Richard Moss asked me talk about

Uncertainty in Global and Regional Emissions from the Energy System

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I think we can all agree that…

…the further we go into the future, the more uncertain the magnitude of those emissions will become.

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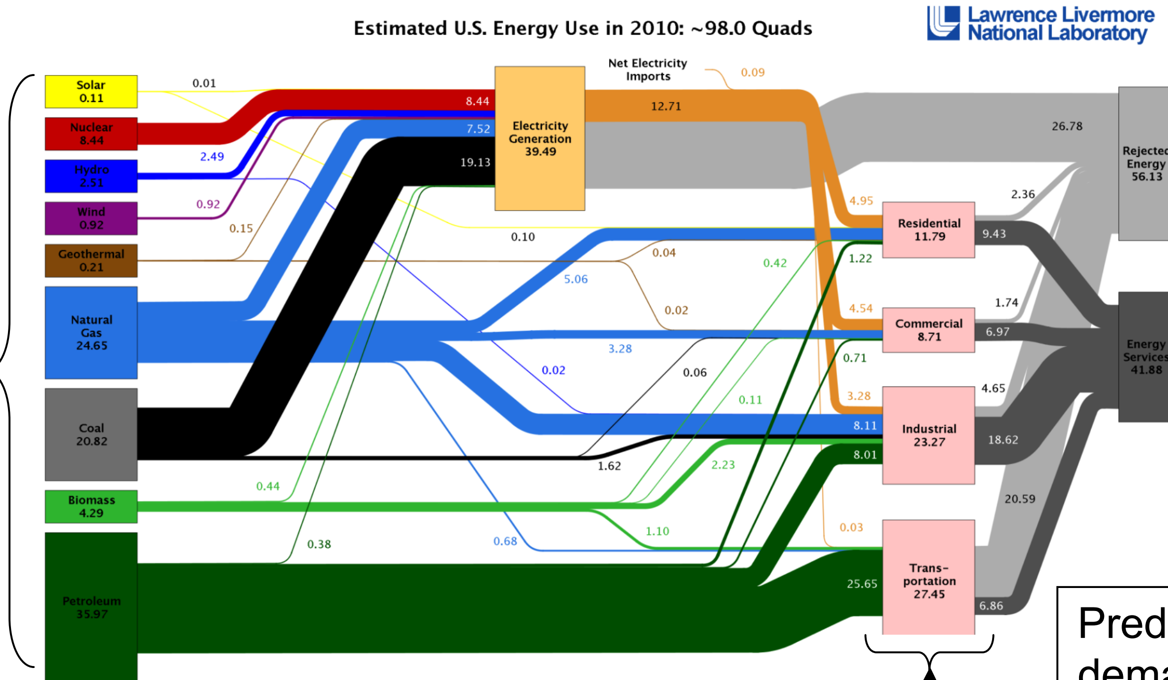
This is because of:

- Changes in regional and global economic and geopolitical conditions;
- Changes in the rate of development in the third world;
- Changes in the end use mix;
- Changes in energy technology and its costs;
- Changes in knowledge about and the cost of resources.

In order to predict emissions…

…from the energy system, we must simultaneously (because, in part, they depend on each other) be able to …



Predict mix of overall system efficiency which depends on conversion, transport and end use efficiencies, all of which depend on technologies which depend on R&D, policy diffusion, regulation, etc.

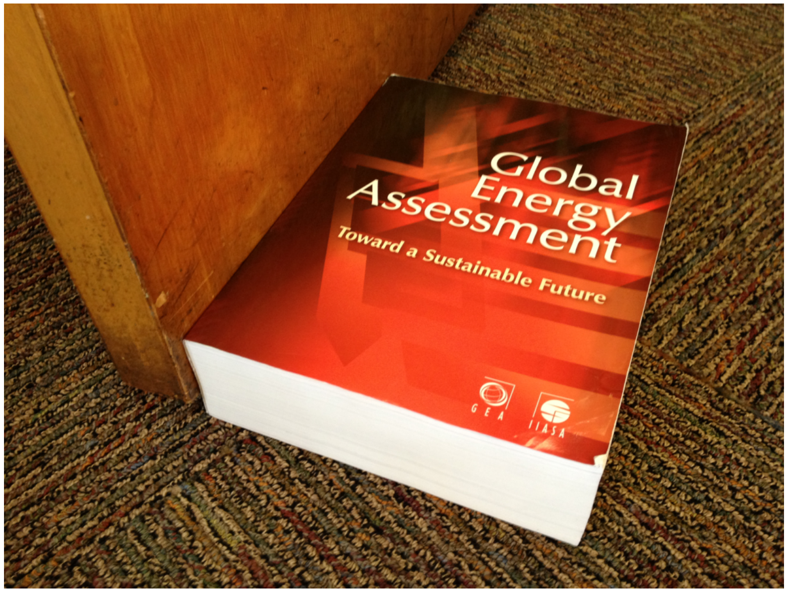
Predict mix of primary energy technologies which depends on R&D, policy, diffusion, regulation, etc.

Predict mix of end use technologies which depend on R&D, policy diffusion, regulation, etc.

Predict end use energy demand which depends on the mix of end use technologies, prices, state of the economy, population, etc. which in turn depend on R&D, policy diffusion, regulation, etc.

Since much of this…

…is spelled out in Naki et al.'s "doorstop," the obvious problem I faced in putting together this talk is what to add.



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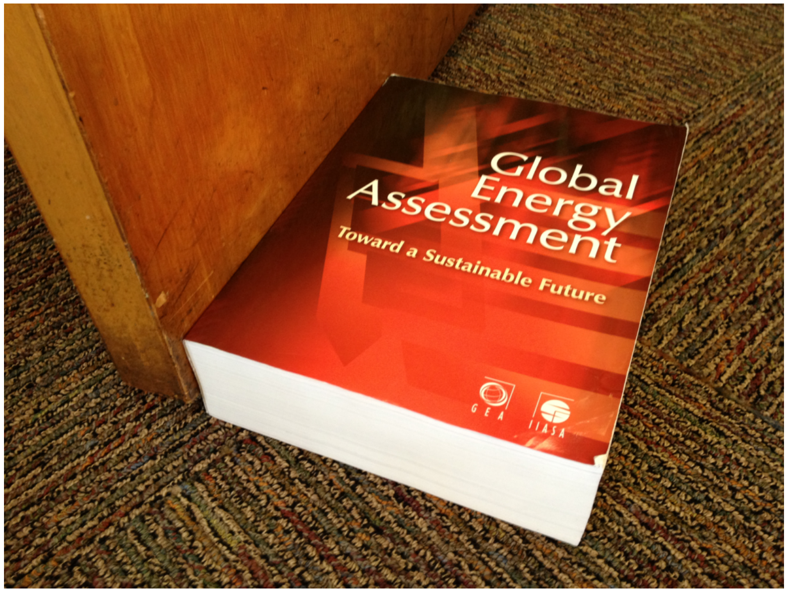
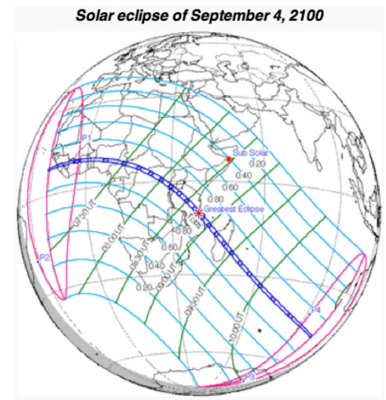


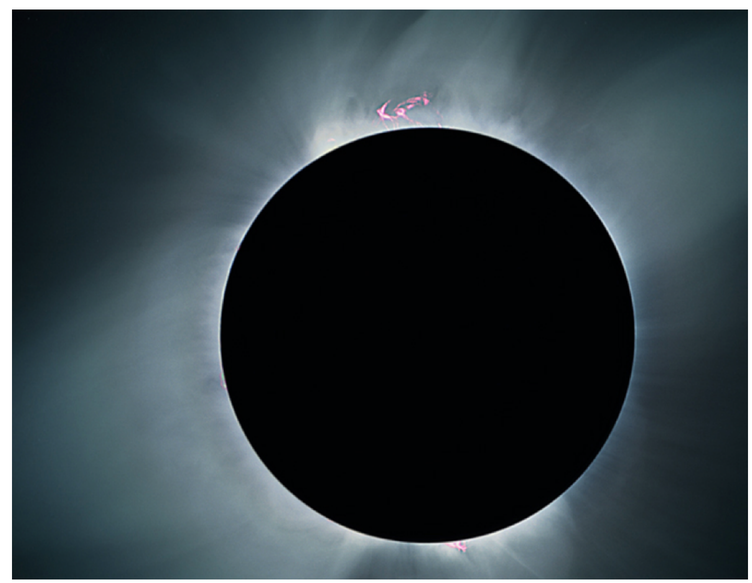
I've decided to talk a bit about how well we have done in making energy predictions in the past, and whether there are things we might do to improve how we do that in the future.

There are *some* future events…

…that can be precisely predicted. For example, thanks to Newtonian mechanics we can confidently say that there will be a total eclipse of the sun on September 4, 2100.

Indeed, we can even say that to within a fraction of a second, the moment of maximum eclipse will occur at 16:57:52 GMT.

