Avalanche Risk and Our Behavioral Response to Safety Improvements

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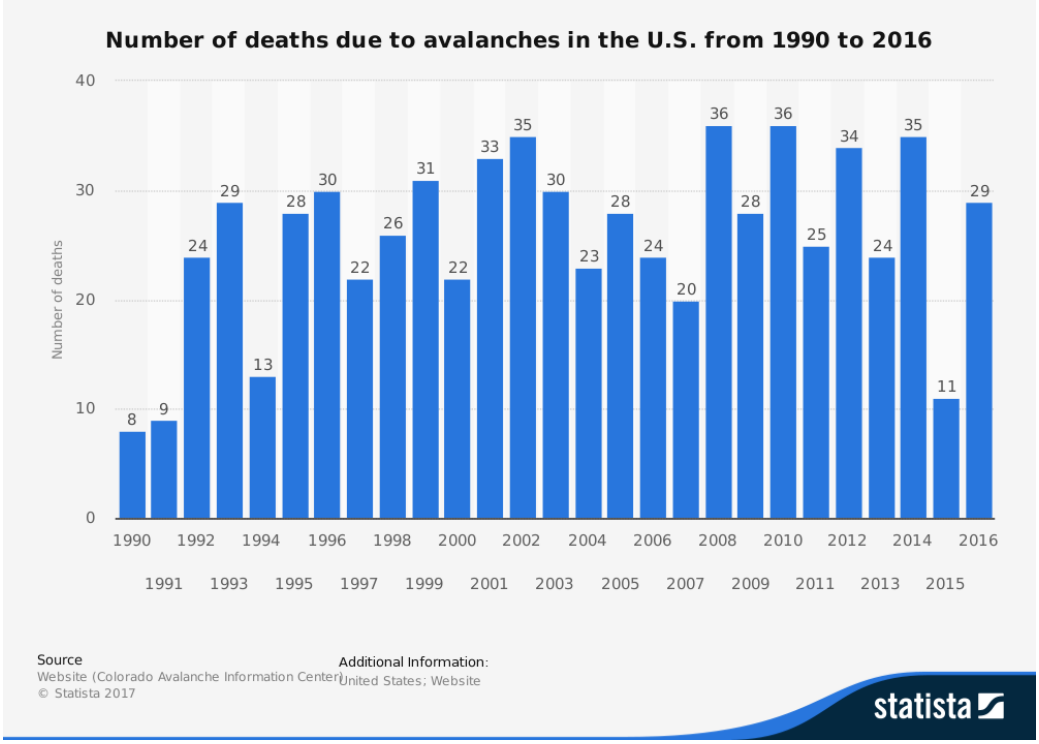
Avalanche forecasters and educators spend considerable time and effort to inform and educate users about avalanche risks, safety measures, and mitigation techniques. [can I get data on expenditures? Reference daily forecasts and advisories in various areas? Swiss or other avalanche research institutes?] In addition, teams of avalanche professionals mitigate avalanche hazard at ski areas and on highways using explosives and/or closures. Safety devices have improved dramatically over the past 50 years, even the past 10 years – the first avalanche transceivers were sold in 1971; vastly improved, digital transceivers were introduced in 1997 and are now used almost universally; the AvaLung can extend air supply for a buried victim and avalanche airbags help keep a victim on the surface of a slide. Rescue techniques, tools, research and public avalanche forecast services have made great strides. And yet avalanche fatalities have not decreased. Figure 1 shows fatalities in the US since 1990. A comprehensive analysis of European data argues that "the number of fatalities in uncontrolled terrain (mostly recreational accidents) almost doubled between the 1960s and 1980s and has remained relatively stable since then." (Techel at al 2016, p 147; Birkeland, K.W., E.M. Greene, and S. Logan. 2017. **In response to avalanche fatalities in the United States by Jekich et al**. *Wilderness and Environmental Medicine* 28(4), 380-382).



