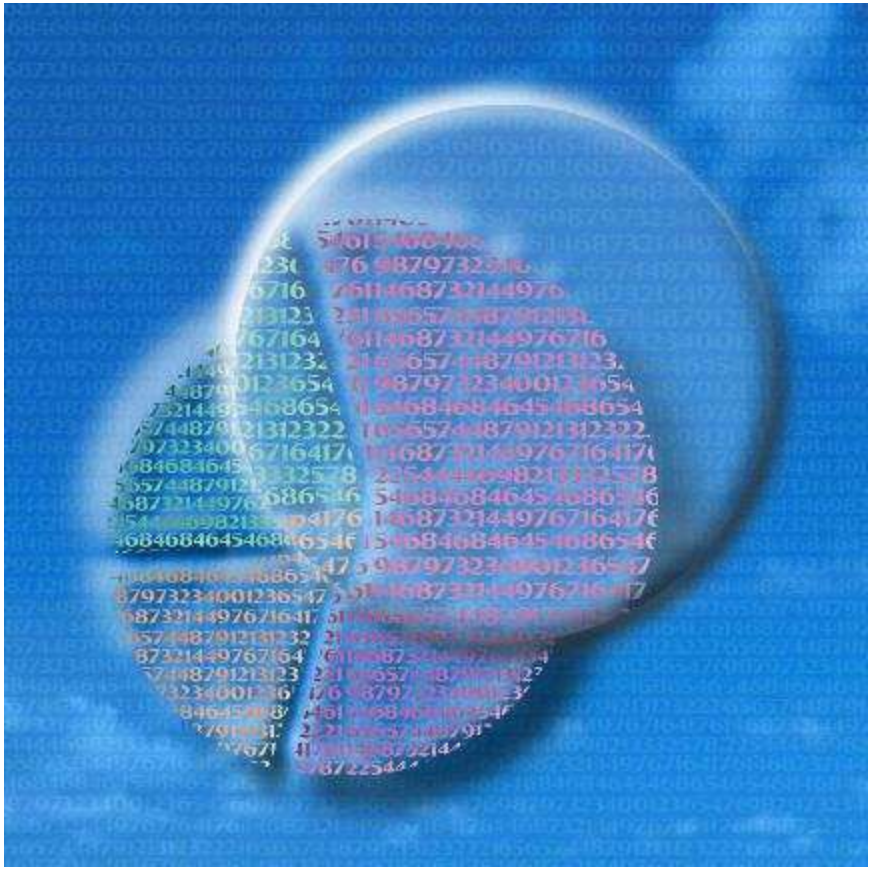

Sensitivity analysis and sensitivity auditing

Bergen, October 19, 2016

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Where to find this talk: www.andreasaltelli.eu

sensitivity analysis, sensitivity auditing, science for policy, impact assessment

= more material on my web site

= more material on Wikipedia

= discussion point

Definition of uncertainty and sensitivity analysis.

Sensitivity analysis: The study of the relative importance of different input factors on the model output.

Uncertainty analysis: Focuses on just quantifying the uncertainty in model output.

Why sensitivity analysis

Some scholars have suggested that sensitivity analysis might help

...

Edward E. Leamer

<<I have proposed a form of organised sensitivity analysis that I call "global sensitivity analysis" in which a neighborhood of alternative assumptions is selected and the corresponding interval of inferences is identified.>>

Edward E. Leamer, 1990, Let's Take the Con Out of Econometrics, American Economics Review, 73 (March 1983), 31-43.

Edward E. Leamer

<<Conclusions are judged to be sturdy only if the neighborhood of assumptions is wide enough to be credible and the corresponding interval of inferences is narrow enough to be useful.>>

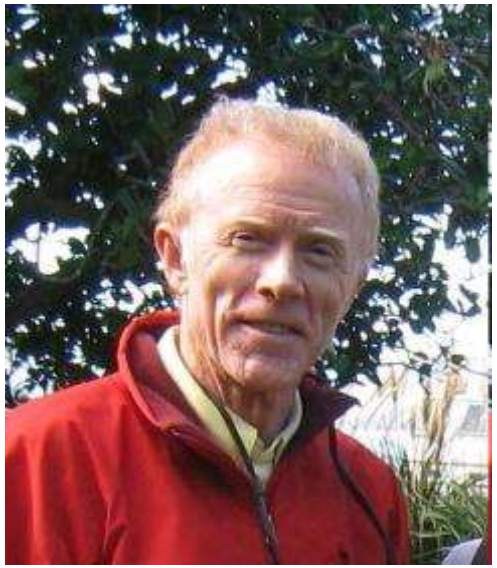
Edward E. Leamer, 1990, Let's Take the Con Out of Econometrics, American Economics Review, 73 (March 1983), 31-43.

