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HORMESIS, NON-LINEARITY AND RISK COMMUNICATION

Introduction

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Hormetic dose responses are commonly observed in the toxicological and pharmacological literature. Using very rigorous a priori entry and evaluative criteria Calabrese and Baldwin (2001, 2003) reported that hormetic dose responses occurred in nearly 40% of dose responses. Further studies from data sets with more than 50,000 dose responses indicated that the hormetic dose response was far more common than the threshold or linear dose response models. In fact, the threshold and linear models were shown to predict low dose effects very poorly whereas the hormetic model performed very well (Calabrese and Baldwin, 2003; Calabrese et al. 2006, 2008). Furthermore, the hormetic dose response is dominant in many areas of the pharmaceutical world including anxiolytic drugs (Calabrese, 2008a), anti-seizure drugs (Calabrese, 2008b), memory enhancing agents (Calabrese, 2008c), neuroprotective agents (Calabrese 2008d, 2008e, 2008f), stroke medication (Calabrese, 2008g), as well as for bone strengthening drugs (Calabrese, 2008h), erectile dysfunction

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agents (Calabrese, 2008h) as well as for growing hair (Calabrese, 2008h). The hormetic dose response is therefore a dominant dose response within the biomedical sciences, including toxicology. In fact, Calabrese and Blain (2005, 2009) have now upwards of 8000 dose responses in the hormesis data base. These data indicate that the hormetic dose response is very generalizable, being independent of biological model, endpoint measured and chemical class or physical agent studied. Furthermore, the largest rodent chronic bioassay (called the mega-mouse study) with over 24,000 animals clearly demonstrated an hormetic dose response for bladder cancer following a detailed assessment by an SOT Task Force of 14 experts (Bruce et al, 1981). Despite the strong performance of the hormetic dose response in the biomedical literature, its use in many of the drugs that humans ingest and its capacity to far outperform the EPA default models in head to head competition, the regulatory agencies continue to use the threshold and linear models for non-cancer and cancer risk assessment while generally ignoring the hormetic dose response. In fact, the EPA and the FDA have used the threshold dose response for decades without ever having validated and vetted the capacity of this model to make accurate predictions in the below threshold zone. The situation exists in which the regulatory agencies refuse to use the hormetic dose response model and continue to use a model that was never vetted and one where the validation test actually supported an hormetic interpretation. This confusing situation not only affects the field and practice of risk assessment but it also impacts risk communication. Realizing that this is a very dynamic area at the present BELLE invited David Ropiek to render his perspectives and opinions of how the concept of hormesis may affect the process of risk communication. A number of experts were asked to develop an independent commentary on the paper developed by Ropiek. Ropiek then was permitted the opportunity to have the final say.

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RISK COMMUNICATION AND NON-LINEARITY

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RISK COMMUNICATION AND NON-LINEARITY

This article will consider non-linearity and hormesis from the perspectives of risk perception and risk communication. The observations that follow do not come from a scientist or researcher. (For a richer academic treatment of the issue of risk communication and non-linearity, see BELLE, Vol. 11, Issue 1, 2002). I was for 25 years a journalist on television and in print, focusing on coverage of environmental issues. I then studied and taught risk perception and risk communication at the Harvard School of Public Health. I now independently consult in these areas. From the academic side I have read a fair amount of the literature that helps explain what I call The Perception Gap, the gap between our fears and the facts. And as a journalist and consultant I have witnessed in the real world people's relatively greater fear of lesser risks, and relatively lower fear of the risks the scientific data suggest they ought to worry about more. I offer the following perspectives based on those foundations.

INTRODUCTION

The idea of non-linearity/hormesis has a problem. The suggestion that low doses of infamous toxins might not be harmful, and may in fact stimulate effects that are positive, will be difficult for many to consider with an open mind. The idea of hormesis will be difficult for the public to accept, because it conflicts with the way they have always thought about what is safe and what is dangerous.

Accepting the idea that a little of a bad thing might not be bad, and might even be good, raises the possibility that it might be okay to be exposed to DDT or dioxins or a host of other supposedly dangerous substances. The scientific facts of non-linearity/hormesis may prove that such exposure is safe. Nonetheless, the idea of that exposure *feels* threatening, the facts notwithstanding.

Those who promote non-linearity/hormesis will not carry the day merely by arguing the science. This will not just be a matter of toxicology and the facts. Non-linearity is about things that can harm us, or kill us, and that evokes powerful affective triggers by which we protect ourselves from such threats. The perception of risk is a combination of rational fact-based analytical thinking *and* affect. Incorporating an understanding of and respect for this affective component of risk perception is critical to more effective risk communication. And effective risk communication will have a lot to do with whether non-linearity/hormesis is able to move from academe into the toolkit of policy makers.

RISK PERCEPTION

Let's say you will die tomorrow, but you have your choice of how. You can die of cancer, or heart disease. Which do you choose?

Let's say you work in a hospital and the government asks you to be vaccinated against smallpox, in case it is used as a weapon by terrorists. There haven't been any small pox cases for more than 30 years, however, and the vaccine carries a 1 in a million risk of killing you. Do you take the shot, which involves taking a chance that you might die, in exchange for apparently no benefit? How about if there is one confirmed case of smallpox in a hospital somewhere in your country? Now the vaccine confers a benefit, though it still might kill you. Do you want the vaccine now?

Let's say you are planning to travel tomorrow by plane, but suddenly all the news channels show dramatic video of an airplane, hijacked earlier in the day from the airport you fly from, that has gone down in terrible fiery crash that kills more than 200 people. There is an interview with a survivor, partially burned, who describes the horror of the crash and fire from which she escaped. Your full trip tomorrow will take 3 hours by plane, including airport time, and four hours by car. Do you consider driving instead of flying?

If you are like most people in the classes I teach, in regards to the first question, you would prefer to die of heart disease rather than cancer. But wait. That's irrational. You should be more worried about heart disease, which kills roughly 20% more people in America each year, in roughly the same demographic groups.

Would you take the smallpox vaccine if there are no cases anywhere, a one-in-a-million risk for zero benefit? Most people say no. Does your choice change if there is one case somewhere in your country? Under those circumstances, the overwhelming majority of my unscientific sample switches from "No thanks" to "Yes, Please!". Again, from a numbers perspective, that choice doesn't seem rational. The risk of death from the vaccine is one in a million in both cases.

Might images of a hijacked plane killing hundreds in a fiery crash alter your travel plans? It did for thousands of people in the United States after the terrorist attacks of September 11, 2001. By many metrics, flying declined and driving increased in the months after those attacks. Separate analyses by the University of Michigan Transportation Institute, and a team of researchers at

Cornell, found that for the period of October-December 2001, roughly 1,000 more people were killed in motor vehicle crashes than would be expected for those months[1, 2]. In terms of making themselves safer, people who chose to drive were statistically wrong…irrational. In general, flying is safer than driving. But their perception of risk was informed by factors well beyond just the statistics, and for many, their perceptions proved deadly.

Why do we make such irrational judgments about the risks we face, experts and lay people alike? Why do some risks *feel* more worrisome than others? Why don't we just use the facts to make our decisions? The answer to these questions are directly relevant to public acceptance of, or resistance to, non-linearity/hormesis

Nearly 40 years of investigation in the field of risk perception has established with research what most of us realize intuitively, that risk means different things to different people[3]. Why? A proposed answer was put forward by Melissa Finucane and colleagues, who wrote "Representations of objects and events in people's minds are tagged to varying degrees with affect." These "…positive or negative affective feelings guide judgment and decision-making." They name this 'The Affect Heuristic'[4]. Simplified, risk is a matter of the facts *and* our feelings.

But while the affect heuristic describes why two people can see the same risk differently, it is a blunt instrument for risk communication. It only tells us generally that our feelings play a part in how we choose. It does not tell us specifically where our positive or negative affect comes from. It doesn't illuminate the underlying characteristics of risks which make some feel more frightening than others.

In order to communicate more effectively about risk, we need to speak, and act, in ways that are relevant to how people feel about that risk. So we need to know the specifics of affect…where do those positive and negative feelings come from...why are some risks scarier than others? I attempt to embody that approach in the following definition of risk communication:

Actions, words, and other interactions, that incorporate and respect the perceptions of the information recipients, intended to help people make more informed decisions about threats to their health and safety.

For effective risk communication, I suggest that we need to understand why people feel about risk the way they do, and respect that those feelings play an integral part in the process of judging how to protect ourselves. Risk perception which is not solely fact-based simply can not be dismissed as "irrational". People who worry more, or less, than the scientific information suggests, are neither wrong nor right. They are trying to survive. It seems perfectly reasonable to use the facts you have, *and* values and emotions and anything else you can, to make sense of a threat.

A range of research supports this perspective. As Herbert Simon's concept of 'bounded rationality' proposes, the ideally rational actor is a myth[5]. Simplified greatly, this idea proposes that we almost never have all the facts, and/or all the time, and/or all the intellectual resources necessary for perfectly rational decision making. But decide we must as we live our lives one moment to the next. Heuristics, or 'mental shortcuts', are what we use to bridge the gap between what we know and the decisions we have to make.

Important contributions confirming this view, and identifying some of the specific heuristics we use, came from research by Daniel Kahneman, Amos Tversky, and others[6]. Kahneman *et. al.* identified several heuristics that are relevant to perception of non-linearity/hormesis. I will discuss several of these in more detail below. (Kahneman won the 2002 Nobel Prize in Economics for this work. Tversky had passed away and the award is not granted posthumously.)

Even more specific insights into risk perception come from psychometric research by Paul Slovic, Baruch Fischhoff, Sarah Lichtenstein, and many colleagues. That work has identified a set of general characteristics that seem to make some risks more worrisome than others[7]. Several of these risk perception characteristics and their relevance to non-linearity/hormesis are also discussed below.

A third field that speaks to the roots of affect is the "Cultural Theory of risk" as put forth by Mary Douglas and Aaron Wildavsky[8]. This view, more anthropological and less empirically established, posits that people's perceptions of risk are produced by, and support, social structures. In essence, what group(s) you belong to, your role in those groups, and how strongly you feel you belong, are important factors in all your worldviews, including your perceptions of risk. Cultural theory identifies four distinct group identifications that inform risk perception. Individualists (low group identity, less concerned with their role within their group…confident that natural systems will reduce many risks), Egalitarians (high group identity but don't feel circumscribed by their place in society…greater concern about low-probability high-consequence risks that threaten the whole group) Hierarchists (high group identity and feel constrained by social expectations… rely heavily on experts to tell them what to be afraid of), and Fatalists (don't identify with any group but feel constrained by behavioral expectations…passive about many risks since they feel they can't do much about them). I note the contribution of Cultural Theory here, but don't go into detail, because I think it offers insufficient precision as a tool for risk communication.

Here then are some of the general heuristics and specific risk perception characteristics which might be relevant to public acceptance or rejection of non-linearity/hormesis.

THE AVAILABILITY HUERISTIC

The more available to our consciousness is information relevant to the choice we face, the more affective influence that "background" information will have on our decision[9]. As a simple example, news coverage creating elevated awareness of avian flu makes many people more concerned about avian flu than about "regular" influenza, which is less in the news.

Availability can, in some ways, be thought of simply as awareness. Awareness can come not only from the information media, but any other source. If you arrive home one evening and someone in your family tells you about the crime she saw on a nearby street corner, you are likely to feel that crime is more likely on that street corner than you thought it was before you got home. Viral marketing (using existing social networks to exponentially increase awareness of a product or service)[10], and the social amplification of risk (social factors amplify or dampen perceptions of risk and create secondary risks in how people behave in response to the initial threat…[11]), both rely heavily on the availability heuristic.

Temporally, availability can be current or latent. That is, we are influenced by what is currently before us, but we also rely on what we already know. If we've had a frightening experience during a plane flight, we will probably be more concerned about flying, regardless of whether a plane crash is currently making news (*and regardless of the statistical facts about flying safety).* If we have learned that some industrial chemicals cause cancer, ready access to that background awareness will inform the judgments we make about such chemicals.

I believe that latent availability bears directly on the risk communication challenge facing proponents of non-linearity/hormesis. There may not be anything in the news about toxins, but most people already have at least a basic mental library of information about toxins in general, and about some specifically. If you say "DDT" to most people, they are like to have some latent awareness on which a very quick and not entirely fact-based judgment will form in their minds. Just the word 'pesticides' is threatening to many, based on what they've read and heard, the facts notwithstanding. Based on my 25 years as a journalist who focused on environmental stories, I can say with confidence that many people are afraid of substances they think are toxic regardless of the actual, *i.e.* scientifically calculated, risk. Their latent availability on such issues is why, to some degree, low doses are unacceptable.

