Surprises and Black Swans in Energy Forecasting, Past and Future

Max Henrion, PhD

henrion@Lumina.com

Chief Executive Officer
Lumina Decision Systems, Inc.
Los Gatos, California

www.Lumina.com

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of Northern California

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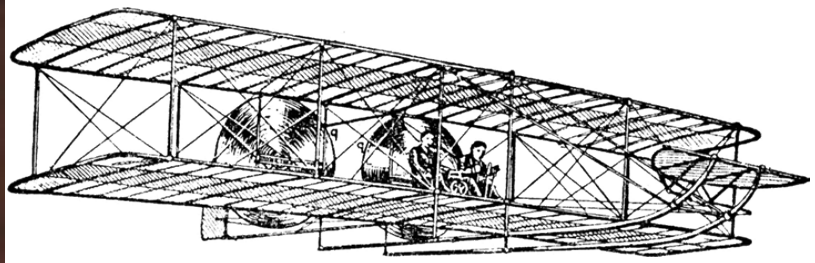
Bringing clarity to difficult decisions

There is nothing new to be discovered in physics now. All that remains is more precise measurement. 1900

Heavier-than-air flying machines are impossible.

Sir William Thompson, Lord Kelvin 1824-1907



1903

Wilbur Wright

"I confess that in 1901, I said to my brother …that man would not fly for 50 years.

Ever since I have distrusted myself and avoided all predictions."

Overview

- Overconfidence in physical constants and energy forecasts
- Black swans and surprises in energy forecasting
- Brainstorming for future surprises

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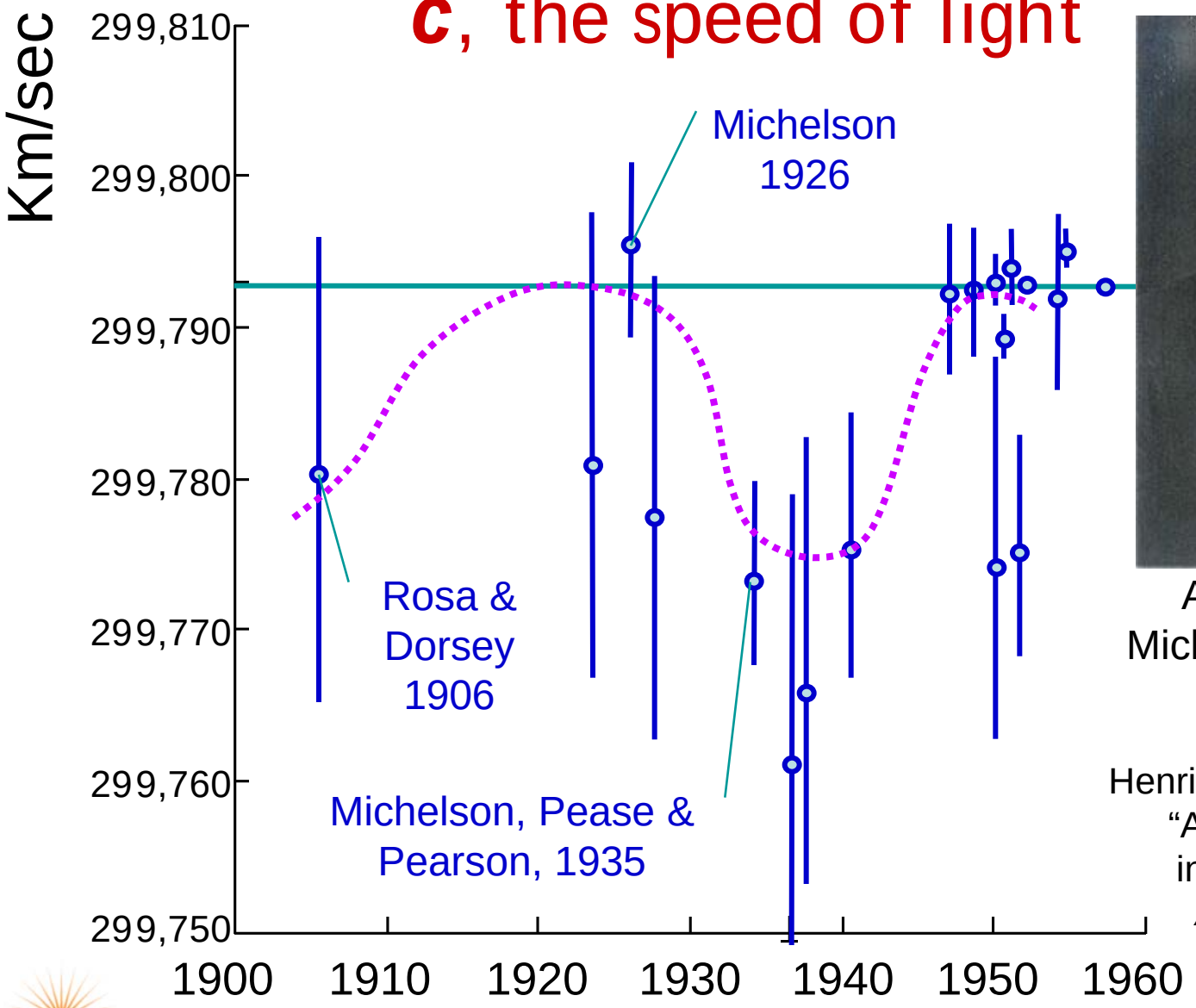
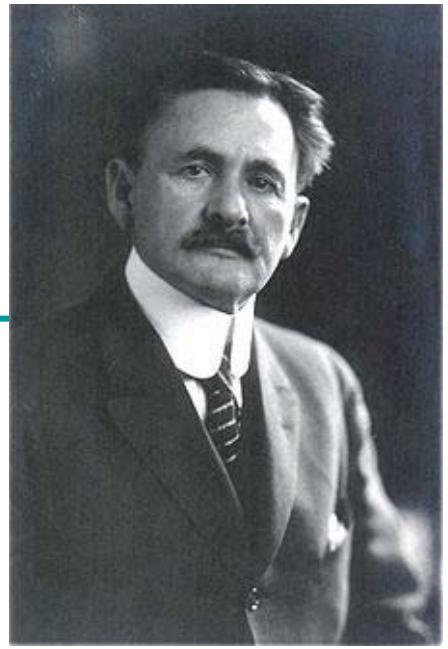
Reported uncertainty in measurements of *c*, the speed of light





Albert Abraham
Michelson 1852-1931

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

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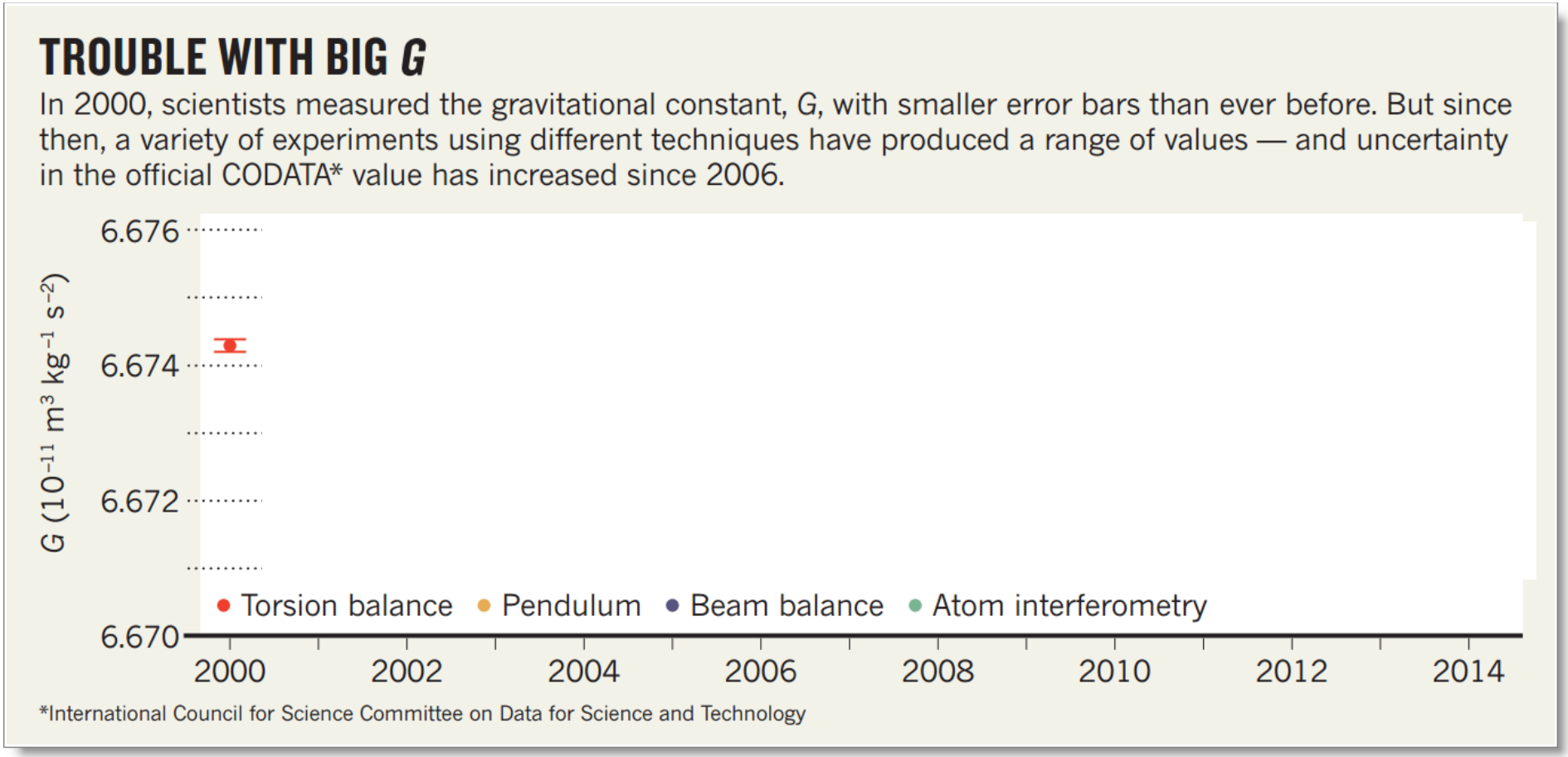
Calibration of uncertainty in measurements of physical constants