Funtowicz & Ravetz's GIGO (Garbage In, Garbage Out) Science – or pseudo-science –

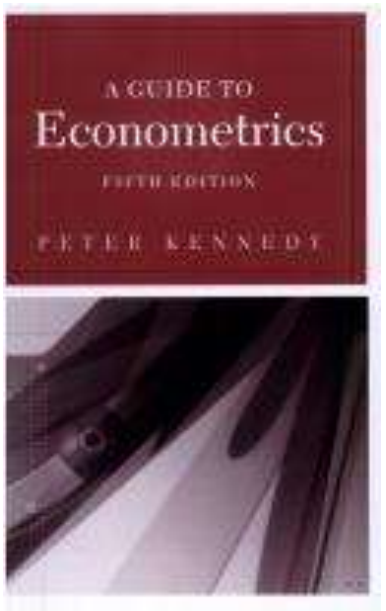
"where uncertainties in inputs must be suppressed least outputs become indeterminate"

Funtowicz, S. O. and Ravetz, J. R., 1990. Uncertainty and quality in science for policy. Dordrecht: Kluwer.

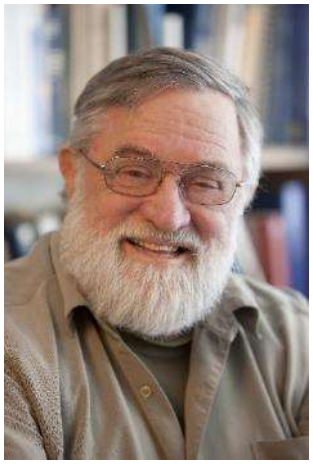
Peter Kennedy, A Guide to Econometrics.
Anticipating criticism by applying sensitivity analysis. This is one of the ten commandments of applied econometrics according to Peter Kennedy:



<<Thou shall confess in the presence of sensitivity.
Corollary: Thou shall anticipate criticism >>



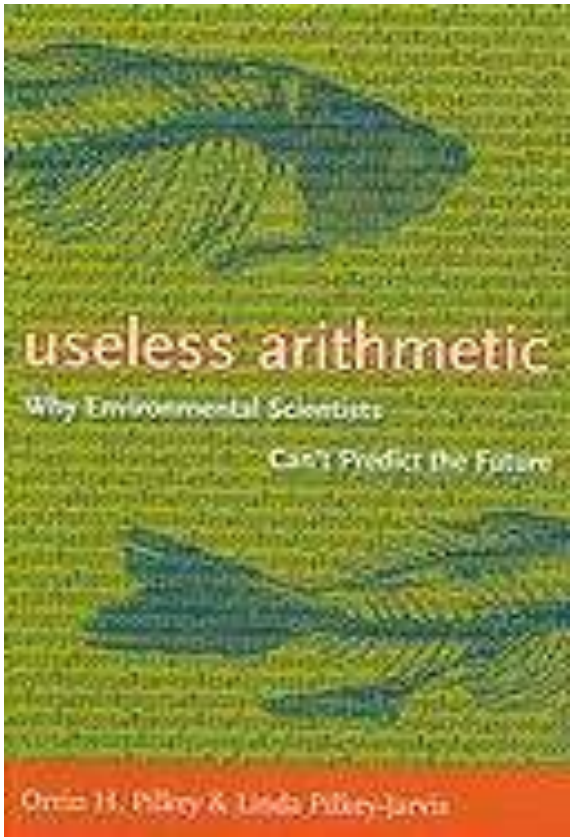
Limits of sensitivity analysis



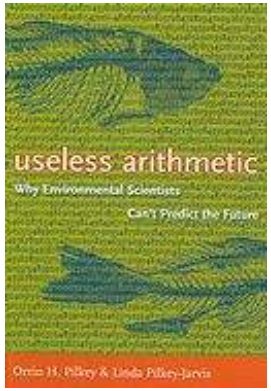
Orrin H. Pilkey
Duke University, NC

Useless Arithmetic: Why Environmental Scientists Can't Predict the Future

by Orrin H. Pilkey and Linda Pilkey-Jarvis



'Quantitative mathematical models used by policy makers and government administrators to form environmental policies are seriously flawed'

