Reflections on Framing and Making Decisions in the Face of Uncertainty

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Almost all important decisions...

...involve considerable uncertainty.

At a personal level:
  • Where to go to college
  • Who to marry
  • When and whether to have kids

In a company or other organization:
  • Who to hire
  • What products to develop

In a nation:
  • How best to structure taxes
  • How best to deal with social services & health care
  • When to go to war
  • When to sue for peace
In this talk I will:

- Discuss *prescriptive* analytical strategies that suggest how people *should* frame and make decisions in the face of uncertainty.
  - Decision rules
  - Benefit-cost analysis
  - Decision analysis
  - Multi-criteria analysis
  - Real options
  - Bounding analysis

- Discuss how people *actually* frame and make decisions in the face of uncertainty.
  - Cognitive heuristics
  - Ubiquitous overconfidence
  - The need to be quantitative
  - Methods for formal quantitative expert elicitation
  - Problems with the use of scenarios
  - Two comments about integrated assessment.

As I go through these I will briefly mention some relevant literatures.
Decision Rules

Binary or threshold
Safe/Unsafe; Regulate/Don’t regulate; etc.
In the U.S. in addition to chemical risk assessment we have the example of the Clean Air Act which adopts a “rights based” formulation – “choose a level that protects the most sensitive population.”

Balancing
Benefit-Cost; Maximize (expected) Net Benefits; etc.
In the U.S. many federal water quality rules are not rights based. They call for a balance between water quality and control costs.

Avoid extremes
Minimize the chance of the worst outcomes, etc.

Most of the classic literature on decision making focuses on maximizing (expected) net benefits.
Benefit-cost analysis

Suppose I have two feasible options in which I could invest to achieve some desired end.

Choose between two options

Option A
Has attributes A1, A2, A3, etc.

Option B
Has attributes B1, B2, B3, etc.

What strategy should I adopt in making my choice?

I could choose the one that is:
Most energy efficient
The one with the best engineering
The one that increases entropy the least
The one that wins in a survey of consumer preferences
The one favored by the Environmental Defense Fund
The one favored by the U.S. OMB
Choose the simplest
Choose the cheapest (relative effectiveness)

Benefit-cost analysis says choose the one with the highest net benefit:

\[ \sum_{j=1}^{N} B_j - \sum_{k=1}^{M} C_k \]
That sounds simple…

…but the details of how to perform a B-C analysis can get very complicated.

For example, one standard strategy to estimate benefits is to estimate “consumer surplus.”
An example:

While there is no reason...

...that it can’t incorporate uncertainty, most B-C analysis has included little or no characterization or analysis of uncertainty.

The best critical assessment I know of B-C analysis was written by Lester, who was one of the method’s leading practitioners.

The fact that there is uncertainty...

...should not by itself be grounds for inaction. Indeed, the consequences of doing nothing often carry comparable or larger uncertainty.

There is a large literature on analytical strategies for framing and making decisions in the face of uncertainty.
The methods they developed are now termed **Decision Analysis**

Identify a set of choices with outcomes \( x \).

For each choice, use all available current knowledge \( c \) to assess the probability that each of the outcomes \( x \) will occur. That is, assess \( p(x|c) \).

Decide how you value each of those outcomes. That is, assess your “utility function” \( U(x) \).

Make the choice that will maximize your expected utility. That is:

\[
\text{Max} \left[ \int p(x|c) \ U(x) \ dx \right]
\]

Rather than deal with continuous functions DA typically discretizes everything.
Decision Analysis

While I will not take time to talk about them, decision analysis is based on a set of axioms that guarantee that the choice will maximize your expected utility.

The convention in DA is that a square is used to indicate a choice or "choice node" available to the decision maker.

