 1986 tourist plane crash killing 10; the 1991 crash killing 19 tourists; and the *Bahia Paraiso* oil spill in 1989. Therefore, a potential emergency involving tourists is not just a theoretical possibility, and the risks have been increasing as the number of tourists has been increasing. Although tourists presumably understand that travel to Antarctica entails risks to personal safety and those risks are undertaken voluntarily, potential spillover risks are not internalized by the tourists or tour operators. If a tourist expedition is caught in an emergency, the USAP is typically called upon for assistance. This has the effect of not only diverting resources from the scientific program, but also putting at additional risk any personnel who may be involved in a search and rescue operation. Of course, emergencies are likely to occur during extreme weather, when other failures at the USAP stations are also likely to happen.

The *Bahia Paraiso* breakup, which occurred after a tourist visit, is a good example of the enormous resources that may have to be devoted to a tourist emergency. Another incident involving U.S. emergency teams brings out the vulnerability of U.S. support personnel during multiple emergencies. In January 1990 two members of the Indian expedition to Antarctica, in separate incidents, suffered medical emergencies at the same time: The first experienced a severe heart attack and a second suffered a duodenal ulcer and needed immediate evacuation. A request for help was immediately issued to the USAP, despite the fact that the Indian station is located 2,000 miles away from that of the United States. This situation points out the high likelihood of multiple emergencies, especially given the large number of tourists visiting the area (*Hindustan Times*, 1990).

Distributional equity

This section presents models that can represent the fairness of the distributions of risks across groups of people in Antarctica. Such models can take into account the possibility and impact of multiple emergencies at once, using joint probability distributions over mortality or morbidity outcomes. We use the models to compare the fairness of two hypothetical scenarios for Antarctic operations. Such models might be used to help clarify a societal decision maker's thinking about alternatives. The selection of relevant groupings of people would be made by the decision maker, given the decision context and input from members of affected groups.

Fishburn and Sarin (1991) classify distributional equity concepts by the level of specificity in data required to measure each equity notion. See also Sarin (this book) for an overview of equity concepts. For simplicity, assume each person can either live or die, with known probabilities. *Individual risk equity* is modeled using each person's probability of death. Since these are probabilities before an accident or exposure event occurs, this is also called ex ante equity (see, e.g., Keller & Sarin, 1988). Experimental subjects queried by Keller and Sarin preferred an equal distribution of a 1% ex ante chance of death for each of 10 rescuers (attempting to save trapped miners) resulting from each being stationed in a possible cave-in location for 1 hour over an option in which 1 miner would be stationed in the cave-in location for an entire 10-hour shift, with a resulting 10% chance of death. In light of such preferences, Antarctic operating procedures for searches and rescues could be examined for options for spreading risks among workers.

The remaining equity categories require the classification of individuals into mutually exclusive groups. *Group risk equity* is modeled using the probability that an outcome will occur in which a *specific* number of group members die. Because the focus is now on the outcome of an accident or exposure, this is also called ex post equity. Sometimes, there is concern for the distribution of deaths within an outcome. For example, if there is a possible outcome with 100 deaths at an Antarctica Station, they could be distributed as 100 scientists or 100 support staff or some combination dying. In this outcome, there may be concern for the ex post equity of the distribution between the groups.

Sarin (1985), Keeney and Winkler (1985), and Keller and Sarin (1988) offer examples of related models to incorporate measures of individual risk equity and group risk equity into a preference model for guiding decision making on policies involving societal risks. These multiple-attribute preference models are defined over three attributes: ex ante (individual risk) equity, ex post (group risk) equity, and the total number of fatalities. In these models, a utility function is defined over the number of fatalities in the population, to represent preferences. Such preferences might include some equity concerns, such as avoidance of a catastrophe for the entire society. Fishburn and Sarin (1991) note that the probability distribution over the number of fatalities can be used as a datum to directly model *social outcome equity*. They also introduce a modeling approach for *dispersive equity*, which requires information on the joint probability of outcomes with specific numbers of people dying in each group.