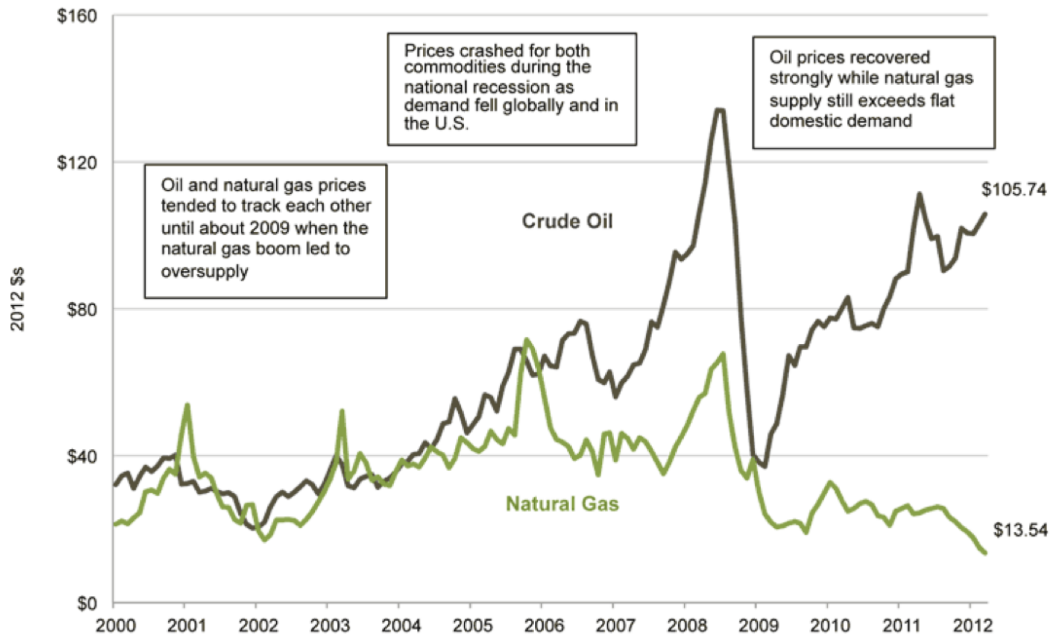




Source: wikipedia; geogdata.csun.edu.

But, given the plot below…

…nobody in their right mind could plausibly argue that we can predict U.S. oil or gas prices to ±50% in 20, let alone 100, years.



Source: headwaterseconomics.org.

Yet…some government agencies, and many policy modelers and economists make such deterministic forecasts *all the time*!

An aside:

How much the precision with which one can predict matters, depends somewhat on *what* one is trying to predict. If what I care about is the *mix* of generation technology, then ±50% might be adequate if the cost of the alternative technology (e.g., the "backstop" technology) is higher than the resulting upper bound.

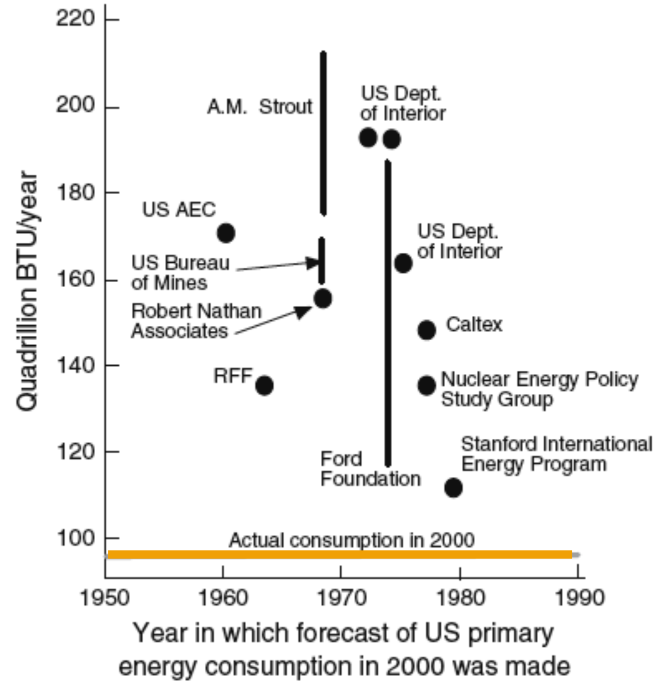
Providers of older technologies will try to extract rent. But their price will be limited (in part) by the level that would allow the competitive new technology to enter. In many cases, the new technology will first enter in niche markets (e.g., high income environmentalists).

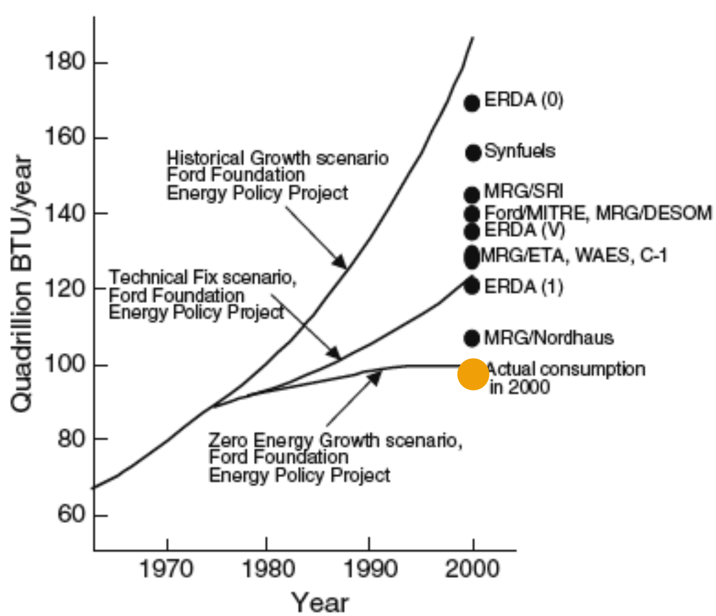
Incumbents have greater power, resources and regulatory advantages, and this can shape and slow such transitions (e.g., legacy utilities blocking μ-grids with DG/CHP).

When you look back…

…past forecasts don't do very well.

Here is a summary of forecasts of U.S. primary energy consumption for the year 2000 compiled by Smile (2003) as a function of the date on which they were made.

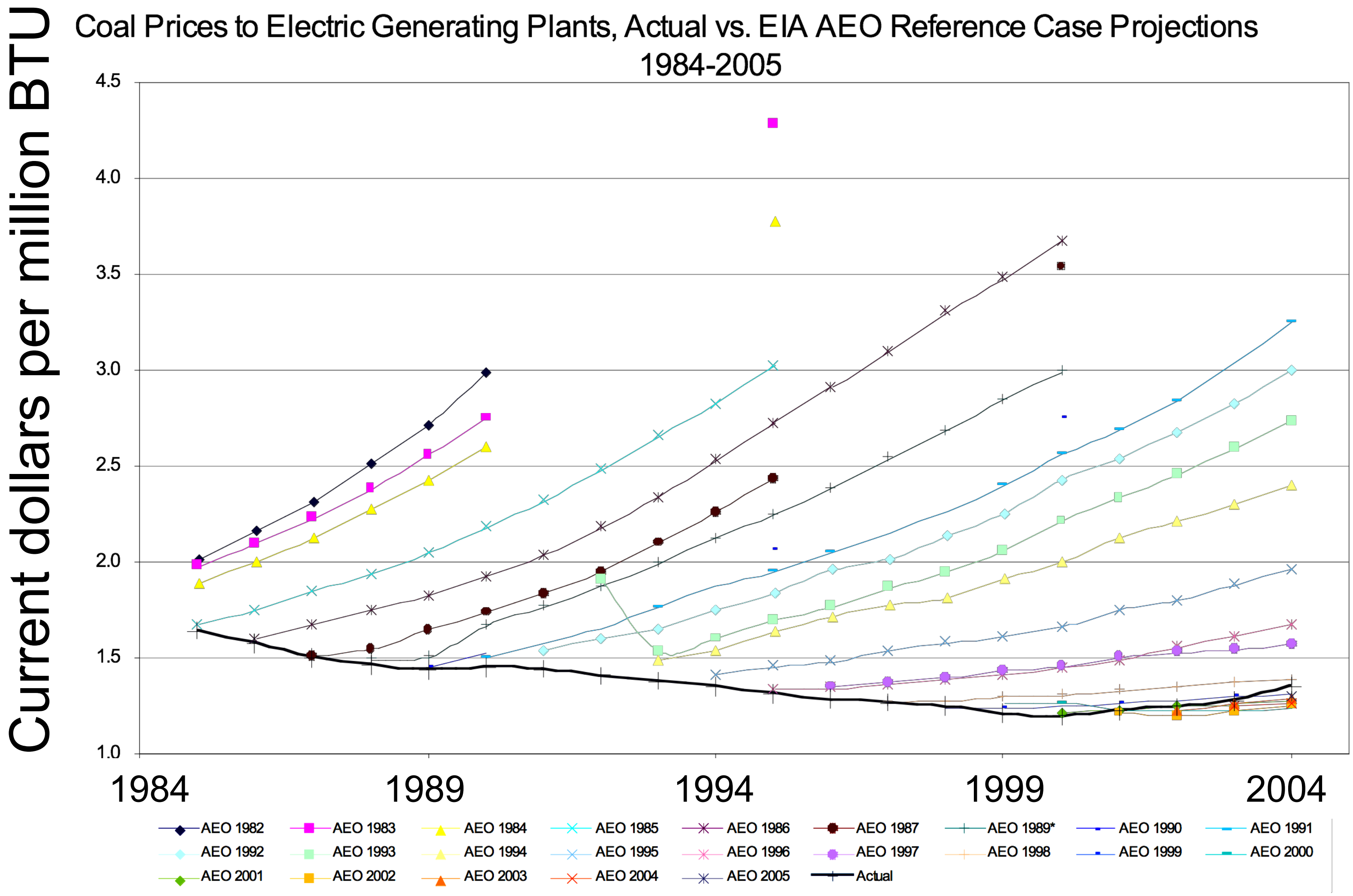




And here are forecasts of U.S. primary energy consumption for the year 2000 compiled by Greenberger in the early 1980s compared with three scenarios developed by the Ford Foundation Energy Project.