The convention in DA is that these values show the probability that the various outcomes x will occur given that choice c has been made.

outcome $x_1$ which has utility $U(x_1)$
outcome $x_2$ which has utility $U(x_2)$
outcome $x_n$ which has utility $U(x_n)$

The convention in DA is that a circle is used to indicate a "chance node" which indicates the range of outcomes that could result if the specific choice is made.
To do a decision analysis one needs to know the decision maker’s preferences

Many economists operate with the assumption that we all have well articulated utility functions in our heads, so the issue is just how best to observe $U(x)$.

Psychologists and decision analysts believe people often need help in figuring our their preferences.

Fischhoff (1991) lays out this continuum of possibilities.
A simple taxonomy of analytical methods

- **MAUT & Multi-objective**
  - Treatment of non-commensurate attributes

- **B-C**
  - Usually for evaluating a single option

- **DA**
  - Focus is on choosing among options

Treatment of uncertainty
Dealing with multiple objectives
One other strategy

The use of real options as an alternative to net present value can and better address uncertain future contingencies.
Bounding Analysis

While there has been no mention of this approach in the talks we have heard, sometimes the best we can (or should) do, is to use order of magnitude methods to set bounds.
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  o Two comments about integrated assessment.
There is a large literature... 

...based on empirical studies, that describes how people make judgments in the face of uncertainty.
Examples of cognitive heuristics

**Availability:** probability judgment is driven by ease with which people can think of previous occurrences of the event or can imagine such occurrences.

**Anchoring and adjustment:** probability judgment is frequently driven by the starting point which becomes an "anchor."


As Scott Ferson noted yesterday, brain science is beginning to figure out where in the brain some of the relevant processes occur.
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Let’s try a demonstration:

I am going to name four canals.
I would like every one to write down three numbers

Your lower 1% estimate of the length of the canal
i.e., only 1 chance in 100 it could be shorter.

Your best estimate of the length of the canal.

Your upper 99% estimate of the length of the canal
i.e., only 1 chance in 100 it could be longer.
Here are the four canals:

Kile Canal
Between the North Sea and the Baltic Sea

Panama Canal
Between the Caribbean and the Pacific Ocean

Suez Canal
Between the Mediterranean and the Red Sea

Cape Cod Canal
Between Cape Cod Bay and Buzzards Bay
Here are the four canals:

- **Kile Canal**: Between the North Sea and the Baltic Sea, 95 km
- **Panama Canal**: Between the Caribbean and the Pacific Ocean, 82 km
- **Suez Canal**: Between the Mediterranean and the Red Sea, 193 km
- **Cape Cod Canal**: Between Cape Cod Bay and Buzzards Bay, 11 km
Over Confidence

Percentage of estimates in which the true value lay outside of the respondent's assessed 98% confidence interval.

Source: Morgan and Henrion, 1990

Surprise index: Should be 2%. The probability that the true value lies below the 1% lower bound or above the 99% upper bound.

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Yesterday…

…Karl Teigen talked at length about the problems associated with using probability words to support decision making.

As he noted, such words can mean very different things in different circumstances and different things to different people in the same circumstance.

I can illustrate with an example from the U.S. EPA’s Science Advisory Board
The SAB was discussing...

...words to use to describe whether a substance is or is not a likely carcinogen.

The minimum probability associated with the word "likely" spanned four orders of magnitude.

The maximum probability associated with the word "not likely" spanned more than five orders of magnitude.

There was an overlap of the probability associated with the word "likely" and that associated with the word "unlikely"!

Without some quantification, qualitative descriptions of uncertainty convey little, if any, useful information to decision makers.

The climate assessment community is gradually learning this lesson.

Steve Schneider and Richard Moss worked hard to promote a better treatment of uncertainty by the IPCC.

At my insistence, the first U.S. National Climate Assessment Synthesis Team gave quantitative definitions to five probability words:

Many other communities have not yet gotten the message... (Cont.)
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Expert elicitation

Eliciting probabilistic judgments from experts requires careful preparation and execution.

Developing and testing an appropriate interview protocol typically takes several months. Each interview is likely to require several hours.