In Antarctica, tourists, rescue workers, and other Antarctic workers are three groups who may have different patterns of exposures to risks. If an air crash of a tourist flight occurs, Antarctic safety personnel will attempt a rescue, but with some risks to themselves. Also, given current resource levels, diversion of personnel efforts for health and safety maintenance are quite costly to the ongoing scientific operations.

Table 1 *Scenarios 1 and 2*

Scenario 1: Status quo

		Groups		
Mutually exclusive states	Prob.	Tourists $N_1 = 3{,}000$	Rescuers $N_2 = 50$	Others $N_3 = 950$
Fatal crash of tourist plane				
Rescuer dies.	.050	100	1	0
No rescuers die.	.100	100	0	0
Fatal emergency occurs in Antarctic operations				
Rescuers and others die.	.110	0	2	5
No rescuers die.	.165	0	0	11
No deaths	.575	0	0	0

Scenario 2: Streamlining option

		Groups		
Mutually exclusive states	Prob.	Tourists $N_1 = 3{,}000$	Rescuers $N_2 = 50$	Others $N_3 = 900$
Fatal crash of tourist plane				
Rescuer dies.	.050	100	1	0
No rescuers die.	.100	100	0	0
Fatal emergency occurs in Antarctic operations				
Rescuers and others die.	.150	0	2	5
No rescuers die.	.200	0	0	10
No deaths	.500	0	0	0

Note: Entries in table are number of deaths in each group in each state.

To illustrate the application of the various equity measures, we developed the two stylized scenarios in Table 1, with a quantification of risks that bears some resemblance to the risks and exposures in Antarctica: Scenarios 1 and 2, respectively, show the status quo and the changes that could result under the streamlining plan proposed in the draft *Supplemental Environmental Impact Statement* of the USAP. Under Scenario 2, the number of Antarctic (nonrescue) workers is decreased, so fewer people are exposed to risks in Antarctica, but there will be fewer people available to aid safety and maintenance operations. So, risks may increase for the fewer people who are there. For example, the risk of workers dying from a fire or other effects of poor maintenance may be increased, if there is a decline in maintenance on the aging USAP dormitories. Such a disaster occurred at the Indian station, where four people died in the men's dormitory of suspected carbon monoxide poisoning from a diesel generator (*Hindustan Times*, 1990).[1]

We constructed Scenario 1 to have ex ante probabilities of death over a one-year period for tourists, rescue workers, and other workers to be of the same magnitude as the actual risks. A tourist's risk is estimated by noting that there have been 3 crashes in about 600 round-trip flights (over 20 years), which is a 3/600 = .005 probability that the tourist's round-trip flight will crash and (nearly) all on board will die. So if each tourist takes only one trip, the individual probability of death due to a crash would be about .005. Other workers' risk is estimated from the information that there have been about 50 deaths since 1946, with roughly 20,000 worker-exposures (on a seasonal rather than annual basis), giving an ex ante probability of death of .0025. We assume rescue workers face a little more than double the risk faced by other workers, modeled in this example with a .0054 probability of death. We used these ex ante probabilities for the simple five-state example in Table 1 to construct compatible probabilities for the five states. In Scenario 1, representing the status quo, the expected number of fatalities is 17.635 in one year, which is close to the actual average number of tourist and worker fatalities over the years. The streamlining option in Scenario 2 reflects higher ex ante risks to workers and rescuers, but the risk to tourists remains the same. The expected number of fatalities in Scenario 2 is 18.100, representing almost one expected death more per each two-year period. In the following subsections, various equity measures are calculated and compared for both scenarios.