Imagine then the difficulty of convincing people that low doses might not be harmful, and in some cases may actually be beneficial. The idea of non-linearity/hormesis is likely to encounter resistance because of this availability heuristic.

THE REPRESENTATIVENESS HEURISTIC

Under the conditions of bounded rationality, an event is judged more likely "…to the extent that it represents the essential features of its parent population or generating process…"[12]. Simplified, when we don't have all the facts, or the time, or all the intellectual capacity to rationally analyze a choice, we fit what we information we do have into the patterns with which we are already familiar. Imagine a football player. Is it more likely or less that he is bigger than you? Imagine a politician. Is it more or less likely he is honest? You don't have the facts, but you have patterns of information on which to base your choice.

If you were to ask most people to make a judgment about whether a toxic substance is dangerous at a low dose, few if any would have all the facts. But they will have a pattern of information about the class of such substances – it's parent population - that they will apply to making their judgment.

This too is likely to cause resistance to the idea of non-linearity/hormesis. Based only on my experience reporting on environmental stories, people lump together any substances that can cause cancer. The dose doesn't matter. The route of exposure doesn't matter. The time period of the exposure doesn't matter. The type of cancer doesn't matter. Carcinogenic substances belong to a class that has certain general characteristics, and by those general characteristics those substances (and the way they are studied) will be categorized.

Non-linearity/hormesis proposes that though many potentially carcinogenic substances have similar general characteristics – many are mutagenic, most are invisible, odorless, tasteless, manufactured, associated with painful death – that each must be considered individually. Non-linearity argues that the blanket assumption that the only safe dose for carcinogens is no dose, is too simplistic. Perhaps so, based on a growing body of scientific evidence. But not in the patterns we non-toxicologists apply to such substances as we subconsciously judge what to be afraid of and how afraid, or not, we should be.

Non-linearity also proposes that, for non-carcinogens, below the threshold dose at which no observable adverse effect occurs, a substance may stimulate activity in an organism that may be positive. That is also a new way of thinking about such substances, outside the background patterns we apply to figure out what to think and how to feel about things that threaten us. "One in a million is too high," people in my stories would often say. "The only safe dose is no dose." Not according to the facts as proponents of hormesis see them perhaps, but certainly that is how the public categorizes such substances.

The research by Kahneman *et.al.* identified general heuristics for making judgments about the *probability* of events. While they can (must) be applied to the understanding of risk perception, I suggest that another field offers a more precise explanation for the emotional components of the affect heuristic. This is the study of risk perception, pioneered by Paul Slovic, Baruch Fischhoff, Sarah Lichtenstein, and others, which goes beyond just how we judge probabilities. This research has identified specific affective characteristics of potentially threatening circumstances which shape our subconscious 'decisions' about what to be afraid of, and how afraid to be. These risk perception characteristics go a long way toward helping us understand public attitudes toward risks, and therefore help predict how people are likely to respond, affectively, to the idea of non-linearity/hormesis.

In my view, relevant risk perception characteristics include:

TRUST

If trust is low, fear is likely to be higher, and vice versa. A friend of mine, a college educated Democrat, said "I used to think avian flu was a big risk, but now that Bush says it is, I'm not so sure." Trust

can be a matter of who is communicating about the risk, but it can also be a matter of how much people trust the competence and honesty of the agency that is supposed to protect them, or how open and honest is the process by which risk policies (*e.g.* acceptable threshold doses) are made.

As this pertains to non-linearity/hormesis, if neutral experts communicate about this new approach, or if consumer or environmental groups do, the same information is likely to be more trusted and cause less worry than if the communication comes from a scientist who is a known advocate on one side or the other, or if the information comes from industry, or from a scientist supported by industry money.

This bears emphasis. The more the scientific work on non-linearity/hormesis is supported by industry, the greater will be mistrust among the press and public. The stereotype that money always corrupts is ludicrously unfair. (The problem, of course, is that money does corrupt science just enough to raise these blanket suspicions.) And the assumption that consumer and environmental groups are pure of bias is naïve. But these perceptions are real, and based on trust, which is one of the most powerful elements of our affective decision making. It is vital for anyone communicating about non-linearity/hormesis, or any risk, to recognize and respect the importance of trust.

CHOICE

When a threat is imposed, it causes more worry than when the same hazard is engaged voluntarily. The substances under scrutiny in toxicology and risk assessment are, for the most part, substances over which we have little choice. They are in our food and air and water, and we effectively have no say in whether we will be exposed, or at what levels. These potentially threatening agents are imposed on us. The suggestion that they might not be harmful, or might even be beneficial, will likely encounter resistance from anyone who, like most people, worries more about any risk that is imposed.

NATURAL OR HUMAN-MADE

The work of Slovic, Fischhoff, *et.al.,* has found that most people are more afraid of a risk that is human-made than a similar threat that is natural. For example, many people are more afraid of nuclear radiation than solar radiation, even though nuclear radiation is estimated to have caused 500 cancer deaths among more than 80,000 survivors of Hiroshima and Nagasaki over 60 years[13], while solar radiation causes approximately 8,000 melanoma deaths in the U.S per year[14]. The substances investigated by toxicology are mostly human-made. They are *by nature* more worrisome. Again, this bodes poorly for open minded acceptance of non-linearity/hormesis.

DREAD

This factor offers an explanation for why most people fear dying of cancer more than heart disease. In simple language, the more painful the consequences of a threat, the more fearful it seems. Most of the people in the courses I teach and audiences I speak to perceive cancer as a more painful way to die than heart disease. This probably helps explain why the United States has a declared "War on Cancer", but not an official "War on Heart Disease." In 2004 the National Cancer Institute had a budget of $4.7 billion[15]. In 2002, cancer killed 557,271 Americans[16]. That same year, heart disease killed 696,947[16]. Yet in 2004 the National Heart, Lung, and Blood Institute spent approximately $1.8 billion on all cardiovascular diseases[17]. The public demands more protection from threats that are more frightening because they involve more pain and suffering. This is yet another reason, and probably an important one, why many people are likely resist the idea that a little dose of a cancer-causing agent may not cause cancer, and may even be beneficial.

UNCERTAINTY

This is a simplified term for what the research refers to as 'knowable vs. unknowable". Can we see it, taste it, sense it in some way? Do we know who or what might harm us, where, when, how? Does science have all the answers (or at least most of them)? Does science have the answers but we can't understand them? If the answer to any of those questions is no, our ability to be rational is severely bounded, and we are likely to turn more to precaution as protection. Uncertainty is pivotal to the entire concept of the Precautionary Principle.

The substances considered by non-linearity/hormesis fit many of the characteristics of uncertainty. They are almost always beyond our conscious senses. We are exposed to many of them in ways of which we are unaware. Honest scientists acknowledge the uncertainty of their analyses of these substances. And most people, myself included, don't have the intellectual background and capacity to fully understand what science *does* know. For many reasons, there is a lot of uncertainty about these substances, and that is yet one more reason why non-linearity/hormesis will be difficult for many to accept.

A few qualifications on the above list.

- It does not claim to be comprehensive. It is one person's selective summary of *some* of the heuristics and risk perception factors that relate to the risk communication challenge facing advocates of non-linearity/hormesis.
- These heuristics and risk perception characteristics seem to be generally applied by most people. But on top of those general 'rules of thumb', our decision making also relies on the experiences and life circumstances that make each of us unique. So the factors listed can only be a general guide to people's perceptions of risk.
- Though they are listed separately, several of these factors are usually relevant to any given situation. Rarely is one heuristic or perception factor the sole determinant of affect, though frequently, one or two predominate.

- How these factors bear on risk perception is dynamic. As facts and circumstances change, each of these factors may be more or less powerful in shaping affect. Think of them in the metaphor of a set of scales, or a seesaw.
- In the simple terms of "How afraid are you?", I suggest these factors move perceptions one way or another, but do not make them absolute. That is, they make us more afraid or less, but not absolutely terrified or totally unafraid. They impact our perceptions in shades of gray, not black and white

RISK PERCEPTION AS A TOOL FOR RISK COMMUNICATION

As stated earlier, knowing why people feel the way they do is the first step toward respecting their perceptions. That, in my view, is a prerequisite for the honest respectful dialogue vital to effective risk communication. But if you ask ten practitioners of risk communication to define it, you'll get that many different definitions. As a 1986 summit of leaders in the field reported, "…there is no single overriding problem and thus no simple way of making risk communication easy. [18]" So while the following perspectives offer general guidance on risk communication as it relates to non-linearity/hormesis, I don't claim they are definitive. They are offered as suggestions.

- ***Include risk communication in decision making. Far more is communicated to people by what you do than what you say.*** "Risk communication…must be understood in the context of decision making involving hazards and risks, that is, risk management"[18]. Information that affects how people think and feel about a given risk issue is conveyed in many of the management actions an organization takes on that issue.

This means that risk communication should not be thought of as merely which words to use after policies are set. Risk perception and risk communication need to be incorporated at the decision making level of organizations, which means that ***organizations should include risk communication in the job responsibilities of senior managers, not just of the public relations or communications staff***. As the NRC report finds, "Risk managers cannot afford to treat risk communication as an afterthought," that comes at the end of the process after risk assessment has been done and policy set[18].

This particularly matters if risk communication is to build on the importance of trust. People measure the trustworthiness of a person or organization in all of what he/it does. So decisions on things like which financial support to accept, who to include on a board of advisors, how strident to be in one's advocacy, all help determine how trustworthy you will or won't be perceived. The more trustworthy, the more influential you are likely to be as a risk communicator.

- ***Trust is fundamentally important for effective risk communication, and it is on the line with everything you do.*** As important as trust is to the communication of non-linearity/hormesis, it merits consideration in more detail.

As Bennet and Calman observe, trust is determined in part by *who* does the communicating. "…messages are often judged first and foremost not by content but by the source: 'Who is telling me this, and can I trust them?' If the answer to the second question is 'no', *any* message from that source will often be disregarded, no matter how well-intentioned and well delivered."[19]

When the anthrax attacks took place in the fall of 2001, the principle federal spokespeople were the Attorney General, the Director of the FBI, and the Secretary of Health and Human Services, and not the head of the CDC or the U.S. Surgeon General, doctors likely to be more trusted than politicians. A survey by Robert Blendon *et.al.* of the Harvard School of Public Health, 10/24-28/2001, found that 48% of Americans would trust the head of the CDC as a source of reliable information in the event of a national outbreak of disease caused by bioterrorism. But only 38% would trust the Secretary of Health and Human Services (HHS), and only 33% would trust the Director of the FBI[20]. Had risk communication been considered by senior managers as the anthrax issue was beginning to develop, it would have been wiser to have the more trusted officials do the majority of the public speaking, which might have done more to help the public keep their concern about the risk of bioterrorism in perspective.

But trust is more than who does the talking. Trust is also heavily dependent on honesty. Honesty means many things, of course. As it pertains to non-linearity/hormesis, it means the advocates would be wise to temper their support for the idea with equivocation, and opponents should temper their resistance with openness. Absolutes are less trustworthy per se, and certainly create problems for trustworthiness when evidence develops that what you claimed is absolutely so, isn't. If evidence doubts the idea of non-linearity/hormesis, advocates should honestly acknowledge that information. If evidence supports the idea of non-linearity/hormesis, opponents need to acknowledge that evidence. Consider the statements of two prestigious science bodies on non-linearity and low dose radiation in 2005.

A news release summarizing the 2005 report from the National Academies of Science, "Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2", quoted committee chair Richard R. Monson, associate dean for professional education and professor of epidemiology, Harvard School of Public Health, as saying "The scientific research base shows that there is no threshold of exposure below which low levels of ionizing radiation can be demonstrated to be harmless or beneficial".[21] That is dangerously unequivocal, despite reasonable evidence to the contrary, as cited by the French Academy of Sciences just three months earlier. Consider the couched way that report summarized the issue. "…the use of this (linear no-threshold) relationship to assess by extrapolation the risk of low and very low doses deserves great caution."[22] Someone agnostic on the issue might judge the cautious statement of the French more honest than Professor Monson's certainty.

- ***Involve all sides to an issue in advisory groups or other mechanisms as the issue is being considered.*** This speaks to the importance of choice. Give people a say in their fate. Create mechanisms to provide input for relevant stakeholders. This is an important way to follow the widely-accepted recommendation that risk communication is more effective when it is an interaction, not a one-way process.

