Applying risk and uncertainty into decision making

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Guidance from OMB:

How to conduct regulatory analysis

- "For major rules … you should present a formal quantitative analysis of the relevant **uncertainties** about benefits and costs."
- "… **expert solicitation** is a useful way … to quantify the probability distributions of key parameters."
- "These … can be combined in **Monte Carlo** simulations to derive a probability distribution of benefits and costs."
- "Use a **numerical sensitivity analysis** to examine how the results vary with plausible changes in assumptions, choices of input data."

[Emphases added]

OMB Circular A-4, John Graham, OIRA Administrator, 17 Sep 2003

http://www.whitehouse.gov/omb/circulars/a004/a-4.html

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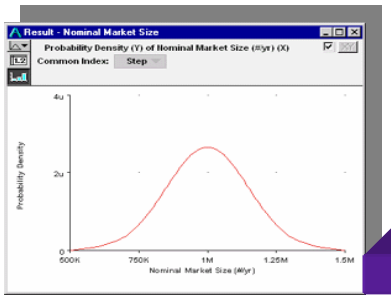
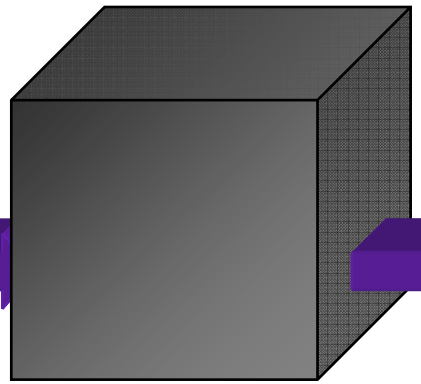
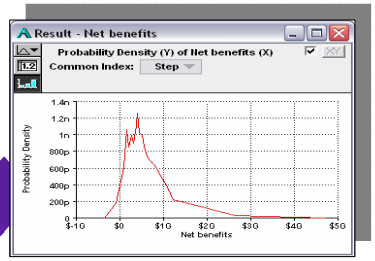
Probabilistic simulation for prospective projections



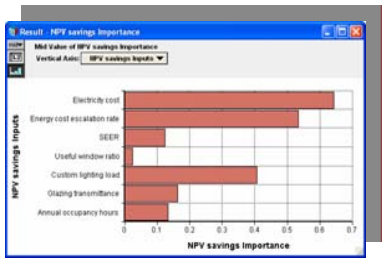
1. Express uncertainty by eliciting **probability distributions** from experts



2. Use **Monte Carlo** simulation to propagate probability distributions through the model.



3. View uncertainty on ke results



4. Use **sensitivity analysis** to compare effects of uncertain assumptions on results

5. Make a decision

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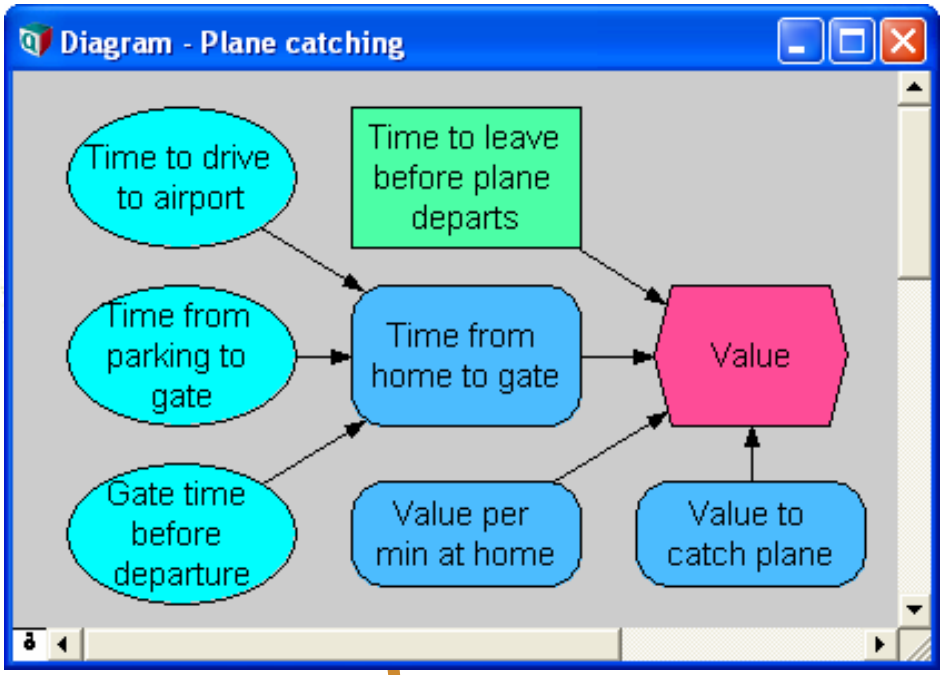
A personal decision under uncertainty: When to leave for the airport?



- On average,
  - it takes about 40 minutes to drive from my home to San Jose International Airport,
  - plus 30 minutes to park, get through security and walk to the gate;
  - I'm supposed to be at the gate 20 minutes before departure.
  - 40+30+20 = 90
- So, I should leave 90 minutes before departure, right?
- **Umm, no.** That way I would miss my plane about half the time.

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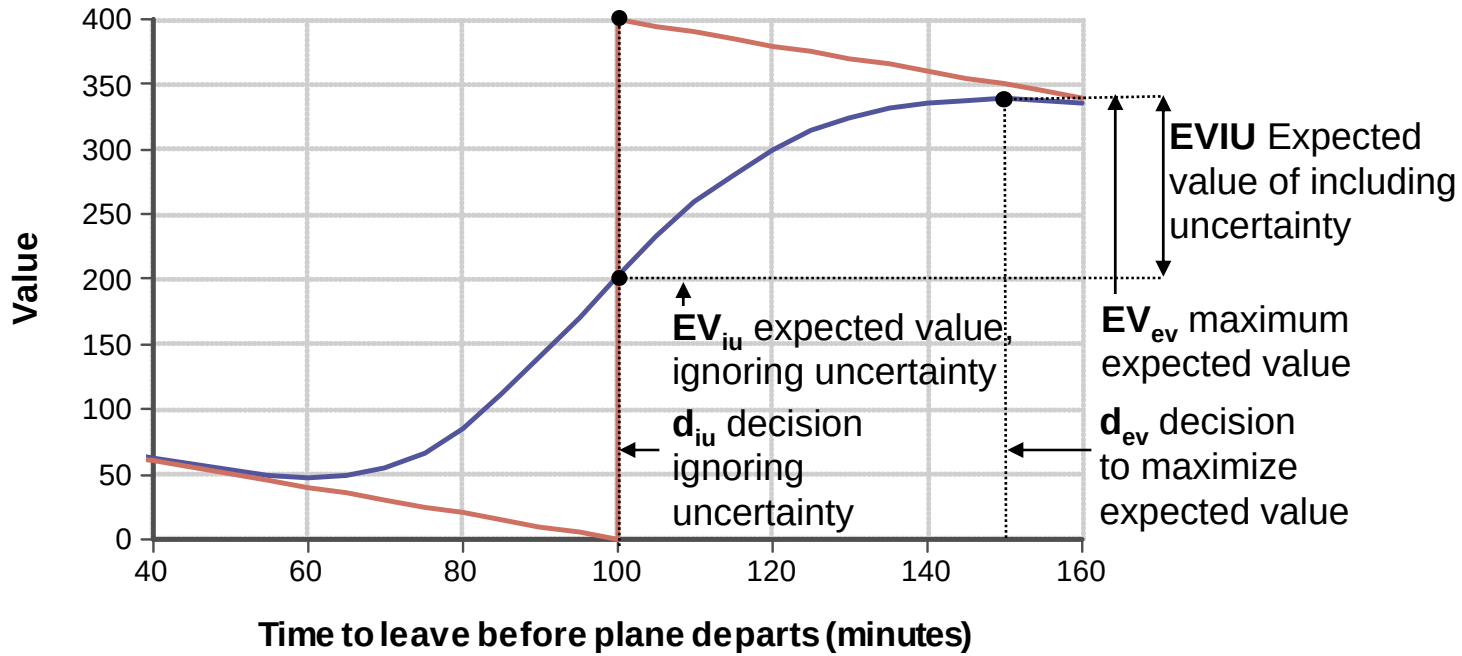
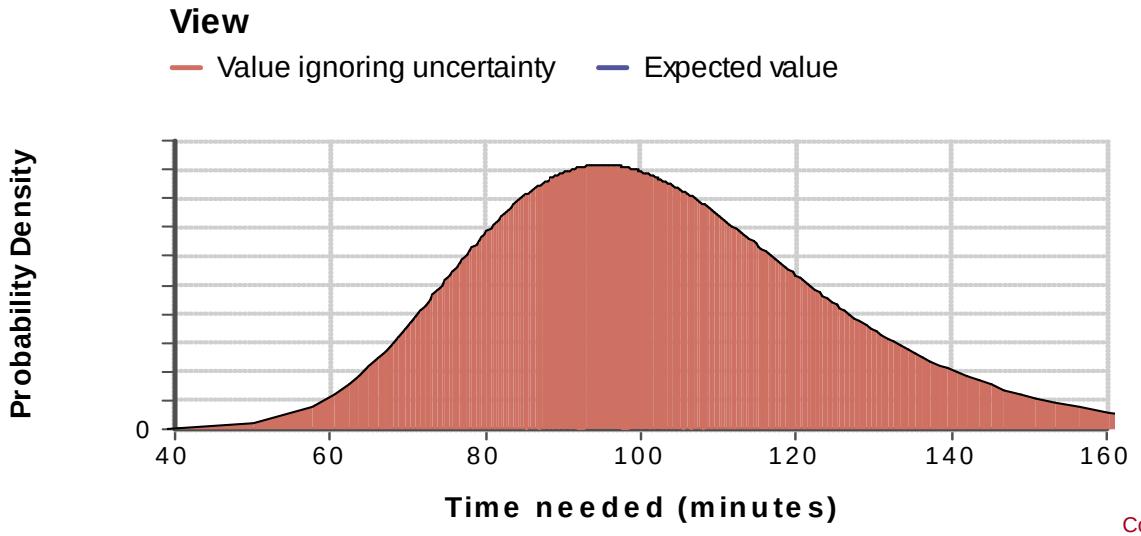
Value function for plane catching