Quantity	Date	N	Birge ratio	Surprise index
c, speed of light	1875 - 1964	27	1.42	11%
G, gravitational const.	1798-1983	14	1.38	29%
μ'_p/μ_n magnetic moment	1949-1967	7	1.44	14%
α^{-1}, inv. fine structure		24		38%
$\Omega_{ABS}/\Omega_{NBS}$	1938-1968	7	0.40	0%
Particle lives		92	1.26	9%
Particle masses				6%
Recommended values	1928 - 1973	40	7.42	57%
Gaussian distribution			1.00	2%

Henrion, M & Fischhoff, B, Assessing Uncertainty in Physical Constants, *American J. Physics*, 54 (9), 1986

A brief history of Big G



Nature Vol 514, 9 Oct 2014 News in Focus

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Why do precision metrologists underestimate extremes?

- Trim outliers
- Keep refining the apparatus and eliminating biases until the results seem as expected
- Unexpected results are harder to publish

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Causes of overconfidence in assessing probability distributions

- **Anchoring and adjustment heuristic**
- **Confirmation bias:** Seek confirming evidence and ignore the rest
- Could we reduce overconfidence by focusing attention on extremes, or possible surprises?

Daniel **Kahneman** & Amos **Tversky** "Heuristics and biases", *Science*, reprinted in Thomas Gilovich, Dale W Griffin, Daniel Kahneman, *Heuristics and Biases: The Psychology of Intuitive Judgment*, Edited by Cambridge UP, 2006.

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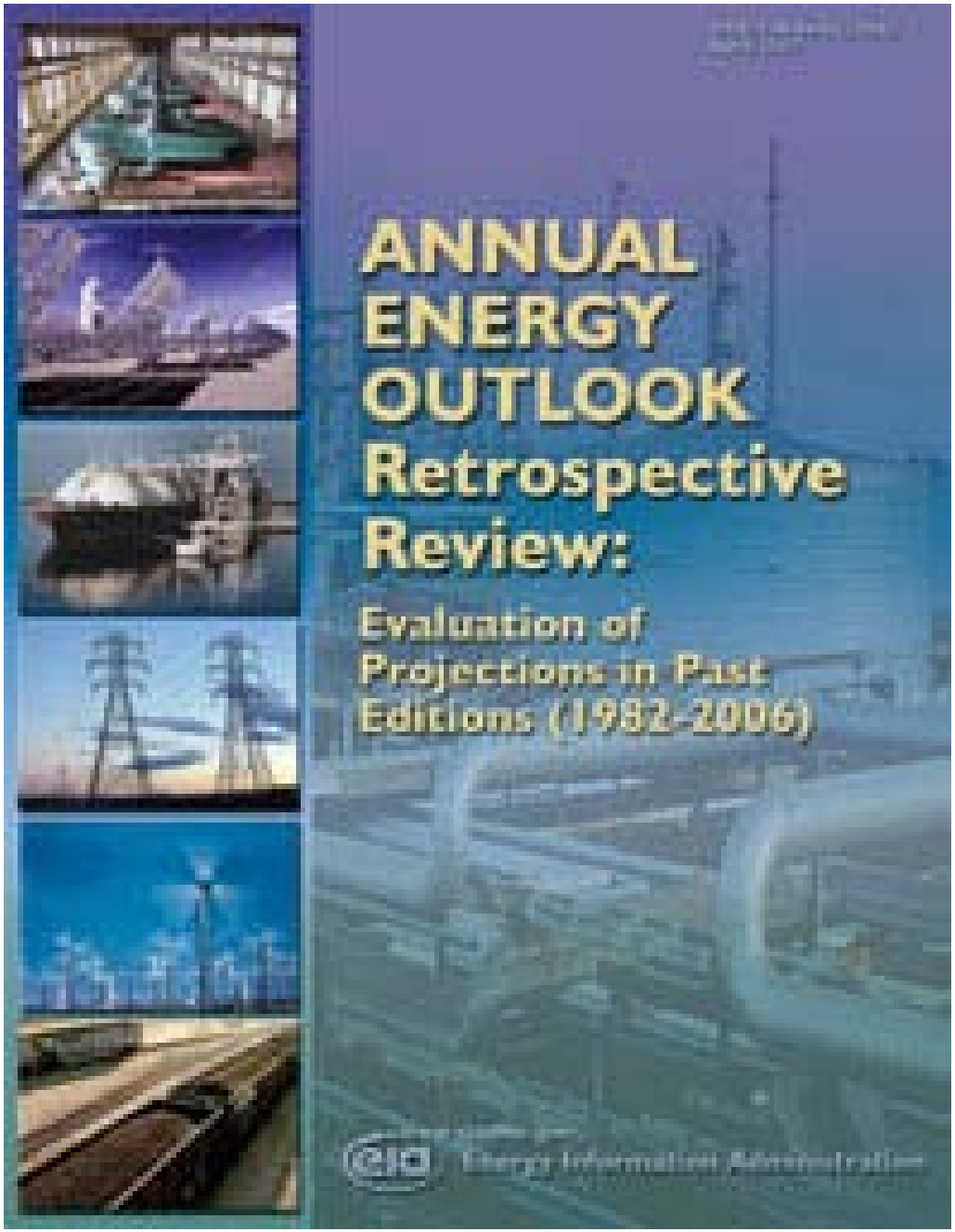
Past energy forecasts

The US Energy Information Administration *Annual Energy Outlook: Retrospective Review*

"The projections in the AEO are not statements of what will happen but of what might happen, given assumptions and methodologies."