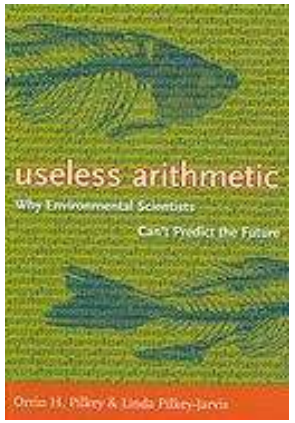


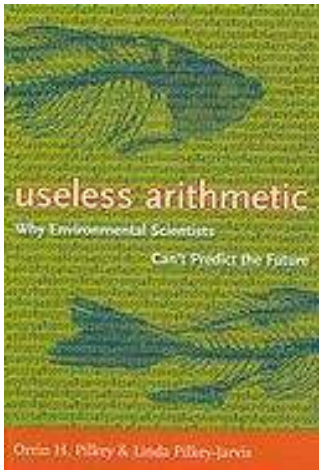
<<It is important, however, to recognize that the sensitivity of the parameter in the equation is what is being determined, not the sensitivity of the parameter in nature.

[…] If the model is wrong or if it is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit.>>

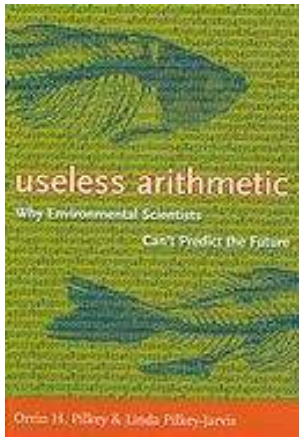
One of the examples discussed concerns the Yucca Mountain repository for radioactive waste. TSPA model (for total system performance assessment) for safety analysis.

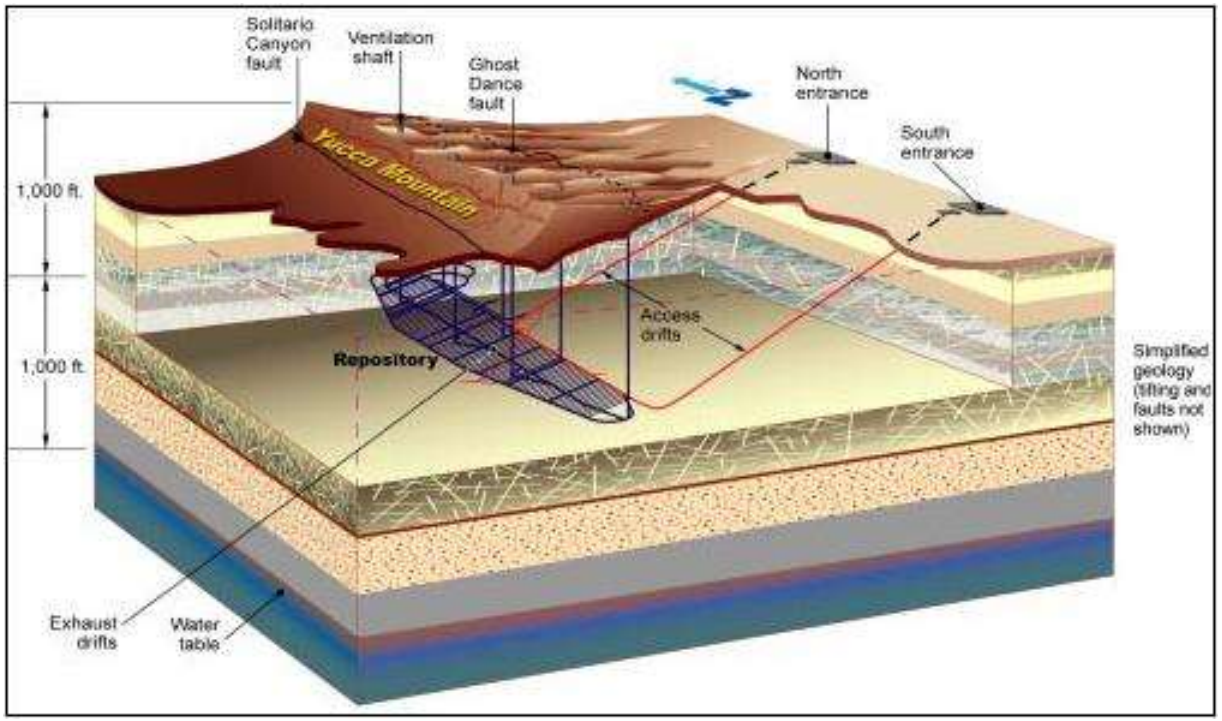
TSPA is Composed of 286 sub-models.





TSPA (like any other model) relies on assumptions → one is the low permeability of the geological formation → long time for the water to percolate from surface to disposal.