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Avalanche professionals sometimes express concern that, with fatalities failing to trend downward, their work is for naught. [quote? Reference?] This ignores, of course, the fact that recreational activity in avalanche-prone terrain has increased dramatically, so the number of people exposed has increased.[3] Maybe we should conclude that the flat trend in fatalities is a testament to the effectiveness of avalanche risk management. Various authors have discussed the increase in recreational exposure. (For example Techel at al 2016, Birkeland et al 2017)

But when we consider users' motivations and consider their decisions within a rational choice framework there are more subtle issues at play. Recreational users put themselves at risk for a reason. Playing in avalanche terrain – whether skiing, snowmobiling, climbing, snowshoeing, or hiking – provides benefits through enjoyment and satisfaction. Improvements in safety equipment, better forecasting, education, these all decrease the cost of playing in avalanche terrain by making it safer. This is good but it could induce users to take on more risk. Is this something avalanche professionals should be concerned about? This paper argues both yes and no. No because if users are informed and appropriately understand the risks and safety measures, then increases in safety tools are unambiguously good; even in the case where users take on more risk users are still better off because of the combined utility from both safety benefits and recreation benefits.

But the answer is yes – avalanche professionals should worry – if users over-estimate safety improvements or their own skills. Users choose their level of activity in avalanche terrain based on their subjective assessment of the risk and their confidence in their ability and safety equipment. Mother nature cares about neither our subjective assessment nor our confidence. She imposes reality – she imposes the true risk and tests our true abilities. If users over-estimate the level of safety they will choose a high level of exposure and take on more risk than they realize and more risk than they desire – they will make choices that leave them worse off than they would be without the (misunderstood) safety improvements.

UTILITY OR RATIONAL CHOICE FRAMEWORK

We want to lay out a simple framework, used in the field of economics, for thinking about how we, as human beings, make choices about risk and rewards when considering entering avalanche terrain. We are

[3] The full quote from Techel et al (2016) is "The number of fatalities in controlled terrain (settlements and transportation corridors) has decreased significantly since the 1970s. In contrast to this development, the number of fatalities in uncontrolled terrain (mostly recreational accidents) almost doubled between the 1960s and 1980s and has remained relatively stable since then, despite a strong increase in the number of winter backcountry recreationists." (Techel at al (2016) p 147)

not claiming that this answers all our questions but it does provide a framework that is both realistic and informs our thinking about the problem.[4]

"Risk Compensation" or "Risk Homeostatis" are often posited as a theory where people adjust behavior in response to perceived risk, becoming less careful when they perceive less risk (increased safety).[5] We believe that this approach is incomplete for a very simple reason: it focuses on the risk alone and ignores the benefits that accrue to the risky behavior. Venturing into avalanche terrain is a perfect example. All of us who knowingly venture into avalanche terrain do so in pursuit of some benefit or reward or return. It may be for the ecstasy of ski turns or snowmobiling in deep powder on a beautiful blue-sky day; it may be for mountaineer to reach a summit; it may be for a quiet hike in snow-bound landscape; or it may be for professional avalanche workers to open terrain at a ski area or a highway in avalanche terrain. . But there is some reason, and some benefit, for being in the mountains and potentially putting ourselves in harm's way.

Rather than talk about avalanche "risk" let's consider avalanche "safety". Avalanche safety is a benefit – a good thing that we all want. But the benefit we receive in the mountains and avalanche terrain (whether for fun or paycheck) is also a good thing and something we all want. The cruel fact of the world we live in is that we cannot have both perfect safety and mountain benefits (such as recreating in avalanche terrain). There is some trade-off between them, some set of constraints that forbid us from having both perfect safety and mountain benefit. The left panel of Figure 2 shows a diagram representing these constraints – the line represents the trade-off between safety and mountain benefits.[6] With no mountain benefit (no venturing into avalanche terrain) there is perfect safety, represented by the point "N". As we venture into avalanche terrain our safety unavoidably goes down. There is no way around this – going into avalanche terrain requires us to take on some avalanche risk.

We can always achieve perfect avalanche safety by the simple expedient of not going into avalanche terrain – shown in Figure 2 as the point "N" – perfect safety and no avalanche-terrain benefit. This choice is perfectly acceptable and in fact is the choice made by most people in the world.