Individual risk (ex ante) inequity

Fishburn and Sarin (1991) outline desired properties of equity models and give suggestions of functional forms satisfying certain properties. They suggest the following measure of individual risk inequity, where subscript *I* represents individual inequity, which neutralizes the effect of differences in expected numbers of fatalities:

$$d_I(m_1, m_2, \ldots, m_N) = \sum_{i=1}^{N} (m_i/\bar{m} - 1)^2.$$

If each individual i had probability of death $m_i = 0$, the formula would require division by zero, so in this special case $d_I(0, 0, \ldots, 0)$ is defined to be 0, with no disutility or inequity. Higher numbers indicate more inequity.

For this example, d_I(Scenario 1) = 236.5. For Scenario 2, in comparison with Scenario 1, the ex ante probability of death (a) remains at .005 for each of the 3,000 tourists, (b) increases from .0054 to .0070 for each of the 50 rescuers, and (c) increases from .0025 to .0031 for the 900 other workers (which is 50 fewer workers than in Scenario 1). These changes result in Scenario 2 being more individually risk equitable, with d_I(Scenario 2) = 138.8, which is roughly 60% of the d_I value for Scenario 1. This decrease is primarily due to the smaller difference in the ex ante probabilities of the two heavily weighted large groups in Scenario 2 (a range from .0031 for other workers to .0050 for tourists) compared with Scenario 1 (a wider range from .0025 to .0050).

Group risk (ex post) inequity

Two components of group risk inequity have been distinguished by Fishburn and Sarin (1991), intergroup and within-group inequity. They suggest modeling *nonuniformity of expected fatality rates across groups* by

$$d_G{}^1(\text{Scenario}) = \sum_{j=1}^{n} (r_j - \bar{r})^2,$$

where

r_j = expected fatality rate for group j,

$\bar{r}$ = mean group fatality rate = $\sum_{j=1}^{n=3} r_j/n$, and

the subscript G represents group risk inequity.

This measure is calculated for Scenario 1 with the following information:

	N_j	Expected fatalities	r_j
Tourists	3,000	.05(100) + .1(100) = 15.00	15/3,000 = .0050
Rescue workers	50	.05(1) + .11(2) = .27	.27/50 = .0054
Other workers	950	.11(7) + .165(11) = 2.59	2.59/950 = .0025
			Mean group fatality rate $\bar{r}$ = .0043

So $d_G{}^1$ is 4.98×10^{-6} for Scenario 1 and 7.78×10^{-6} for Scenario 2. Thus, Scenario 2 is less group risk equitable in the sense of having less uniformity of expected fatality rates across groups, with r_j values ranging from .0031 to .0070 rather than the narrower range from .0025 to .0054 for Scenario 1.

Note that in this simple example, the ex ante probability of death is the same for each person in a group, so the expected fatality rate r_j for a group is the same as the ex ante probability of death for one group member. Scenario 2 is more inequitable with respect to the individual risk inequity measure (which uses each person's ex ante probability, weighing each person equally and thus larger groups more heavily) but Scenario 1 is more inequitable with respect to the measure of the nonuniformity of expected fatality rates across groups, which weighs each group equally.

Groups' sizes will usually vary, requiring a choice between using the *number* of fatalities in a group or the *proportion* of a group's population dying. The fatality rate is used in this $d_G{}^1$ measure of intergroup risk inequity. So, if 15 of 3,000 tourists die, this is represented not as the absolute number who die, but as a rate of 15/3000 = .005 dying in the group. But when judging the fairness or acceptability of risk distributions, the public may sometimes focus more on the absolute number dying (weighing groups equally) rather than focusing on the fraction of the group dying. Then, equalization of the numbers dying across groups may be seen as most fair.