Figures from Morgan and Keith, 2008.

EIA - AEO



Complied by Adam Newcomer, 2007.

EIA - AEO…(Cont.)

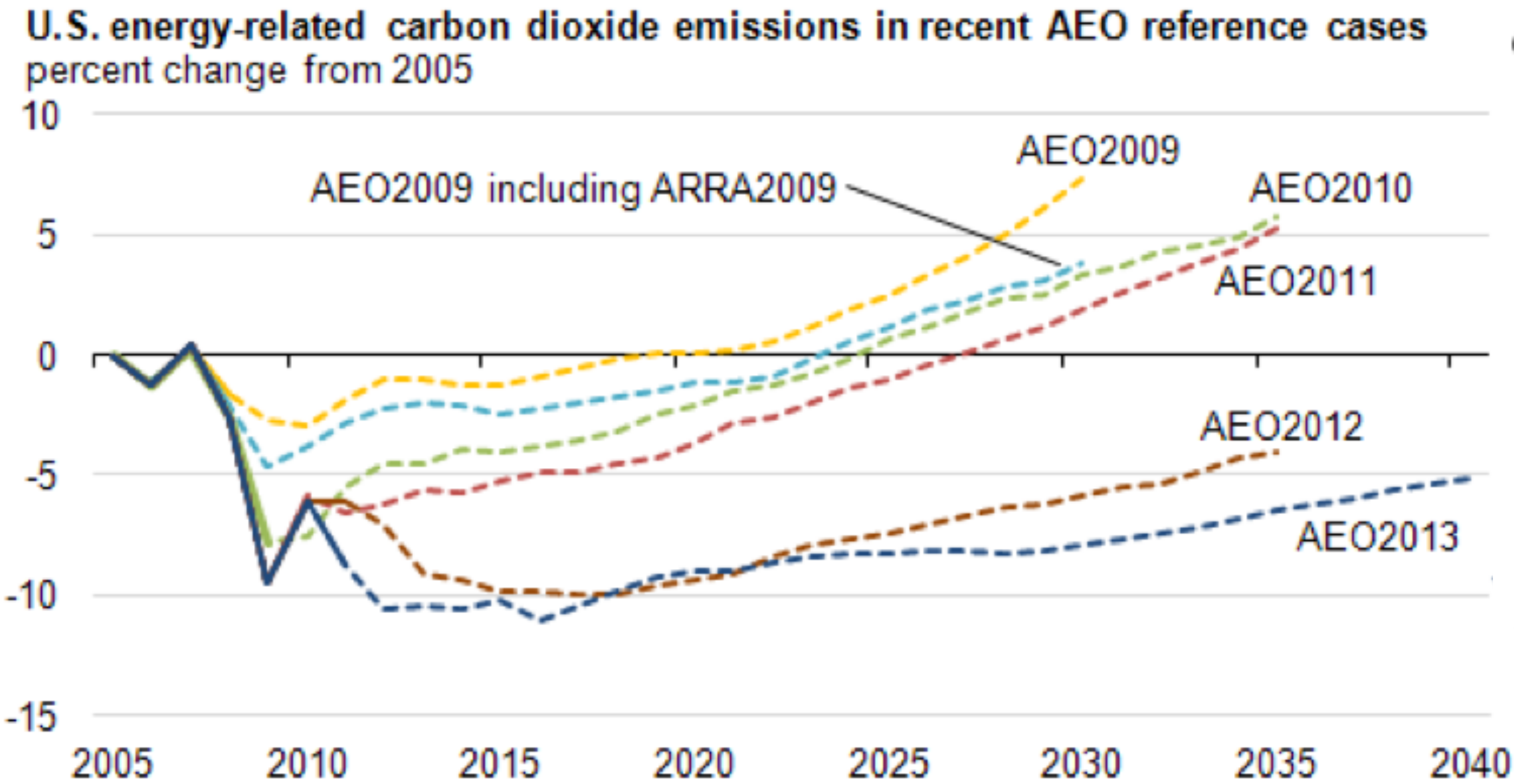
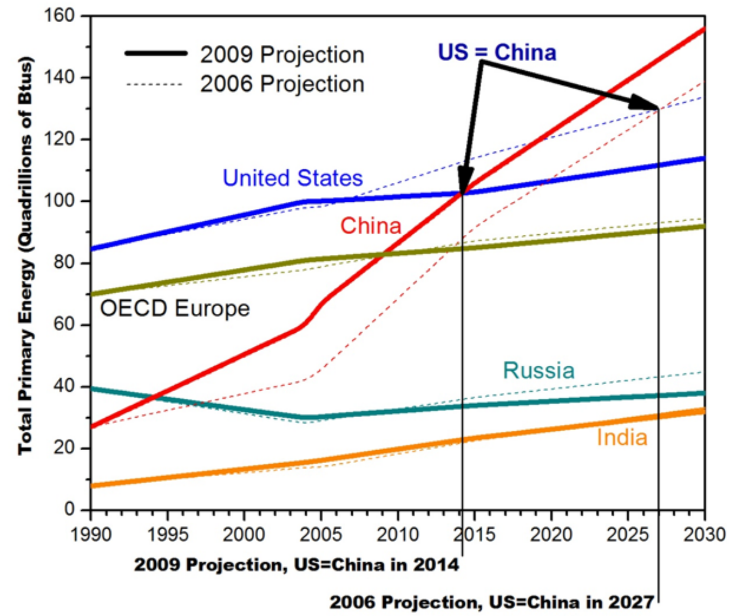


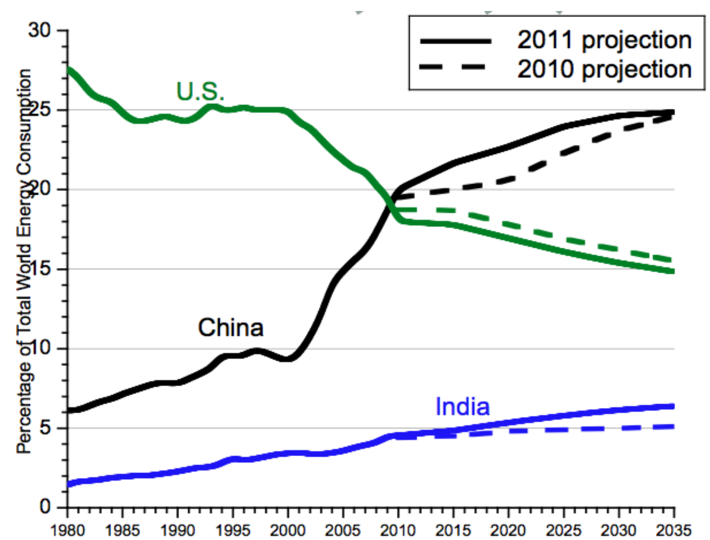
Figure from Maxine Savitz.

Predictions of when China would pass the U.S.

The year in which EIA projected that China's total primary energy would exceed the U.S. has steadily moved closer.



China's energy consumption actually exceeded that of the U.S. even sooner.



Note too that China's investments in wind and solar PV have grown faster than many predicted.

Data for plots from Energy Information Administration, International Energy Outlook. Figures from Maxine Savitz.

It turns out there is…

…a fair amount of literature on how well past forecasts have performed. Some examples worth reading:

- Paul P. Craig, Ashok Gadgil and Jonathan G. Koomey, "What Can History Teach US? Examination of long-term energy forecasts for the United States," *Annual review of Energy and the Environment*, *27*, pp. 83-118, 2002.
- Vaclav Smil, "Perils of Long-Range Energy Forecasting: Reflections on looking far ahead," *Technology Forecasting and Social Change*, *65*, pp. 251-264, 2000.
- Hans H. Landsberg, "Energy in Transition: View from 1960," *The Energy Journal*, *6*(2), pp. 1-18, 1985.
- Hans Linderoth, "Forecast Errors in IEA-Countries' Energy Consumption," *Energy Policy*, *30*, pp. 53-61, 2002.
- James J. Winebrake and Denys Sakva, "An Evaluation of Errors in U.S. Energy Forecasts: 1982-2003," *Energy Policy*, *34*, pp. 3475-3483, 2006.
- Brian C. O'Neil and Mausami Desai, "Accuracy of Past Projections of U.S. Energy Consumption," *Energy Policy*, *33*, pp. 979-993, 2005.
- Hilliard G. Huntington, "Oil Price Forecasting in the 1980s: What went wrong?" *The Energy Journal*, *15*, pp. 1-22, 1994.

Jonathan Koomey, Paul Craig, Ashok Gadgil and David Lorenzetti, "Improving Long-Rage Energy Modeling: A plea for historical retrospectives," *The Energy Journal*, *24*, pp. 75-92, 2003.