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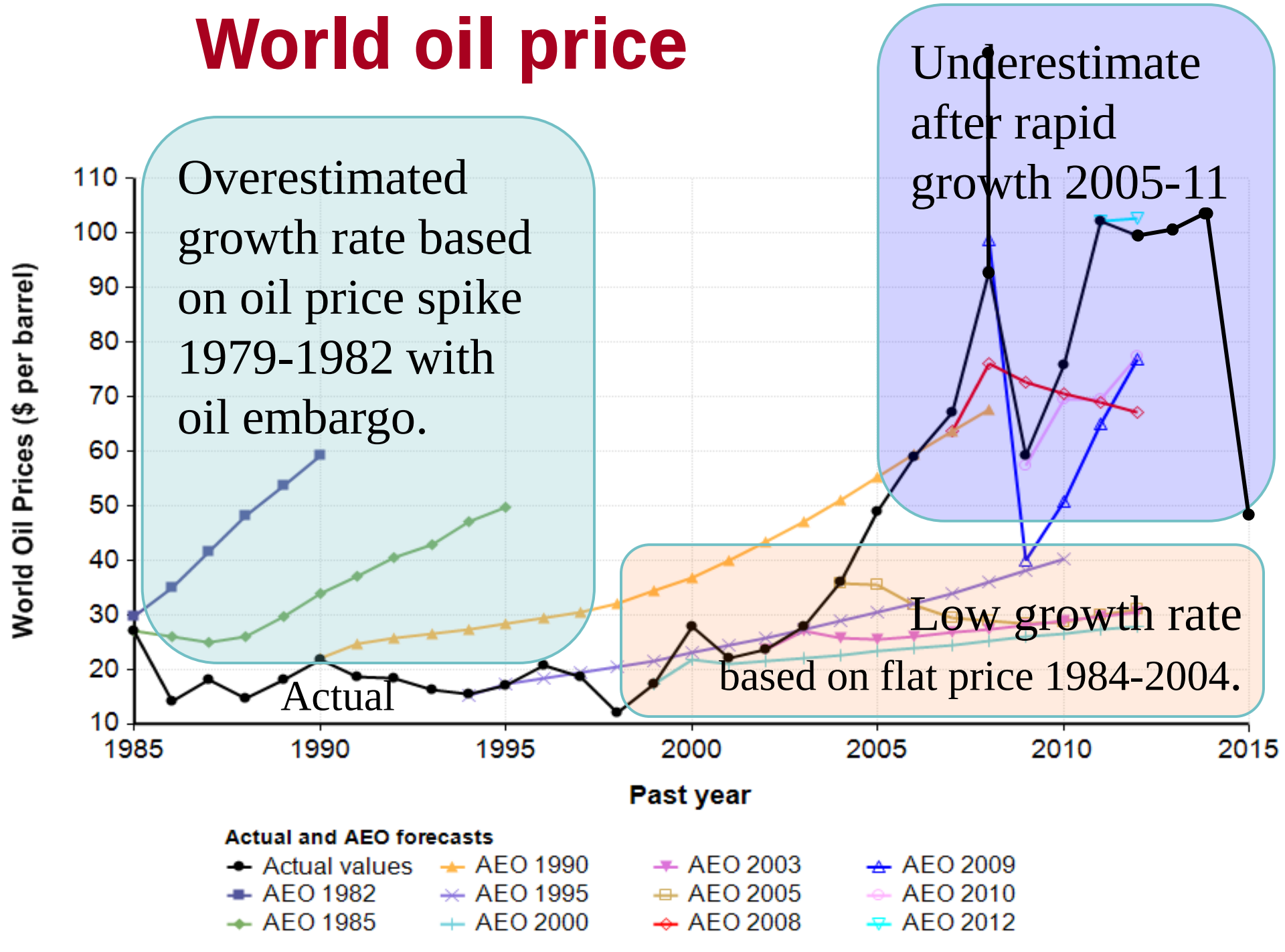
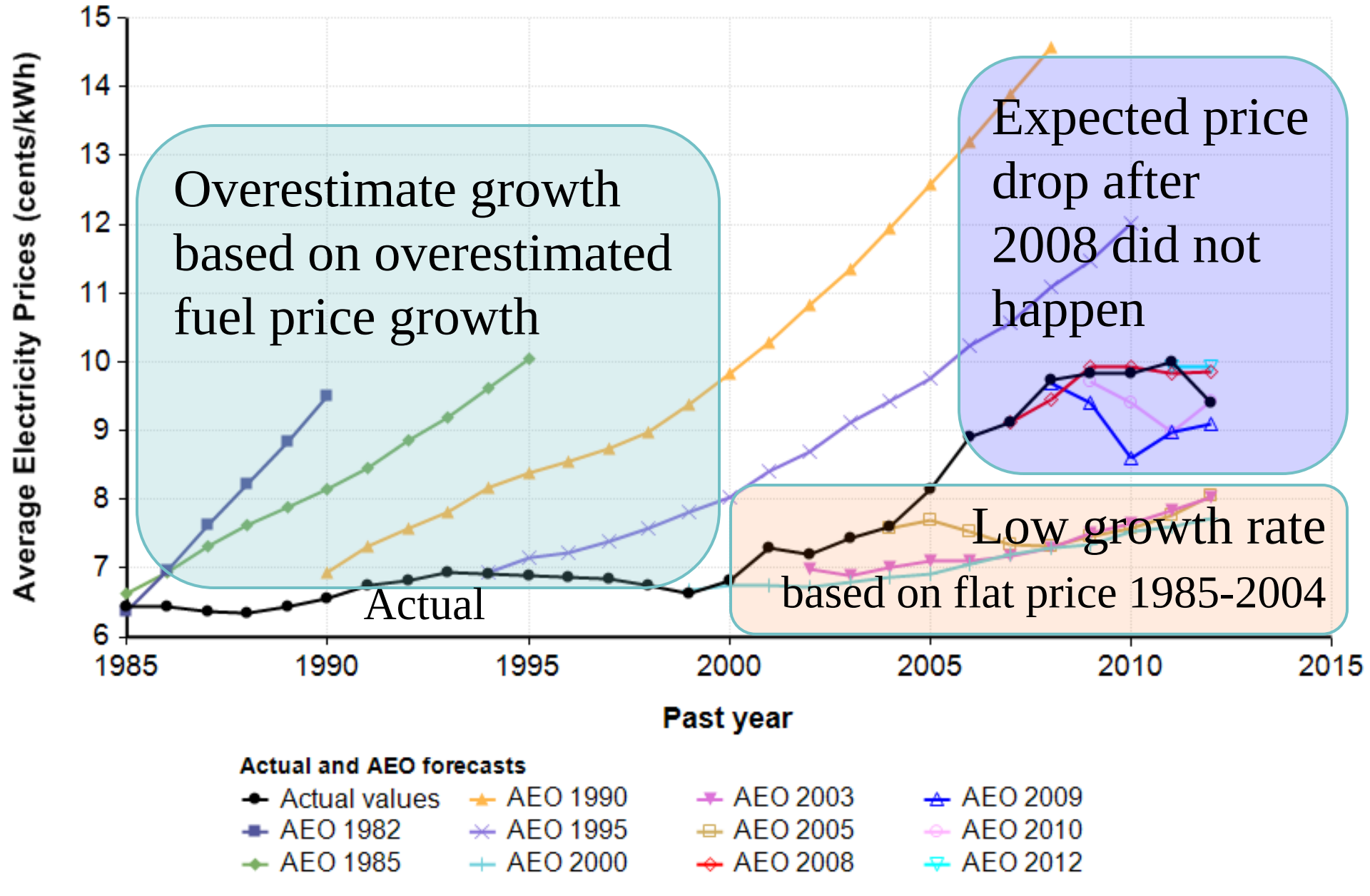
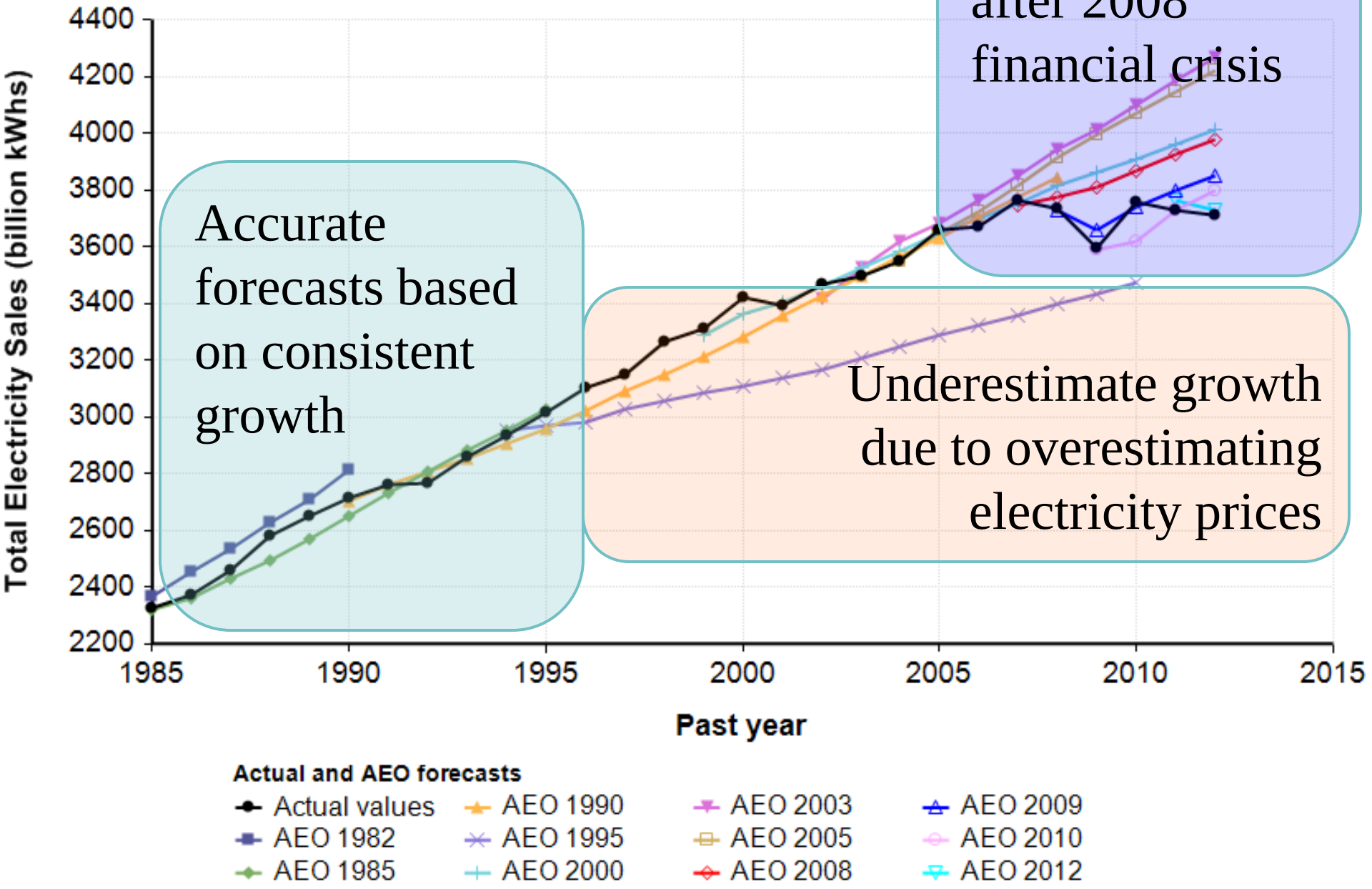
World oil price