For more, see chapter 12 of *Uncertainty: A Guide to Dealing with Uncertainty in Risk and Policy Analysis*. M Granger Morgan & Max Henrion, Cambridge UP, 1990

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Sample decisions under uncertainty for an energy consumer

- Should we retrofit buildings to reduce energy usage? To what level?
- Do we need backup batteries or generators in case of power outage? What capacity is cost-effective?
- Should we install photovoltaics now, when CA offers a large subsidy, or wait a few years until PV is cheaper, but lower subsidy?
- Should we purchase long-term energy supply contracts or hedges to protect against price volatility?

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Sample decisions under uncertainty for an energy R&D organization

- **Deep or wide?** Should we spend most funds on a few, promising projects, or spread funds over a wider range?
- **R or D?** How should we balance early-stage seed research vs. late-stage commercial development?
- **When to start:** Should we start funding when early research indicates technical success is conceivable, or wait until commercial success is likely – or somewhere in between?
- **When to stop:** How soon should we abandon a project when it starts to look like it may not succeed?

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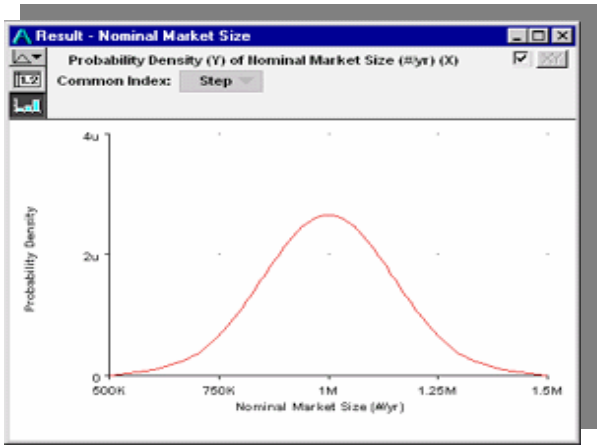
1. How to express uncertainty as probability distributions



- Probability is the clearest, most widely used language for expressing uncertainty.
- Statistics helps us understand the uncertainty in historical data
- The quantity we want is not usually one for which we have data
- Judgment is unavoidable in extrapolating from what we have to what we want.
- Let's be explicit about it
- Obtaining probability distributions from a range of experts is the best way to quantify the current state of knowledge (and lack thereof)
- There are well-developed methods for obtaining expert judgment as probability distributions

Uncertainty: A Guide to Dealing with Uncertainty in Risk and Policy Analysis. M Granger Morgan & Max Henrion, Cambridge UP, 1990

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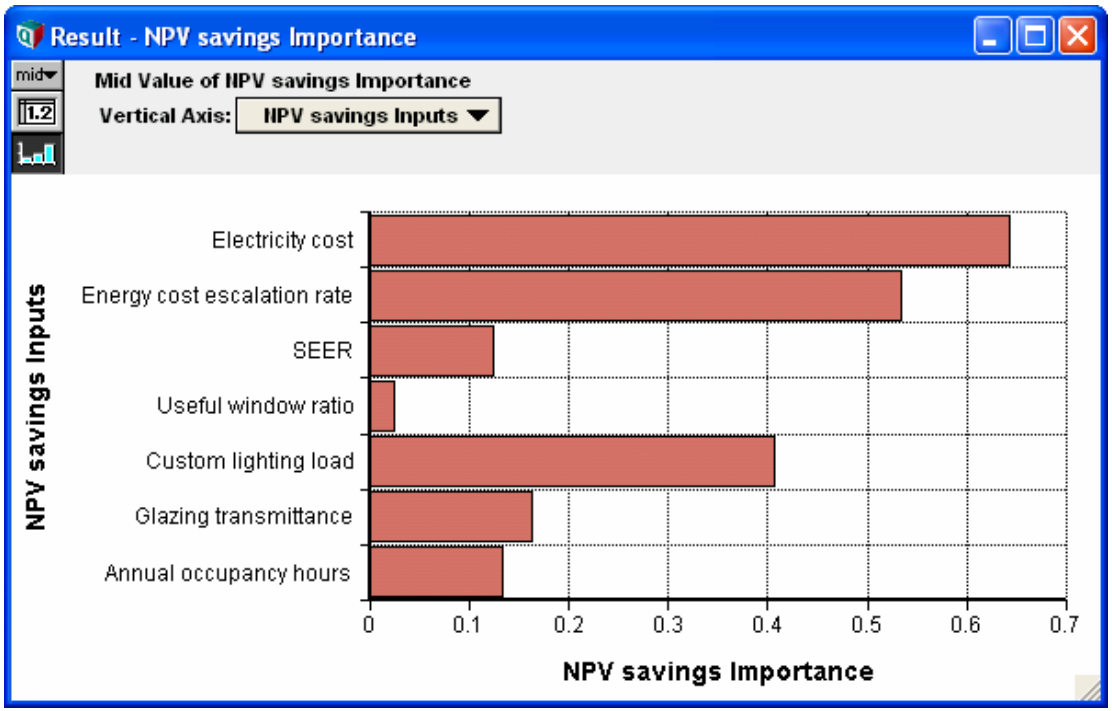
4. Sensitivity analysis: Which uncertainties matter? When? Why?