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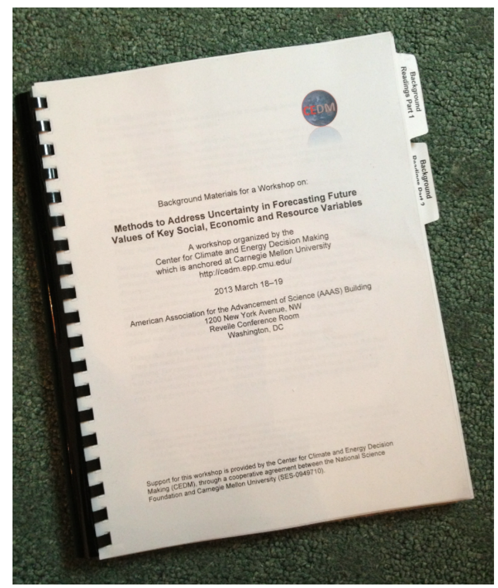
- Bent Flyvbjerg, Mette K. Skamris Holm and Søren L. Buhl, "How Common and How Large are Cost Overruns in Transport Infrastructure Projects?," *Transport Review*, *23*(1), pp. 71-88, 2003.
- RAND Project Air Force, "Historical Cost Growth of Completed Weapons System Programs" 2006 and "Is Weapon System Vost Growth Increasing?" 2007.

In order to explore these issues…

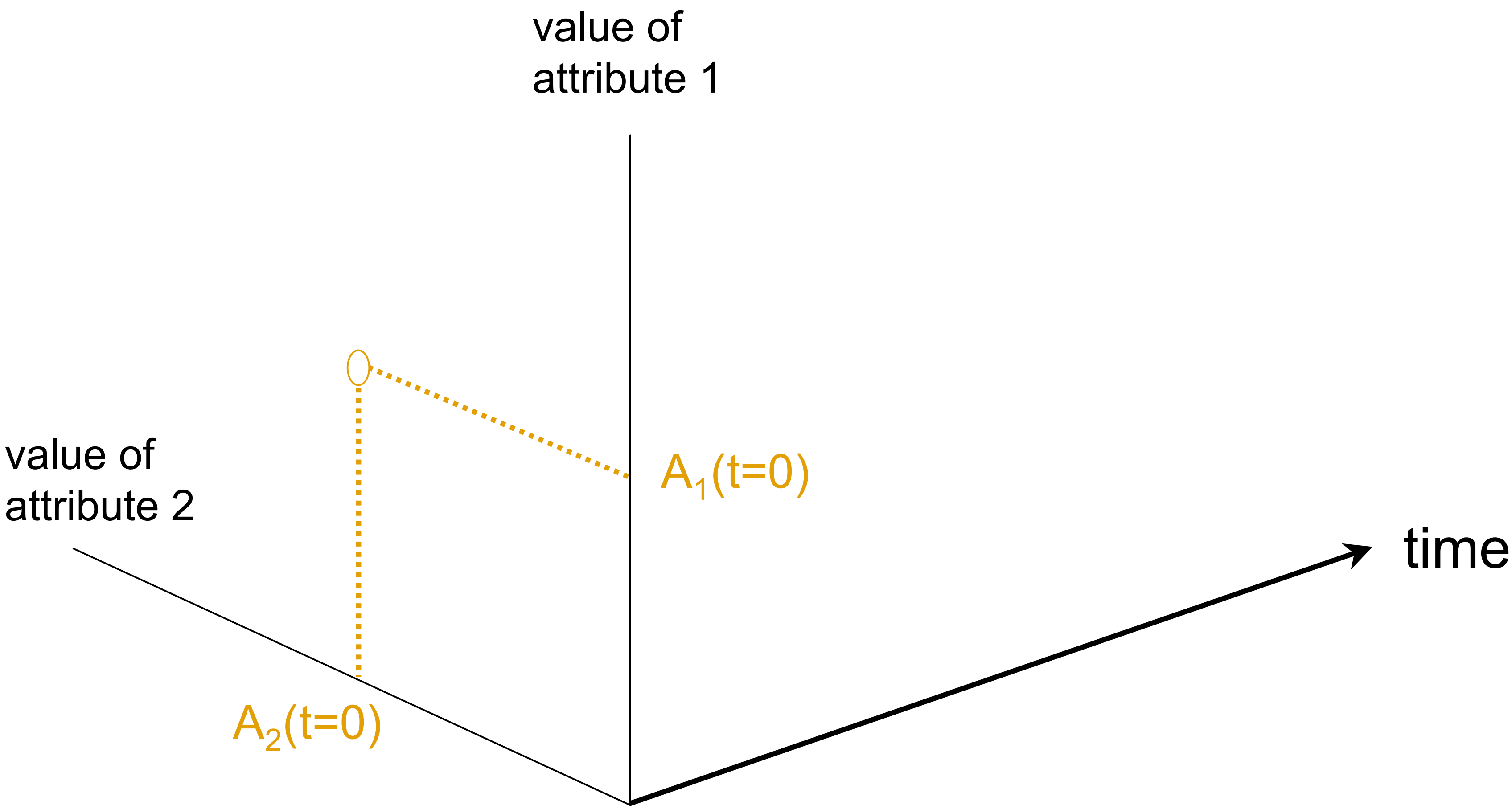
…on March 18-19 of this year our NSF center on Climate and Energy Decision making ran a workshop on Uncertainty in Forecasting in Washington, DC.



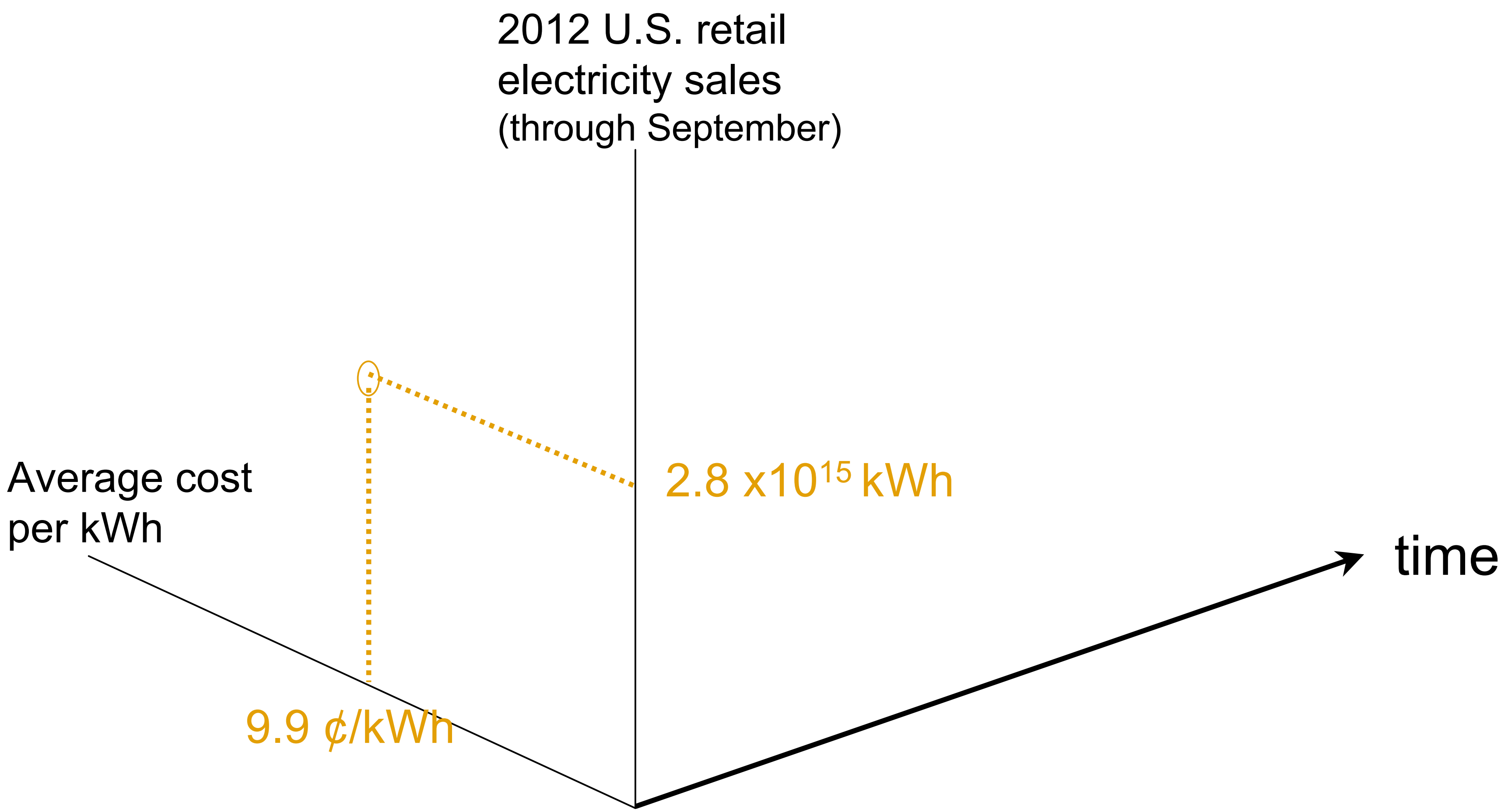
In the balance of this talk I will:

1. State what I see as the problem in general terms.
2. Consider why (some) people persist in making deterministic forecasts when it is very clear that such forecasts are often close to meaningless.
3. Suggest some strategies we should be developing and demonstrating, and other things we should be doing, in order to improve in the future.