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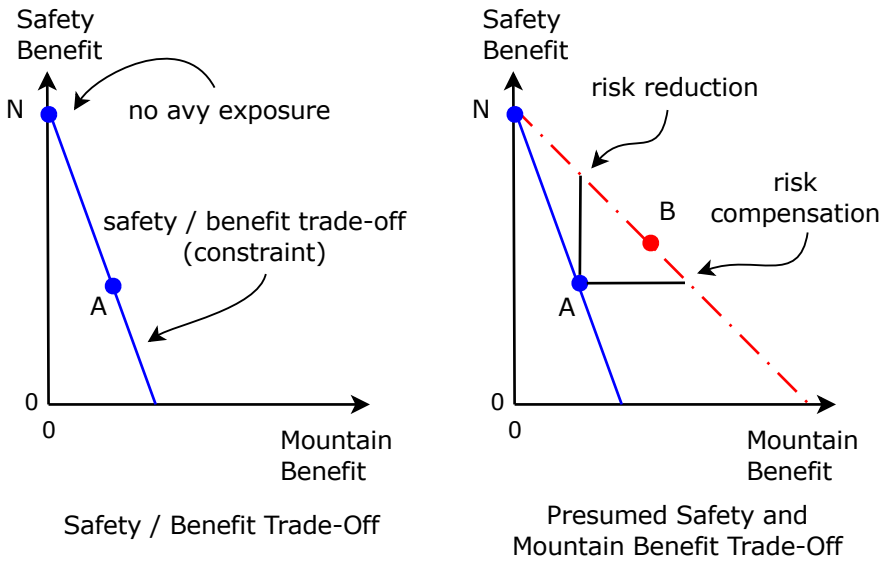
[4] This approach is not new, originally developed by [Alchian & Allen?] and Sam Peltzman in discussing auto safety (Peltzman, Sam. 1975. "The Effects of Automobile Safety Regulation." *Journal of Political Economy* 83 (4): 677–725. https://doi.org/10.1086/260352)..

[5] See, for example, chapter 8 of, Tremper, Bruce. 2013. *Avalanche Essentials: A Step-by-Step System for Safety and Survival*. Ist edition. Seattle, WA: Mountaineers Books. For a discussion of risk homeostatis see Wilde, Gerald J. S. 1998. "Risk Homeostasis Theory: An Overview." *Injury Prevention* 4 (2): 89–91. https://doi.org/10.1136/ip.4.2.89.

[6] Economists call this a "budget line" or "budget constraint" because the idea originated with purchased goods and a monetary budget constraint. The idea carries over to here, however, where nature provides us with a limited "budget" of safety and mountain benefits.

Figure 2



Although Mother Nature enforces her constraints – the trade-off between safety and benefit – this trade-off is not immutable and unchanging. We can, through our actions, loosen the constraints, improve the safety / mountain benefit trade-off, and increase our opportunities. The invention of avalanche transceivers pushes out the constraint – for any given exposure to avalanche terrain we are now safer (or, for any chosen level of safety we can now reap more avalanche-terrain benefit). Introduction of avalanche airbags, better digging techniques, better individual terrain management and hazard evaluation and better information from avalanche forecasts, all of these push out the constraint and increase our opportunities, moving us from the solid blue line to the dashed red line in the right-hand panel of Figure 2. This paper is dedicated to exploring the implications of the improvement of avalanche safety, this loosening of constraints and expansion of our opportunities.

To understand this, and all that follows, we need to recognize that individuals – users and potential users of avalanche terrain – will care about or have preferences over both safety and mountain (avalanche-terrain) benefits. Both are "goods" in the sense that we want more of them, so moving to the north-east in the diagram is a good thing But we cannot, of course, move beyond the constraint; Mother Nature insists we remain on (or inside) the constraint.

We can follow the path of economists and think of those preferences as forming a hill that rises towards the north-east (called "utility" by economists). When we consider all the various tradeoffs between safety

benefits and mountain benefits, by an individual it forms contour lines or "indifference curves" which represent the trade-off between safety and benefit that an individual makes – the comfort level between safety and benefit. Many people, maybe most, will have preferences that push them to point N, perfect safety and no avalanche exposure. But many people will value mountain benefits and wish to trade off some safety for mountain benefit, and will choose a a position like "A" in the left panel of Figure 2.