- Sensitivity and uncertainty analysis quantify relative contribution of each input to uncertainty in output
- A potent source of insights.
- Suggests priorities for further research

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5. Making decisions under uncertainty

- Virtually, *all* important decisions are made under uncertainty – whether we acknowledge it or not.
- Usually, we select the decision with the maximum *expected* value (net social benefit)
- If net benefits are large relative to the uncertainty, we can act now
- If not, we can weigh expected benefits of awaiting better information
- We can assess the value of more research using the expected value of information

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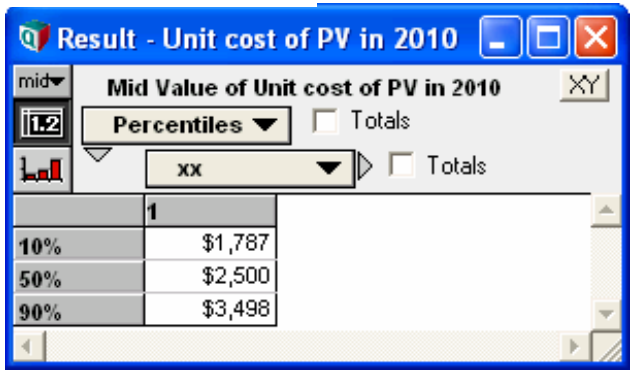
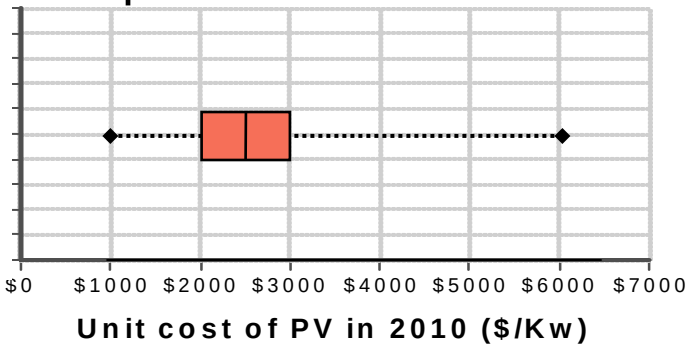
3. How to display uncertainties to decision makers

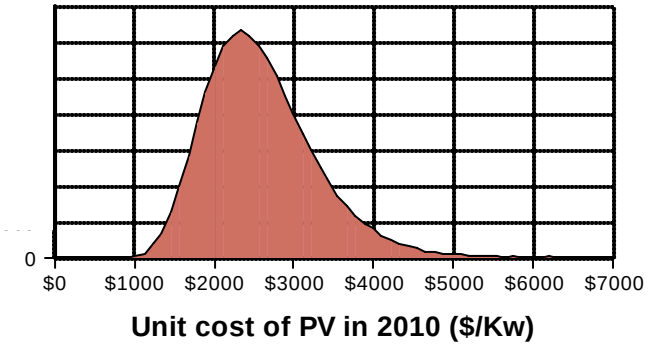
Numerical percentiles



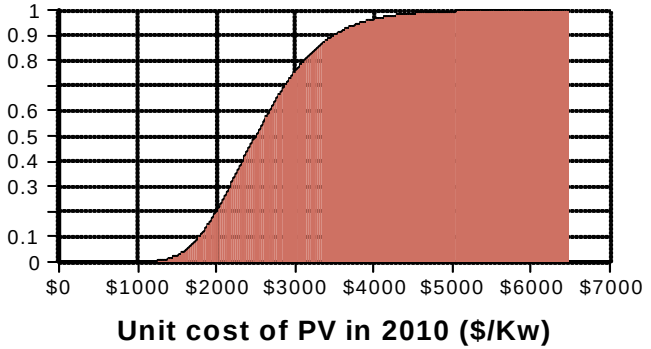
Box plot



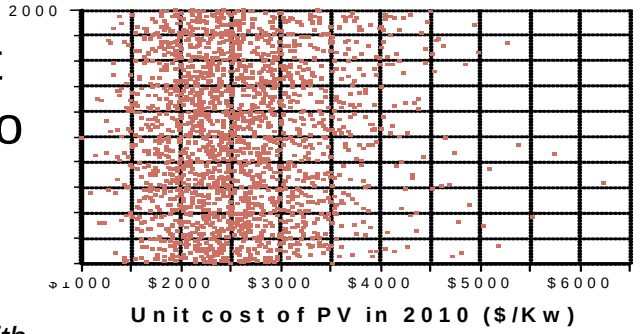
Probability density function



Cumulative probability function



Scatter plot Monte Carlo sample



For more, see chapter 9 of *Uncertainty: A Guide to Dealing with Uncertainty in Risk and Policy Analysis*. M Granger Morgan & Max Henrion, Cambridge UP, 1990

How to assess the uncertainty in projections from models

- **Probabilistic simulation for prospective projections:** Assess uncertainties on all key inputs, and propagate them through the model with Monte Carlo
- **Retrospective evaluation**: Compare results from past projections with what actually happened

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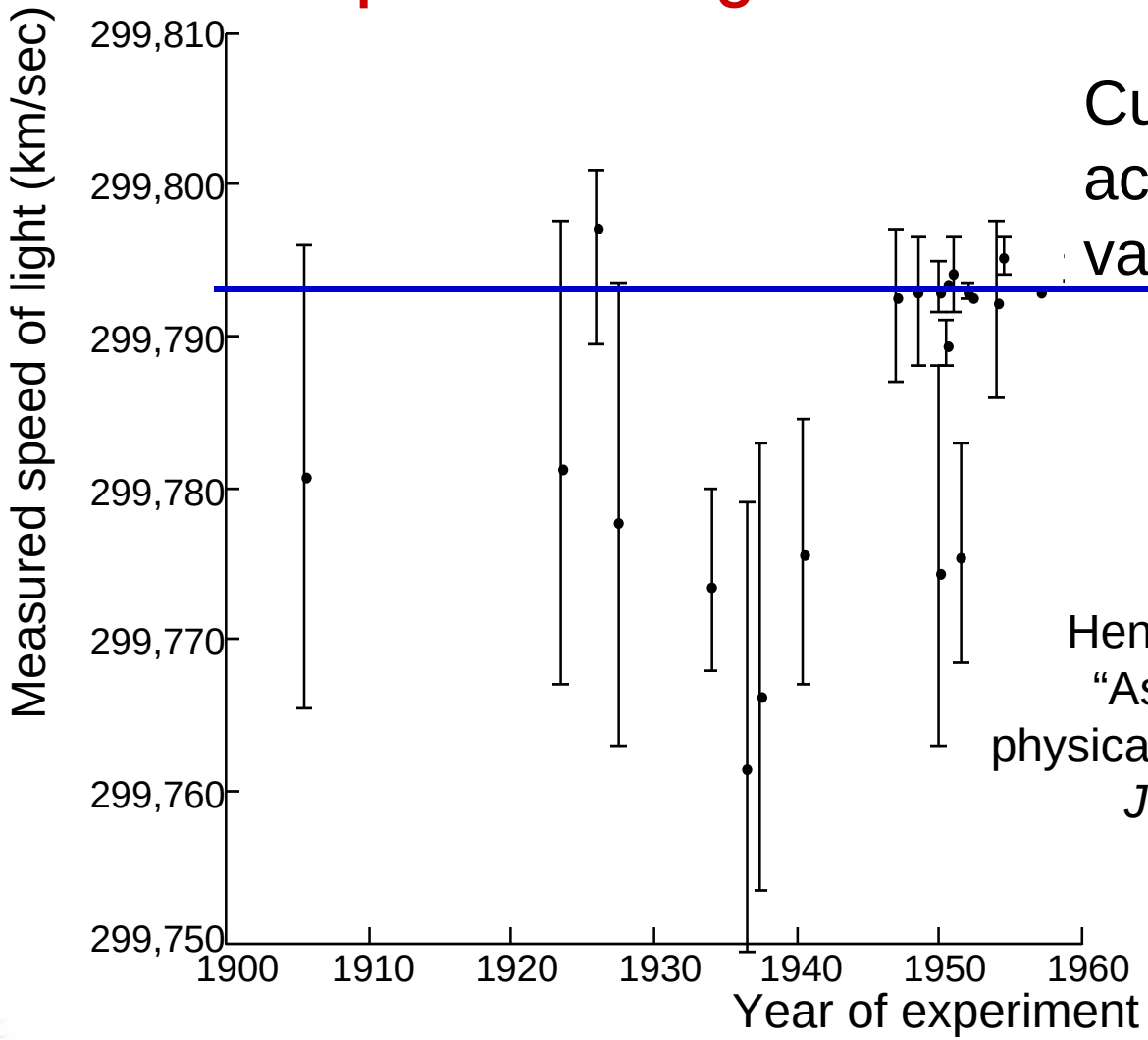
Retrospective assessment:
Reported uncertainty in measurements of the speed of light 1900 to 1984