Fishburn and Sarin (1991) suggest that *within-group risk inequity* can be modeled as follows, assuming preference for common fates. In this formula, it is seen as fairer for people in a group to have identical outcomes:

$$d_G{}^2(\text{Scenario}) = +\sum_{j=1}^{n}\sum_{k=0}^{N} p_j(k)k(N_j-k)/(N_j^2),$$

where $p_j(k)$ = probability of k deaths in group j; N_j = population size of group j, assumed to be all even numbers; and n = number of groups. Higher numbers are more inequitable. The positive sign in front of the double summation is for the common-fate form of the measure; a negative sign would be for the catastrophe-avoiding version. Note that in the catastrophe-avoiding form, a common fate of 0 deaths in a group of 10 contributes $-k(N_j-k)/(N_j^2) = -0(10-0)/100 = 0$ to the calculation, which is less equitable than 1 death, which contributes $-9/100 = -.09$ to the calculation.

For Scenario 1, $d_G{}^2 = .0125$ and for Scenario 2, $d_G{}^2 = .0146$. So, streamlining (Scenario 2) is more inequitable in the common-fate preference form of within group inequity, due to a combination of factors. Each component of the calculation, corresponding to one group and one state, is $k(N_j-k)/N_j{}^2$, which is weighted by the probability. So, increasing the probability of the outcome that 2 rescuers and 5 other workers die from .11 to .15, and increasing the probability of the outcome when only other workers die from .165 to .200 (despite one less worker dying in that outcome), makes Scenario 2 more inequitable. Also, streamlining the number of other workers from the status quo of 950 to 900 in Scenario 2, and keeping the same numbers of deaths (0, 5, or 11), makes the components corresponding to the other worker group bigger and thus less equitable: 5 deaths out of 950 people is more equitable $[5(950-5)/950^2 = .005235]$ than 5 deaths out of 900 people $[5(900-5)/900^2 = .005525]$.

Note that, in the catastrophe-avoidance form of the model, a catastrophe is the loss of nearly all of a group's population. The impact of a catastrophe is represented by the product of the number of fatalities times the number of survivors in the entire group. When this product is small, as in when almost all die, this model yields high inequity, since the sign is negative and higher numbers represent more inequity. The model yields minimum inequity when exactly half the population dies, since the product of number of deaths times number of survivors is maximized.

However, in the case of airplane crashes, all travelers in one plane may die, but the entire population of travelers won't die. The layperson still tends to call such an outcome a catastrophe and react to the event as a horrible, upsetting disaster. So, a modification of the measure might be made to account for the modal size of a catastrophic event. For this example, such a modification might treat any number of deaths from the modal amount M_j to the total population size as equally onerous, by replacing $k(N_j-k)$ with $M_j(N_j-M_j)$ for all $k > M_j$, and using the common fate preference version (with the positive sign). Then the maximum product, indicating *maximum* inequity, would occur at any number of deaths k equal to the catastrophic modal amount of deaths M_j or larger.

Finally, a possible measure of *total group risk inequity* could combine the intergroup and within group inequity measures. One possible combined measure would calculate the weighted average,

$$d_G(\text{Scenario 1}) = c_1 d_G{}^1(\text{Sc. 1}) + c_2 d_G{}^2(\text{Sc. 1}),$$

where c_1 and c_2 are positive scaling constants.

Social outcome inequity

Social outcome inequity can be modeled, assuming common-fate preference, by

$$d_s(\text{Scenario}) = +\sum_{y=0}^{N} y(N-y)p(y),$$

where $p(y)$ = probability of y fatalities in the total population of size N (see Fishburn & Sarin, 1991). Opposite orderings would be obtained with the catastrophe-avoiding form, with a negative sign before the summation. For Scenario 1, $d_s = 69004.6$, and Scenario 2 has greater inequity from the social outcome measure with $d_s = 69957.6$. Scenario 2's worse performance is due to the increase from .11 to .15 in the probability of 7 rescue and other workers dying, and to the increase from .165 to .200 in the probability of only nonrescue workers dying, despite the decrease from 11 to 10 worker deaths.