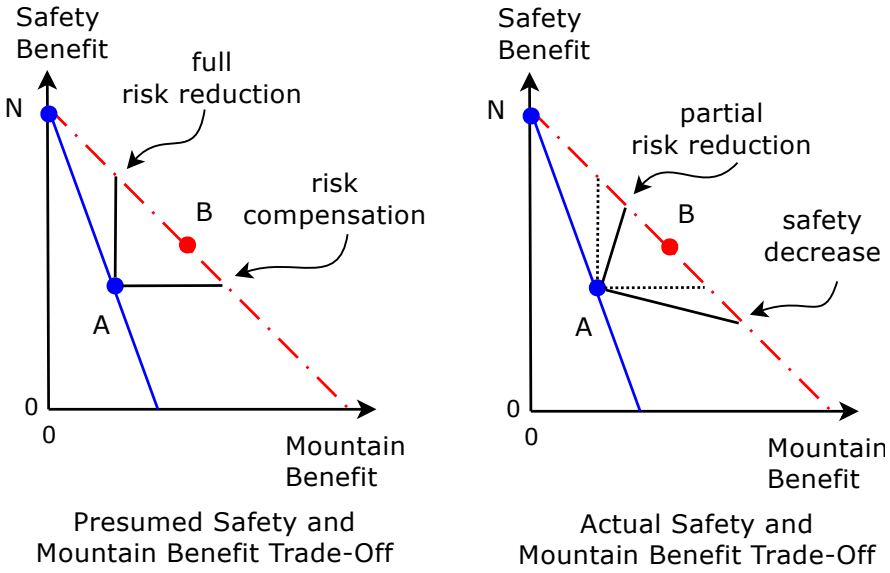
We need to stop for a moment and recognize the implication of choosing point "A": the mere fact of choosing "A" shows that the individual is willing to give up safety in return for mountain benefit. Going into avalanche terrain (point "A") testifies to the trade-off between safety and mountain benefit, that individuals are willing to give up safety (take on risk) in return for the benefit of going into avalanche terrain.

Now let us consider an improvement in avalanche safety technology or techniques that increases opportunities and shifts the constraint from the blue solid to the red dashed line in the right panel of Figure 2. The individual originally at point "A" will shift to some new point, say "B", on the new constraint line. We might think of two extremes: full risk reduction (no increase in avalanche exposure) or full risk compensation (a large increase in avalanche exposure with no change in safety). Given that individuals value both safety and mountain benefits it seems natural that the new choice ("B") will take some of both safety and mountain benefit improvement and will not end up at either extreme.

This goes far towards explaining what is sometimes considered a risk compensation puzzle: that with the introduction of new safety technology individuals adjust behavior in response to the new technology. Economists would never expect full risk reduction because of the risk / benefit tradeoff inherent in our choices.

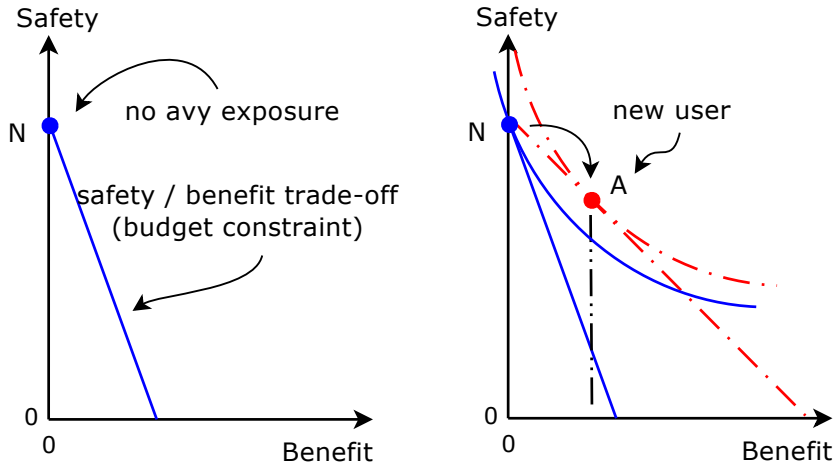
But an economist can go even further, to predict that full risk reduction and risk compensation are *not* in fact the extremes. The actual situation is shown in the right panel of Figure 3, with the extremes of *partial risk adjustment* and *safety decrease*. There are strong behavioral and economic arguments (laid out in the appendix) that avalanche exposure will always increase – never remain the same or decrease – and thus we will see at most partial risk reduction. And furthermore individuals could actually go beyond full risk compensation, increase avalanche exposure so much that overall safety *decreases*. These would be fully rational responses to an increase in avalanche safety technology, as individuals balance the choice between the benefits of safety and mountain access.