Henrion, M & Fischhoff, B, "Assessing uncertainty in physical constants", *American J. Physics*, 54 (9), 1986

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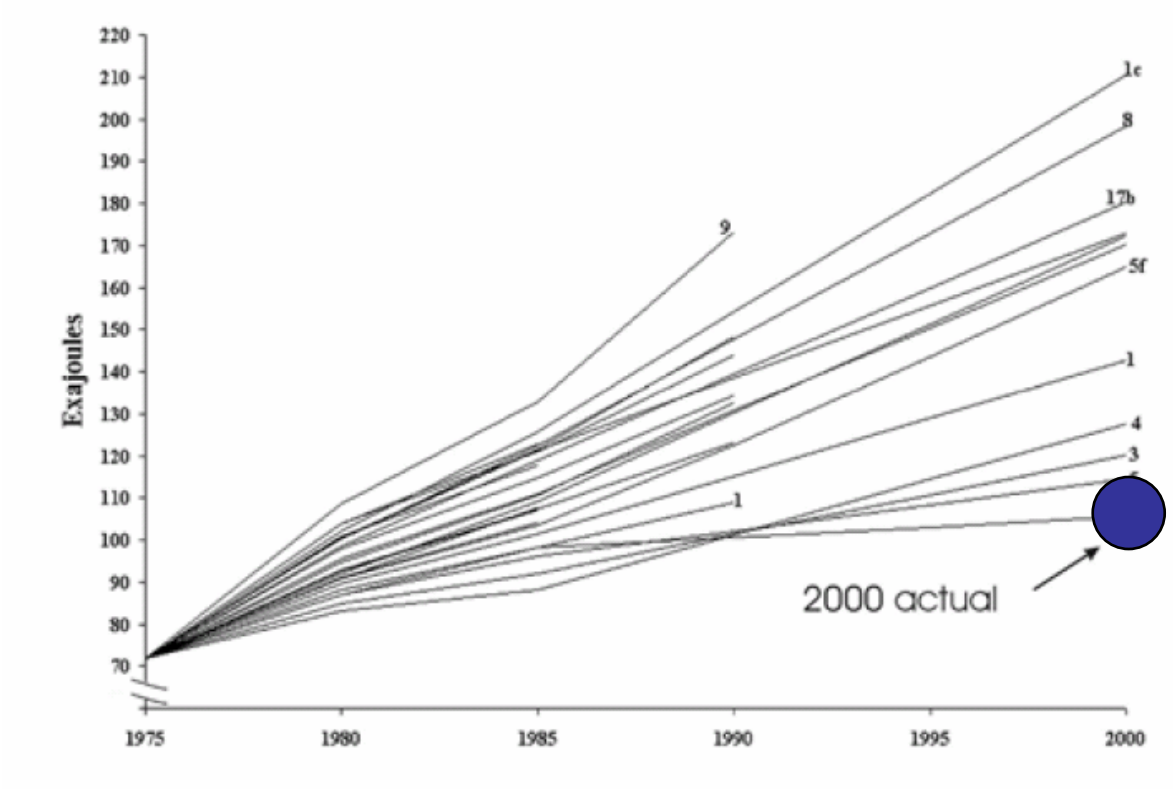
Retrospective assessment:
US Primary energy use in 2000 from 1970s



Projections of total US primary energy use from the 1970s

From "What can history teach us? A Retrospective from Examination of Long-Term Energy Forecasts for the United States" PP Craig, A Gadgil, and JG Koomey, *Ann. Review Energy Environ*. 2002. 27.

Redrawn from US Dep. Energy. 1979. *Energy Demands 1972 to 2000. Rep. HCP/R4024-01*. Washington, DC: DOE.

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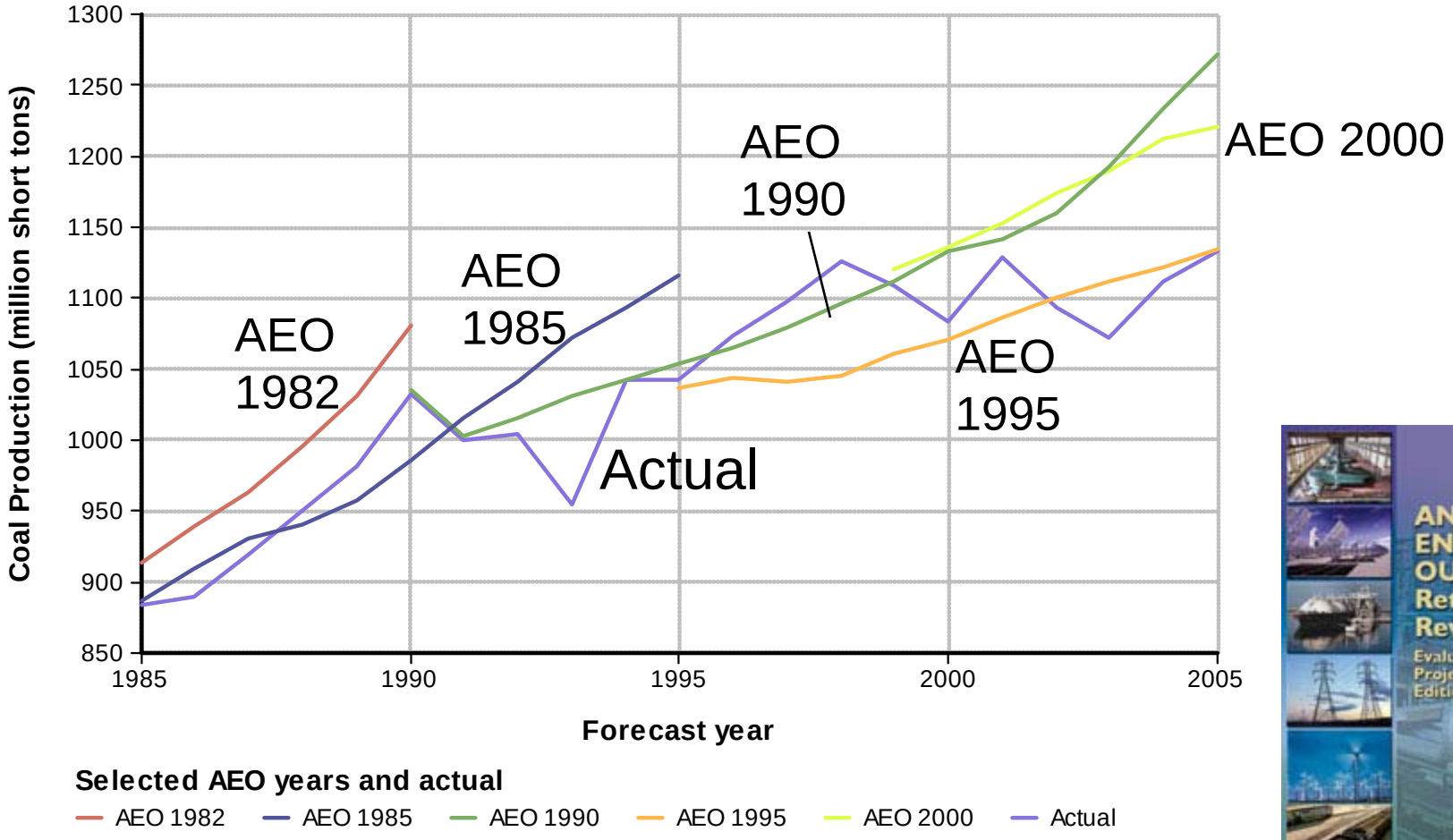
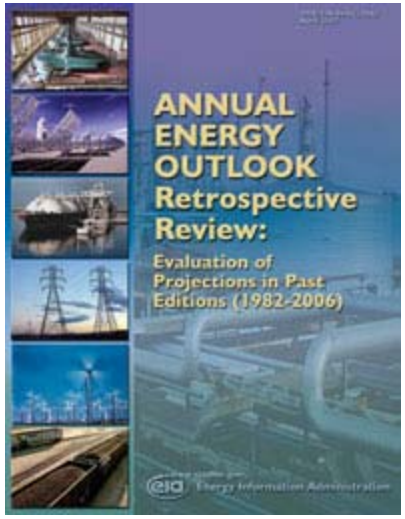
Retrospective assessment:
Coal production (million tons)





Data from Annual Energy Outlook: Retrospective Review 2007.