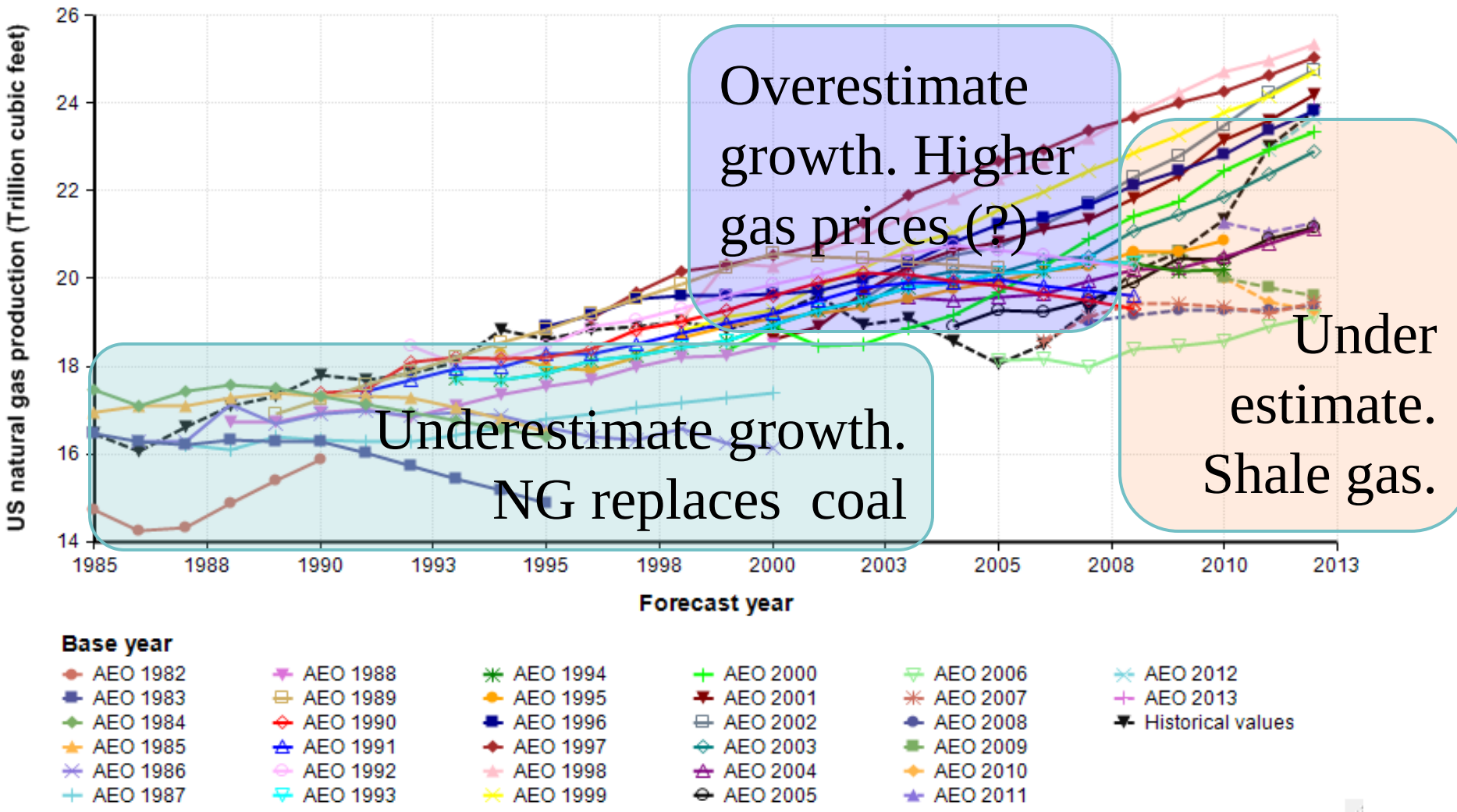
US Electricity Prices



US electricity sales



US Natural Gas consumption



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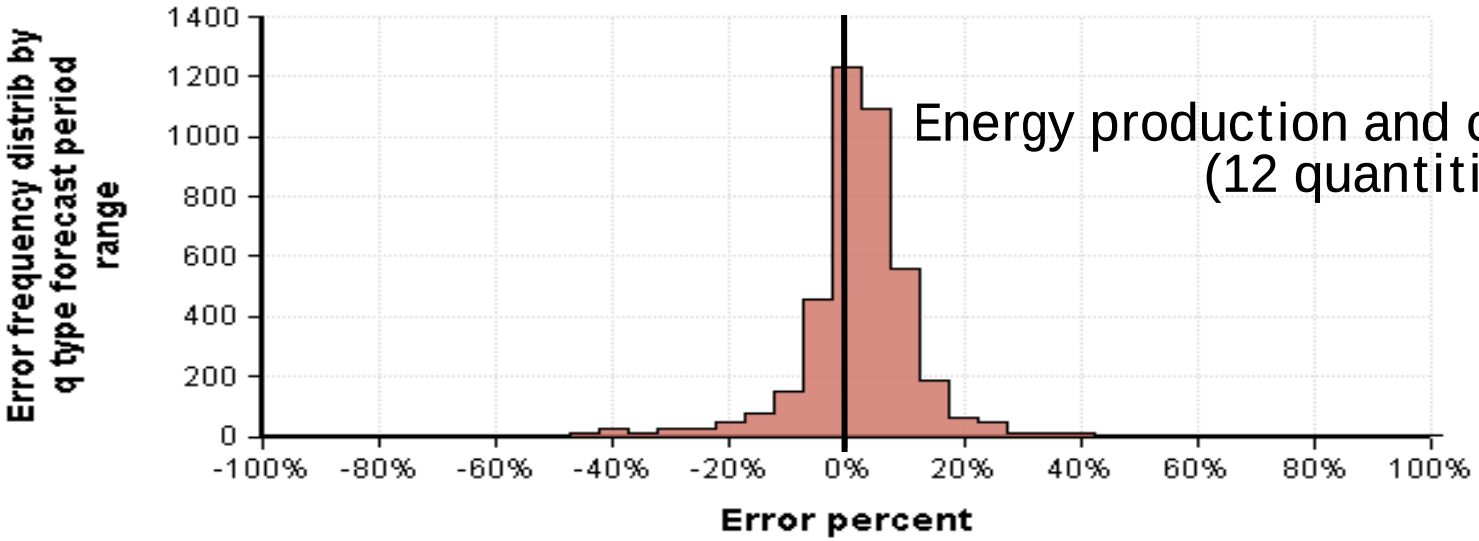
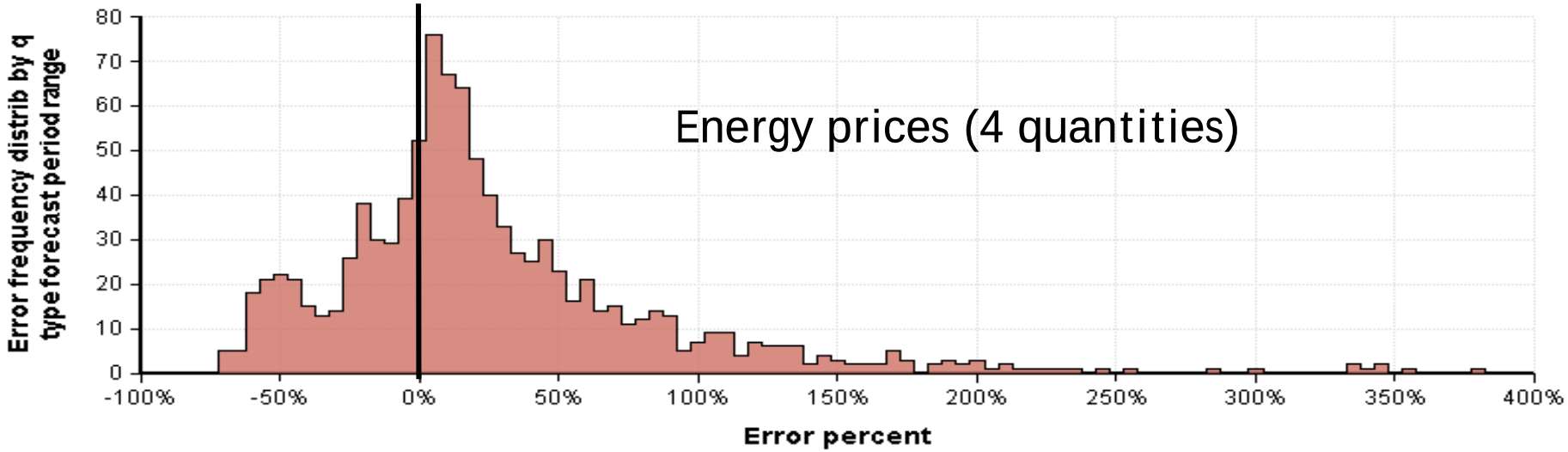
LNG Liquefaction Plant