Figure 3



As a further exercise, let us consider new users. Many people, maybe most, will have preferences that push them to point N in the left panel of Figure 4, perfect safety and no avalanche exposure. But when safety improves and the constraint line shifts out, as in the right hand panel of Figure 4, some people will find that the benefit of entering avalanche terrain is now worth some reduction from perfect safety – they will enter avalanche terrain and reduce their avalanche safety somewhat.

Figure 4



So we find that improvements in avalanche safety will both induce new users to enter avalanche terrain, and (importantly) will induce them to decrease their avalanche safety. These new users are better off then they were before, unambiguously because they increase their utility from the combination of both safety benefits and mountain benefits. The safety improvements have expanded their opportunities and allowed them to reap the benefits of entering avalanche terrain, and at a level of safety which (while lower than before) nonetheless improves their well-being.

USING THE UTILITY OR RATIONAL CHOICE FRAMEWORK

We have laid out a framework for thinking about how we make trade-offs between safety and mountain benefits. We now examine how we can apply this framework to some specific situations.

Overestimating Effectiveness Of Safety Technology

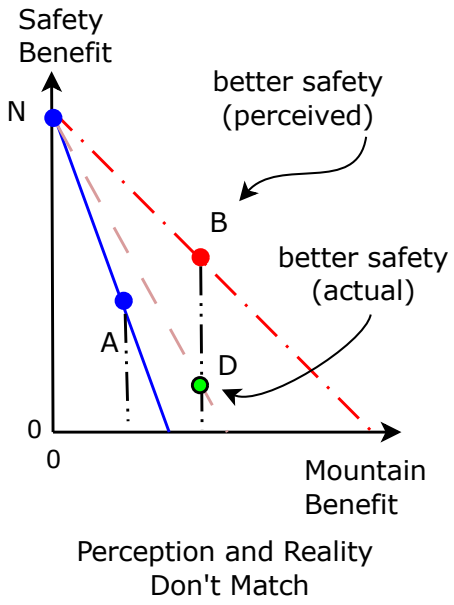
So far we have considered that users are knowledgeable, informed, and skilled. Any safety improvement is correctly interpreted by users and equipment is understood and properly utilized. What happens when this is not the case? It turns out that this will almost certainly lead to users misguidedly choosing a level of mountain benefit (exposure in avalanche terrain) that is higher than they should, leading to a decrease in safety that makes them worse off – more likely to be injured or die – without reaping the higher benefits from venturing into avalanche terrain.

Figure 4 shows the choice resulting from an increase in safety technology (as in Figures 2 and 3) where the constraint shifts out from the solid blue to the dash-dot red. The user moves from "A" to "B" with increases in both safety and benefit. But what if the new constraint line (dash-dot red) is only the subjective constraint line and does not correspond to reality? What if the user underestimates the avalanche risk, is over-confident in his or her abilities, and does not know the proper way to use their safety equipment (transceivers, probe, shovel, avalanche airbag)? Their *subjective* constraint is the dash-dot red and they will base their decision (to go to "B") based on that constraint. But nature knows the true score and will use the true constraint – the dashed brown line.

The user chooses how much to venture into avalanche terrain and so chooses the horizontal position. But whatever we may believe nature chooses the true avalanche risk, and so chooses the vertical position.

This puts us at “D” – much lower avalanche safety than we meant to choose. If we knew the true constraint – if we correctly estimated the risk and our own abilities – then we would choose somewhere between “A” and “B”. This would be moderate benefit and slightly increased safety. Instead we have chosen, mistakenly and unfortunately, a higher mountain benefit and reduced safety. We have chosen too much exposure and too little safety.

Figure 5



This final outcome is bad news, but it also highlights the importance of education and training. Improved safety measures, when properly known, will make everyone better off, with users choosing sometimes more and sometimes less safety. The true problem arises when users over-estimate the safety improvements and base decisions on the false perception that the budget line and opportunities have shifted more than they have. This will lead to too much use of avalanche terrain and safety lower than anyone would choose.