A summary comparison of the various equity measures for both scenarios shows that changing group size and changing risks affected the relative inequities between scenarios. Note that these equity measures can be modified by dividing by a constant to avoid numbers being close to zero. Since the purpose is to compare across scenarios, the relative numerical values are of more importance than the absolute numbers. As shown in Table 2, Scenario 2's streamlining option is less individually risk inequitable than Scenario 1 (the status quo), but more intergroup risk inequitable, more within-group inequitable, more social outcome inequitable, and more dis-

Table 2 *Summary of equity measures for scenarios*

	Scenario 1	Scenario 2
Expected number of fatalities	17.635	18.100
Inequity measures		
Individual risk inequity d_I	236.5*	138.8
Group risk inequity		
Intergroup d_G^1	.00000498	.00000778*
Within-group d_G^2	.0125	.0146*
Social outcome inequity d_S	69004.6	69957.6*
Dispersive inequity d_D	.00022	.00026*

*Larger numbers are more inequitable and are indicated by asterisks.

persive inequitable. (Dispersive equity modeling is discussed in the next section.) So, although streamlining results in a more equal distribution of individuals' ex ante probabilities of death, from the view of different groups, it is less fair than the status quo. In addition, streamlining results in a higher expected number of fatalities. The U.S. Antarctica Program is considering streamlining of personnel numbers to decrease risks to the environment. But an unintended outcome of streamlining may be to worsen the distribution of risks among groups of individuals at risk in Antarctica, so careful consideration of the trade-offs between risks to the environment and risks to humans must occur.

Equity measures are one component in decision making about risks in Antarctica. They can aid in selecting among alternative policy options. Hypothetical scenarios similar to the ones here can be used to help create new policies with more fair distributions of risks, by identifying variables that affect fairness.

Overlapping memberships

Although the equity models discussed in the preceding section assume mutually exclusive groups, meaningful classifications of people are not always mutually exclusive. For example, people may be described by their membership in non–mutually exclusive classifications defined by gender and by role. We can define four mutually exclusive groups from the two classifications of males versus females and Antarctica workers versus tourists. Equity models generally treat the mutually exclusive groups equally, perhaps adjusting for size of the group, but not considering varying interactions among different sets of groups.

The best way to model dispersive equity for classifications meaningful to people that span multiple mutually exclusive groups is an open research question. Sarin (this book) provides a motivating example, shown in Table 3, adapted here for the Antarctica context. This simple example has just four people, one in each of the four groups of government-employed scientists, nongovernment scientists, government-employed support staff, and nongovernment support staff. In both Scenarios A and B, each person has an equal 50% chance of death, so the scenarios are equitable with respect to individual risk equity. However, Scenario A leads to an inequitable distribution of risks by government-employment classification, but an equitable distribution by role. Scenario B leads to an equitable distribution of risks by both government classification and role. Over all four groups, both scenarios lead to the same level of dispersive inequity.

Table 3 *Dispersive equity with interrelated groups*

Scenario A:	50% chance of outcome 1	50% chance of outcome 2	Prob. of death
Government scientist	Dies (1)	Lives (0)	.5
Nongovernment scientist	Lives (0)	Dies (1)	.5
Government support staff	Dies (1)	Lives (0)	.5
Nongovernment support staff	Lives (0)	Dies (1)	.5
Summary			*Expected dispersive inequity*
Over all 4 groups	$d^1_{\text{outcome 1}} = 1$	$d^1_{\text{outcome 2}} = 1$	Inequitable $d_D = 1$
By government/nongovernment	Both gov't die $d^1_g = 1/2$	Both nongov't die $d^1_g = 1/2$	Inequitable $d_{Dg} = 1/2$
By role	1 of each dies $d^1_r = 0$	1 of each dies $d^1_r = 0$	Equitable $d_{Dr} = 0$
Scenario B:	50% chance of outcome 1	50% chance of outcome 2	Prob. of death
Government scientist	Dies (1)	Lives (0)	.5
Nongovernment scientist	Lives (0)	Dies (1)	.5
Government support staff	Lives (0)	Dies (1)	.5
Nongovernment support staff	Dies (1)	Lives (0)	.5
Summary			*Expected dispersive inequity*
Over all 4 groups	$d^1_{\text{outcome 1}} = 1$	$d^1_{\text{outcome 2}} = 1$	Inequitable $d_D = 1$
By government/nongovernment	1 of each dies $d^1_g = 0$	1 of each dies $d^1_g = 0$	Equitable $d_{Dg} = 0$
By role	1 of each dies $d^1_r = 0$	1 of each dies $d^1_r = 0$	Equitable $d_{Dr} = 0$