This input role must be more than perfunctory. Many government public hearing processes allow people to speak, but proscribe officials conducting the meeting from answering the public's questions and concerns. Such an interaction fails to give the audience a sense of control, and more, can destroy trust since it seems disingenuous to claim to want public input but then not acknowledge it with at least a reply.

- ***Acknowledge and validate the affective component of people's risk perception as you speak to them.*** Dialogue begins before you say the first word. Dialogue begins with acceptance of the realities of people's feelings, though their perceptions may seem to fly in the face of the facts. If you don't respect people's feelings, and try to make them understand the facts as you see them, you won't sound like you are trying to help them make an informed choice. You will sound like you're trying to convince them to make *your* choice. Their receptivity to your messages will likely be reduced. When you do respect their affective perceptions, and say so, receptivity to what you have to say will increase.

Advocates of non-linearity might consider saying things such as "I know it sounds really hard to believe based on everything we've learned about DDT up to this point, but…" **(insert description of hormesis here)**. This acknowledges the availability and representativeness heuristics. Or they might say "The way we assess the risk of these substances is designed to protect us from cancer, and as awful and painful as cancer can often be, we all want to use the most precautionary way to protect ourselves. I do too. But… **(insert description of non-linearity here)**. This acknowledges our intrinsically greater fear of threats that can cause more dreadful outcomes.

The important thing in the above examples is not the semantics. Note that the first thing said is an acknowledgement of the way people feel, not a factual argument in favor of your point of view.

- Finally, for effective risk communication, ***research people's perceptions of non-linearity/hormesis as much as you research the toxicology and epidemiology.***

"We wouldn't release a new drug without adequate testing. Considering the potential health (and economic) consequences of misunderstanding risks, we should be equally loath to release a new risk communication without knowing its impact."[23] It is intellectually inconsistent at best, and arrogant at worst, that scientists ignore or scoff at the need to understand people's perceptions. Why not do the same careful work on perceptions as they do on the risk assessment sciences with which they are more familiar? If they want to know whether a substance has a hormetic effect, they test that substance on animals. Risk communication should also be tested.

An empirical process by which to do this has been labeled the mental models approach. As its developers say "…in the absence of evidence, no one can predict confidently how to communicate about a risk. Effective and reliable risk communication requires empirical study. Risk messages must be understood by recipients, and their effectiveness must be understood by communicators." [i] The basic components of the mental models approach are:

1. Understand the mental model of the issue from the view of the experts in the field, based on review of the scientific literature and in consultation with those experts, that describes in detail the nature of the risk; its hazards, where exposures occur, the range of consequences, and the probabilities.

2. Understand the mental model of the issue held by your audience(s). Conduct open-ended interviews to find out what your target audience(s) already know or don't know about the risk.

3. Based on this first audience interview sample, create a questionnaire to administer to a larger sample to see how well the mental model of the smaller group corresponds to what the larger sample knows and doesn't know about the risk.

4. Draft risk communication messages that address incorrect beliefs and fill in knowledge gaps between what people don't know and what the expert model indicates they need to know. Pay attention to the tone and affective qualities of the messages.

5. Evaluate and refine the communication using one-on-one interviews, focus groups, closed-form questionnaires, or problem-solving tasks, trying to develop messages that have the most impact on the greatest number of recipients. Repeat the test-and-refine process until evaluation shows the messages are understood as intended.

CONCLUSION

The Roman philosopher Epictetus said "Men are disturbed not by things, but by the view which they take of them." Fear is not just the product of fact-based rational analysis. It is a product of everything we can bring to bear on choices about survival… the facts, and our feelings.

Risk communication must respect this affect heuristic. It must validate it, not dismiss it as irrational. Risk communication will be less effective if it relies only on the facts to try and get people to think and do what the communicator would have them think and do. Risk communication will be more effective if it respects the fact that feelings guide our decision making, lay people and experts alike. Understanding the specific affective characteristics of non-linearity/hormesis is vital if those who support it want the public to consider the radical and potentially threatening idea that small doses of dangerous things might not be dangerous, or might even be beneficial.

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FOOTNOTES

[i] *ibid*, p 182

RISK COMMUNICATION IN PRECAUTIONARY CULTURE – THE PRECAUTIONARY COALITION

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INTRODUCTION

The Canadian rock band *Rush*, on their 1984-album *Grace under pressure*, contemplates in *Distant Early Warnings* the worry and fear of the modern world: 'An ill wind comes arising Across the cities of the plain There's no swimming in the heavy water No singing in the acid rain Red alert Red alert.' Combined with the music the lyrics make for an ominous song filled with dread about environmental decay and nuclear destruction. This song is an expression of the antithesis of 'progress' of post-war civilisation when Western civilisation became distressed by stories and facts about pollution and the degradation of nature.[1]

Communicating about risks in a fearful society has proven to be a sustained conundrum. David Ropeik boldly addresses this issue. We fully sympathize with his objective to elucidate the problems thereof.[2] These problems come to the fore most forcefully in situations where the public is fearful while most experts think this is unwarranted. Ropeik focuses on hormesis and that is a special case in this context. Here the experts do not just maintain there is nothing to fear but go beyond that and claim that low dose exposure actually might be beneficial. As Ropeik later shifts his attention to the problems of risk communication more generally, so will we.

However, we would like to focus on the broader context in which risk communication, as described by Ropeik, takes place. We consider this context as a 'precautionary culture', which we will contrast with 'risk culture'. In the next section we briefly describe these two concepts in a strongly contrasting ideal type fashion.[3] This will show that beyond the usual factors that determine specific risk perceptions there is a more general outlook towards potential risks in which uncertainty and fear take centre stage.[4] In this climate, a precautionary logic comes to the fore that drives modern societies towards ever more stringent controls which, increasingly, use criminal law to assure compliance.[5]

Everyone who, like Ropeik, wants to promote rational risk policies is up against more than lay risk perceptions. This we shall stress in the third section, which focuses on some social actors that have strongly institutionalized interests in stressing the fearful nature of technology.[6] All of this bears directly on Ropeik's ideas for more effective risk communication. While he is right to stress that affect has to be taken seriously, in a precautionary culture this invites certain strategic problems. In the final section we offer our own thoughts on how to promote rationality in the ways our society dealt with uncertain threats.[7]

CULTURAL CONTOURS

'Unless we announce disasters, no one will listen.'
Sir John Houghton, first chairman of IPCC

During the 20th century the attitudes towards technology has changed dramatically. In very broad terms we see a shift away from a positive attitude, which stressed the opportunities for social and personal growth. A very good example of this positive, technology-embracing attitude is the way president Eisenhower presented the plans for the development of nuclear energy.[8] More and more since the 1970s we find a sceptical or outright negative, distrustful attitude towards science and technology.[9]

Living in industrial society, 'risk culture', as Beck would have it, governed the outlook on life.[10] Confidence in science and technology and support for their use in industry in order to alleviate society's predominant problem, which is poverty and hunger, is dominant. The logic of wealth distribution on account of economic growth is the primary goal of 20th century public policies, and industry is the tool for its attainment. Certain problems with industrial production are acknowledged and tackled, but the principal goal remained growth. Goklany describes this well in his *Clearing the air*, which shows that already around 1850 we find the first protests against air pollution *and* the first policies that try to do something about it.[11]

The issue of workman's injuries, an important aspect of industrial growth, was increasingly dealt with in insurance schemes. In fact, insurance is a crucial characteristic of risk culture. It shows, for instance, our trust in (actuarial) knowledge. More importantly, it shows our acceptance of the occurrence of accidents. By creating insurance schemes society acknowledges that it is impossible and undesirable to prevent all accidents. Instead, their occurrence is accepted provided that the victims can be compensated for their damages. It was left to the captains of industry to fine-tune their production to the optimal balance of compensation and prevention.

Economic rationality, therefore, was a crucial component of the risk culture. The major problem in this context was the incorporation of external damages into the industrial production schemes and their insurance back-ups.

Strong overall economic growth created the opportunities for the development of the Welfare State. We have to acknowledge that different nations created welfare regimes with different mixes of private and public insurance schemes. Nevertheless, during the 1960s Western industrial societies largely solved the basic problems of poverty. Simultaneously, life expectancy grew as for instance life became safer. Fewer accidents happened and the dwindling amount of victims (relative to the 'Dickens period') were compensated for their damages progressively more expansively. As accidents became less frequent they also became less acceptable. People moreover became accustomed to the fact that they were not individually held responsible for their mishaps. On the contrary, the industrial and social 'system managers' were increasingly held responsible for accidents which they should have foreseen and prevented.

In modern Western societies, as material needs are met for most people, the logic of wealth distribution that has shaped the Western world, loses its immediate relevance, subsequently assenting to the logic of risk distribution.[12] A society in which citizens are privileged to enjoy and value their health, wealth, safety, security, and longevity paradoxically becomes gripped by the hazards and potential threats unleashed by the exponentially growing wealth-producing forces that mark the later stages of the modernisation process.[13] As Beck asserts: 'The driving force in the class society can be summarized in the phrase: *I am hungry!* The collective disposition of the risk society, on the other hand, is expressed in the statement: *I am afraid!*'[14] Industrial society with its risk culture thus developed into risk society with, is our contention, a precautionary culture. With the rise of risk society came a different attitude towards industry and technology: the solution became the problem.[15] What is more, ecological tenets gained prominence.[16]

Concomitantly, in economically and industrially highly developed societies, diverse regulation of a mainly precautionary nature[17] has found its way into many areas.[18] Societies' shift to a culture of precaution galvanises citizens' insistence on *advance proof* that activities and products pose no risk to human and environmental health, especially in the long term. Uncertainty has become central. Not so much science, but available scientific knowledge becomes the bone of contention in contemporary culture. Then again, scientists are quite aware of the limitations of scientific knowledge. Within science verification is beyond our capabilities. Indeed, examples abound in which science comes up with surprising new insights overturning old ideas and concepts. In the celebrated BBC documentary *The Ascent of Man*, Jacob Bronowski memorably assessed what science in fact *is*:

'… Science is a very human form of knowledge. We are always at the brink of the known; we always feel forward for what is to be hoped. Every judgement in science stands on the edge of error and is personal. Science is a tribute to what we *can* know, *although* we are fallible. In the end, the words were said by Oliver Cromwell: 'I beseech you, in the bowels of Christ, think it possible you may be mistaken.'

When we expand our demands for safety, as precautionary culture does, into a by definition *unknown* distant future, the confines of even our best scientific knowledge will surface progressively more poignantly. Here we enter the realm of uncertainty. And scientists warning about what can go wrong are much more trustworthy then scientist that try to tell us there is very little chance for worst-case scenarios.[19]

In this context the precautionary principle is developed. There are almost as many definitions of this principle as there are treaties that incorporate it. However, for the sake of brevity and clarity we can state it in the following fashion, which stresses the characteristic triple negative formulas most often used: uncertainty about possible damage is not a valid reason to abstain from or postpone protective action. This principle is the ideal type expression of the 'better safe than sorry' attitude, which Ropeik and many others find so worrisome. An integral part of the attitude that promotes this principle is the statement that 'absence of evidence is not evidence of absence'. This statement –which is a logical truism and therefore empty– offers the rationalization for the continuance of fear even when an extensive search for empirical evidence has not been successful.[20]

Proposals like the ones Ropeik puts forward can be described as attempts to promote the attitudes of the risk culture against the presence of precautionary attitudes. By framing Ropeik proposal thus, we stress that there is a much broader context, which influences the risk communications about specific issues, than affect heuristics. We do not claim that today the precautionary culture is overriding. We do claim, however, that it is a cultural repertoire that is readily available to be used by those who have an interest in doing so. This is the topic of our next section.

VESTED INTERESTS IN FEAR AND PRECAUTION – THE PRECAUTIONARY COALITION[21]

From the 17th century onwards, the long experience in the Western world with the concept of balancing powers within society, teaches us that opposing forces in society should not be trusted on their intentions, but on their constructive societal results. Coldly stated, there is no reason to trust the advocates of the precautionary approach beforehand because we trust the cautious scientific community and environmental NGO's or distrust the business community and governments. As the precautionary principle is put forward as a counterforce to the hubris of science and business interests then who are its adherents?