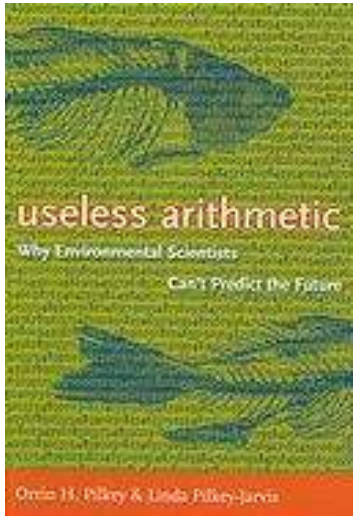




The confidence of the stakeholders in TSPA was not helped when evidence was produced which could lead to an upward revision of 4 orders of magnitude of this parameter
(the ^{36}Cl story)

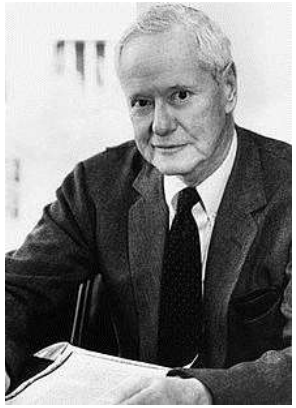
In the case of TSPA (Yucca mountain) a range of 0.02 to 1 millimetre per year was used for percolation of flux rate.

→… SA useless if it is instead ~ 3,000 millimetres per year.



"Scientific mathematical modelling should involve constant efforts to falsify the model"

Ref. ➔ Robert K. Merton's 'Organized skepticism '



Robert K. Merton

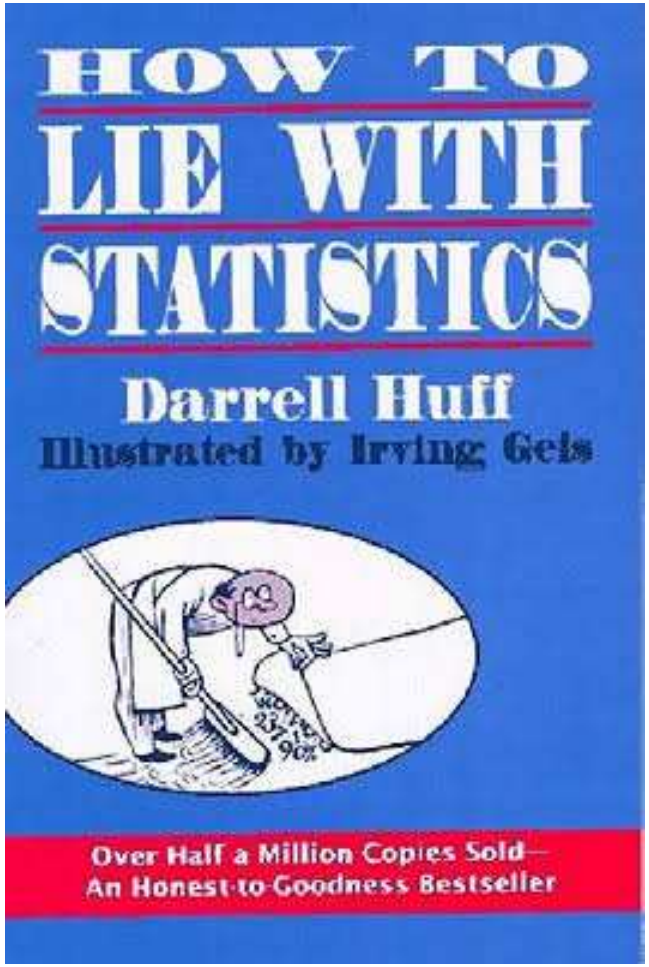
Communalism - the common ownership of scientific discoveries, according to which scientists give up intellectual property rights in exchange for recognition and esteem (Merton actually used the term Communism, but had this notion of communalism in mind, not Marxism);

Universalism - according to which claims to truth are evaluated in terms of universal or impersonal criteria, and not on the basis of race, class, gender, religion, or nationality;

Disinterestedness - according to which scientists are rewarded for acting in ways that outwardly appear to be selfless;

Organized Skepticism - all ideas must be tested and are subject to rigorous, structured community scrutiny.

Will any sensitivity analysis do the job? Can I lie with sensitivity analysis as I can lie with statistics?