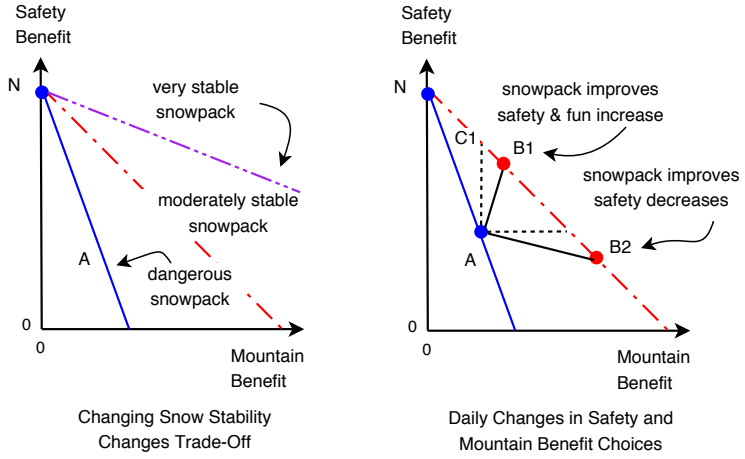
Changing Conditions and Changing Decisions

We have framed the discussion so far in terms of safety technology improvements. We have assumed that the original before-technology constraint or safety / benefit tradeoff – the blue line in the left panel of Figure 2 – is fixed. But we all know that the objective danger and the safety / benefit trade-off changes every day and throughout each day, as the snowpack and weather conditions evolve. The tradeoff may

improve as we go from dangerous to moderately stable to very stable snowpack or may deteriorate as the snowpack deteriorates. The left panel of Figure 6 shows the idea schematically.

The right panel of Figure 6 shows what happens as the snowpack improves, and this exactly reproduces the right panel of Figure 3, the result of technological safety improvements. As discussed in the appendix we may end up at "B1" where both safety and mountain benefit increase (our choice shows some trade-off) but we should never expect to end up at "C1" where we choose only to improve safety (with no increase in mountain benefits).

Figure 6



The fact that we should expect to move (at most) to "B1" and not "C1" is a natural result of our utility or economics framework.[7] The fact that we should not expect to move from "A" to "C1" is a very good thing when we realize that the safety /benefit trade-off can both improve (improving snow stability) and deteriorate (worsening stability) – if we move from "A" to "B1" when the trade-off improves we will move from "B1" to "A" when the trade-off deteriorates. The move from "B1" to "A" implies a large *decrease* in the choice of safety but with some compensating decrease in mountain activity. If a move from "A" to "C1" were possible then, conversely, we would move from "C1" to "A" when snowpack deteriorated and would make a choice to reduce safety with *no* compensating decrease in mountain activity.

[7] This is sometimes viewed as a puzzle and the ideas of risk compensation and risk homeostasis are often discussed as explanations.

The point "B1" is one extreme, and the other is "B2", choosing to increase mountain activity so much that the level of safety actually decreases. This initially seems counter-intuitive but it is possible. However, economic theory tells us it might not be likely. But considering the converse – a deterioration in the safety / benefit tradeoff – shows that it is only from positions like "B2" that we should expect to find deteriorating snow stability leading us to choose *more* safety. We should expect that when the safety / benefit tradeoff deteriorates from one day to the next, our choice is likely to be some decrease in choice of safety.

Behavioral Strategies (Heuristics) for Managing Risk / Reward Tradeoffs

Sometimes utility and rational choice theory are criticized for assuming perfect rationality.[8] Heuristics and mental short-cuts are often aids that can improve decision-making. Longtime Canadian helicopter ski guide Roger Atkins (2014, referencing Todd and Gigerenzer (2000), Gigerenzer et al (2000), and others)), discusses how helicopter guides come up with a "strategic mindset" for the day as a way to manage desire, which also helps manage behavior of both guides and clients. For instance, on high hazard days, they agree to only recreate in non-avalanche terrain such as gentle slopes not underneath steeper terrain.