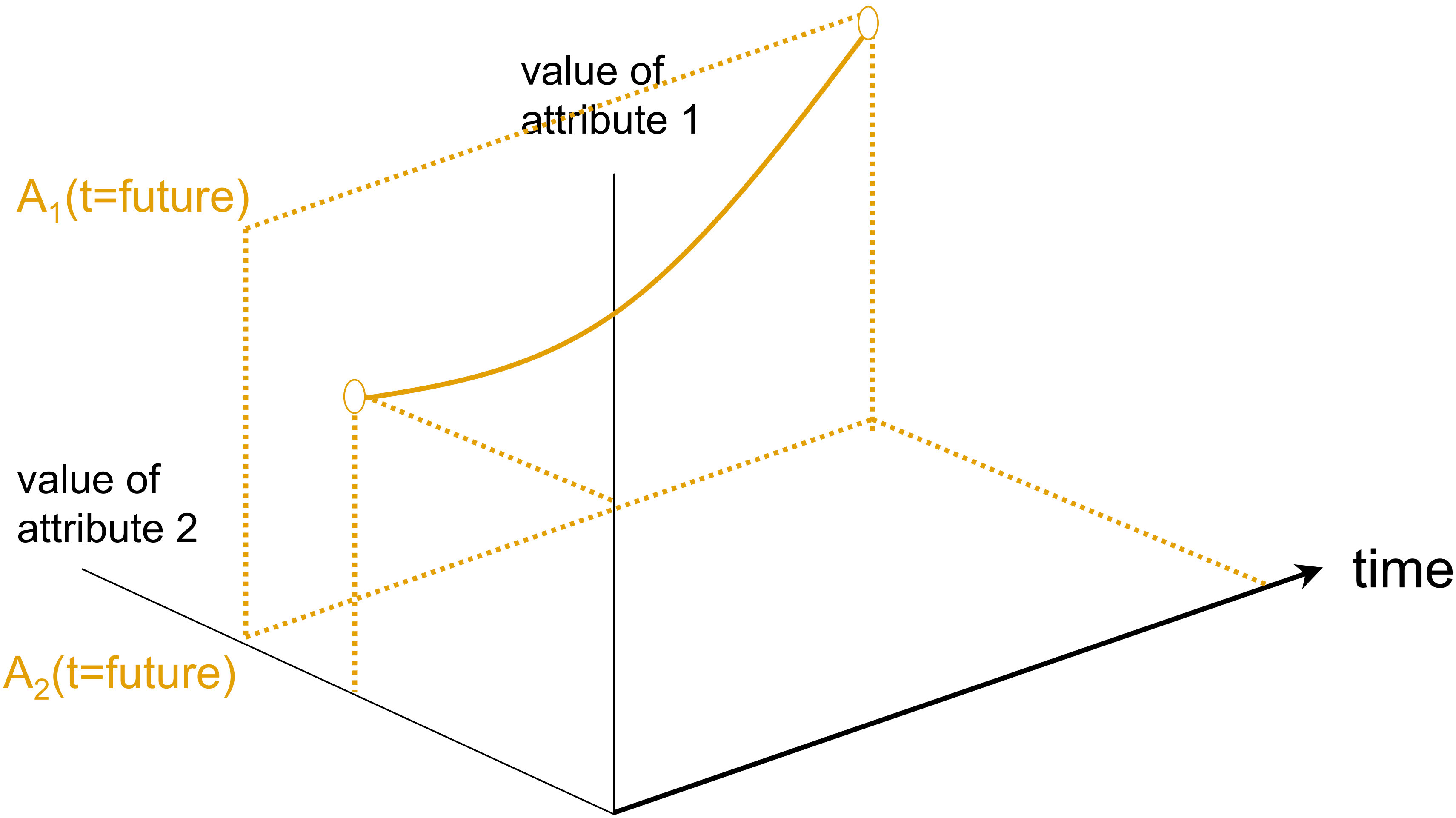
The basic problem:



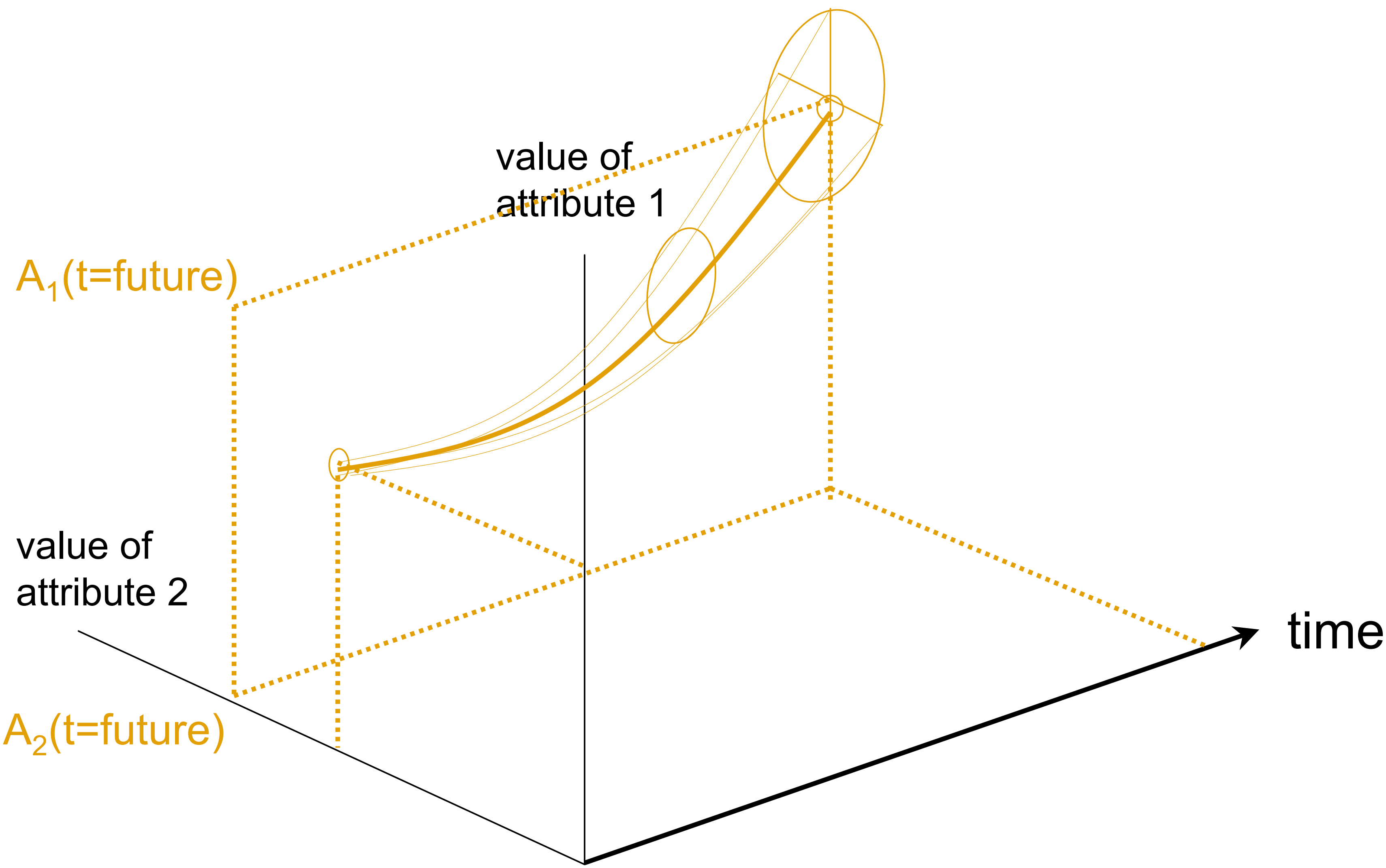
For example:


2012 U.S. retail
electricity sales
(through September)
2.8 x10^15 kWh
Average cost
per kWh
9.9 ¢/kWh
time

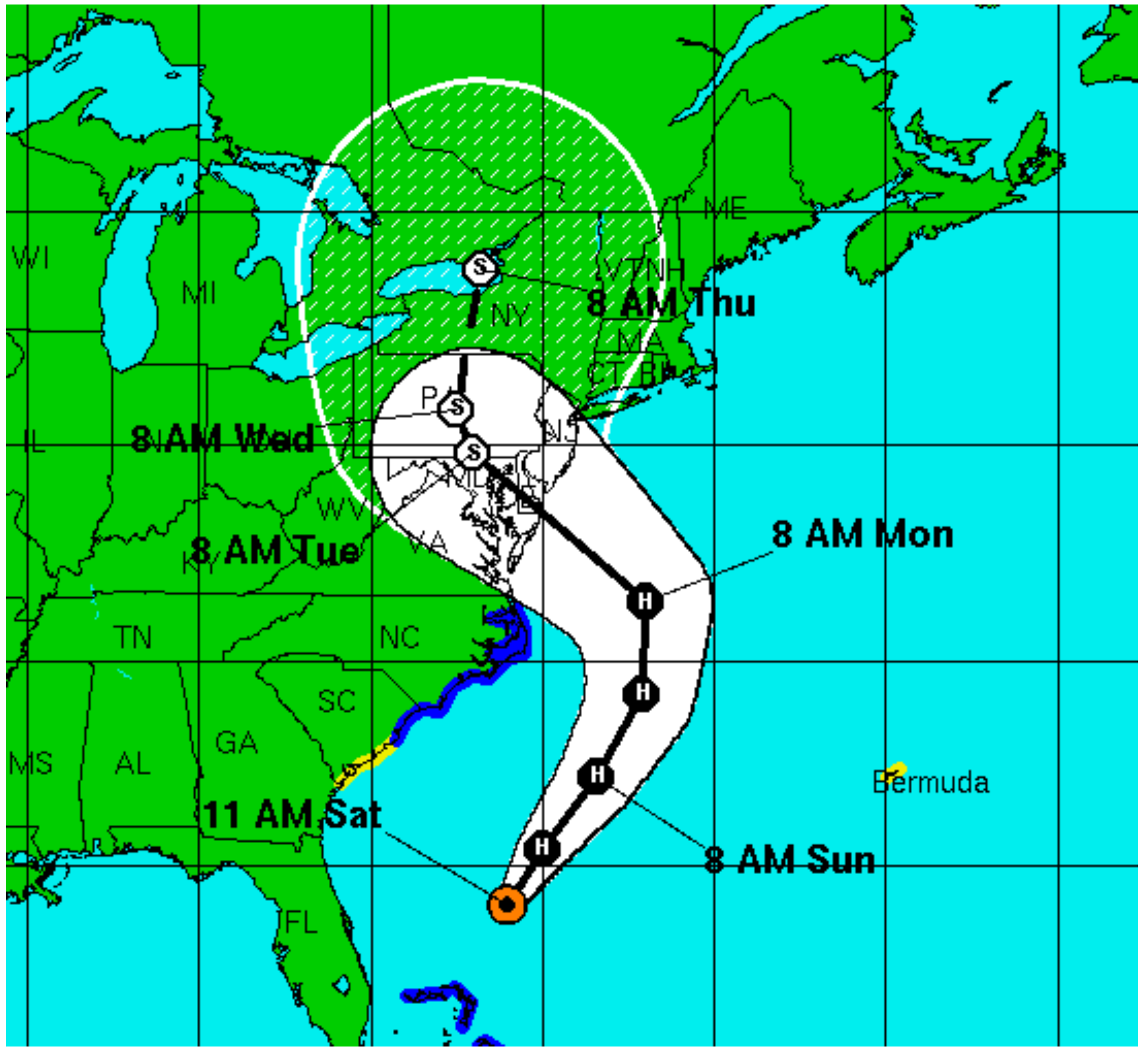
Back to the basic problem:



But, the future is uncertain:

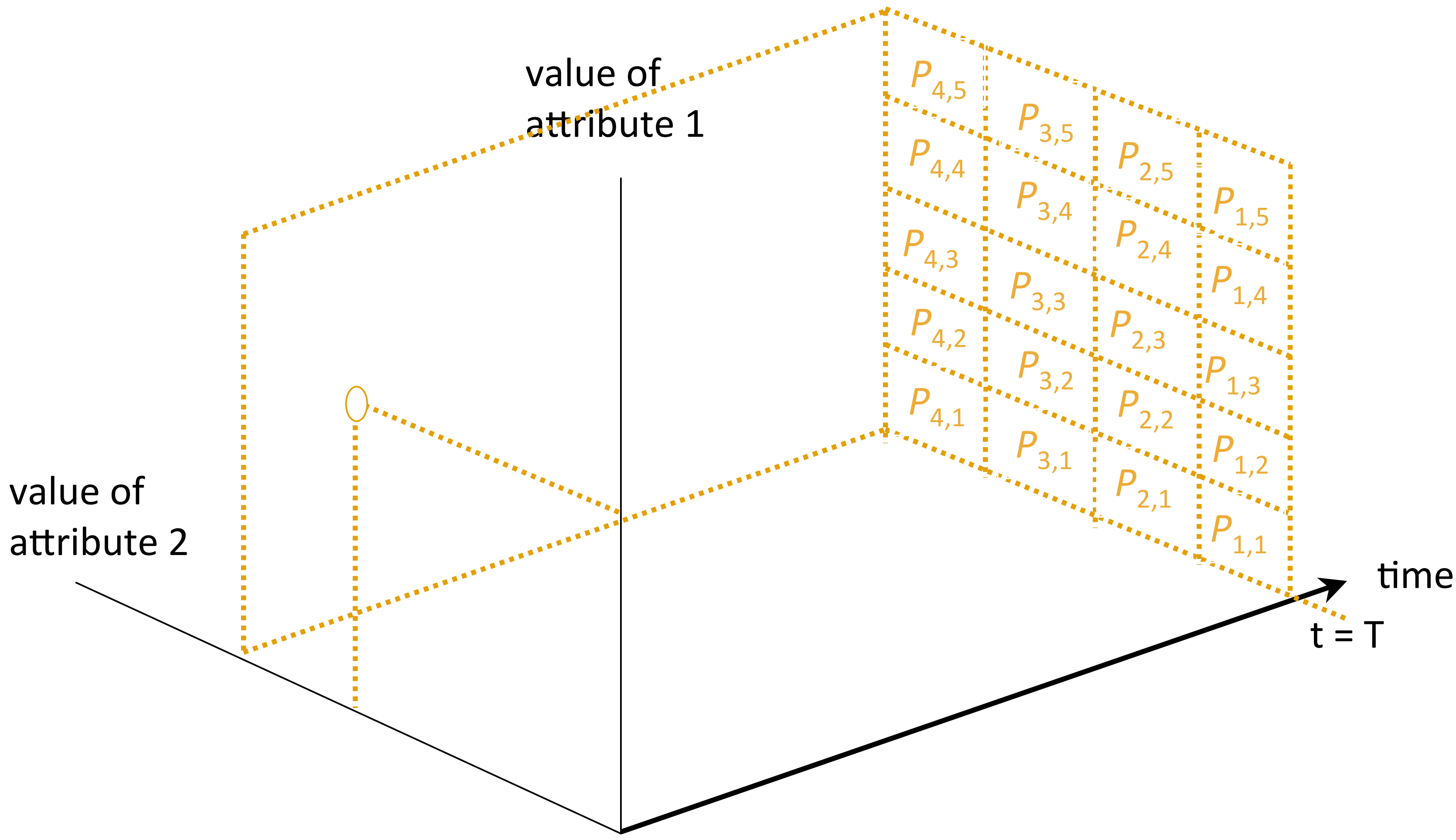


We all know about such "cones of uncertainty"



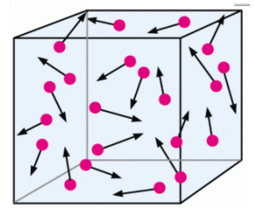
Source: NOAA.

One *can* attach probabilities to cones or regions (but *not* to lines)

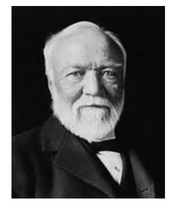


What creates uncertainty about future values?

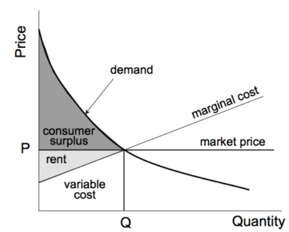
- Random physical processes.



- Choices by key decision makers.



- Emergent consequences of many individual "agents."



- New technology.

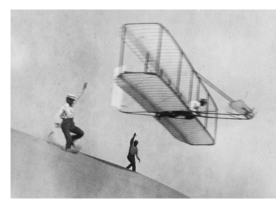
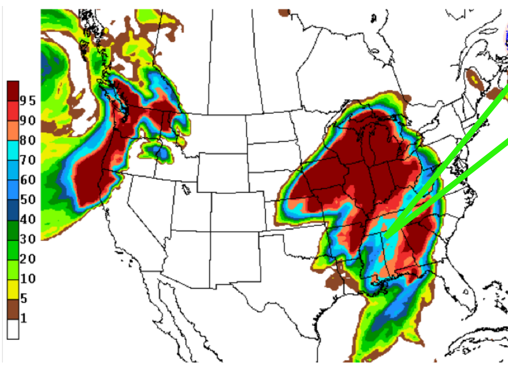


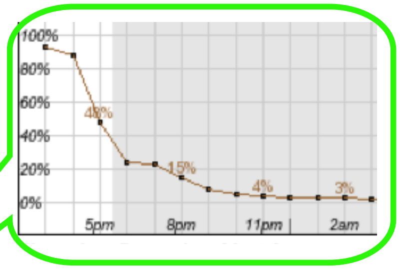
Figure sources: jimmyakin.com; www.kutl.kyushu-u.ac.jp; www.moonmentum.com; eh.wikipedia.org; hardygreen.com; i.telegraph.co.uk; 3.bp.blogspot.com; memory.loc.gov; vneagoie.wordpress.com; wikipedia.

While they do not…

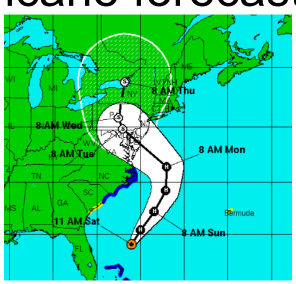
…do it perfectly, laypeople are capable of acknowledging and dealing with uncertainty.