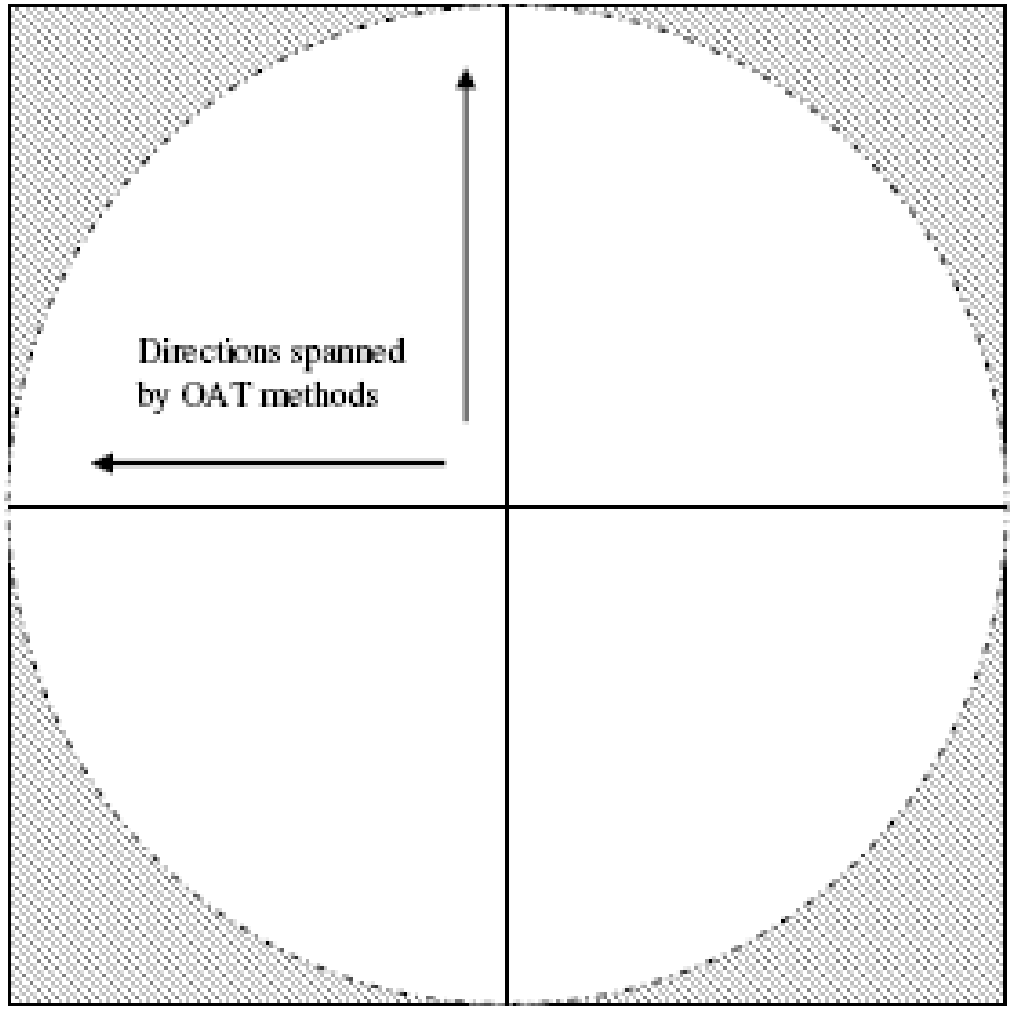
Saltelli, A., Annoni P., 2010, How to avoid a perfunctory sensitivity analysis, *Environmental Modeling and Software,* **25**, 1508-1517.

What do these have in common?

J. Campbell, *et al.*, *Science* **322**, 1085 (2008).
R. Bailis, M. Ezzati, D. Kammen, *Science* **308**, 98 (2005).
E. Stites, P. Trampont, Z. Ma, K. Ravichandran, *Science* **318**, 463 (2007).
J. Murphy, et al., *Nature* **430**, 768-772 (2004).
J. Coggan, *et al.*, *Science* **309**, 446 (2005).

They use a one factor at a time approach (OAT)