We can firstly ascertain that uncertainty, even distrust, has become an important source for scientific investigation as such. Today, there are a vast number of academic disciplines that focus on the problems man produces through science, technology and industry. Rachel Carson, or indeed the Club of Rome could not have foreseen this tremendous increase in the number of concerned scientists

having a professional career focused on elucidating the impact of man on the planet. However, it is not only at the level of academic studies that the focus on technological risks has gained prominence. All those academics hold positions in institutions that are expressly created to further the social, political and economic awareness of the problems technology poses for our environment and our health. One particular example is the European Environmental Agency, which published *Late Lessons from Early Warnings*, in which, among many other things, it was remarked about chemical technology that '... their very novelty might be taken as a warning sign'.[22]

In order to be accepted among fellow professionals, within such institutional context, individuals have to take their duty to warn against possible problems – that could be potential disasters – very seriously. They similarly have an interest in keeping their job and in promoting the interests of their organization. We do not mean to say this is *all* manipulative strategic action, far from it. Because of their training, their self-esteem and their job satisfaction the scientific professionals in these organizations *must* believe that what they do is essential to the welfare of society. In other words, their professional convictions are truth-conducive.[23]

One of the drivers of such organisations is to point to a constellation of vested interests, which influence the debates on truth.[24] Obviously, as far as such analyses are valid, they apply equally to the precautionary coalition of which environmental and consumer NGOs, apart from sections of the scientific community, are important contributors. They have their own political agenda. The precautionary principle has given NGO's a weapon to fight against business corporations that might be subdued by precautionary-inspired environmental legislation. Consumer organisations are, by their nature, obliged to find potential harm caused by technology; it is their *raison d'etre*. They have been successful in cultivating their image as champions for the good society. This sometimes obscures the fact that, like any other organization, their first interest is their own continued existence. This means they need a steady cash flow. Consider, from this perspective the following quote from the www.wwfplush.com website: 'Passionate, optimistic, credible, and inspiring. That's what the WWF Plush Collection stands for. When you buy these beautiful animals, you contribute to a future in which humans live in harmony with nature.'[25]

A third party in the precautionary coalition are supra-national political bodies. Through the politicisation of the European consumer, with the introduction of accountability as the market was deregulated in the 1980s with the obvious loss of political power of the nation state, EU governments (re-)established their legitimacy.[26] Through the institutionalisation of uncertainty and mistrust, regulation of an in essence deregulated market was established. The insistence on advance proof, with the aid of the precautionary principle, that products are safe galvanizes consumer-suspicion even further, for which increasing amounts of regulation is required. Fourthly, the mass media is a key coalition partner as it is well-equipped to find stories of harm, guilt and blame. The distrust of technology and science has grown into a profitable business. As Forbes remarks in relation to the BSE-episode in the UK: 'Fears about the safety of beef bloomed like so much algae under the heat of the *Sun* and other media exposure.'[27]

From this and the prior section we can observe that the kind of risk communication Ropeik tries to promote is up against strong countervailing powers. Even with the best of intentions and supported by strong scientific consensus, people who want to make sure that 'the facts' get a fair hearing, have more to worry about than citizens who are disinclined to believe them. The starkest example of this is the treatment of climate skeptics and CEOs of the oil and energy companies. Because the science is supposed to be settled, there are those who try to bar the skeptics from participating in the public debate. For the same reason the CEOs of companies like Exxon are branded for financing misinformation. NASA's Jim Hansen, in a statement to the House Select Committee On Energy Independence And Global Warming, has gone so far as to affirm that these 'CEOs of fossil fuel energy companies know what they are doing and are aware of long-term consequences of continued business as usual. In my opinion, these CEOs should be tried for high crimes against humanity and nature.[28]

Admittedly, this is an extreme example yet it is precisely in such impassioned contexts that Ropeik's proposals for effective risk communication are important. In the next section we explain some ideas, which we feel are important in this respect.

SOME THOUGHTS ON EFFECTIVE RISK COMMUNICATION IN A PRECAUTIONARY CULTURE

Ropeik rightly stresses the need to take subjectivity seriously when the goal is to defuse heated debates on environmental and health problems generated by technology. It will not do to just try to get the 'bare facts' across. We think Ropeik's concrete proposals are valuable, but we also contend that the problem he discusses is fundamental. Not only do we need to consider the points we made above. We also think there is a real dilemma here, regrettably one that in general cannot be solved in straightforward terms.

We like to put this dilemma in the following way. On the one hand democratic governments are obliged to take their citizens seriously. This is true even when the citizens are 'irrationally' afraid for things that all experts agree are not dangerous at all or at least much less dangerous than people usually think. For a number of reasons – one being political suicide and another paternalism – it will not do to just tell the public 'not to worry'. On the other hand, however, democratic governments have a duty – often inscribed in law – to provide as much good for society as it can generate from the public means. The duty of wealth distribution is a strong driver of numerous public policies in diverse fields. These two duties in not a few instances do not match up. Margolis terms this conflict persistently as 'expert/lay controversies'.[29]

Margolis' book was published over ten years ago and tells us that this kind of controversy tends to persist for a long time. Take for instance the fear for EMF radiation, which are transmitted by radar

and power lines, computer screens and UMTS masts.[30] Billions have been spend on research and the science remains clear: the feared health problems are not associated with this kind of radiation. Nevertheless, precautionary proponents usually succeed in convincing new groups of people to be afraid of new EMF sources. What we witness here is a continued contestation over the 'truth' as part of a power struggle, which also is an ideological struggle.[31]

At one side of the ideological rift we find Ropeik, Margolis and many others, including the authors of this contribution. They are rooted in industrial society and its corresponding risk culture. The primary societal goal thereof is development and growth. In order to bring that goal closer, this side of the debate stresses that we need to take the best available scientific knowledge seriously in order not to misspend public funds. On the other side we find people firmly rooted in risk society and precautionary culture, and strongly convinced of the crucial importance of ecological tenets and goals. They are the ones who will stress the importance of taking the public fears seriously. In recent proposals for new forms of governance, transparency and participation are stressed, and the expert/lay distinction is disqualified: experts are handicapped by the fundamental limits of specialized and fragmented science, and lay people's knowledge is praised as that of 'user experts'. This kind of attitude can be labeled 'subjectivity realism'.[32] With reference to the classic Thomas theorem, the subjective realists stress that when people think something is real, it will become real in its consequences.[33]

Incontrovertibly, the most critical and most volatile problems cannot be solved without the effective marshalling of expert scientific knowledge and judgment. We should not include lay knowledge into science, peer review or anywhere else. These are in fact opinions that need to be interrogated just as much as scientific evidence itself. 'We owe a debt to those who, in the past, were prepared to put their heads above the parapet of perception, prejudice and power, in order to expose the real workings of the world. This was not done by accommodating to majority, or even minority, views.'[34] This is not to say that science has a monopoly of some sorts or another. As Noam Chomsky puts it: 'Science is tentative, exploratory, questioning, largely learned by doing. One of the world's leading physicists was famous for opening his introductory classes by saying that it doesn't matter what we cover, but what we discover, maybe something that will challenge prevailing beliefs if we are fortunate. …'[35] Therefore, the only way out of the conundrum we sketched above is to reiterate the values of knowledge, information, education, ethics of responsibility and the individual capability of judging freely.[36]

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In a Dutch advertisement showing a close-up of a polar bear's head, the WWF, in collaboration with a major department store, this collection is promoted with the following text: 'It is now or never for the North pole. Buy your favorite polar animal from the WWF plus collection now and contribute to a white Northpole.'

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29 See Margolis, note vii, p. 1.

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RESPECT FOR LAY PERCEPTIONS OF RISK IN THE HORMESIS CASE

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INTRODUCTION

David Ropeik has written an excellent introduction to the literature on risk communication, together with a thoughtful application of this material to the hormesis case. In the present commentary, I focus on one particular theme that runs through much of his piece: his emphasis on *respect* for the risk perceptions of laypeople. He even defines risk communication as "Actions, words, and other interactions, that incorporate and respect the perceptions of the information recipients, intended to help people make more informed decisions about threats to their health and safety." I heartily support his emphasis on respecting the perceptions of information recipients, and I want to explore this idea in somewhat greater detail. The first section of this paper highlights some important ambiguities in the notion of respecting people's risk perceptions. The second section then develops some normative reflections about what respect for lay risk perceptions ought to involve. I conclude by applying these ideas to the hormesis case, suggesting that respect in this case should involve instituting the sort of analytic-deliberative risk characterization framework proposed by the National Research Council in its volume *Understanding Risk* (1996) (see Elliott 2008a).

THE AMBIGUITY OF RESPECT FOR LAY RISK PERCEPTION

The notion of "respecting" the risk perceptions of information recipients is ambiguous. In many cases, respect for others and their beliefs involves holding them in high regard, esteeming them, showing deference, or possibly even being obedient to them. It seems unlikely that Ropeik thinks that we should generally respect laypeople's risk perceptions in these ways, however. Consider, for example, the cases of "irrational" risk-related decisions that Ropeik considers at the beginning of his paper. Perhaps the most vivid example is the thousands of Americans who chose to travel via car rather than plane in the months after the September 11 attacks. As a result, it appears that there were about 1,000 more deaths from car accidents than would have otherwise occurred. In cases like this one, Ropeik does not give the impression that he would want to respect laypeople's risk perceptions by holding them in high regard or showing deference to them. Instead, one suspects that he would respect them in a much weaker sense—perhaps by acknowledging that there are understandable reasons for their faulty judgments and by insisting that problematic perceptions should be corrected in a considerate fashion.

There are two extreme positions that one might take when reflecting on how to respect laypeople. A "technocratic" position would regard information recipients as simply wrong if they disagree with expert risk perceptions. For the technocrat, respecting the risk perceptions of laypeople would involve regarding their mistakes as understandable consequences of human emotion and "bounded rationality." On the opposite extreme, a "relativist" view might hold that respect for risk perceptions requires that one regard each person's perspective as equally valid. The relativist would insist that it is disrespectful to criticize or question any one else's perceptions of risk. Stated so baldly, most analysts would probably want to avoid either extreme. Contrary to the relativist position, it seems obvious that information recipients sometimes have false or misguided beliefs. The technocratic position might appear to be more tempting, but the later sections of this chapter highlight cases in which laypeople can make legitimate contributions to risk assessment.

A recent interchange between some of the leading lights in risk analysis and perception illustrates some of the positions that commentators are currently taking on the question of how to respect the risk perceptions of information recipients. The influential law professor Cass Sunstein argues for something close to a technocratic position in his recent book *Laws of Fear: Beyond the Precautionary Principle* (2005). Like Ropeik, he emphasizes a number of heuristics and biases that cause people to misjudge the probabilities of various hazards. Moreover, he argues that experts are less likely to make mistakes as a result of these biases, because they more frequently employ calculative "System II" modes of reasoning (as opposed to intuitive "System I" reasoning) in an effort to analyze risks. Therefore, he insists that "if highly representative institutions, responding to public fear, are susceptible to error, then it is entirely appropriate to create institutions that will have a degree of insulation. Democratic governments should respond to people's values, not to their blunders" (2005, 126). One of his preferred strategies for shielding decision makers from the false risk perceptions of the public is to perform cost-benefit analyses (CBA). He believes that experts performing CBA can make a good start at regulating hazards by integrating probability assessments of hazards (provided by experts) with monetary measures of how much the public disvalues those hazards (as revealed through market behavior).

In an extensive review of Sunstein's book in the *Harvard Law Review* (2006), Dan Kahan, Paul Slovic, Donald Braman, and John Gastil (hereafter KSBG) criticize Sunstein's technocratic perspective. They argue that he pays inadequate attention to the "cultural theory" of

risk that Ropeik acknowledges briefly in his own piece (see Douglas and Wildavsky 1982). In particular, they provide empirical evidence that people's cultural world views (i.e., their views about what makes for a good society) have a significant impact on their risk perceptions—and this holds not only for laypeople but also for experts. "Egalitarians" and "solidarists" rate risks associated with environmental hazards like global warming, nuclear power, and pollution more highly than "hierarchical" and "individualist" thinkers do. In contrast, "hierarchists" and "individualists" rate the risks of restricting gun ownership (thereby undermining the ability of citizens to defend themselves) more highly than other groups. Moreover, "hierarchists," but not "individualists," worry a great deal about societal risks from drug distribution, promiscuous sex, obtaining an abortion, and contracting AIDS from surgery. KSBG sum up their findings by stating that "citizens invariably conclude that activities that affirm their preferred way of life are both beneficial and safe, and those that denigrate it are both worthless and dangerous" (2006, 1105). Therefore, they claim that Sunstein's rejection of public risk perceptions in fact constitutes a disrespectful overriding of public *values*, not just of their *blunders*, because values play an important role in both expert and lay risk perception.