Precipitation forecasts:





Hurricane forecasts:



Race track betting odds:

			WIN		PLACE	
NO	RUNNER (BARRIER)	FLUCS	FIXED	SUPER BEST + (APPROX)	FIXED	SUPER MID (APPROX)
1	Dunaden (16)	7.00, 7.00	7.50	SUPER BEST +	2.90	SUPER MID
2	Americain (12)	6.50, 7.00	6.50	SUPER BEST +	2.60	SUPER MID
3	Jakkalberry (19)	61, 61	71.00	SUPER BEST +	17.50	SUPER MID
4	Red Cadeaux (18)	9.00, 9.00	9.50	SUPER BEST +	3.50	SUPER MID
5	Winchester (22)	51, 51	51.00	SUPER BEST +	13.50	SUPER MID
6	Voila Ici (13)	151, 151	151.00	SUPER BEST +	30.00	SUPER MID
7	Cavalryman (6)	34, 34	34.00	SUPER BEST +	9.70	SUPER MID

Point spreads in sport

NFL Point Spreads For Week 16 - Week Sixteen NFL Football Point Spread - NFL Spreads 12/22 - 12/23, 2012

Date & Time	Favorite	Spread	Underdog
12/22 8:30 ET	Atlanta	-3.5	At Detroit
12/23 1:00 ET	At Green Bay	-12.5	Tennessee
12/23 1:00 ET	At Carolina	-8	Oakland
12/23 1:00 ET	At Miami	-4.5	Buffalo
12/23 1:00 ET	At Pittsburgh	-3.5	Cincinnati
12/23 1:00 ET	New England	-14.5	At Jacksonville
12/23 1:00 ET	Indianapolis	-7	At Kansas City
12/23 1:00 ET	At Dallas	-3	New Orleans
12/23 1:00 ET	Washington	-6.5	At Philadelphia
12/23 1:00 ET	At Tampa Bay	-3	St. Louis
12/23 4:25 ET	NY Giants	-2.5	At Baltimore
12/23 1:00 ET	At Houston	-7.5	Minnesota
12/23 4:05 ET	At Denver	-13	Cleveland
12/23 4:25 ET	Chicago	-5.5	At Arizona
12/23 8:30 ET	San Francisco	-1	At Seattle
12/23 1:00 ET	At NY Jets	-2.5	San Diego

Sources: forecast.weather.gov; www.hpc.ncep.noaa.gov; centrebet-nrl-grandfinal.com.au; www.footballlocks.com.

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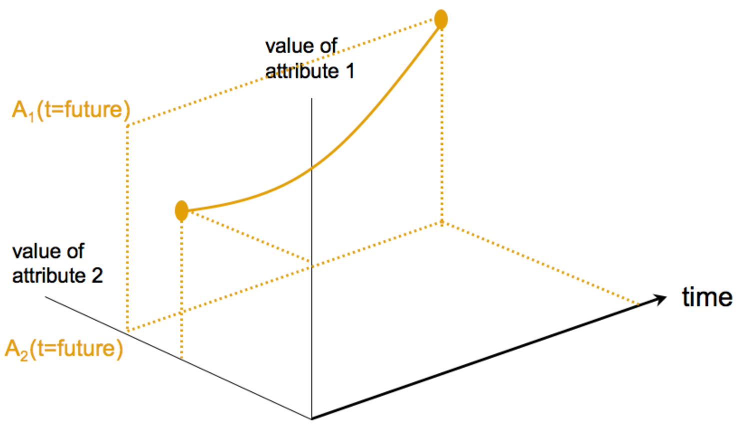
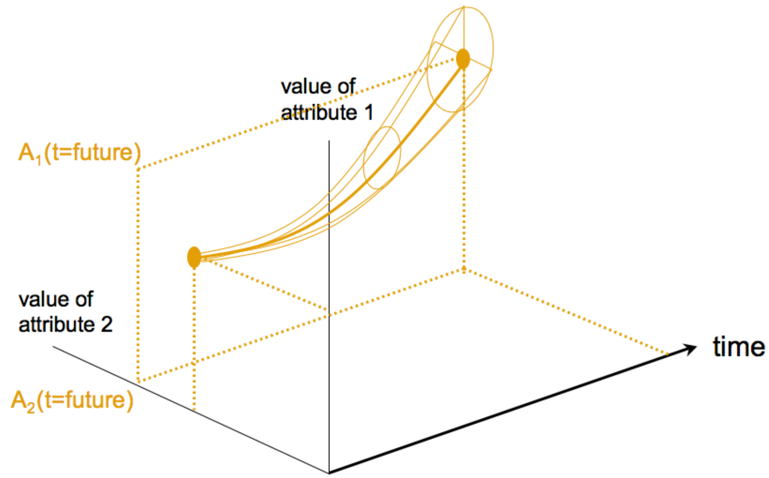
So, why is it that…

…most Government Ministers; many Government Ministries; many economists; and a wide variety of modelers (economics, energy, climate, etc.) persist in making single value forecasts with little or no discussion of uncertainty. In short:

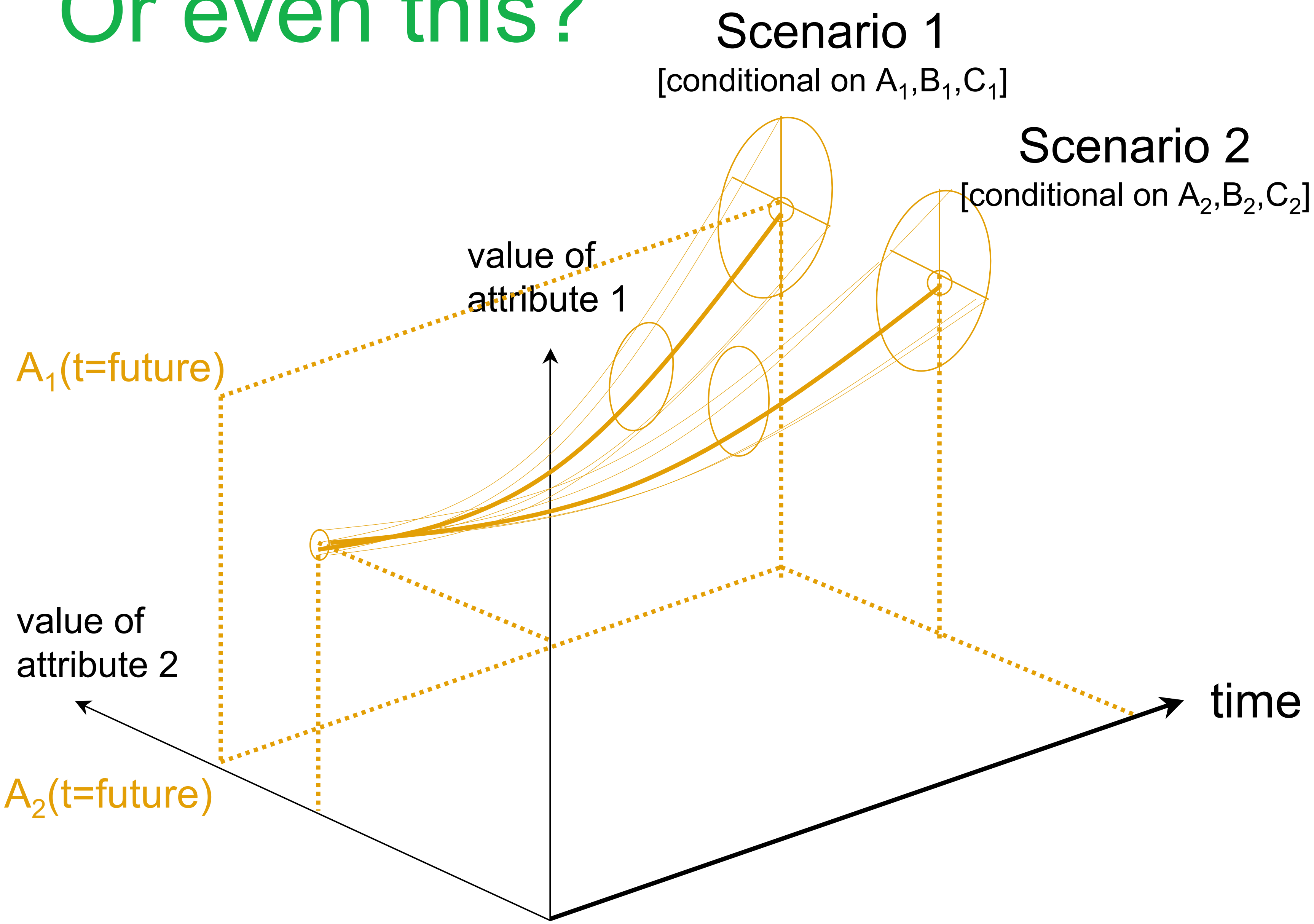
Why this…



Rather than this?



Or even this?


Scenario 1
[conditional on A1,B1,C1]
Scenario 2
[conditional on A2,B2,C2]
value of
attribute 1
A1(t=future)
value of
attribute 2
A2(t=future)
time

Some hypotheses

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- They are lazy - they find it too hard to do anything else;

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- They believe that if they include uncertainty, people will perceive them to be less expert;
- They have no idea what else they could do.

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Strategies for the shorter-term

(≤ a few decades)

1. Refine the official forecasts

Using EIA, IEA and/or others' past forecasts, a group could start to calibrate their performance, start adding uncertainty bounds to their future forecasts, and make the results widely available to the community.

Persuade EIA, IEA and/or others to do the job themselves, using all the embedded assumptions that they make in developing their forecasts.