Fishburn and Sarin (1991) suggest a possible measure for *dispersive inequity*,

$$d^1(y)\sum_{j=1}^{n}(x_j-\bar{x})^2.$$

The fatality vector $y=(y_1, \ldots, y_j, \ldots, y_n)$ lists the number of fatalities in each of the n groups that would result with one specific outcome. The proportional fatality vector $x=(x_1, \ldots, x_n)=(y_1/N_1, \ldots, y_n/N_n)$ adjusts the number of fatalities y_j in each group j by the group size N_j. So, this measure of dispersive inequity, $d^1(y)$, sums the squared differences between the fatality rate x_j in each group and the mean fatality rate,

$$\bar{x}=\sum_{j=1}^{n}(y_j/N_j)/n=\left(\sum_{j=1}^{n}x_j\right)/n.$$

For outcome 1 in Scenario A, the fatality vector y is (1, 0, 1, 0). The proportional fatality vector x is (1/1, 0/1, 1/1, 0/1) = (1, 0, 1, 0), since each group j has size $N_j=1$. The mean group fatality rate is $\bar{x}=(1+0+1+0)/4=1/2$. So, the dispersive inequity of outcome 1 over all four groups can be measured by $d^1_{\text{outcome 1}}(1,0,1,0)=1$. Higher numbers indicate greater inequity.

The dispersive inequity with respect to government-employment classification is

$$d_g{}^1{}_{\text{outcome 1}}(\text{2/2 gov't workers die, 0/2 nongov't die})=1/2.$$

The dispersive inequity with respect to role is

$$d_r{}^1{}_{\text{outcome 1}}(\text{1/2 scientists die, 1/2 support workers die})=0.$$

So outcome 1 is dispersive equitable with respect to role, but not government classification. Then, the expected dispersive inequity for a scenario can be calculated by weighting the dispersive inequity for each outcome by the probability of the outcome. For example, over all four groups, the expected dispersive inequity for Scenario A is

$$d_D(\text{Scenario A})=.5d^1{}_{\text{outcome 1}}+.5d^1{}_{\text{outcome 2}}=1.$$

The challenge now is to develop a measure of dispersive inequity that takes into account the overlapping membership structure. One possibility is to sum the three measures of dispersive inequity, $d^1+d_g{}^1+d_r{}^1$. For scenario A this would result in $1+.5+0=1.5$ for each of the two outcomes. In contrast, the fairer scenario B would have $d^1+d_g{}^1+d_r{}^1=1$ for both outcomes. A refinement of this would be to weight the dispersive inequity measures by a parameter reflecting their relative importance,

$$\text{Overall dispersive inequity:}\quad od^1=d^1+w_gd_g{}^1+w_rd_r{}^1.$$

The judgment of the magnitude of the weights, w_g for government-employment classification inequity and w_g for role inequity, would be made by the decision maker. More research is needed on the advantages and disadvantages of this type of model of dispersive inequity for overlapping memberships.

Sometimes, mutually exclusive groups cannot be formed, such as the following classifications: Antarctic staff working versus Antarctic staff on off-hours recreation, scientists using military airplanes versus scientists using civilian airplanes. At different times, a person, say Smith, can be in each of the four groups. One possibility for future research is to make a person into a vector of entities, such as Smith–civilian worker, Smith–off-hours recreation user, Smith–scientist, and Smith–expeditionary adventurer. Then, these entities are not overlapping and can be placed in mutually exclusive groups to which the existing equity models could be applied.