HOW NOT TO RESPECT LAYPEOPLE'S RISK PERCEPTIONS

Having highlighted some of the ambiguities surrounding "respect" for lay risk perceptions, I want to provide some normative reflections on how we ought to go about respecting laypeople. This section highlights four reasons to avoid drifting toward a technocratic approach, in which expert risk perceptions are automatically privileged relative to the perspectives of laypeople. These arguments do not yield a simple answer for how to assess risks, but as a group they do suggest that an approach like Sunstein's (in which only the probability assessments of experts are granted legitimacy) is problematic. Risk assessments should generally leave room not only for expert analyses but also for input from laypeople.

The first, "ethical," argument against automatically privileging expert risk perceptions is that people arguably have rights to play a role in deciding how to respond to risks that significantly affect their well-being. As Kristin Shrader-Frechette puts it, "If my ox is in danger of being gored, I have the right to help determine how to protect it, even if I may be wrong" (1995, 117). This ethical argument is far from conclusive, however, because it is not clear that policy makers are always under an ethical obligation to accept people's desires when those preferences are based on erroneous information. Therefore, fully evaluating this ethical argument would require analyzing the conditions under which paternalism (i.e., sacrificing people's self-determination for the sake of their well-being) is justified in public policy making. It would also require evaluating how much influence laypeople need to have over public policy in order to respect their rights to self-determination.

Another objection to the ethical argument is that, even if it were successful, it might require only that lay risk perceptions be allowed to *influence* policy making, not that they be regarded as factually *legitimate*. Thus, one could accept the ethical argument while holding that experts have the responsibility to do everything possible to correct and eliminate faulty lay risk perceptions so that they do not corrupt the formulation of policy. Proponents of the ethical argument are likely to respond that, even if experts do have privileged knowledge about probabilities, the riskiness of an activity involves not merely those probabilities but also a range of ethical considerations and consequences. These include the *distribution* of costs and benefits, as well as whether there is *due process* and adequate *compensation* when imposing potential costs. Moreover, the presence of these ethical considerations challenges any simple description of risk perception as a combination of only "rational fact-based analytical thinking" and "affect" (as Ropeik seems to do in his paper), because it is not clear that ethical reasoning falls neatly in either category (Korsgaard 1986; Sagoff 1981).

In evaluating the ethical argument, thinkers like Shrader-Frechette and Sunstein are likely to reach an impasse, based on an ontological disagreement about the nature of risk. Sunstein defines risk as the probability of a hazard, and he focuses on hazards that are easily quantifiable by experts (e.g., fatality). Therefore, he acknowledges that the public should play a role in evaluating ethical consequences (like whether there will be due process in imposing the risk) while insisting that those factors are distinct from the assessment of risk itself (which should be left to experts) (see Sunstein 2002). In Shrader-Frechette's view (1991, 58), it is dubious to define risk in such a way that the hazard includes only fatality and not a broader range of ethical and cultural consequences (see also NRC 1996; Slovic 1992; Thompson 1999). She appeals to psychological research, indicating that the public sometimes distinguishes between the *probability* that a technology like nuclear power will result in fatality, as opposed to the *riskiness* of the technology (Slovic et al. 1980; Slovic 1992). As KSBG emphasize, if one includes ethical and cultural factors (rather than merely the probability of fatality) as part of the concept of risk, then allowing the public to have a say with respect to these ethical issues entails allowing them to contribute to risk *assessment* and not merely the *management* of risks that experts have already quantified.

A second, "conflicted-interests," argument provides reason for questioning expert risk perceptions even if one grants that the concept of risk involves only the probability of a straightforwardly quantifiable hazard like fatality. According to this argument, laypeople have reason to be suspicious of expert risk analyses, because those studies are often affected by conflicting interests (Rampton and Stauber 2001). Industry groups are notorious for manipulating and even falsifying scientific results in an effort to minimize the risks associated with their activities (Beder 2000; Fagin et al. 1999; Markowitz and Rosner 2002). Moreover, Sheldon Krimsky (2003) argues that university researchers have become increasingly likely to be affected by these corporate influences (see also Elliott 2008). Federal regulatory agencies also often appear to be "captured" by the businesses that they are supposed to be regulating, with "revolving doors" between high-level corporate jobs and government posts (Shrader-Frechette 2007). Furthermore, conflicts of interest are not

associated only with industry; one might raise similar worries about the ability of scientists affiliated with environmental groups to supply neutral risk assessments. Partly because of these dynamics, conflicts over risk do not typically involve experts uniformly arrayed on one side of an issue, pitted against laypeople on the other side. Instead, some experts (and laypeople) are typically arrayed against other experts (and laypeople) (see Kahan et al. 2006; Rampton and Stauber 2001). Given this context, it seems quite rational for members of the public to regard expert risk perceptions with a healthy dose of suspicion.

The third, "tu quoque," argument provides reasons for doubting expert risk perceptions even when experts are free of conflicting interests. According to this argument, experts exhibit the same sorts of mistakes and influences as laypeople when they perceive risks. For example, a central theme of the KSBG response to Sunstein is that experts as well as laypeople are influenced in their risk perceptions by their cultural perspectives on what constitutes a good society. They note that gender, political ideology, and institutional affiliation (academic or industrial) predict systematic differences in expert risk perception (2006, 1093). They also appeal to empirical research indicating that the calculative, expert, System II reasoning that Sunstein lauds as a protection against error is actually vulnerable to a variety of biasing influences. In particular, defense motivation (the desire to protect one's existing beliefs) "biases individuals' use of System II reasoning, causing them to use deliberate, calculating, and methodological analysis to support beliefs dominant within their group and to debunk challenges to those beliefs" (2006, 1094).

Similarly, Daniel Kahneman and Amos Tversky, the psychologists who first highlighted many of the heuristics and biases that Ropeik described in his essay, showed that experts also display "bounded rationality" (Tversky and Kahneman 1982; see also Solomon 2001). This is especially disconcerting, given that expert risk assessors often have to rely on their own subjective probability estimates rather than actual frequency data about the hazards that they study. Unfortunately, as Roger Cooke reports, "Expert opinions in probabilistic risk analysis have exhibited extreme spreads, have shown clustering, and have led to results with low reproducibility and poor calibration" (1991, 40). In particular, Cooke explains that the "dramatically poor" calibration of expert opinion (relative to actual data) reflects a worrisome overconfidence bias (1991, 63). As an example, he describes a study that attempted to calibrate expert judgment about nuclear reactor safety. The study took subjective probability estimates for seven events (i.e., types of system failure) that were part of the classic WASH-1400 risk assessment and compared those estimates with subsequently collected frequency data about the same seven sorts of events. The calibration study found that the actual frequency data for *all seven events* fell outside the 90% confidence bands that the expert groups had provided with their subjective probability estimates. If the experts had evaluated the quality of their opinions properly, the actual frequency data should have fallen outside those bands in only one out of every ten cases (1991, 36).

A fourth, "socially-robust-knowledge," argument may provide the strongest reason for taking lay perceptions of risk seriously in the policy domain. In recent years, philosophers and sociologists of science have highlighted the complexity of the scientific research that informs political decision making (see e.g., Jasanoff 1990; Jasanoff 2002; Nowotny et al. 2001; Nowotny 2003). They have emphasized that, in addressing risks, scientists are frequently asked to address questions that stretch (or go beyond) the limits of their knowledge. Experts are then forced to make difficult judgments about which models to use, how to extrapolate beyond existing data, how to evaluate conflicting lines of evidence, and when to trust laboratory results as an adequate representation of what will happen in the "real world." In these contexts, it is easy for experts to misjudge the extent to which their knowledge is applicable to new contexts, and the "local knowledge" of laypeople can sometimes make a significant contribution to expert analyses. In a particularly famous example, Brian Wynne (1989) argued that expert analysts made serious mistakes when evaluating risks from radioactive contamination of British sheep following the Chernobyl nuclear accident of 1986. Notably, they failed to account for details of sheep behavior and soil type that were well known to the affected farmers. Other cases, including debates about GMO's, Gulf War syndrome, and mad cow disease, display similar dynamics. Thus, some sociologists have proposed that what we need to develop in the policy arena is "socially robust" knowledge that has been evaluated and accepted not only by scientific experts but also by a wide range of stakeholders (Nowotny et al. 2001; Nowotny 2003).

Together, these four arguments provide a strong case for taking lay perceptions of risk seriously in the policy domain. The socially-robust-knowledge argument stands well on its own. The other three arguments receive support from one another. For example, the tu quoque argument gains significance when it is conjoined with the ethical and conflicted-interest arguments. After all, even if experts sometimes make the same mistakes as laypeople, Sunstein would insist that policy makers are still likely to get better information over the long run by relying on experts. But Sunstein's position loses strength when one adds both the practical consideration that the expert assessments may be influenced by competing interests and the ethical consideration that, all else being equal, people ought to be able to make their own decisions about the risks that they want to face. To put it cynically, if the experts cannot even agree among themselves, why not let people "hang themselves" with their own limited risk perceptions rather than forcing them to be hanged by the questionable claims of experts? Fortunately, one does not have to make such a pessimistic "either-or" choice between appealing to experts or granting legitimacy to lay perspectives. In the concluding section of this commentary, I briefly suggest how one might incorporate both expert analysis and respect for lay risk perceptions in the hormesis case.

LESSONS FOR THE HORMESIS CASE

Over a decade ago, the National Research Council published a volume that provides a helpful model for avoiding both technocracy

and relativism. The book, *Understanding Risk* (NRC 1996), argued (along the lines of the socially-robust-knowledge argument) that risk characterization needs to incorporate a combination of expert analysis and broadly-based deliberation. It affirmed that analytic, "rigorous, replicable methods, evaluated under the agreed protocols of an expert community" are crucial components of good risk characterization (1996, 3). Nevertheless, it also insisted that these analyses ought to be framed by appropriate deliberation:

> Involving the spectrum of interested and affected parties in deliberation can make the process leading to risk characterization more democratic, legitimate, and informative for decision participants. It has this potential in several ways: improving problem formulation, providing more knowledge, determining appropriate uses for controversial analytic techniques, clarifying views, and making decisions more acceptable. (1996, 79)

The authors of the *Understanding Risk* volume acknowledged that it is not always easy to figure out how to integrate analysis with deliberation in actual practice, but they suggested a range of potential mechanisms: public hearings, citizen advisory committees and task forces, alternative dispute resolution, citizens' juries and citizens' panels, surveys, focus groups, and interactive technology-based approaches (1996, 199-205). Ropeik seems broadly sympathetic to these strategies, because he claims that we should "involve all sides to an issue in advisory groups or other mechanisms as the issue is being considered."

Based on the arguments listed in the preceding section, I suggest that adequate respect for lay risk perceptions in the hormesis case means that the expert research on this phenomenon should be contextualized with something resembling the deliberative mechanisms proposed in the NRC volume (see Elliott 2008b). The decision to ease regulations on normally toxic chemicals that are believed to be hormetic raises major concerns about environmental and public health. The ethical argument suggests that risk assessments and policy changes of this significance should receive significant public input. Moreover, as the conflicting-interests argument suggests, the public has reason to be suspicious of the fact that organizations like the Air Force and the chemical industry have helped to fund hormesis research (Kaiser 2003). I do not mean to imply that the research on hormesis is illegitimate or tainted because of its funding sources, but rather that it is understandable that public-interest groups would want to scrutinize this research with extra care because of the context in which it has been produced.

Finally, in accordance with the socially-robust-knowledge argument, applying hormesis to public policy provides an excellent example of the challenges involved in taking laboratory results and applying them to complex real-world scenarios. Much of the evidence for hormesis involves non-human organisms living under controlled conditions for limited periods of time. There are concerns about whether the same sorts of hormetic effects will occur on human beings of varying sensitivities and ages, experiencing exposure to multiple chemicals over extended periods of time (see Elliott 2006; Shrader-Frechette 2008). This appears to be exactly the sort of case where it is valuable to get a variety of perspectives from different constituencies so that we can see how "socially robust" the evidence for hormesis really is. Hormesis proponents have already made an effort to address many of the concerns raised by their critics (Cook and Calabrese 2006). Nevertheless, deciding how much evidence for hormesis we should require in order to change public policy is itself an ethically loaded question that merits significant deliberation (Elliott 2008b). Thus, I think that Ropeik's call to respect lay risk perceptions in the course of risk communication is both timely and important, and I contend that it should be interpreted in a way that promotes deliberations of the sort proposed by the NRC (see also Elliott 2008a).

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COMMENTARY: RISK COMMUNICATION AND NON-LINEARITY

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Dr. Ropeik presents a timely contribution to the on-going debate about scientific challenges to the traditionally used dose-response model in risk communication and risk assessment. Numerous scientifically defensible articles have been published showing strong evidence of hormesis making the application of low level non-linearity critical in a wide range of scientific, medical, regulatory, legal and societal implications.