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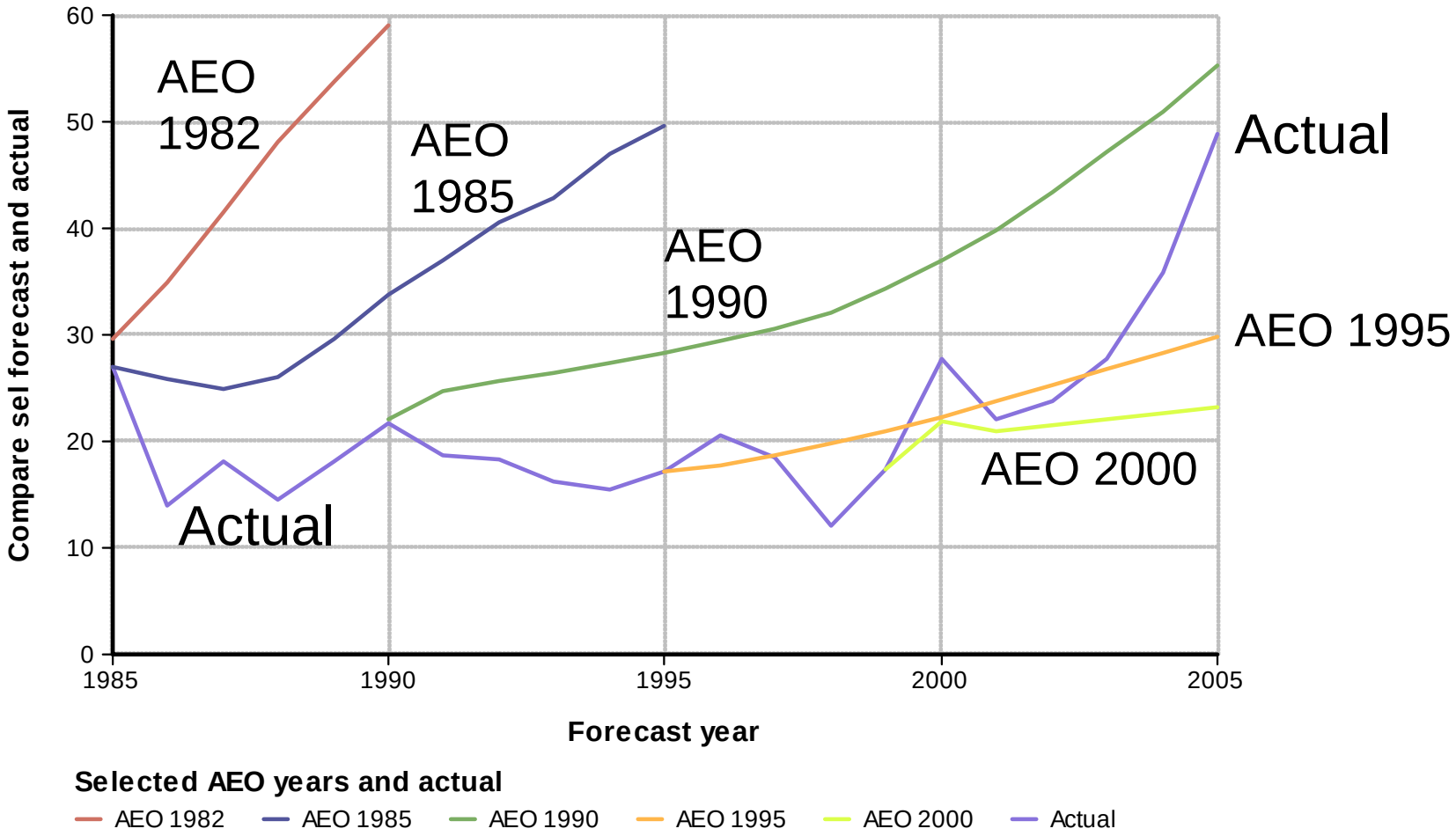
Retrospective assessment:
World oil price ($/barrel)



Data from Annual Energy Outlook: Retrospective Review 2007.

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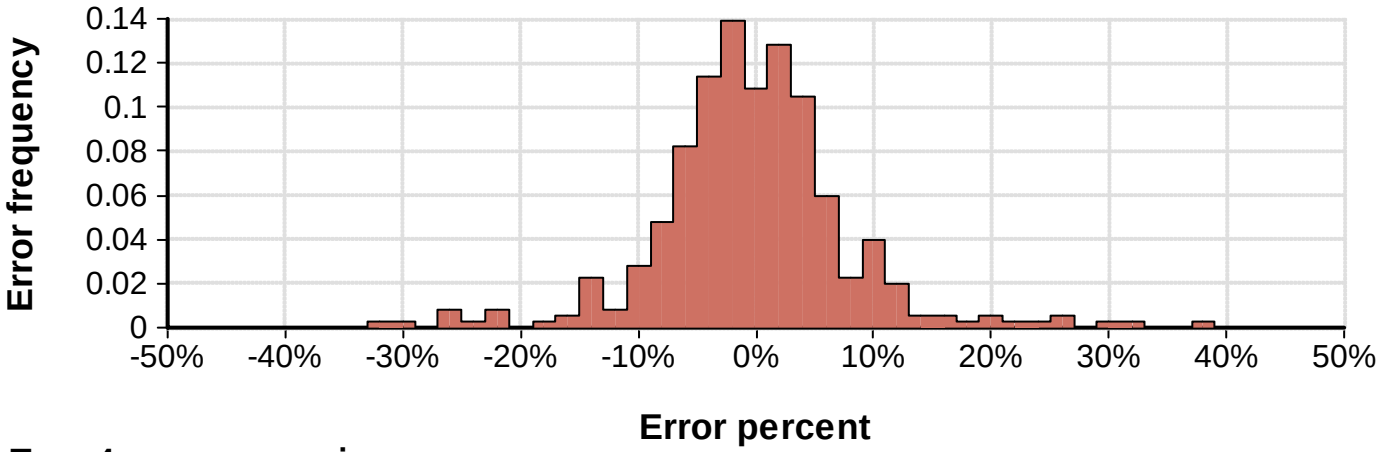
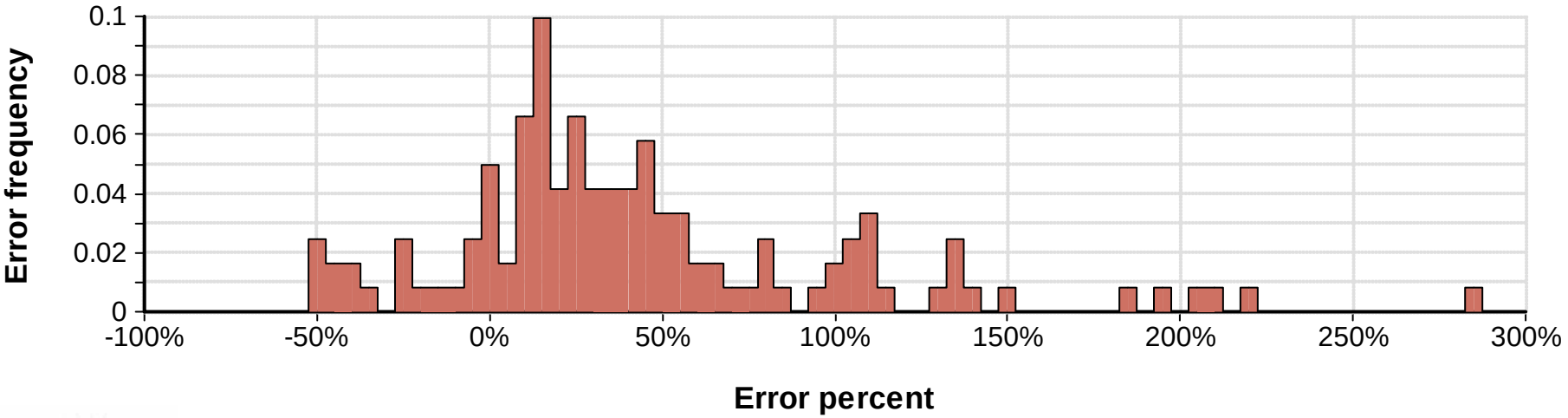
Retrospective assessment:
Error frequency distributions