Conclusions and future research

We have identified a number of implications for incorporation of fairness concerns into preference models for societal risk, motivated by the application arena of Antarctica. The Antarctic risk examples used in this chapter are only meant to be suggestive. Before any thorough scientific analysis can proceed, a quantification of the risks, costs, and benefits of the status quo and alternative programs must be undertaken. Because of the implications for scientific research and therefore the greater societal benefits, it is important that estimates of the risk/cost/benefit distributions be made and used in cost/benefit and equity modeling. This step is critical if the methodologies suggested in this chapter are to be used to clarify risk and equity trade-offs in Antarctica. Nevertheless, it may always be difficult to get the detailed probability distribution information needed for the equity measures as they currently exist. One possibility is to modify the measures to include components that could be estimated by expert judgment. For example, when modeling overlapping memberships (say voluntary and work activities), the correlation could be estimated between the probabilities of death for each person due to volunteer versus work activities.

More attention should be placed on extending the equity modeling work to multiple, rather than just binary, outcome levels (see Harvey, 1985b). In many cases, hazards can lead to multiple morbidity and mortality outcome levels across the population.

Also, the equity models discussed above focus only on the fairness of the distribution of the risks, disregarding jointly received benefits. But Keller and Sarin (1988) found that subjects tended to prefer a distribution of risks that matched the distribution of benefits (in a facility siting scenario) over a more equal distribution of risks. In Antarctic operations, there are sizable scientific benefits plus the benefits to tourists and expeditions. Sometimes a scientist with preexisting health risk factors will be given a medical waiver allowing travel to Antarctica to carry out research. In such a case, the medical risks must be weighed against the criticality of the person to the scientific mission. Most people voluntarily choose to go to Antarctica, and thus the personal benefits are probably relatively clear, but the corresponding health and safety risks may not be accurately perceived. Furthermore, even if Antarctic workers and tourists are willing to accept accurately perceived risks, the risks may not be acceptable to Congress or the public. The public's reaction to the Challenger disaster may give insight into the greater risk aversion of the public compared to that revealed by the voluntary choices of the astronauts.

Future equity modeling efforts should include both risk and benefit information. In some situations, such as siting noxious facilities, an envy-free allocation of benefits and risks may be achieved by adjusting the benefit and risk distributions so each participant prefers his or her own allocation over any one else's, thus creating a state of equilibrium (see Sarin, this book, and Keller & Sarin, 1988). However, in the Antarctic case of voluntary risk exposures, the members of different groups already accept the risks (so the status quo is in equilibrium), but policymakers may feel the current risk and benefit allocations are unacceptable.

The contexts of the risk exposures faced by different groups in Antarctica vary by factors that have been shown to affect perceived riskiness and that may affect perceived fairness of distributions of risks (see, e.g., Slovic, Fischhoff, & Lichtenstein, 1979; and Gould et al., 1988). These factors, which frame the risk in alternative contexts, include:

1. voluntary versus involuntary exposures to hazards or toxics;
2. exposures during work, off-hour recreation, expeditionary adventures, or as a tourist on a cruise ship or airline charter flight;
3. the degree of actual and perceived control over risks or exposures.

Thus, it is important to examine how such factors affect the perceived fairness of distributions of risk. In one experiment, Keller and Sarin (1988) observed that framing risks in alternative contexts affected perceived fairness. Further experimental and modeling work is needed on this topic.

Finally, one way of incorporating the risk exposure context into models is to represent the risks faced by one individual by a vector of probabilities of fatality due to different risk contexts. So, if the distinction between work and recreational exposure is important in a specific problem, a person could be identified by the probability of death due to work activities and the probability of death due to recreational (nonwork) activities. Then, preference models and equity measures would keep track of the risk exposure context, perhaps by having different weights on different contexts. Instead of modifying the measures, the group definition could be modified. For example, we could split the group of personnel into volunteers and nonvolunteers. But one person may be exposed to the same risk sometimes in a voluntary status and sometimes in an involuntary status, so the problem of overlapping memberships will be faced. Further, there may be too many alternative frames or contexts to distinguish each of them in the model.