His article addresses non-linearity from the perspective of risk communication and the perception of risk. In particular, Dr. Ropeik provides examples of the many problems associated with an individual's perception of risk and provides guidance regarding what needs to be done to aid individuals and groups to make more informed decisions about daily threats to their perceived safety. His central theme is that risk communication must be a two-way interchange between source organizations and the public or representatives who are the recipients of risk communication. His evidence would indicate that risk communicators have simply not been doing a good job of getting their message across. The author clearly outlines the hurdles hormesis must overcome to be accepted by the general public, regulators and the legal system.

There is no doubt that successful risk communication is an interactive process of exchange of information and opinion among individuals, groups and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangement for risk management. In the absence of evidence, no one can predict confidently how to communicate about a risk.

This article focuses on improving the understanding of what the problems are in today's attempt in communicating risk. For individuals to consider that below a threshold dose, at which no adverse effects occurs, and that even smaller doses of a dangerous substance may actually simulate activity and be beneficial, requires an honest and effective communication of the perceived risk. The author fully recognizes that making decisions about risk is complex, whether done individually or as a part of a larger social-polical process.

The authors have successfully interpreted a wide range of evidence and interpretations of the concept of non-linearity and hormesis focusing on risk communication. While this presentation will be of interest to individuals who are familiar with homesis and non-linearity, it could also have a major impact if it were to be published in a popular magazine(s) that would enhance the ability of lay people and groups to understand and participate in their own risk management activity and influence how they think about the concept of risk. In other words… risk communication.

DOSE-RESPONSE MODELS: HOW MIGHT WE *THINK* ABOUT LINEAR AND NON – LINEAR?

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ABSTRACT

We add to the issues raised by Dr. David Ropeik's paper *Risk Communication and Non-Linearity* (forthcoming, *BELLE Newsletter,* 2008) regarding the thinking about the acceptance of linear and non-linear (hormetic) dose-response models. We summarize some of the perceptual aspects discussed by Ropeik (2008) and comment on decision-making by the single decision-maker. It seems that the heuristics discussed by Ropeick (2008) are related to those private decision-makers who may not benefit from extensive technical, scientific, and legal advice sufficiently to make well-informed decisions and, perhaps more importantly, may not have the funds for that advice. Dose-response models are intangible, abstract quantities: unlike private goods and services, they are not priced by the market. We suggest a duality between the private and the public decision-maker that, in the end, may loose its crispness, because it can occur in the same person. Nonetheless, this duality is evident at the *analysis* phase of decision-making, relative to the *decision* phase, and thus provides a convenient way to address the issues developed by Ropeik (2008). In particular, for a least legal and common sense reasons, the public decision-maker must follow a scientific-analytical causal process – as represented by models of dose-response -- to select and justify her choice of one over the other. Whether the final *decision* as to which model is to be used in regulatory law is a matter that goes beyond the analytical aspects of the choice and is governed by political and other aspects of governance.

Key words: Linear, non-linear dose-response, causality, risks, decision analysis, paradoxes.

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INTRODUCTION

Society increasingly faces a serious, possibly paralyzing, but invariably very costly, paradox: as individuals, we often concentrate on hazards that are not factually significant, but cavalierly confront hazards that can ruin us. For example, we – as private decision-makers -- enter into contractual arrangements without help from unbiased experts, and accept financial balloons (that blow-up when due) because we believe that real estate values will always generate increasing amounts of equity. More generally, as individual decision-makers, we seem not correctly to focus on numbers such as magnitude, probability, and severity of the outcomes from many perceived hazards; we disregard the probable impact on our actions by things over which we have no control. Nor are we able to deal with the calculus that allows us correctly to assess with uncertainty, such as that measured by probabilities, and thus make decisions that are incoherent. This paper tries to bridge over this paradox.

The paradox may be due to brain physiology: the immediate response *fight-or-flight* is dictated by of a brain compartment (the amygdala), with higher levels of analysis following in other regions of the brain. But, by then, the first impression of the hazard has made its mark: it stays with us. In this case, perhaps, there is not a paradox: we have the *Eureka Hunt*[2], which is however unexamined by the surviving smoke jumper: he is reported to say that what he did ... *just seemed to be the logical thing to do*. This sort of reasoning-response is not at all what we address. We are concerned with public choices between completely different processes of disease at low dose-rates: the scientific issue is that there are two – diametrically opposite causal alternatives; the management issue is that we do have the time and the science to assess them.

_J_-shaped *v.* linear at low doses model (LNT): private versus public decision-making for reducing cancer risks.

Our legal system requires a formal, validated causal basis for justifying a public decision-maker's choice of standard or guideline number (Ricci, 2006). Unlike private individual decision-makers, public decision-makers must legally have studied the theoretical and empirical basis of causal models – from the set of alternative models -- that they opt use to regulate human or ecological exposure to hazardous agents because it is that choice that determines their eventual decision to either act in a certain way (e.g., regulate or ban) or not to act. More specifically, in the context *J*-shaped *v.* linear at low doses model (LNT), using either of these dose-response models provides the causal basis for environmental and health protection. Here, exposure probably causes either an adverse or a beneficial response at low doses. Thus, understanding

[2]*The New Yorker*, (July 28, 2008) examines how one of other 13 smoke jumpers opted for a particular strategy to survive – and did -- the fire that killed those 13. The decision involved start a localized fire, within the major fire that surrounded him, following it as it burnt an formed an island of burnt grass, laying down and breathing air a few inches above the soil, using a wet handkerchief as a mask.

why these different theories are maintained, in the face of much empirical evidence to the contrary, involves perceptions and numbers that are often misunderstood or misused, or both. Moreover, much has been said about hazard *control* and *familiarity* – real or perceived: the private decision-makers may dread a hazard more than another, if they have less control over it.

Ropeik's is quoted in *The New York Times* (Dec 4, 2006, p. 68) as saying that dread of flying after the 9/11 terrorist attack on United States, *the 9/11 effect … produced a third again as many fatalities as the terrorist attacks*. Driving was felt to be safer than flying.

What about the public decision-makers? *The New York Times* (Dec 4, 2006, p. 71) states (about the *1%* doctrine) that the:

… White House determination that if the risk of a terror attack in the U.S. is even 1%, it would be treated as if it were a 100% certainty.

They are not immune to false perceptions. Although this Administration's doctrine may be relevant to political, or perhaps strategic, justifications for a *decision*, it cannot be squared with the analysis of risk of each action open to the Administration. For it is the *analysis* of risks that identifies the optimal choice, if it exists, and contributes to arguments necessary for well-informed decisions when societal stakes are high.

Regarding expert opinion, it seems that that it is also questionable. *The New York Times* (op. cit, p. 71) describes the results of a study done by Fischhoff, in which he is reported to have:

asked 20 communication and finance experts what they thought the likelihood of human-to-human transmission of avian flue would be in the next three years. They put the figure at 60%. He then asked a panel of 20 medical experts the same questions. Their answer: 10%.

But, at the time this article was written, no one had been killed by avian flue in the U.S. (U.S. data from 2003, *The New York Times*, op. cit.). One might argue that the physicians provide a better probability than the non-expert. They, on the other hand, might as well guess.

These three situations are disassociated from the amount of analysis that should buttresses them: in none of them the time and expertise necessary to assess the optimal outcome is sufficient. Roughly speaking, the first situation involves no explicit calculations, seemingly it is a choice that avoids a fearful event; the second is a policy fiat; and the third seems to point, at least in part, to ignorance of the base rate. We suggest that rational decision-making is the benchmark, if not the hallmark, of reasoning about linear and non-linear dose-response models.

REASONING FRAMEWORKS

Rational decision-making is the core of many of the issues that Ropeik (2008) discusses. Herbert Simon (1957) defined decision-makers to be *substantially rational* if they use theoretically sound decision criteria, such as the maximization of the expected utility, to select the optimal choice. Simon's *procedural rationality* occurs when a decision-maker follows a process in which duration and intensity vary according to the perceived importance of the problem. Whether a decision-maker should make a *decision* -- for the action that *on paper* and as result of a decision-theoretic analysis from which, according to a suitable criterion (maximizes the net expected benefits), the optimal choices is identified -- is beyond the scope of this paper. The actual decision can involve political and geopolitical, ideological, and social welfare (welfare economics/public administration) aspects. Many studies that dealt with perception have used private decision-makers. Some argued that the respondents, often graduate students and in classroom settings, might not be the appropriate models for understanding *socia*l decision-making. It is hard to conceive a realistic classroom experiment in which the pros and cons of the *J*-shaped and the linear, no threshold cancer models are discussed and the correct model obtained, as we will discuss later in this paper.

Choosing between different and possibly alternative causal models for regulatory law and policy goes beyond any analogy to individual – microeconomic or behavioral economic -- consumer choice. We see no obvious commonality between reasoning about the causal effect of low dose rates on a specific cancer, involving complex biological pathways, genetics, molecular and cellular biology that are formalized mathematically as system of differential equation, the solution of which then requires statistical estimation of the parameters of the solution to those equations, and consumer choices involving a product or service. The context of Ropeik's paper and ours is removed from most common experiences. For example, policy choices based on either of these models result from using a very low doses and risks (the latter being almost infinitesimally low probabilities of cancer over back ground rates). Those probabilities have often been stated as one in a million (individual excess lifetime cancer risk) that cannot be related to everyday's consumer choices as those are nowhere near the actual consumer's sense-perception-beliefs or even to matters studied in basic statistics (as a reminder, a commonly thought statistical level of significance is a chance that equals *0.05*, leading to the rejection of the null hypothesis).

Both pubic and private decision-makers must first have a sound description – using formal methods to guarantee invariance as to the locus of application of those methods – of alternative actions, causation, and magnitude of the consequences of each action, while accounting for the probable occurrence of the consequences. Here, uncertainty is measured by probabilities, rather than by other representations of uncertainty such as possibilities. The analysis uses utilities, monetized values of deaths and illnesses or other outcomes that characterize the magnitude of the consequences. In particular, the linear or non-linear dose-response discussed by Ropeik (2008) are formal statements of causation that fall within risk assessment, guide risk management choices, and shape eventual decisions. Risk definitions are unambiguous: they may different from area or field of application but they are characterized by probability and magnitude of response. However, the individual perception of both of these can be ambiguous. In the context of communicating complex ideas about causal models --

rational decision-making is a sound and plausible guide for the individual social decision-maker because it provides a process that:

1. Is replicable and formal (e.g., it is axiomatic),
2. Is coherent (e.g., excludes actions that are equivalent to taking bets that result in sure ruin),
3. Accounts for uncertainty or risk by using the appropriate measures and calculus,
4. Is well-established in law and science,
5. Can account for departures from the initial axiom, and
6. Can be transparent and understandable by the stakeholders, who must be given the correct frames of reference and tools to assess risky or uncertain information.

Although we do not discuss communication, in the sense of Ropeick's (2008, and see Peters et al., 2008 for discussion of the communalities between media contacts and scientists), all our hazards-based choices are geared towards communicating ideas and facts to inform and convince stakeholders – the metaphorical *we* in the two issues:

1. We first should determine whom the *we* is.
2. Then the *we* should decide what is that *we* are talking about, and in what context: e.g., the personal and immediate as opposed to the abstract and removed.
3. Then *we*, with a stake in the matter, should establish why someone would use linear or non-linear dose-response models.

As to the first issue -- There are at least two *wes*: i) the individual decision-maker who acts for herself or her immediate group, and ii) the social decision-maker who acts for, and is accountable to, society. The context is the many agents (e.g., environmental chemicals, radiations, pharmaceuticals) that can be beneficial at very low doses but noxious at high doses. Most people heuristically know that some small level of exposure can be beneficial. Yet, it also appears that those same individuals, when confronted with potential (not yet implemented, and thus *on paper*, rather than concrete) choices that can lead to large statistical losses – with small probability of occurring – act in ways that differ from standard rationality. Their choice, when assessed against the maximization of net expected benefits, turns out to be an inferior one. So, for example, when faced with a lottery in which the expected value is larger than the certain outcome of smaller magnitude, there seems to be a majority view that the latter is preferable to the former.

As to the second issue -- The choices are: i) the *J*- or linear at low dose ones for cancer and, ii) in the toxicology, the *S*-shaped or threshold models versus inverse *J*-shaped model. Although the biological arguments made for the *J*-shaped model are symmetric to those that that apply to the inverse *J*-shaped model, there is a remarkable asymmetry between having to make an individual choice as a lay individual interested in the issue and a choice to be made in the public interest. The latter choice is made by an individual who acts in the public interest: an lay individual's choices cannot be equated with choices made by an individual who has the legal responsibility and accountability for the outcome of that decision. Thus, for example, even when given perfect information, one – as a private decision-maker -- can choose to act irrationally (e.g., make a decision that does not conform with the EUT axioms, discussed later) or, more simply, just ignore the best science or advice and even the optimal choice and proceed to drive recklessly (nonetheless being liable when someone or something suffers from the reckless *decision*).