- 2000-2010: Expected shortfall in US NG production → Build LNG export terminals.
- 2009-2015: Shale gas US production way up and prices down.
- → Now replacing import with LNG export terminals

Distributions for percent error in past AEO Forecasts





Data from Annual Energy Outlook: Retrospective Review 2009.

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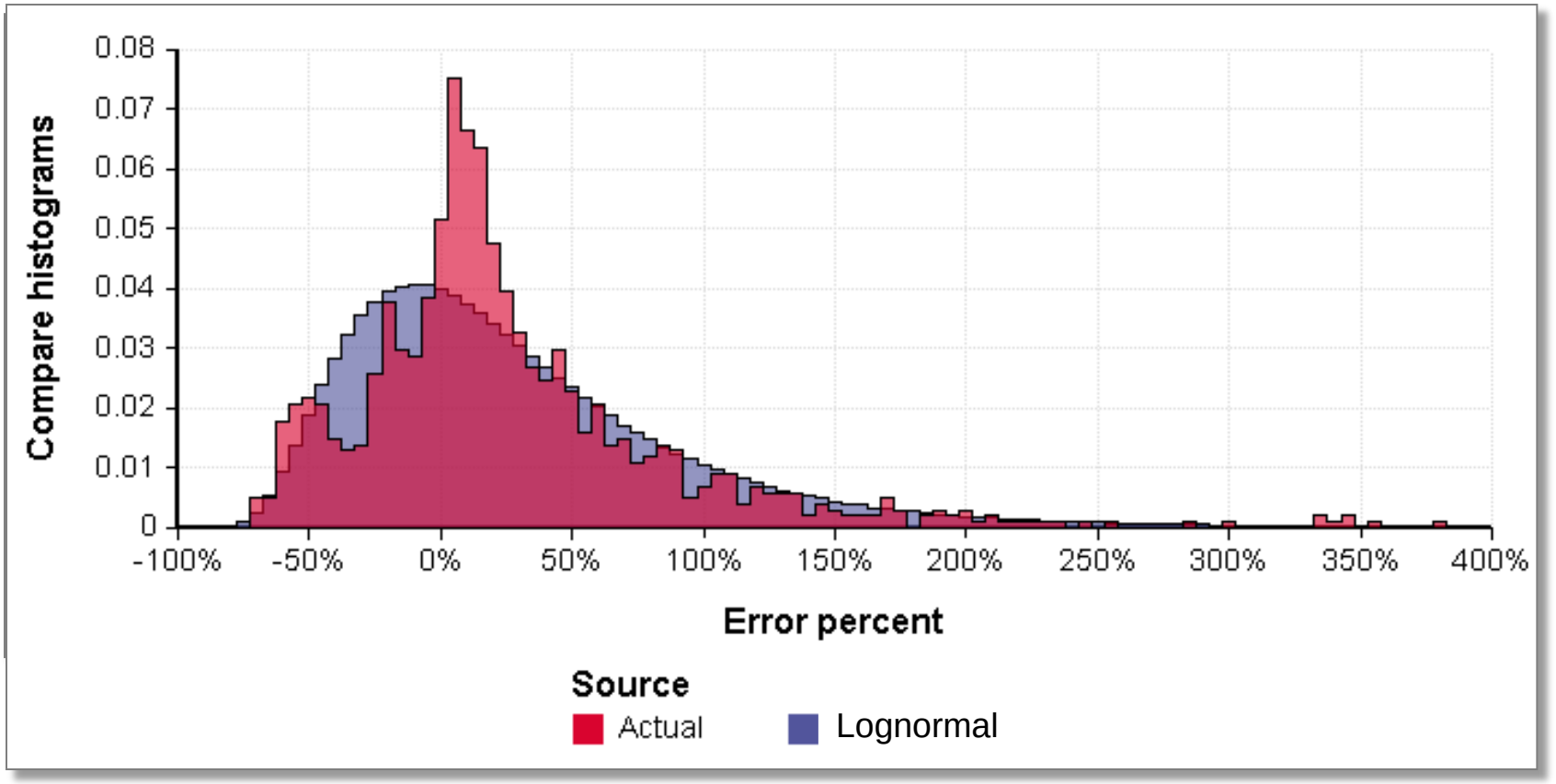
Fitting the empirical error distribution
for AEO energy price forecasts



Fit lognormal distribution to error distributions for quantities and prices:

	Quantity	Price
Geometric mean	1.001	1.118
Geometric st dev	1.087	1.638

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Can we use past forecast errors to estimate uncertainty in future energy projections?

The next 30 years may be (even) less predictable than the last 30:

- Volatility of fuel prices may be increasing.
- There are many new energy technologies in development, renewable and fossil
- Financial crisis adds further uncertainty