For 12 energy quantities

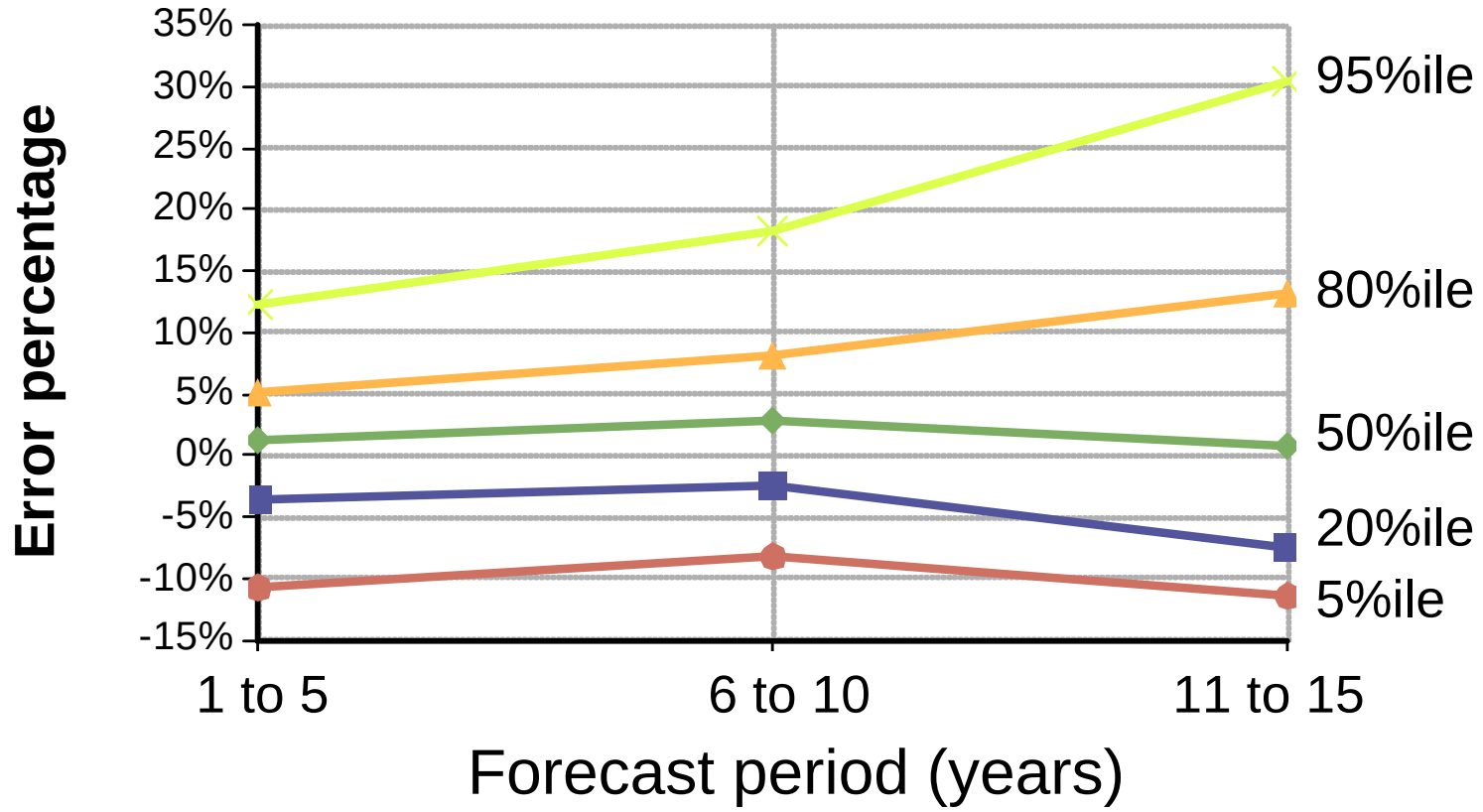


For 4 energy prices



Data from Annual Energy Outlook: Retrospective Review 2007.

Retrospective assessment: Error widths by forecast period for projections of 12 energy quantities



Data from Annual Energy Outlook: Retrospective Review 2007.

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Retrospective assessment:
Some observations

- You need a long history of projections for useful results.
- Some types of quantity (e.g. prices) are less predictable than others (e.g. energy flows).
- Error distributions have long tails (not normal).
  - Alexander I. Shlyakhter, Daniel M. Kammen, Claire L. Broido and Richard Wilson : The credibility ofenergy projections from trends in past data: The US energy sector, *Energy Policy*, Feb 1994
- Large errors are often due to rare events, outside and beyond the model.
  - *The Black Swan: The Impact of the Highly Improbable*, Nassim Taleb, Random House, 2007

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Comparing ways to assess uncertainty in model projections

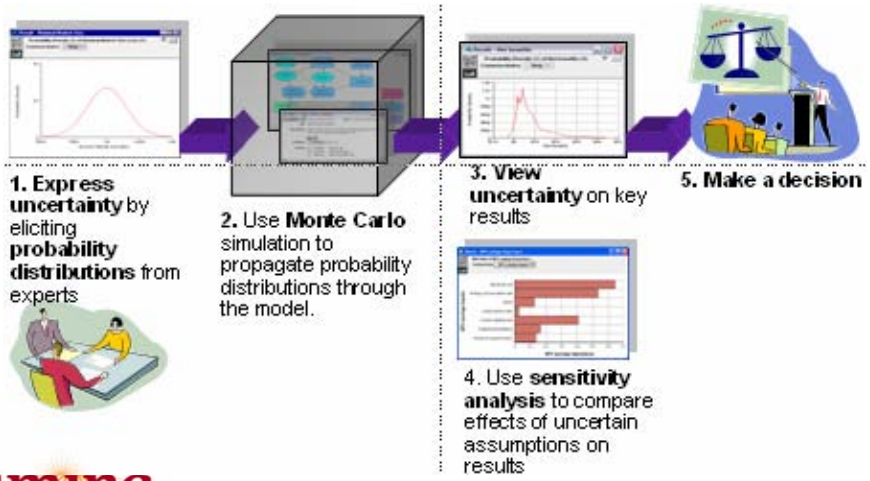
Prospective probabilistic simulation

Pros:

- Works for new models.

Cons:

- Liable to omit important sources of uncertainty.