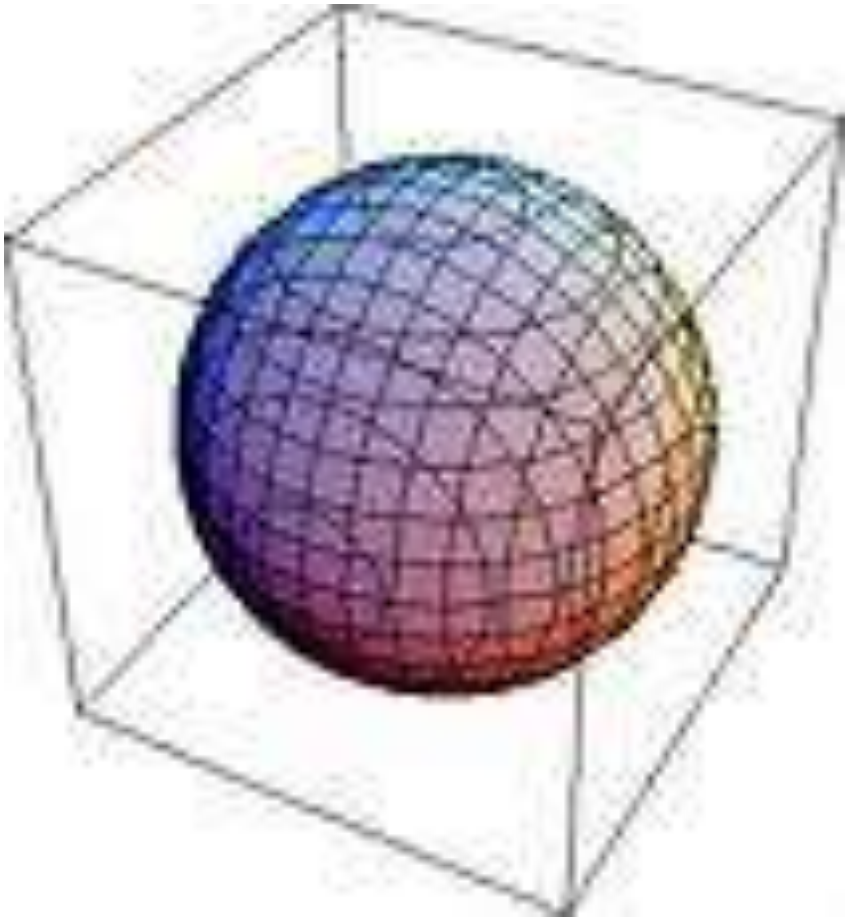
OAT in 2 dimensions



Area circle / area square =?

~ 3/4

OAT in 3 dimensions



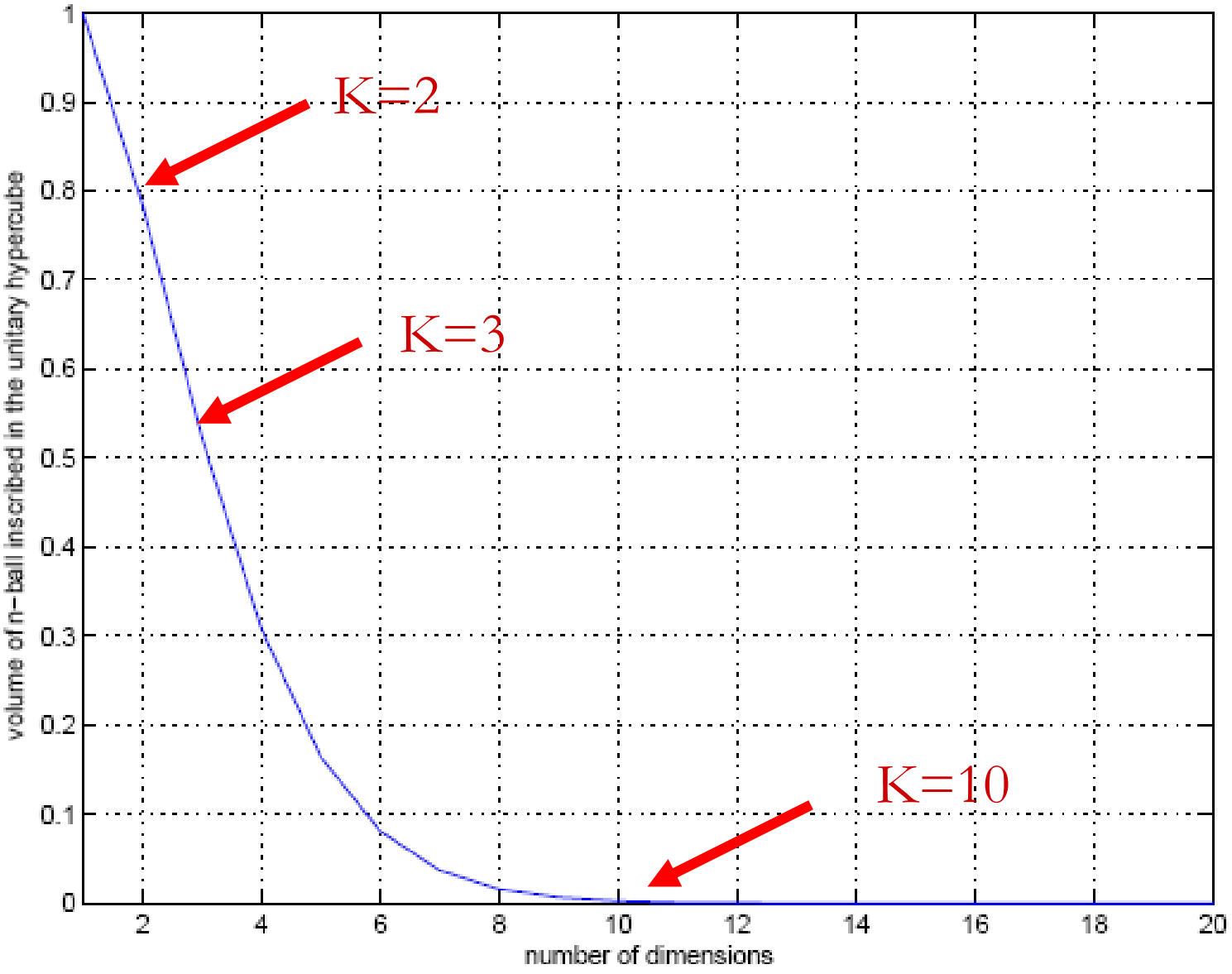
Volume sphere / volume cube =?