References

Antarctica Journal of the United States. (1989, June). NSF, *24* (2).

Bly, L. (1989, September 10). Antarctica tourism worries authorities. *Milwaukee Journal.*

Booth, W. (1990, September 28). Face-off forming on Antarctic ice: Watchdog group threatens to sue NSF over researchers' waste. *Washington Post.*

Fishburn, P. C. (1984). Equity axioms for public risks. *Operations Research, 32,* 901–908.

Fishburn, P. C., & Sarin, R. K. (1991, July). Dispersive equity and social risk. *Management Science, 37,* 751–769.

Fishburn, P. C., & Straffin, P. D. (1989). Equity considerations in public risks evaluation. *Operations Research, 37,* 229–239.

Gould, L. C., Gardner, G. T., DeLuca, D. R., Tiemann, A. R., Doob, Leonard W., and Stolwijk, J. A. J., (1988). *Perceptions of technological risks and benefits.* New York: Russell Sage Foundation.

Harris, R. J. (1976). Handling negative inputs: On the plausible equity formulae. *Journal of Experimental Social Psychology, 12,* 194–209.

(1980). Equity judgments in hypothetical four-person partnerships. *Journal of Experimental Social Psychology, 16,* 95–115.

Harvey, C. M. (1985a). Decision analysis models for social attitudes toward inequity. *Management Science, 31,* 1199–1212.

(1985b). Preference functions for catastrophe and risk inequity. *Large Scale Systems, 8,* 131–146.

Hindustan Times. (1990, January 21). US aid for Indian Antarctic team.

Jasanoff, S. (1986). *Risk management and political culture.* New York: Russell Sage Foundation.

Kanamine, L. (1990, November 19). Summit held on Antarctic future. *USA Today,* p. 11A [summit on mineral exploration].

Keeney, R. L. (1980a). Equity and public risk. *Operations Research, 28* 527–534.

(1980b). Utility functions for equity and public risk. *Management Science, 26,* 345–353.

(1980c). Evaluating alternatives involving potential fatalities. *Operations Research, 28,* 188–205.

Keeney, R. L., & Winkler, R. L. (1985). Evaluating decision strategies for equity of public risks. *Operations Research, 33,* 955–970.

Keller, L. R. & Sarin, R. K. (1988). Equity in social risk: Some empirical observations. *Risk Analysis, 8* (1), 135–146.

Levitt, A. (1990, October 13). Mutually inclusive. *Washington Post,* p. A19.

Noblet, K. (1989, October 15). Antarctica: End of the innocence. *The Sun Sentinel,* Fort Lauderdale, FL.

Safety in Antarctica, (1988). Report to the National Science Foundation.

Sarin, R. K. (1985). Measuring equity in public risk. *Operations Research, 33,* 210–217.

Slater, S., & Basch, H. (1991, August 4). Antarctic tourism issues surfacing. *Los Angeles Times*, p. L18.

Slovic, P., Fischhoff, Baruch, & Lichtenstein, S. (1979). Rating the Risks. *Environment, 21*, 14–20, 36–39.

Supplemental Environmental Impact Statement for the United States Antarctic Program. (1990, December) draft.

Walster, E., Walster, G. W., & Berscheid, E. (1978). *Equity: Theory and research.* Boston: Allyn & Bacon.

Washington Post. (1991, February 19). 19 US tourists killed in Beagle Channel Crash: Chilean plane was on leg of Antarctica trip. p. A14, Associated Press.

Note

1 Although the people who would lose their jobs in Antarctica due to streamlining would face risks in their new jobs, those risks are excluded from the model of Scenario 2, since they won't be in Antarctica. In that sense, this is analogous to a partial equilibrium model.

Part VI

Conclusion