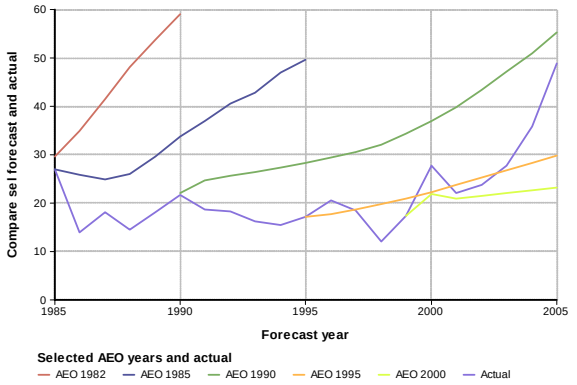
Retrospective assessment

Pros:

- Easy to do for past years.
- Interesting and informative.

Cons:

- Requires judgment to apply to the future: New models, and the world they represent will be different.



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Understanding probabilistic assessments of uncertainty

- A degree of judgment is unavoidable:
  - **Prospective simulation:** To assess input uncertainties and to judge missing sources of uncertainty
  - **Retrospective evaluation:** To apply results for prospective projections
- Assessment of uncertainties are *lower bounds* on calibrated uncertainty

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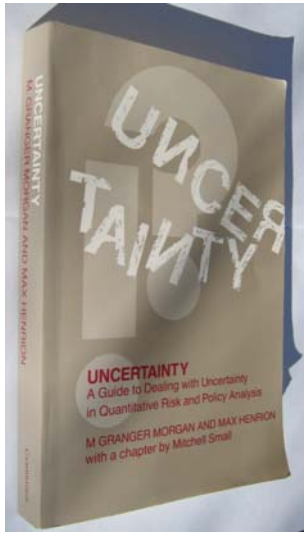
For more...



***Uncertainty**:*
A Guide to Dealing with Uncertainty in Risk and Policy Analysis. M Granger Morgan & Max Henrion, Cambridge University Press, 1990

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Summary

- It is well worth the effort to quantify explicitly the uncertainties in model projections.
- Quantifying uncertainties unavoidably involves judgment. Better make it explicit.
- Retrospective assessments of error distributions in past projections are a valuable complement to prospective: We should do more of it.
- Error distributions are long-tailed – not normal – because rare events are not so rare: we can't model everything.
- We and decision makers should understand that probabilistic projections are really *lower bounds* on uncertainty.

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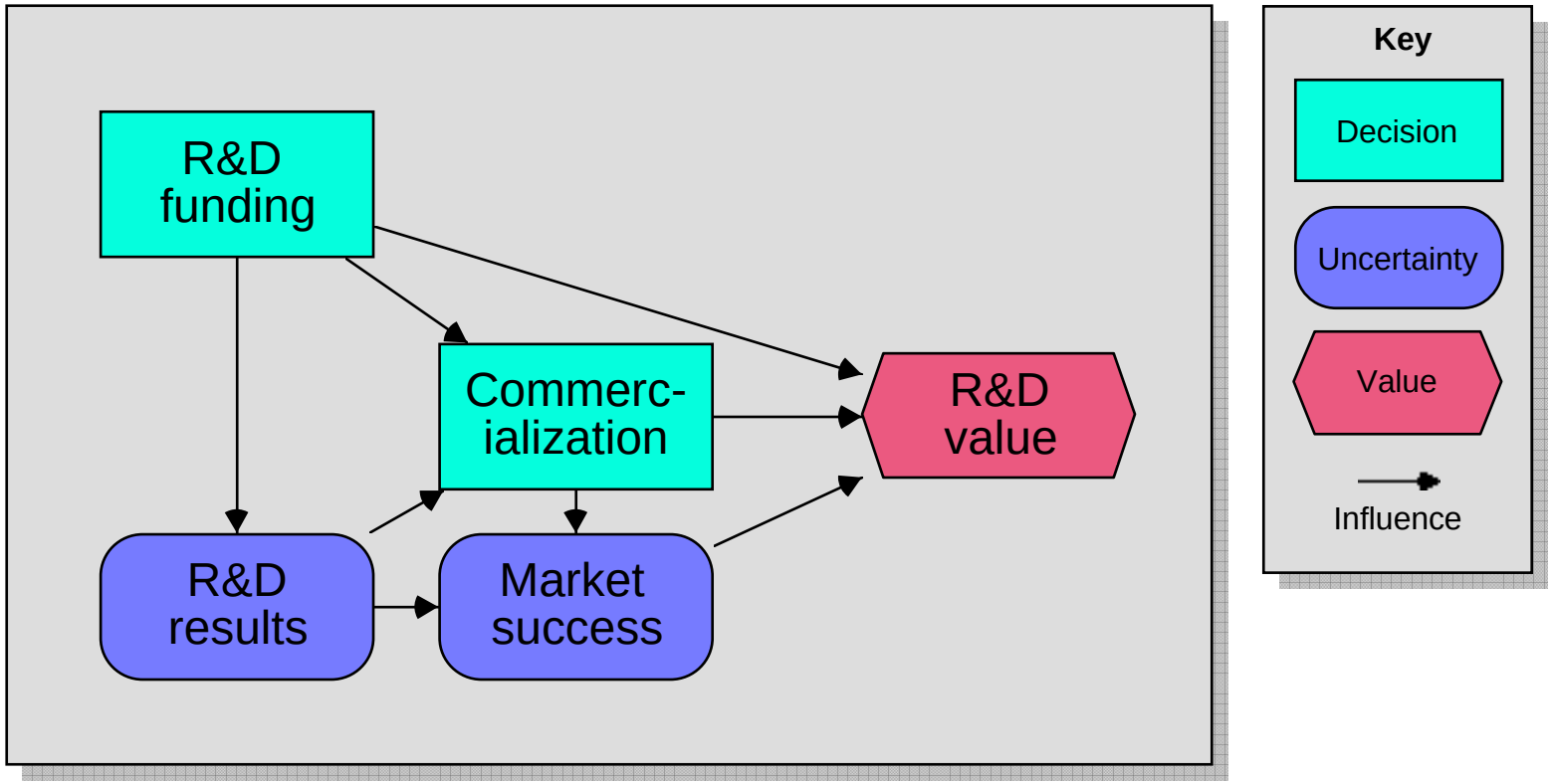
An Influence diagram for R & D decision analysis



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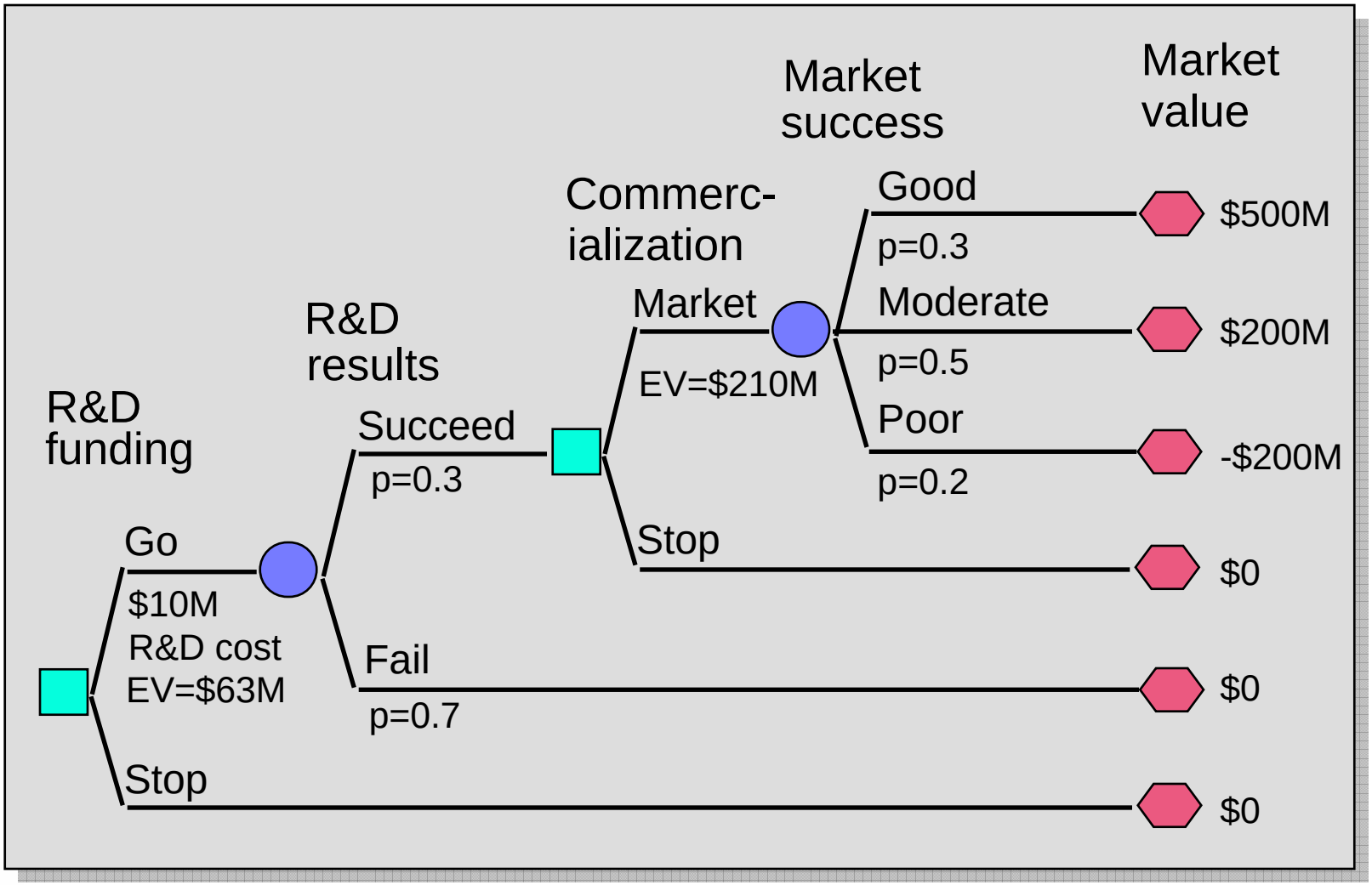
A decision tree for R&D decision analysis