~ 1/2

OAT in 10 dimensions

Volume hypersphere / volume ten dimensional hypercube =? ~ 0.0025

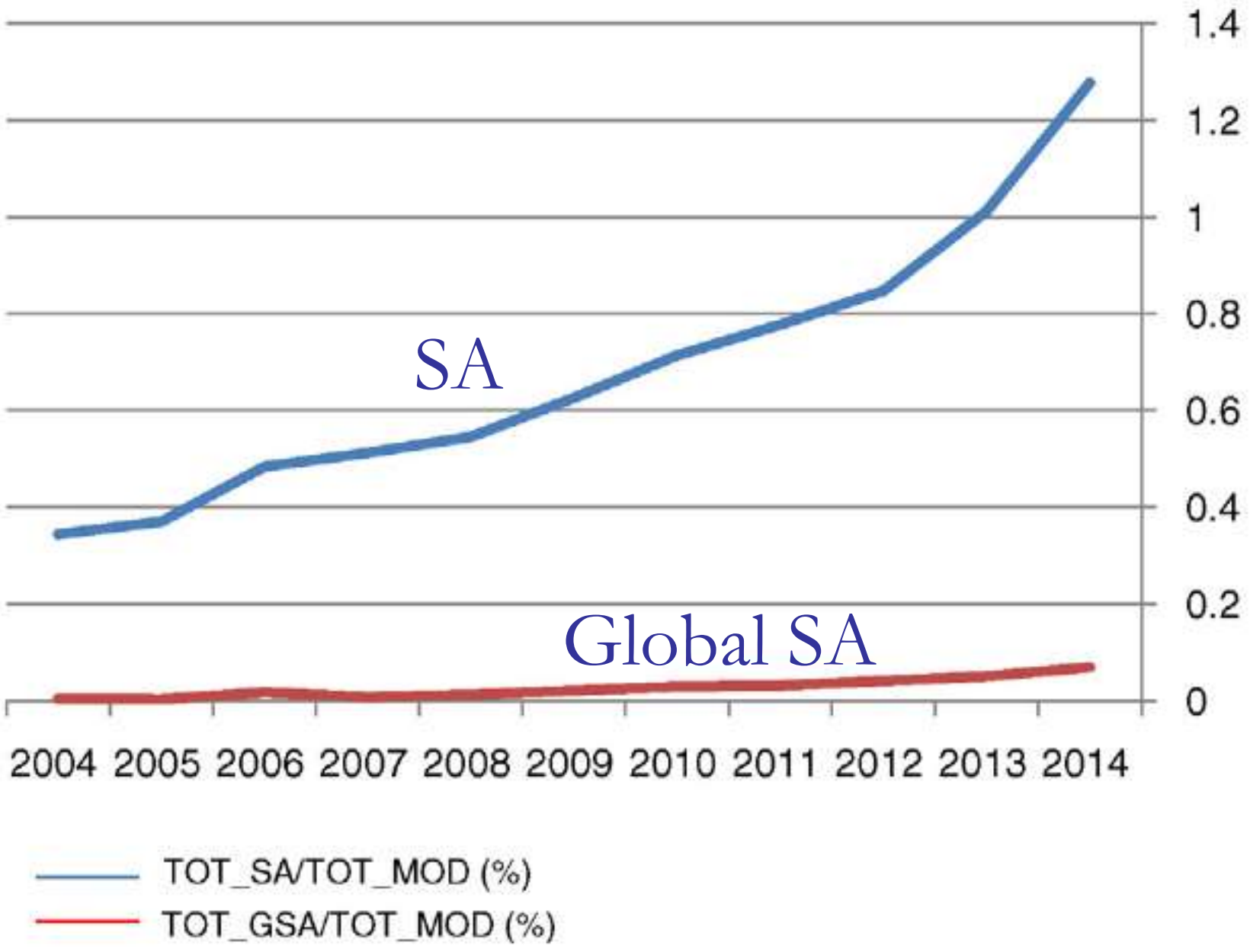
OAT in k dimensions



How are we doing in 2016?