Unlike the private decision-maker, the public decision-maker – e.g., the Administrator of a federal agency – must make decisions in the public interest and can, and probably will, be sued if that decision is seen to be based on personal beliefs. Fortunately, many of the issues developed by Ropeik (2008) apply there. We agree with Camerer (2003, citations omitted) that:

> *A large body of evidence accumulated over the last three decades shows that many people violate the rationality and preference assumptions that are routinely made in economics. Among other things, people frequently do not form rational beliefs, objectively irrelevant contextual details affect their behavior in systematic ways, they prefer to be treated fairly and resist unfair outcomes, and they do not always choose what seems to be in their best interest. It seems obvious that these violations of the rationality and preference assumptions will appear in the behavior of aggregate entities like markets and organizations or in political processes. This view is premature, however, because many experiments also indicate that a share of the subjects do not violate the above assumptions and, as we will show, the existence of these subjects may cause aggregate outcomes to be close to the predictions of a model that assumes that everyone is rational and self-regarding.*

As to the third issue -- Regarding the acceptability of non-linear dose-response models consider that:

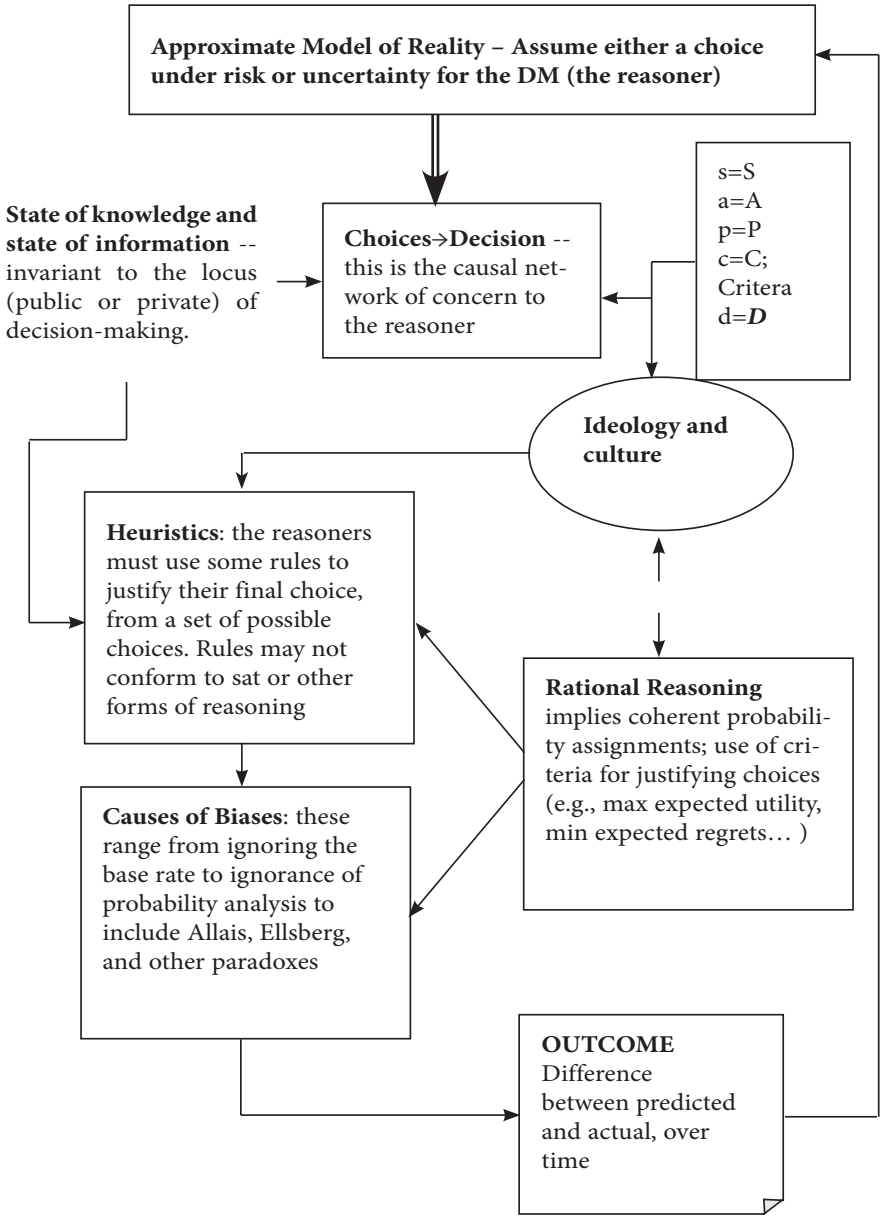
- Public choices buttressed by a cadre of scientific, policy, legal and other advisory systems (including the National Academies of Science) are different from private and unaided decisions
- Private choices that are not supported by scientific expertise are unhelpful to discourse about the acceptance of bi-phasic (the *J*- and inverse *J*-shaped) models in regulatory analyses
- The scientific debate about non-linear and linear models – and their choices –also involves biases and heuristics that color the final scientific advice given to the ultimate decision-maker.

The aggregate context of decision-making consider in this paper can be summarized in an overall reasoning process map, shown in Figure 1, that is independent of whom the individual decision-

maker is – she can be either public or private. This Figure simply identifies the basis of a decision process, i.e., the sets of *probabilities*, *acts*, *states-of-nature*, *consequences*, and *decisions*. The causal network *acts – decisions* links analysis to the eventual – actual -- decision, which is *factual* and is the *responsibility and accountability* of the decision-maker to make. *Analysis*, involving those elements that precede *decision*, informs but does not supplant responsibility and accountability.

Some might argue, in some contexts, that such knowledge can increase the liability of the decision-maker. Although perceptual issues, as correctly identified and analyzed by Ropeik (2008), affect the entire process describe in this Figure, there are several checks and balances that provide degrees of fairness in the outcome – the *decision* -- for the stakeholders. These checks and balances include: allowing for public comments on the decision, administrative and legal review, congressional oversight and budgeting, and so on. Clearly, no similar system exists for individual, lay decisions, other than ethical, tortious, and criminal law potential sanctions.

Figure 1, A Synthesis of the Decision-Making Process (S is the set of states-of-nature, A the set of actions, P the probabilities attached to the states of nature, C the magnitude of the consequences, and D the decision criteria that can justify a *choice* over another). The *choice* is analytical: it uses an axiomatic basis; the *decision* is not necessarily analytical because it depends on political and other factors (see the discussion below and the references in the text).



We agree with Thaler and Sunstein (2008) that there is no practical way to develop a risk *architecture* that is value neutral: it is the product of our thinking and that is known to be biased either genetically or environmentally, or by both. For example, the very basis of rational decision-making is utilitarian: it is implicitly biased. To complete the discussion, we suggest at least two different sets of considerations – centered on the individual:

- Public versus the private decision-maker: biases, preconceptions, sense of fairness, education, and so on
- Brain neurology and functioning: operations by lower (amygdala, e.g.,) and higher (prefrontal and anterior cingulated) cortex, aggregation processes by left and right side by the prefrontal cortex, morphological or other changes (reversible and irreversible), and so on

Regarding the choices between non-linear or LNT models of dose-response, it seems plausible that the public decision-maker will consider that:

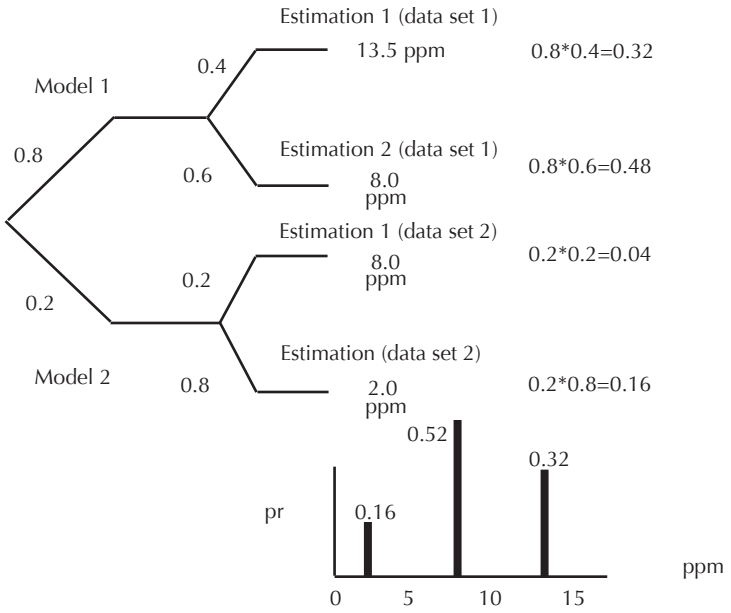
- The cost of information should be related to the expected magnitude of the loss (potential actions known to lead to either trivial losses or gains do not warrant complicated analysis)
- Decision rules should be related to the state-of-knowledge (e.g., the maximization of the expected net benefit rule requires that its application be limited to situations in which there is very extensive knowledge of cause and effect), and
- The axioms of EUT, even when violated, still provide a useful basis for considering alternative decision-making approaches that can account for those failings

The last point leads naturally into the discussion of decision theory, behavioral economics that seeks to explain how individuals commit to certain courses of action, and to the various findings discussed by Ropeik (2008). Briefly, the principal axioms – the foundation of modern expected utility theory, EUT, developed by von Neumann and Morgenstern (vN-M) in 1944 -- include:

Because of the many empirical findings that demonstrate violations of these axioms and assumptions that characterize EUT theory, several new theoretical variants have been proposed. Those weaken one or more of the axioms: e.g., the independence axiom in weighted utility theory and in rank-dependent utility theory (Quiggin, 1982). Thus, a fundamental reason for the appeal of EUT is its axiomatic basis and formalism. When coupled to decision criteria, such as the maximization of the expected net benefits, it provides clear guidance for determining the optimal action (from axioms, probability rules and assessment of the consequences, situations over which the decision-maker has no control (*states-of-nature*), and decision rules). The criterion for choosing between alternative probabilistic choices (or prospects, represented by lotteries) is to choose the action that yields the maximum expected utility (or the minimum expected disutility). If monetary values are used instead of utilities, the criterion is the maximization of the net expected benefits from each action, over all possible actions (Figure 1). A typical decision tree is shown in the example below, which is the background that allows a simple assessment of a choice between two models (Ricci, 2006).

Axioms about an individual's preference over acts	**Interpretation of the preferences by DM regarding prospects (a prospect is lottery characterized by probabilities and outcomes or consequences)**	**Comment**
Reduction	If two acts have the same distribution, over their consequences, then the DM should be indifferent between them	If these axioms are met, expected utility is either a descriptive or a normative guide for choosing between actions; the overall utility of a prospect is its expected value
Ordering	Preferences should be transitive	
Independence	Take 3 lotteries, then if one has the same outcome of the other then it can be ignored	
Continuity	Some real value can be attached to each ad every prospect under analysis.	
Completeness	Either a lottery is preferred to a certain outcome or vice versa	
Monotonicity	A prospect dominates another if, over all of the ordered (worst to best) outcomes considered, the former's probabilities and values of the outcomes are greater than or equal to those of the latter.	

A risk assessor has used two data sets and two models to estimate the tolerable exposures, measured in parts per million to a toxic agent found in soil. He has used $1*10^{-5}$ as the tolerable risk level, but is unable to determine which of these results is most credible. The risk manager has hired an independent consultant who, based on her experience with the substance, its biological effects and knowledge of exposure-response, has developed the decision tree that follows.



Distribution of exposures at an individual lifetime tolerable risk level 1/100,000, resulting from fitting two different exposure-response models to two different data sets. ppm is parts per million.

On the basis of these results, he recommends to the risk managers that the most plausible exposure level is *8.00* ppm.

Cox (2002) discusses and exemplifies many of the issues with this approach, and concludes that:

> [d]espite (its) limitations, social utility theory makes a useful starting point for analyzing societal risk management decisions, just as (expected utility) theory makes a useful starting point and baseline for discussions of individual decision-making.