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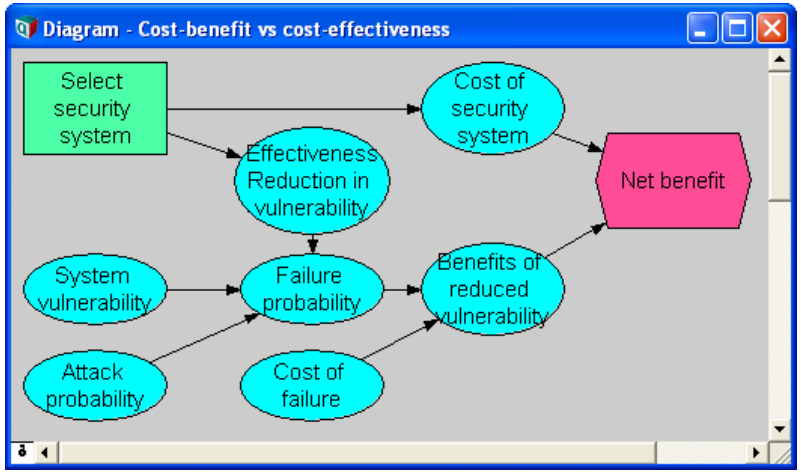
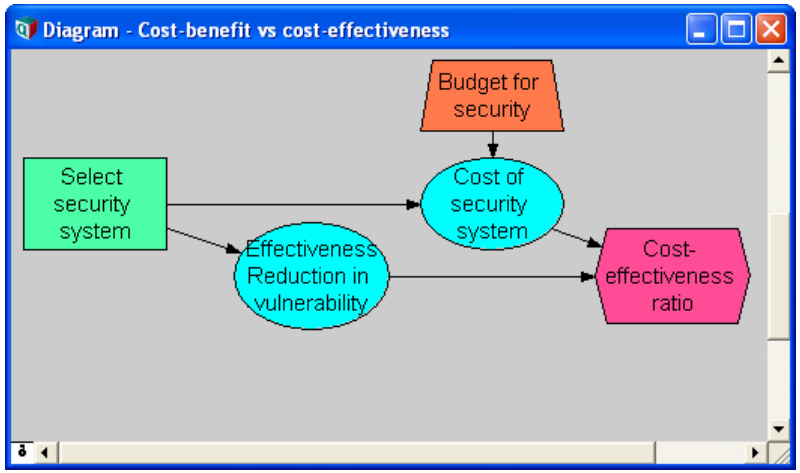
Making decisions with limited information: Cost-effectiveness vs. cost-benefit analysis

- Coping with the threat of terrorism on power transmission system: How should we design a security system?
- For cost-benefit analysis, we need to estimate the probability of terrorist attack and the cost if successful to compare with cost of security system
- For cost-effectiveness: Choose the security system with maximum effectiveness in reducing vulnerability given budget available





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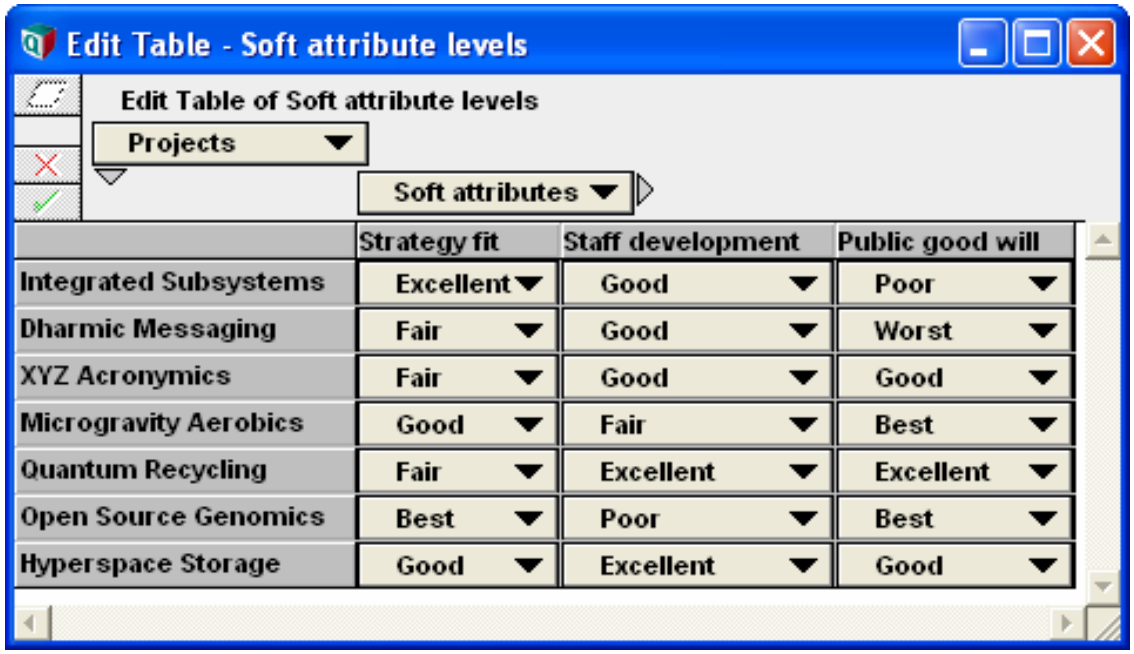
Rating projects on “soft” objectives: Beyond hard NPV revenues



	Strategy fit	Staff development	Public good will
Integrated Subsystems	Excellent	Good	Poor
Dharmic Messaging	Fair	Good	Worst
XYZ Acronymics	Fair	Good	Good
Microgravity Aerobics	Good	Fair	Best
Quantum Recycling	Fair	Excellent	Excellent
Open Source Genomics	Best	Poor	Best
Hyperspace Storage	Good	Excellent	Good

- Don’t let “hard” numbers (monetized objectives) drive out the soft numbers
- Actually, all the numbers are soft to a degree

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- Don’t let hard numbers drive out soft criteria
- Analyzing cost-effectiveness under a budget can let you make meaningful decisions even when some factors are too hard to quantify.

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