In our safety / benefit tradeoff rational choice framework this is simply changing our definition of fun and also changing our perceived safety / benefit tradeoff. Recreating in gentle terrain is safer and the desire to recreate in extreme terrain is dangerous; redefining the meaning of "fun" can help us make better decisions.

[8] As Todd & Gigerenzer (2000) say "Traditional models of unbounded rationality and optimization in cognitive science, economics, and animal behavior have tended to view decision-makers as possessing supernatural powers of reason, limitless knowledge, and endless time." And such assumptions are clearly not realistic. (But see Becker (1962) for what one of us (Coleman) view as a rather strong refutation of such arguments.)

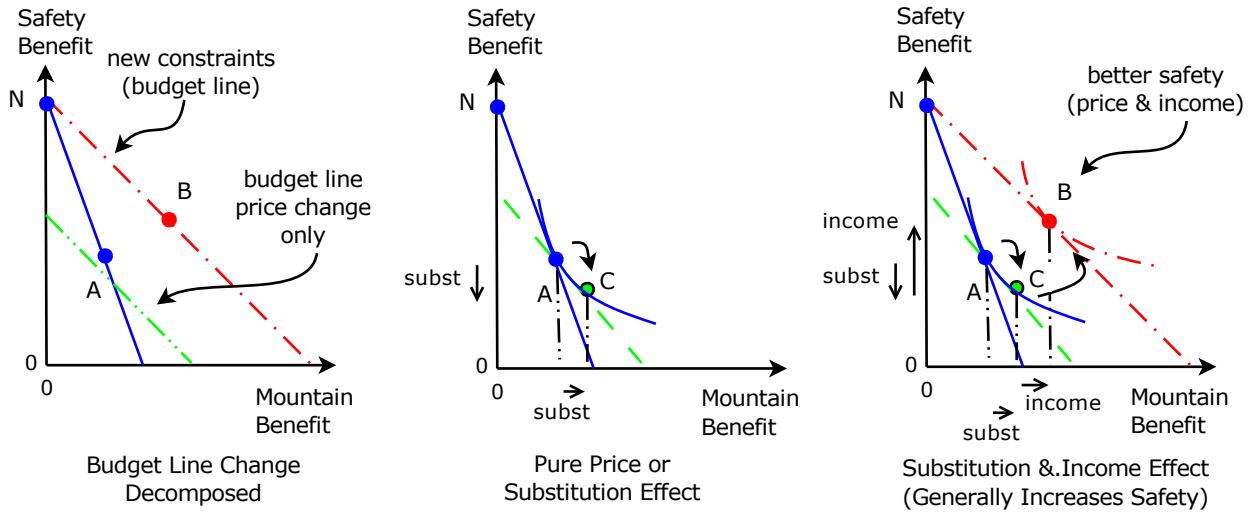
APPENDIX

The Economics of Price (Substitution) and Income Effects

This appendix lays out the economic and behavioral arguments for the choice of new safety / mountain benefit as shown in the right panel of Figure 3. In particular, why "full risk reduction" will not occur and the choice should lie between the extremes of "partial risk reduction" and "safety reduction".

Economists like to split or decompose the choice resulting from a change in opportunities – the original choice "A" to the new choice "B" in Figure 2 or Figure 3 – into two components, called a pure price (substitution) effect and an income effect. Doing so clarifies why "full risk reduction" will not occur.

Figure A1



The left panel of Figure A1 shows the original constraint line (what economists call a "budget line") and the original choice "A", together with the new budget line (red dashed) and new choice "B". The green dotted line is a budget line with only the change in slope; no shift out or increase in opportunities.

Why is it important to focus on change in slope? Because the slope represents the "price" of safety in terms of mountain benefit. Improved safety technology makes it easier to access the mountains safely, effectively reducing the price or cost (in terms of risk) for going into avalanche terrain. In a true sense it

makes mountain benefits cheaper: Technology improvements reduce the price of mountain benefits. But the flip side of this is that by necessity it increases the price of safety.