When addressing complex, scientifically subtle questions of the sorts involved with problems like climate change, there are no satisfactory short cuts. Attempts to simplify and speed up the process almost always lead to shoddy results.
I’ve done a bunch of expert elicitations

While I was going to talk about a couple I’ve decided instead to offer just three insights on:

• Motivational bias;

• Individual elicitation versus group consensus;

• Combing experts – and situations where different experts have different view about of how the world works.

<table>
<thead>
<tr>
<th>Year</th>
<th>Topics we asked about.</th>
<th>Reference at the end of this chapter to the paper we published that describes the results.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-1</td>
<td>Interviews with 9 air pollution experts and with 7 health experts to better understand and model the health impacts of the sulfur air pollution that comes from power plants that burn coal.</td>
<td>Morris, Henrion, Amaral and Rish, (1984); Morgan, Morris, Henrion and Amaral (1985).</td>
</tr>
<tr>
<td>1993-4</td>
<td>Interviews with 16 leading U.S. climate scientists to ask about how much warming may happen and other uncertainties in climate science.</td>
<td>Morgan and Keith (1994)</td>
</tr>
<tr>
<td>1999-2000</td>
<td>Interviews with 11 leading forest experts (and 5 biodiversity experts) to ask about the impacts that climate change may have on tropical and northern forests.</td>
<td>Morgan, Pitelka and Shevlikova (2001)</td>
</tr>
<tr>
<td>2005-6</td>
<td>Survey of 24 leading atmospheric and climate scientists to explore how the direct and indirect ways in which high-altitude small particles in the atmosphere warm or cool the planet.</td>
<td>Morgan, Adams, Keith (2006)</td>
</tr>
<tr>
<td>2006-7</td>
<td>Interviews with 18 experts about conventional and advanced technology for solar cells to explore how cost and performance may change over time.</td>
<td>Courtright, Morgan, Keith (2008)</td>
</tr>
<tr>
<td>2008-9</td>
<td>Interviews with 14 leading U.S. climate scientists (four who were the same as in the earlier study) to ask about how warming will change over time and about other uncertainties in climate science.</td>
<td>Zickfeld, Morgan, Frame and Keith (2010)</td>
</tr>
<tr>
<td>2011-12</td>
<td>Interviews with 16 nuclear engineers about how the cost and future performance of small modular nuclear reactors (MRs) are likely to compare with the cost of existing large reactors.</td>
<td>Abdulla, Azevedo and Morgan (2013)</td>
</tr>
</tbody>
</table>
Equilibrium change in global average temperature

200 years after a 2xCO$_2$ change

Probability allocated to values above 4.5°C
Total aerosol forcing
(at the top of the atmosphere)

Comparison with IPCC 4th assessment consensus results

Summary from TAR

The global mean radiative forcing of the climate system for the year 2005, relative to 1750

Summary from FR4

Total aerosol forcing from Morgan, Adams and Keith

IPCC reports are available at www.IPCC.ch
Different experts have different views of how the world works.

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Scenarios are widely used

For example, the previous IPCC assessment made use of the very detailed SRES scenarios in making its projections.

While in principle there are ways to create scenarios that span ranges across the space of plausible futures, this is very rarely done.

Folks who construct scenarios often argue that they should not be viewed as “predictions” but rather as a strategy to help people think about how things might unfold in the future.

But, there is a problem with this argument…

SRES is at: www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0
Again, from the work of Tversky and Kahneman

Tom W. is of high intelligence, although lacking in true creativity. He has a need for order and clarity, and for neat and tidy systems in which every detail finds its appropriate place. His writing is rather dull and mechanical, occasionally enlivened by somewhat corny puns and by flashes of imagination of the sci-fi type. He has a strong drive for competence. He seems to have little feel and little sympathy for other people and does not enjoy interacting with others.

**Group 1 got Q1:** What is the probability that Tom W. will select journalism as his major in college?

**Group 2 got Q2:** What is the probability that Tom W. will select journalism as his major in college but decide he does not like it and decide to change his major?