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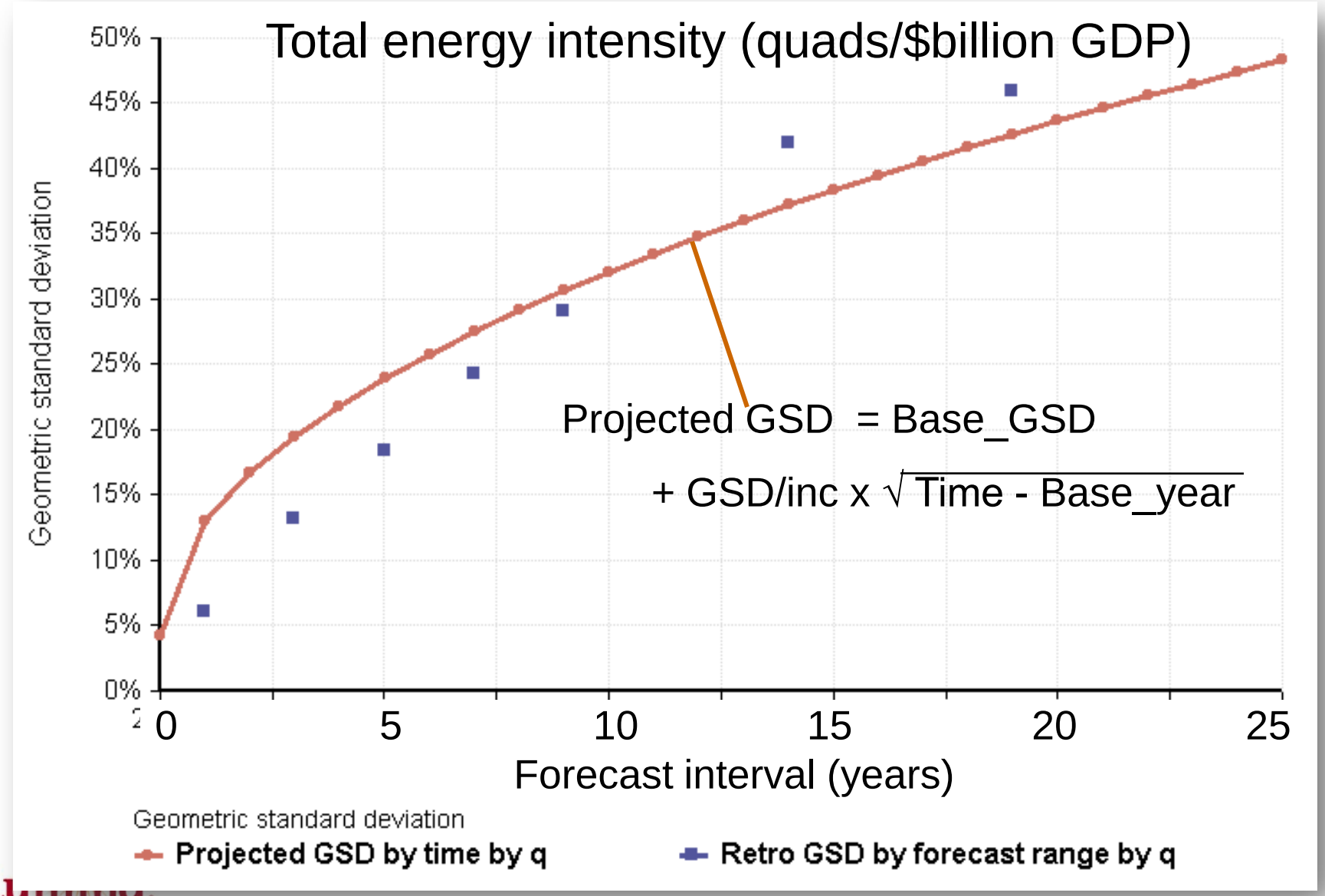
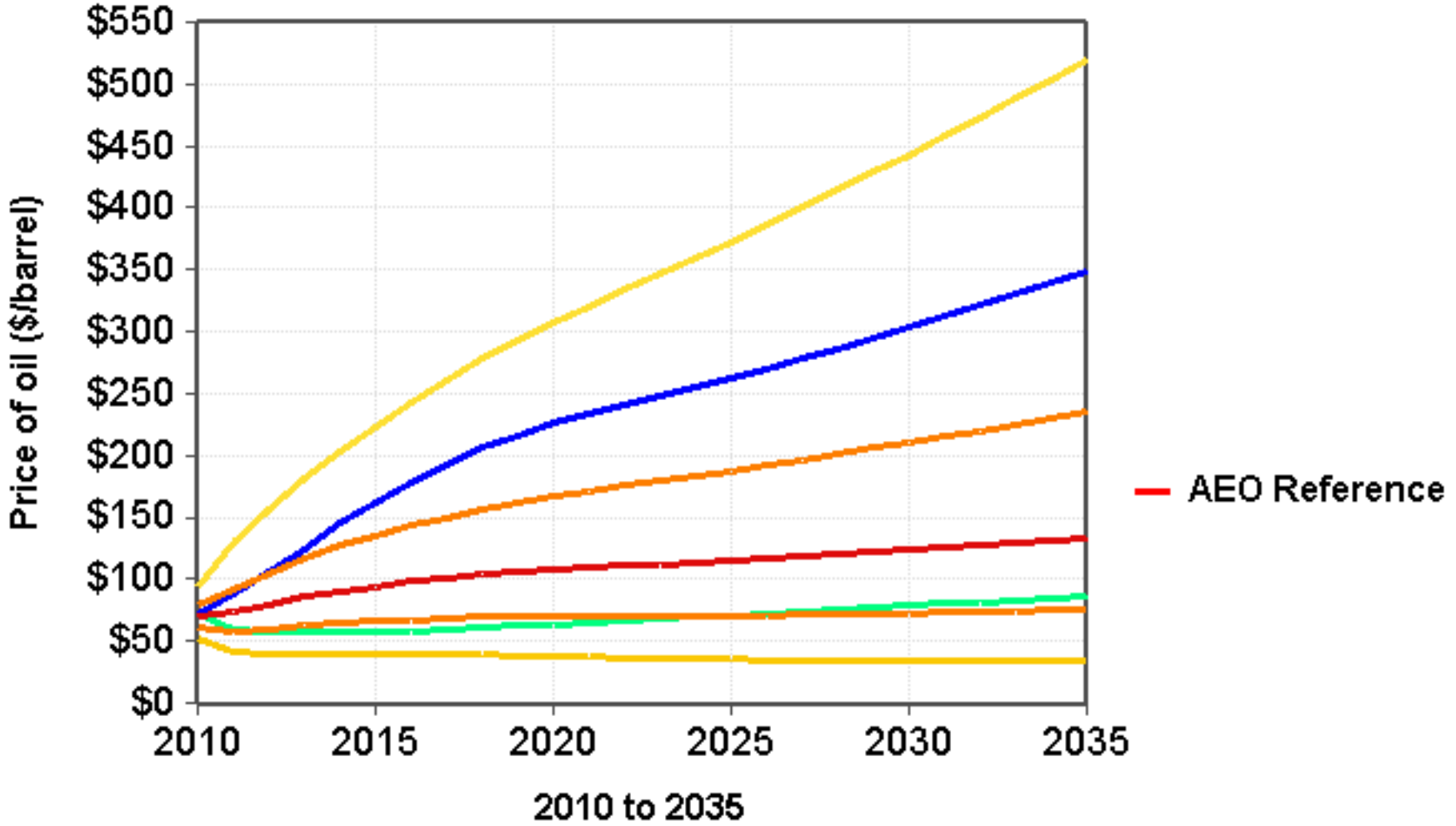
Error by forecast range:
Geometric standard deviation (GSD)



Price of oil: AEO scenarios vs. percentiles of probabilistic forecasts



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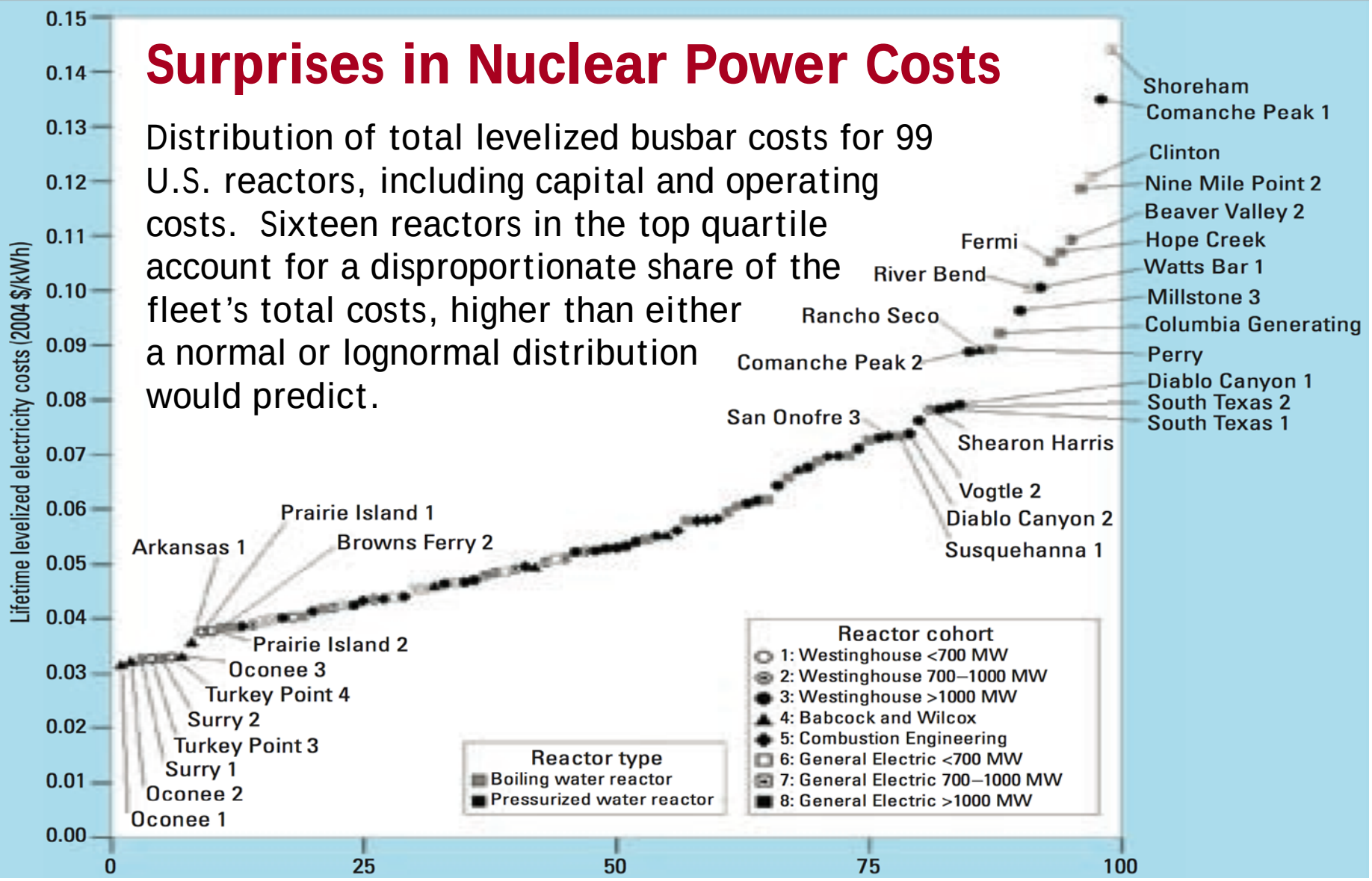
Surprises in Nuclear Power Costs