Strategies for the shorter-term

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2. Engage in backcasting

John Weyant has observed:

> …other earth systems communities put great weight on backcasting – running the model starting in the past to see how close it matches actual history…doing this with socio-economic models is more complicated and may not be as meaningful. Nonetheless, more work on thinking through what type of backcasting would be beneficial could be quite useful to IAM community itself and useful in responding to the interests of the other earth systems research communities and model users.

John P. Weyant, "Lessons Learned From Past Energy-Environmental Inter-Model Comparison Projects; With Opportunities and Challenges Remaining," Energy Modeling Forum and Department of Management Science and Engineering, Stanford University, 175pp., 2012.

Backcasting…(Cont.)

And Tony Janetos and colleagues (2009) have written:

> Despite difficulties in backcasting with IAMs, comparing IAM results with actual outcomes in a historical period that has taken place since the model was run could be useful in developing a set of case studies. This process would allow separating factors that are hard to project - like the demise of the Soviet economy - from those that should be easier to project- like the price elasticity of energy demand. Such studies could yield both benchmarks for future model-building efforts and lessons on the predictability of major trends in the structure of the world economy.

Anthony C. Janetos et al., *Climate Change Integrated Assessment Research*, U.S. DoE Office of Science, 79pp., 2009.

I agree…

…that doing some (more) backcasting is a very good idea.

We know, of course, that the results will suggest we don't always do very well.

I don't see that as a problem so much as an opportunity to calibrate uncertainty estimates that we could start adding to models as we run them out for the next few decades.

Let's turn now to forecasts that extend out for multiple decades…

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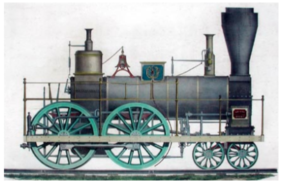
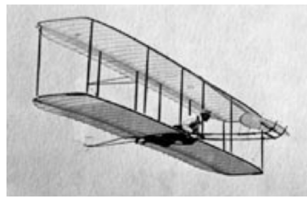
But first, a reminder…

1850	1900	1950	2000





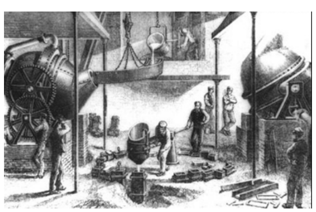











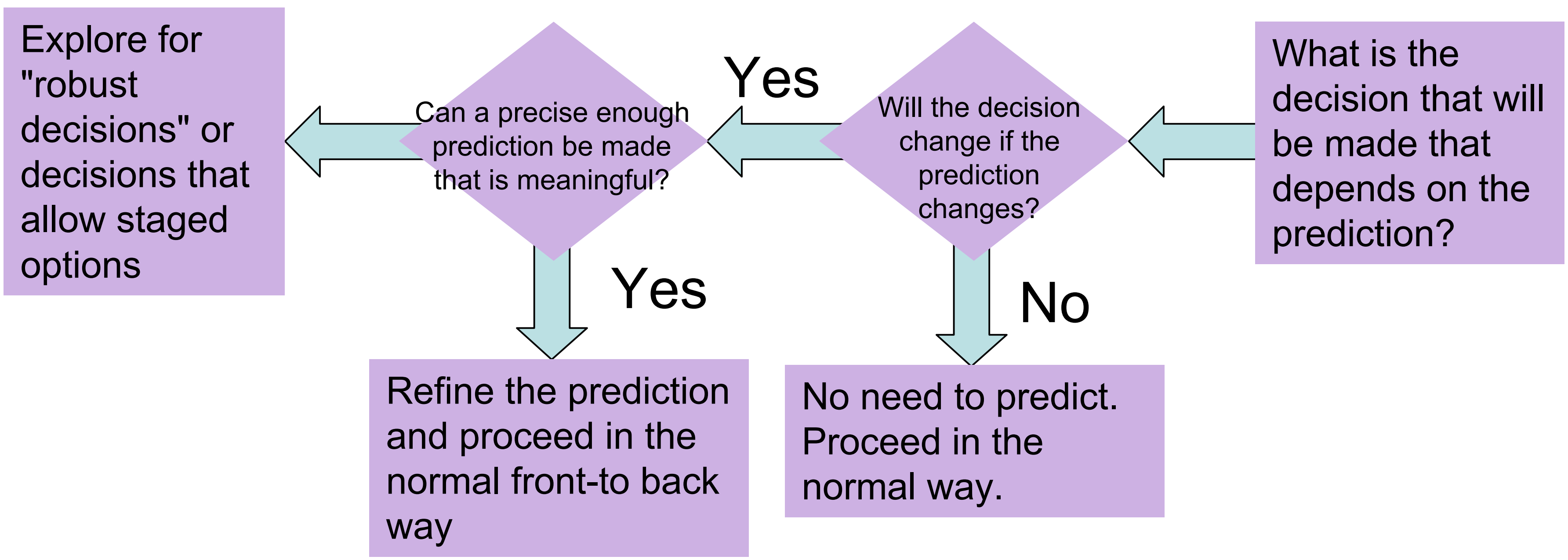




Sources: www.the-ashpit.com; www.railroad.net; wikepededia commons; www.virtualtourist.com; airandspace.si.edu; www.rwf2000.com; www.islandregister.com; www.islandregister.com

Strategies for the longer-term
(> decades)

1. Work decision problems backwards

Most people find it more natural to work in the causal direction: predict then decide. Turning things around can help give insight about whether and how well we need to predict.



Strategies for the longer-term

(> decades)

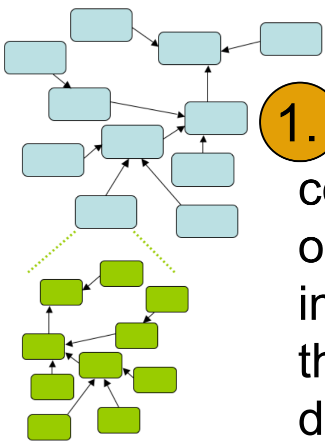
2. Use progressively simpler models

It is great fun to build complex models, but often there is reason to believe that their underlying structure and assumptions will not be valid for the full time interval over which the prediction is to be made.

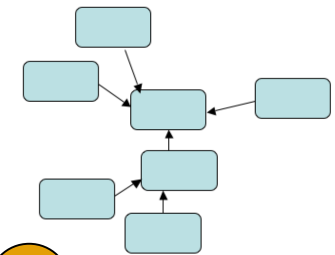
My Bayesian colleague says model all future possibilities, weight them and combine them. However, as an engineer I'm not prepared to make my model more and more complex as I become less and less certain.

An alternative involves a process of moving to simpler and simpler models as uncertainty grows.

Getting simpler and simpler

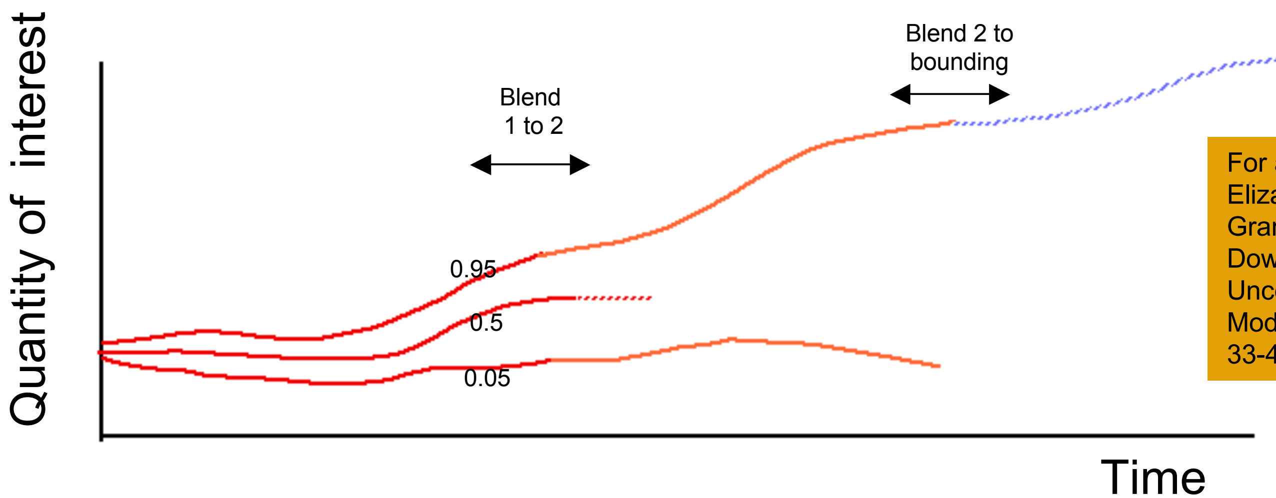


1. Start with a complex model but only run it as far into the future as the most time-dependent assumptions hold.



2. Blend over to a much simpler model that is likely to be robust further into the future.

3. Finally blend over to a bounding analysis based on conservation and similar first principles.



For a worked example see: Elizabeth A. Casman, M. Granger Morgan and Hadi Dowlatabadi, “Mixed Levels of Uncertainty in Complex Policy Models,” *Risk Analysis*, *19*(1), 33-42, 1999.

General conclusions:

We need to be much more humble and explicit about our inability to make reliable predictions about future energy use and associate emissions.

We should develop and demonstrate an expanded set of strategies to describe and deal with the uncertainties that are involved in such predictions.

We should think carefully about why we need such predictions, and what alternatives we might have when the sorts of forecasts we'd like to have are simply not sensible (e.g. perform simple parametric analysis).

We should search much harder for adaptive robust solutions.

End

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