**Group 3 got Q3:** What is the probability that Tom W. will select journalism as his college major but become unhappy with his choice and switch to engineering?

Assessed probabilities went *up* but should have gone down.
All people who fit…

The set of all who select journalism.

The set of all who select journalism but decide to change their major.

The set of all who select journalism but decide to change their major to engineering.
The more detail…

…that gets added to the “story line” of a scenario, the harder people find it to remember that there are typically many other ways that one could reach the same outcome, as well as many other possible outcomes that could result - this is because of the heuristic of “availability.”

For additional elaboration of this and related arguments, and some suggestions for how to improve on past practice, see:

My concern with scenarios is well illustrated…

…by a quotation from a book by W.L. Gregory (2001) promoting the use of scenarios who argues:

Practitioners can find several advantages in using scenarios. First, they can use scenarios to enhance a person's or group's expectancies that an event will occur. This can be useful for gaining acceptance of a forecast. . . Second, scenarios can be used as a means of decreasing existing expectancies. . . Third. . . scenarios can produce greater commitment in the clients to taking actions described in them.

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Comparison of two approaches to integrated assessment models to support decisions about climate change

**DICE**
Dynamic Integrated Climate-Economy model.
Bill Nordhaus et al.

**ICAM**
Integrated climate assessment model.
Hadi Dowlatabadi et al.
ICAM
Integrated Climate Assessment Model

A very large hierarchically organized stochastic simulation model built in Analytica®.

See for example:

and
ICAM was focused on…

...doing a good job of dealing with uncertainty.

It treats all important coefficients as full probability distributions and produces results that are PDFs.

It contains switches that allow the user to use a variety of different functional forms.

We found that:

• One could get a large variety of answers depending on how the model was structured.

• In light of this, we concluded that global integrated assessment models that do optimization, using just one assumed structure, make absolutely no sense.

So...while others continue to build optimizing IA models, we now just focus on how to reduce GHG emissions. See: CEDMCenter.org
Incidentally, on the subject of model and parameter uncertainty…

…Ullrika Sahlin and I have been having fun discussing types of uncertainty. In my recent book on theory and practice in policy analysis I wrote

Much of the literature divides uncertainty into two broad categories, termed opaquely (for those of us who are not Latin scholars) *aleatory* uncertainty and *epistemic* uncertainty. As Paté-Cornell (1996) explains, aleatory uncertainty stems "…from variability in known (or observable) populations and, therefore, represents randomness" while epistemic uncertainty "…comes from basic lack of knowledge about fundamental phenomena (…also known in the literature as ambiguity)."

While this distinction is common in the more theoretical literature, I believe that it is of limited utility in the context of applied problems involving assessment and decision making in technology and public policy where most key uncertainties involve a combination of the two.

A far more useful categorization for our purposes is the split between "uncertainty about the value of empirical quantities" and "uncertainty about model functional form." The first of these may be either aleatory (the top wind speed that occurred in any Atlantic hurricane in the year 1995) or epistemic (the average global radiative forcing produced by anthropogenic aerosols at the top of the atmosphere during 1995). There is some disagreement within the community of experts about whether it is even appropriate to use the terms epistemic or aleatory when referring to a model. The Random House Dictionary defines *aleatory* as "of or pertaining to accidental causes; of luck or chance; unpredictable" and defines *epistemic* as "of or pertaining to knowledge or the conditions for acquiring it."
Five bottom lines

1. Uncertainty is present in virtually all important decisions.

2. We make decisions in the face of such uncertainty all the time.

3. Our mental capabilities are limited when it comes to assessing and dealing with uncertainty.

4. Hence, especially for important decisions, we should seek help in making such decisions.

5. There are a wide variety of formal analytical strategies, such as decision analysis, that can be very helpful in providing insight and guidance when we need to make important decisions in the presence of uncertainty.
Finally I have written…

...quite a bit on how to incorporate many of these ideas into policy analysis. For example:

Acknowledgments

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