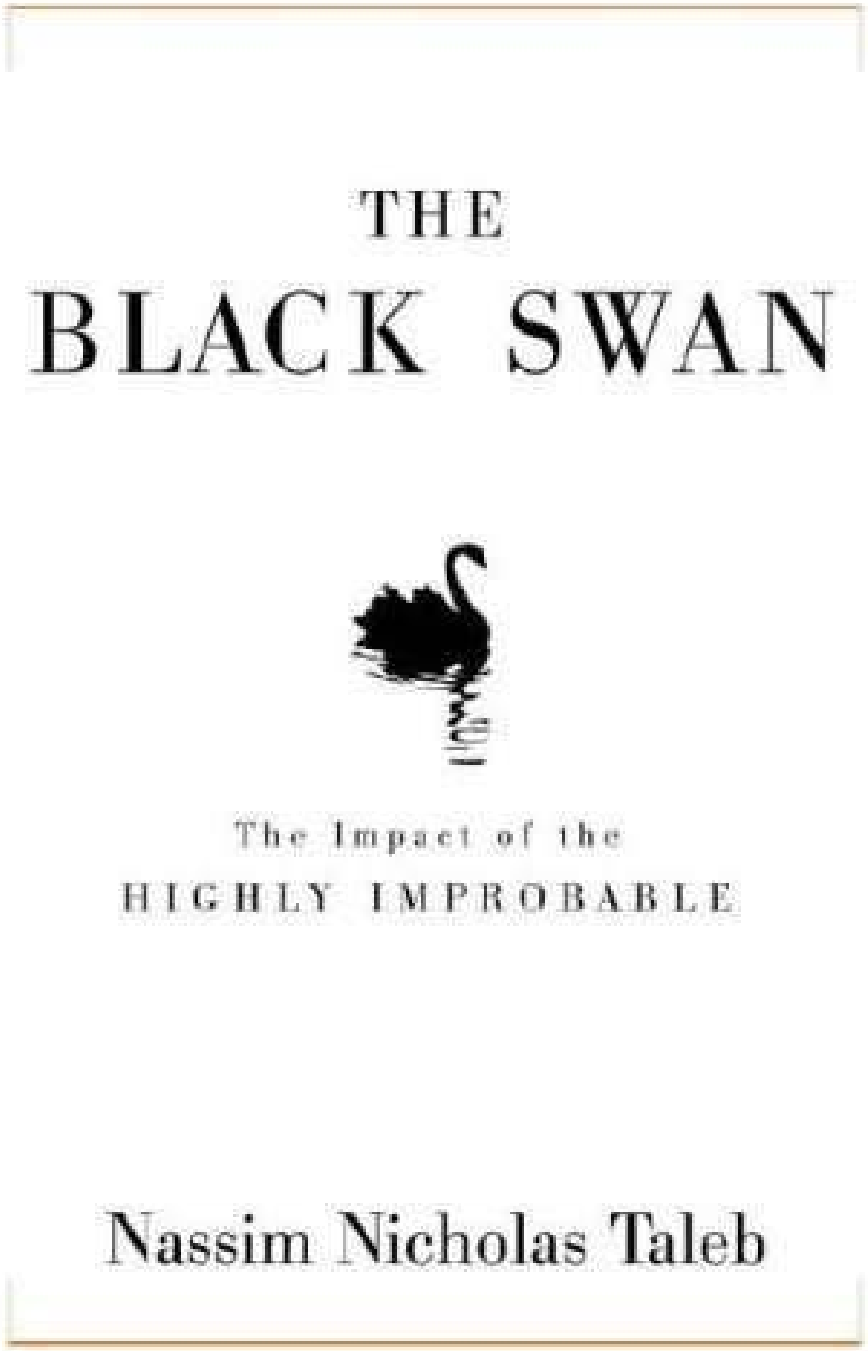
Distribution of total levelized busbar costs for 99 U.S. reactors, including capital and operating costs. Sixteen reactors in the top quartile account for a disproportionate share of the fleet's total costs, higher than either a normal or lognormal distribution would predict.



What History Can Teach Us about the Future Costs of U.S. Nuclear Power?

"Past experience suggests that high-cost surprises should be included in the planning process."

Nathan E. Hultman, Jonathan G. Koomey, Daniel M. Kammen, Env. Sci. and Tech, April 1, 2007



Nassim Taleb

A Black Swan is an event that

- is an outlier – *rare and unexpected*
- has extreme impact
- is explainable and predictable – *only in retrospect*

Black (and Gold) Swans in energy, past and future

Past

1950's nuclear power "too cheap to meter"

Oil prices: 1978, 2004, 2008, 2011

Low cost of sulfur controls on power plants to meet US Clean Air Act 1990 SOx emissions

Natural gas price dropped due to abundance from shale gas and oil 2008-

Future

Oil price>$300/bbl in 2015

Grid-parity for photovoltaics in 2017: $1/Watt -> $0.06/kWh

Americans embrace small, light vehicles

"Artificial leaf" catalytic photosynthesis of hydrogen for storable electricity

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Could we have predicted past "surprises"?

- Taleb says no
- We might rather ask, how early could we have identified the possibility, and the probability they might happen?
- For example, some invested in horizontal drilling and hydraulic fracturing in the 1990s…
- Gas production starting growing noticeably in 2007.

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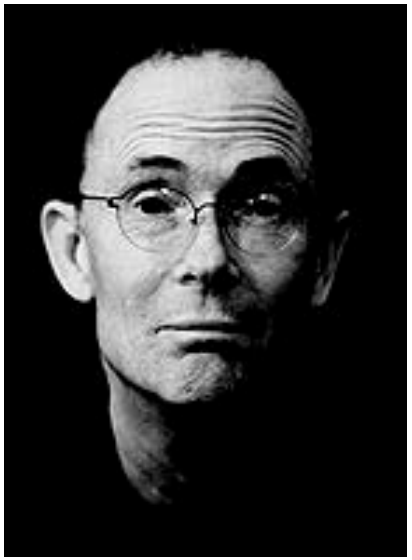
How can we imagine the future?

"The future is already here —
it's just not very evenly distributed."
William Gibson



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Brainstorming for Surprises

- A pilot experiment to explore the potential for improving forecasts by brainstorming for surprises, extreme events, Black and Gold Swans
- Carried out with 25 experts on energy scenarios and modeling
- By Max Henrion, Inês Azevedo, Marie-Valentine Florin, & Anjali Nursimulu
- At a session of the **Workshop on Energy Scenarios and Models:** Improving Methods to Assess Future Energy Demand, 9-10 October, 2014, in Karlsruhe, Germany.
- Co-organized by the International Risk Governance Council (IRGC), the Center for Climate for Energy Decision-Making (CEDM) at Carnegie Mellon University (CMU) and the Helmholtz-Alliance Energy-Trans, and hosted by the Institute for Technology Assessment and Systems Analysis, Karlsruhe Institute of Technology.