ISSUES WITH RATIONAL DECISION-MAKING

As discussed by Ropeik (2008), the communication of risky or uncertain choices – and their understanding – is complicated by many violations of the axioms we discussed. Some of the best-known examples of these violations include the one we exemplify next. The maximization of the expected utility criterion is often invoked as a normative criterion, rather than a descriptive criterion, for choosing an act and deciding that this act is to be implemented. In this paper we do not need to be normative because we deal with the social decision-makers and seek to inform them of the various possibilities, but leave the eventual decision outside the analysis. The axioms of subjective utility theory (SUT) are: transitivity, dominance, and invariance. Transitivity means that if *A* is preferred to *B* and *B* to *C*, then *A* is preferred to *C*. Dominance means that if choice *K* is at least as good as *M* in some grounds, and better in one or more additional criteria, than *K* dominates *M*. Invariance means that a preference should not be changed by how a question is framed. Yet, as Tversky and Kahneman (KT) showed, these axioms are violated in practical experimental situations, and thus subjective utility theory becomes questionable, as discussed next.

Presentation of Alternatives -- Suppose that a future event kills 600 individuals for sure. In the alternative, consider 2 possible acts, stated as the choices between lotteries – correctly to reflect the probabilities associated with future outcomes from either choice, such as (KT, 1984):

L_1 = *2/3*(600 prompt deaths) +1/3*((0 prompt deaths)*

v.

L_2 = *400 deaths, here the probability is one (certain deaths, given the choice)*

78% of *152* respondents selected the act that corresponds to L_2 over L_1. Not many lay people actually have had experiences (that they would admit in an open forum) that would either help them understand what is actually being proposed or be in a position responsibly and professionally to make such decision. This is, of course, unlike having to purchasing decision based on statements about the

price of a good or service. For example, even when a consumer decides to purchase a home (generally stated to be the largest investment that the individual can make in her life), there are collateral experiences that serve as a guide. Moreover, the house is a tangible object, unlike an intangible prospect (hypothetical deaths) that bears little, if any, relationship to past experiences and contrived situations are to have had familiarity with and, even if they had observed an accident in which 200 people had died, most likely their role would have been that of incidental observer, not as decision-makers.

The example then continues (KT, 1984) but with a difference in how the statements are framed:

L_3 = *200 lives saved*

v.

L_4 = *1/3*(600 lives saved) + 2/3*(save 0 lives)*

Here, *72%* of those *152* respondents picked the act corresponding to L_3, rather than the act corresponding to L_4. The second aspect of the example has been used to show how most individuals are sensitive to the words of a question (*loss* versus *gain*, even though they should be unaffected by either as these four lotteries are equivalent regarding their expected value).

Responses to Selections – Preferences to a choice are also influenced by the anchoring bias: the availability of an initial values guideline value biases the magnitude of the response by those surveyed. For example (Kahneman et al., 1989) found that the average willingness-to-pay to save about *50,000* birds per year from an environmental risk was stated to be *$20* (with a *$5* anchor) but that willingness increased to *143* when the anchor was increased to *$400*.

Sequential Availability of Information – This example is due to KT (1979):

P_1, *p(win $0) = 0.75; otherwise move to next time period such that pr(win $3,000) = 1*

Then:

P_2, *p(win $0) = 0.75, otherwise move to next time period such that [p(win $ 4,000) = 0.80 and p(win $0) = 0.2]*

Most individuals to whom these two prospects are given opt for P_1, even though P_1 = (*0.25, $3,000*) and P_2 = (*0.2, $4,000*); P_2 should instead be selected.

These findings are not limited to lay persons. It has been known for some time that – when measured against a given wealth level – losses are more important than gains (KT, 1979). Thus the paradox where investors tend to hold on stock that loose value, relative to their price of purchase, but sell stocks that increase in value, against the same benchmark (Odean, 2004). As Camerer (1995) reminds us, medical doctors, dealing with the treatment of lung cancer, to whom information on the effect of radiation therapy versus surgery is stated as *mortality*, rather than *survival*, prefer to prescribe radiation therapy.

The work of KT and others suggested that *norms, habits, and expectations* enter into the making of decisions. These authors have also identified *segregation* and *acceptance* as fundamental decisional factors that prevent rationality from guiding decisions. Here *segregation* (the focus on the seeming relevance of some factors, rather than on the actual factors) and *acceptance* (the insensitivity to a solution even when new facts become apparent). Other, such as Slovic and his colleagues, have identified *dread*, *familiarity*, and *voluntariness* as important predictors of risky decisions. Yet, although familiarity with a hazard seems to make that hazard mere part of life, seems to obfuscate rational reasoning (or else, why would anyone drive at *100* km/hour with a child on their lap?).

To overcome the empirical-behavioral findings that violate some of the axioms of EUT, Kahneman and Tversky developed prospect theory. It predicts that, relative to a probabilistic outcome, people will (KT, 1992; for very small probabilities see Prelec 1998):

1) seeker risk for low-probability gains,
2) risk averse for high-probability gains,
3) risk averse for low-probability losses, and
4) seek risk for high-probability losses.

Decision-making is relative, rather than absolute: the decision-makers' reference point changes depending on the decision at hand because we are more sensitive to difference in the magnitude of gains or losses than to magnitudes alone. To reflect this, KT introduced *decision weights* that are not linear (in probability) to reflect the empirical findings that individuals overvalue small probabilities and undervalue large ones. Accordingly, when confronting small probability events, respondents appear to be very sensitive to what is stated to be *possible* or *impossible*. When confronting large probability events, respondents are also very sensitive to what is asserted to be *certain* or *not certain*. Individuals generally tend to want to eliminate low probability events because these are overvalued relative to moderate probability events. Individuals prefer the sure gain to a lottery that has a larger expected value than the sure gain, an empirical finding that contradicts expected utility theory. Another issue is that – in test situations – most respondents opt for *pseudo-certain* outcomes. For instance, respondents having a choice of insuring against loss from fire and flood allocating *50%* of the premium between these two prefer to pay *100%* of premium to protect against one hazard only.

In EUT, individual preferences are revealed by how they respond to sure outcomes and probabilistic outcomes (i.e., lotteries). Prospect theory is based on a value function for the attribute or attributes of the decision, and a weight function for the actual probabilities: gains and losses are relative to a "reference point" that separates gains from losses. In particular, losses loom larger than gains: a phenomenon that in prospect theory is termed as "loss aversion". The cognitive idea is that change in utility is what matters, rather than the actual value of the gain or the loss: the loss of a benefit is more important than gaining it. Camerer (2000) has apparently concluded that cumulative prospect theory can account for the SEU as well as for deviations from the optimization that SEU mandates as a criterion for choice. Wilkinson (2008) summarizes several

issues that have been leveled against PT, but concludes that there are areas where PT is preferable for analysis to EUT (and other theories) in that it can explain individual choices better and more consistently with empirical findings of violations of EUT.

CONCLUSION

Many individuals do not make choices using decision theoretic or other analytically demanding tools, even when facing complex decision. This seems paradoxically true even when the individual stakes are extremely high, such as the loss of one's home. On the other hand, in regulatory risk assessment and management where linearity and non-linearity play a fundamental legal role, agencies (and other parties) have the expertise and time to identify an optimized choice, to rank its value to society, and to present that ranking to the decision-maker. To assume that private decision-makers are analogous to social decision-maker, in the limited context of having to make choices about the superiority of a causal construct relative to another, is a strong simplification. It seems to gloss over the factual and legal requirements of making public choice that may or may not lead to a final, possibly optimized regulatory choice. It is not clear that this formal difference has been completely discussed and thus we have added it to the discourse initiated by Ropeik (2008).

We suggest that there are two ways to deal with the communication of risky choices and causal constructs. The first is to accept that people are –at least on the average – poor probabilistic reasoners. The second is that, when societal stakes are high, those affected should be given sufficient training about the factual nature of the *hazard → risk* causal network to understand the nature of the potential hazard, its possibly alternative scientific basis, and the cost and benefit implications of each choice. Although the decision is political, nonetheless knowledgeable choices are preferable to acts taken by simple fiat.

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FINAL RESPONSE

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"By the animal instinct that is awakened in us we are led and protected. It is not conscious; it is far quicker, much more sure, less fallible, than consciousness." *Erich Maria Remarque, All Quiet on the Western Front*

The consideration of non-linearity/hormesis as a tool for risk assessment and risk management is just one small scene in a much larger play, as noted by the contributors to this discussion. The issue of how we scientifically investigate toxins is part of the fundamental challenge for a democratic society in dealing with risk; by what standards, indeed by what *definition,* is risk to be understood? And who decides?

It will have to be some combination of science *and* society, which is of course why it matters so much how scientists communicate about non-linearity/hormesis to us non-scientists. Frankly, their efforts so far have been predictably ineffective. Predictably, because scientists usually think that just by explaining the science, their superior reason will carry the day. Which is why much of the discussion about non-linearity/hormesis so far has focused on scientific issues like dose and exposure and hazard. That is insufficient. How we measure and respond to danger as individuals and as a society goes far beyond MTDs and LOAELs. Such a scientific view would be sufficient to define risk if we lived in a world of perfect reason. But we don't.

We live, as humans, with our instincts and emotions and experiences and biases and all sorts of limitations on the ability to be perfectly rational. We live, in a democracy, in a messy system that could not be better designed to preclude perfectly rational policy making, if by rational one assumes some sort of simple definition like the maximization of public welfare with the most efficient use of limited resources.

So we protect ourselves as best we can, using a combination of reason and affect, and seek government protection from threats we can't deal with on our own. Whether risks are actual by some hard scientific measure or perceived doesn't matter. In either case they are real, real enough to affect how we act - the choices we make in our own personal lives, and the policies we demand of government. As observed in the *Social Amplification of Risk Framework* (Pidgeon, Nick, Kasperson, Roger E., Slovic P, The Social Amplification of Risk, Cambridge U. Press 2003), how we act, and the risk management policies of government – driven to some degree by public political pressure - can create new risks. Those secondary risks can lead to just as much harm, sometimes more, than the original peril, such as dangerous personal behavior (to drive instead of fly, as noted in the original article), and policies that devote resources to lesser risks that we're afraid of, diverting those resources away from risks more likely to harm us. The risk of how we respond to risk is tangible.

This is what I mean when I suggest the need to respect the lay definition of risk. The original threat, *and* the ways we respond to it, are *both* part of the overall risk that has to be understood, scientifically assessed, and managed in order to maximize public welfare with the most efficient use of limited resources.

This is the larger meaning of risk in which the discussion about non-linearity/ hormesis fits. It is the social context noted by Hahnekamp and Pieterman, who rightly observe that the rise of a precautionary culture drives more stringent protective policies…a cultural view that bodes poorly for the adoption of non-linearity/ hormesis. (In addition to Hahnekamp and Pieterman's thesis that the rise of material comfort and well-being in western societies is at the root of this rise in precaution, I would suggest it is also the result of a weakening of public trust in government and to some degree in science and technology. Trust is why the matter of who funds non-linearity/hormesis research – including the chemical industry – is so important.)

This is the larger social context noted by Elliott, who cites the National Research Council's efforts to come up with a broader definition of risk in their 1996 publication Understanding Risk, in which they described risk analysis as an "analytic *and deliberative* process", the goal of which is "to describe a potentially hazardous situation in as accurate, thorough, and decision relevant a manner as possible, *addressing the significant concerns of the interested and affected parties…" (my emphasis)* (Stern, P.C., and Fineberg, H.V. eds., Understanding Risk; Informing Decisions in a Democratic Society Report for the National Research Council, National Academy Press, 1996, p.2)

Elliott writes that the consideration of whether to change public policy to include non-linearity/hormesis is an ethical question. Ricci calls it political. Ethics and politics include far more than the narrow scientific issues of MTDs and LOAELs.

And ethics and politics will profoundly shape decisions about whether and how non-linearity/hormesis are applied to policy making. Ricci distinguishes between private decision-makers and social decision-makers, and suggests that the latter have the time and expertise to objectively choose optimal policies. Perhaps to some degree, though the heuristics and biases of decision-making that affect individuals also impact the decision-makers acting on behalf of society who, though they may be acting under different parameters, are still vulnerable to these limitations. In any event, the question of what kind of scientific approach we should use as a foundation for policy making is so overarching that it can not be separated from social values and decided by benign technocrats who will pronounce with supposed objectivity what is best for us.

The non-linearity/hormetic approach promises a more precise and comprehensive way to understand what potentially harmful agents do to us. That is in everyone's interest. But by suggesting that some things that are bad for us at high doses might have some biologically positive effects at low ones, the non-linearity/hormetic approach is also troubling. If the advocates of this new toxicology want to see it brought into use as a policy-making tool, they would be wise to consider the psychology of risk perception, and the tools of risk communication, as they try to make their case.