When only the price changes we can say something important about behavior. When the price of mountain benefits go down individuals will consume more. The price of safety goes up and individuals will consume less safety. This is shown in the center panel of Figure A1: When only prices change the "substitution effect" will be from "A" to "C", with an increase in mountain benefit and decrease in safety.[9]

This may sound a little heretical – increasing safety opportunities decreases the amount of safety – but it simply reflects the changing trade-off where benefits are now easier to get (relative to safety). This will induce any reasonable person to choose more benefits and, since we can't (yet) have more of both, less safety. We call this a pure price or pure substitution effect. It is, of course, only part of the story because so far we have only shifted the *slope* of the constraint and not allowed it to shift out.

The right panel of Figure A1 shows the total or net effect, the price (substitution) effect going from "A" to "C" and the income effect going from "C" to "B". The shift outward from the green dotted to the red dashed line represents an expansion of our opportunities, where we can choose more of *both* safety and benefit. Economists call this an income effect, because it increases our income broadly defined – what we can do with our lives. Because we want both safety and benefit (in the language of economists both safety and benefit will be normal goods that increase when income or opportunities increase) the shift out in the curve will induce us to choose more of both safety and benefit, shown in the right panel of Figure A1.

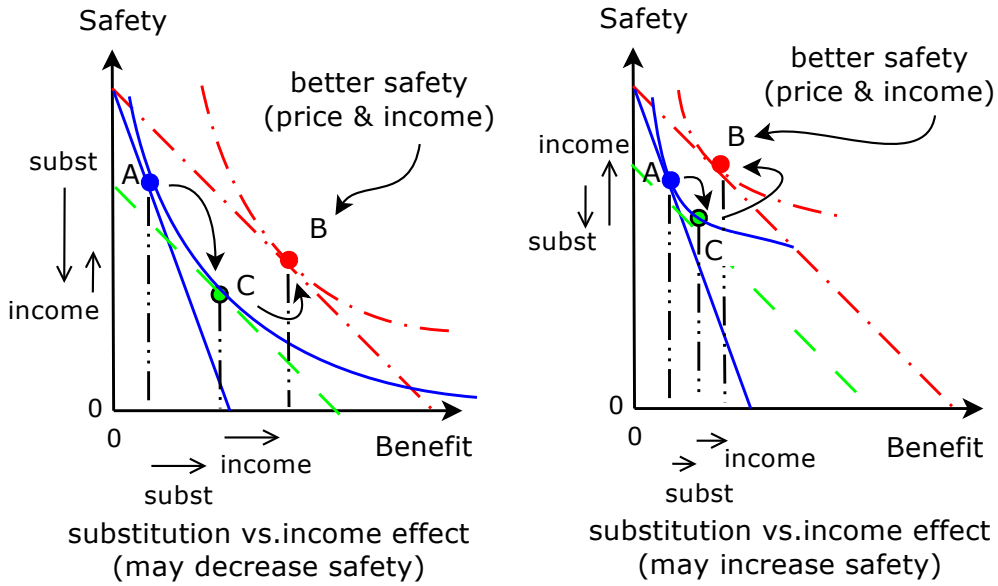
We now have an explanation for why we should expect to see at most partial rather than full risk reduction. The price effect reduces safety and increases mountain benefits. The income effect (shift out in the constraint or budget line, the increase in opportunities) will increase *both* mountain and safety benefits. Overall, mountain benefits must increase, while full risk reduction would require that they remain unchanged. For safety the price effect will reduce safety and although the positive income effect will partially offset the negative price effect we cannot get to the point of full risk reduction.

We can, however, say more. The substitution and income effects explain why it would be possible for safety overall to actually decrease, why we might have "safety decrease" as in Figure 3. The price

[9] This is what economists refer to as a Hicksian substitution effect – the new (green dashed) budget line is tangent to the same indifference curve as the original point "A".

(substitution) effect unambiguously decreases safety. The income effect offsets this decrease. There will be two possibilities for this offset. The first, shown in the left panel of Figure A2, is that the negative price effect for safety is very large and the positive income effect small, so that the net effect will be to *increase* mountain benefit and *decrease* safety. This is possible, but more likely is the case shown in the right panel where the negative price effect is outweighed by the positive income effect, leading to increases in both safety and benefit.

Figure A2



The summary is that when safety measures improve, we should unambiguously see usage of avalanche terrain increase, but we may see safety (and thus fatalities) either increase or decrease.

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