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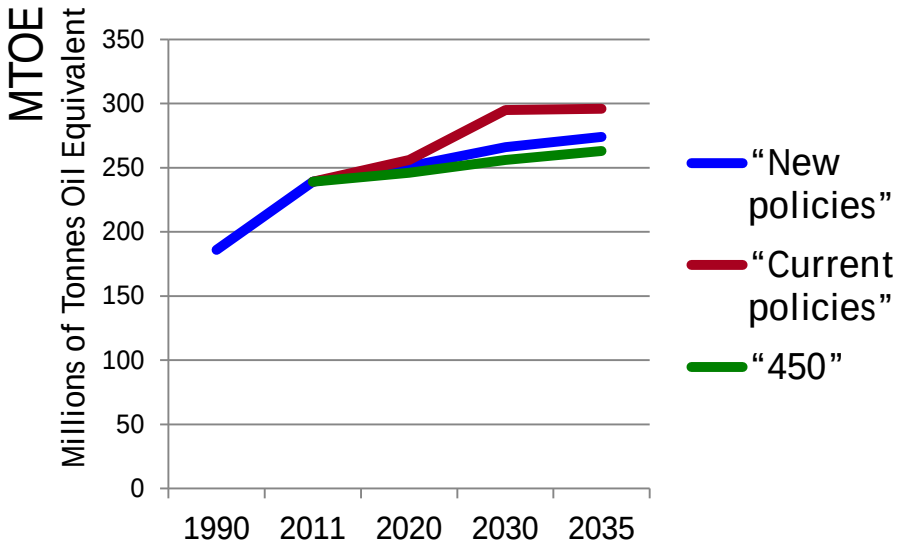
Brainstorming for surprises:
A pilot experiment

- What surprises might affect EU electricity consumption in 2035?
- Divide 25 experts into teams of 5 to brainstorm "surprise" events Black & Gold Swans
- Write events on note cards.
- Teams warm up by identifying "past surprises" over last 25 years that affected EU energy demand
- Then teams identify "future surprises" that might affect EU energy demand in 2035.



- Facilitators collect note-cards one at a time, explain, arrange similar ones together on the wall.
- Refine event definitions to achieve "clarity test"
- Experts individually assess probability and effect of each event.

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Surprise events affecting EU electricity demand in 2035

Lifestyles

- Laboratory meat (due to food safety scare) energy requirement (1)
- Germans drive electric cars (2)
- People want to be frozen after death (1)
- Personal air vehicles (2)Change in environmental values (2)

Demographic

- Drastic population decrease (epidemics, natural disasters) (3)
- Massive migration changes (2)
- Increased life expectancy (1)
- Change in preference for large families (1)

Economic changes

- Shorter work weeks (1)
- The collapse of China (2)
- US depression (2)
- Reduction of energy prices (1)

Natural disasters (climate change induced)

- Shut down of the Gulf Stream, resulting in substantially colder climate in Europe (2)
- US and EU becomes a desert (1)
- Dramatic increase in climate change (2)

Other disasters

- Another nuclear accident somewhere (1), in France (1)
- High-frequency cyber attacks (1)

Policy driven surprises

- Politically/ideology-driven reduction of energy supply (1)
- Less energy security (1)
- EU agrees on a consistent energy policy (2)
- Cars banned from all cities (1)
- German ban on gas-fired heating (1)
- Change in international regulation regarding small modular reactors (1)

Technology breakthroughs

- Cheap and long lasting energy storage (4)
- Widespread electric vehicle adoption (1)
- Private and corporate drones and robots (2)
- Hydrogen cars (1)
- Widespread use of 3D printing
- Affordable electric self-driving cars (3)
- Large-scale smart grid breakthrough (2)
- New generation technologies – fusion (1)
- No baseload at all and renewable breakthrough (3)

Political changes

- The collapse of the EU (2)
- EU gets its act together – EU growth (1)
- East European crisis (1)
- Islamic State controls all Middle-East (1)
- Eco-dictatorship (1)
- WW3 (1)

(In parens are the number of groups that identified each event)

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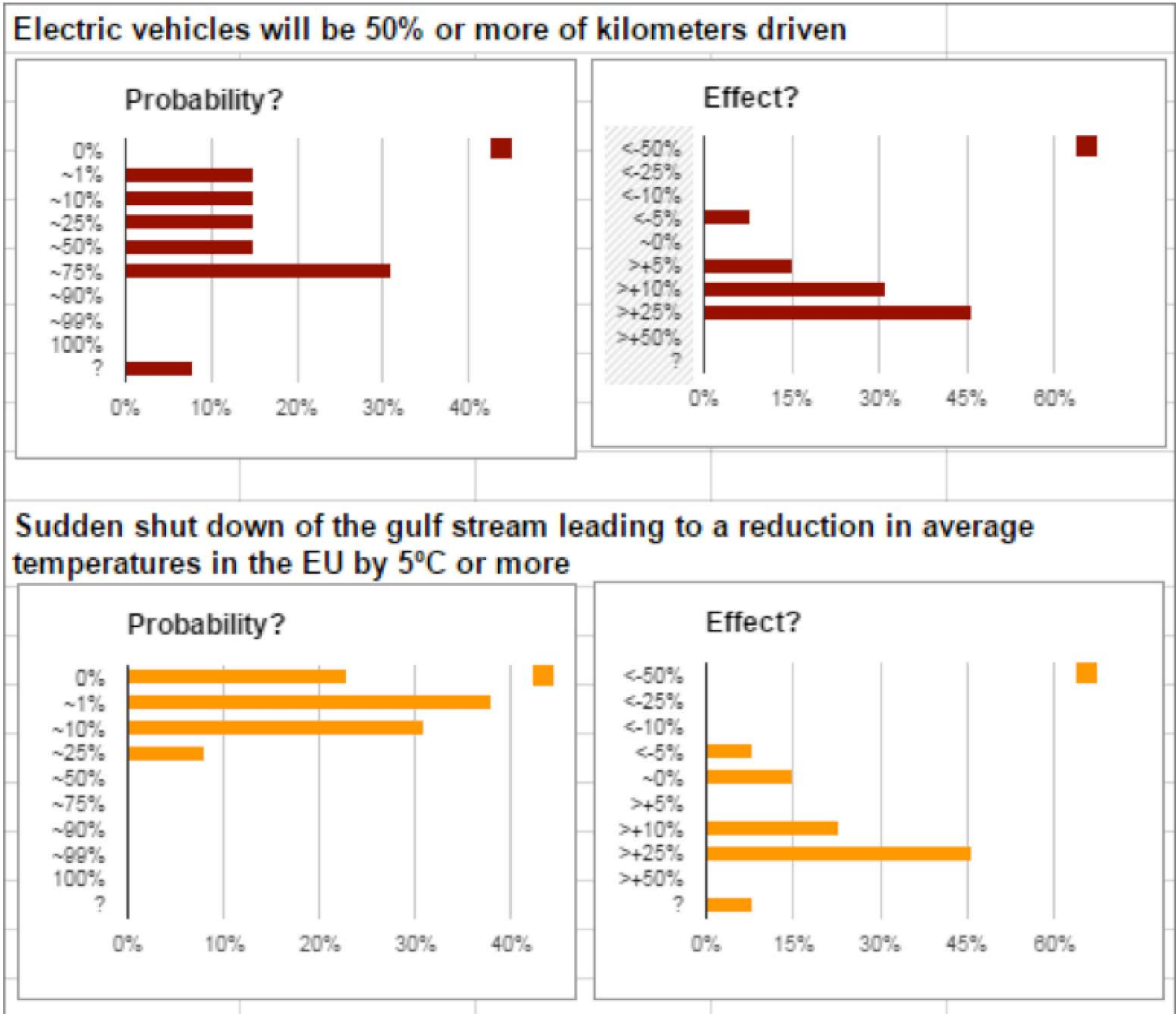
Average assessed probability and effect of surprises on EU electricity demand in 2035

Surprise Event	Prob	Effect
a. Economic depression brings EU GDP down by more than 30%	17%	-24%
b. EU population is reduced by 20% or more due to a natural disaster or epidemic	7%	-24%
c. Cheap energy storage enables 80% or more wind and solarelectricity generation	35%	5%
d. Electric vehicles will be 50% or more of kilometers driven	36%	14%
e. Sudden shut down of the Gulf Stream leading to a reduction in average temperatures in the EU by 5ºC or more	5%	13%
f. There will be a 30% or larger reduction in work-hours for the EU	31%	0%

Assessed prob. and effect for two surprise events



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Discussion of brainstorming for surprises

- Expert teams of 5 put in significant focused attention to identify surprises. They generated many more than the 2-3 surprises suggested.
- Most participants said the process identified events they hadn't thought of.
- Would it lead to identifying more surprises, and wider ranges, and more calibrated distributions?
  - Previous research on increasing attention on extremes suggests yes.

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Six impossible things before breakfast

Alice laughed. "There's no use trying," she said: "one *can't* believe impossible things."

"I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."

Alice Through the Looking Glass, Lewis Carroll, 1871

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How might we be less surprised?

- Apply retrospective error distributions to current forecasts
- Carefully review past surprises to see what we can learn and when we might have identified them
- Structured brainstorming for future surprises

Will these prevent us from being surprised?
No! But they might reduce the frequency.

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