OAT is still the most largely used technique in SA.

Ferretti, F., Saltelli A., Tarantola, S., 2016, Trends in Sensitivity Analysis practice in the last decade, Science of the Total Environment, http://dx.doi.org/10.1016/j.scitotenv.2016.02.133


1.4
1.2
1
0.8
0.6
0.4
0.2
0
SA
Global SA
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
TOT_SA/TOT_MOD (%)
TOT_GSA/TOT_MOD (%)

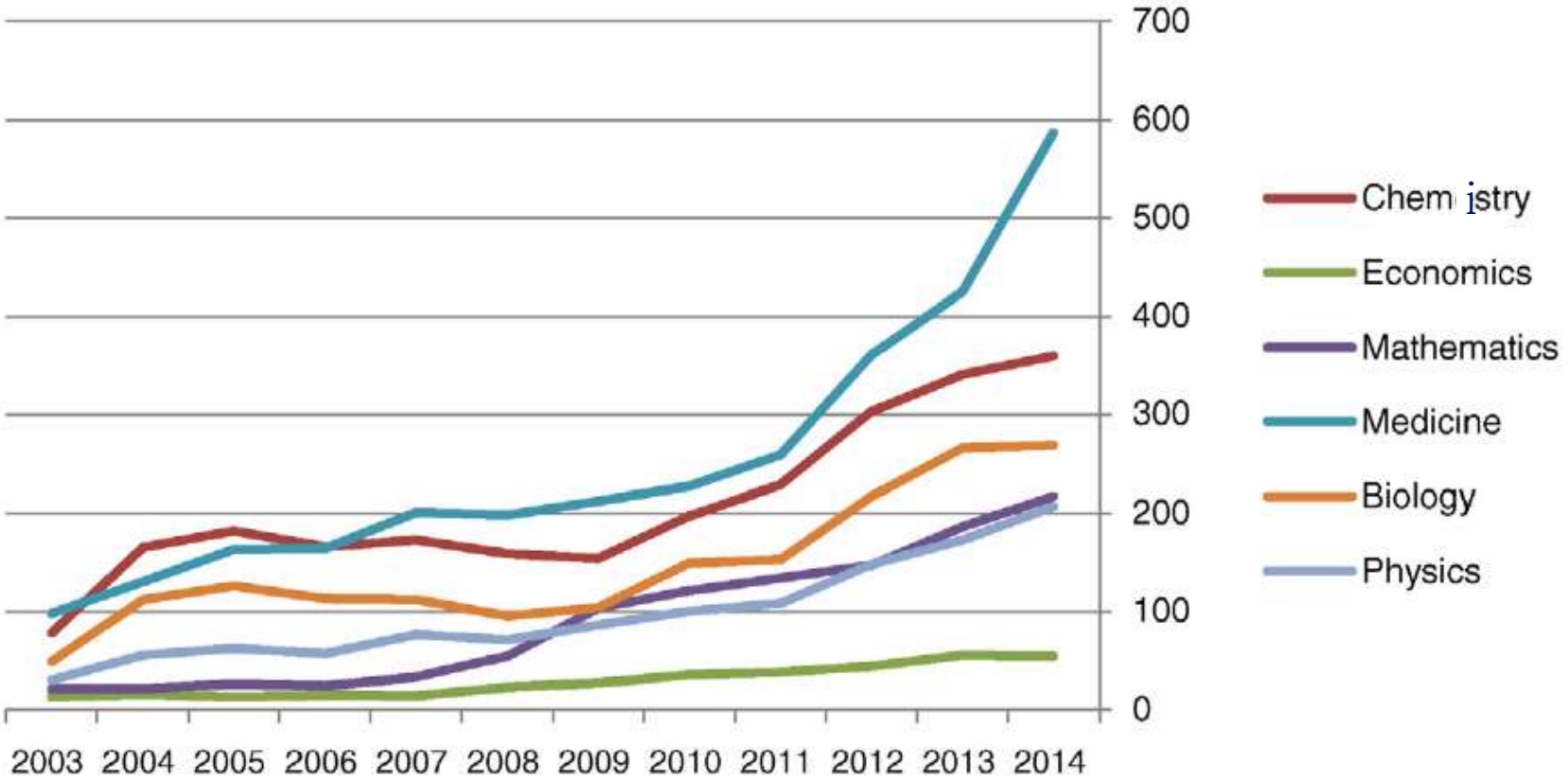


Fig. 4. GSA in the different scientific domains.

[Global*] sensitivity analysis: "The study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input"

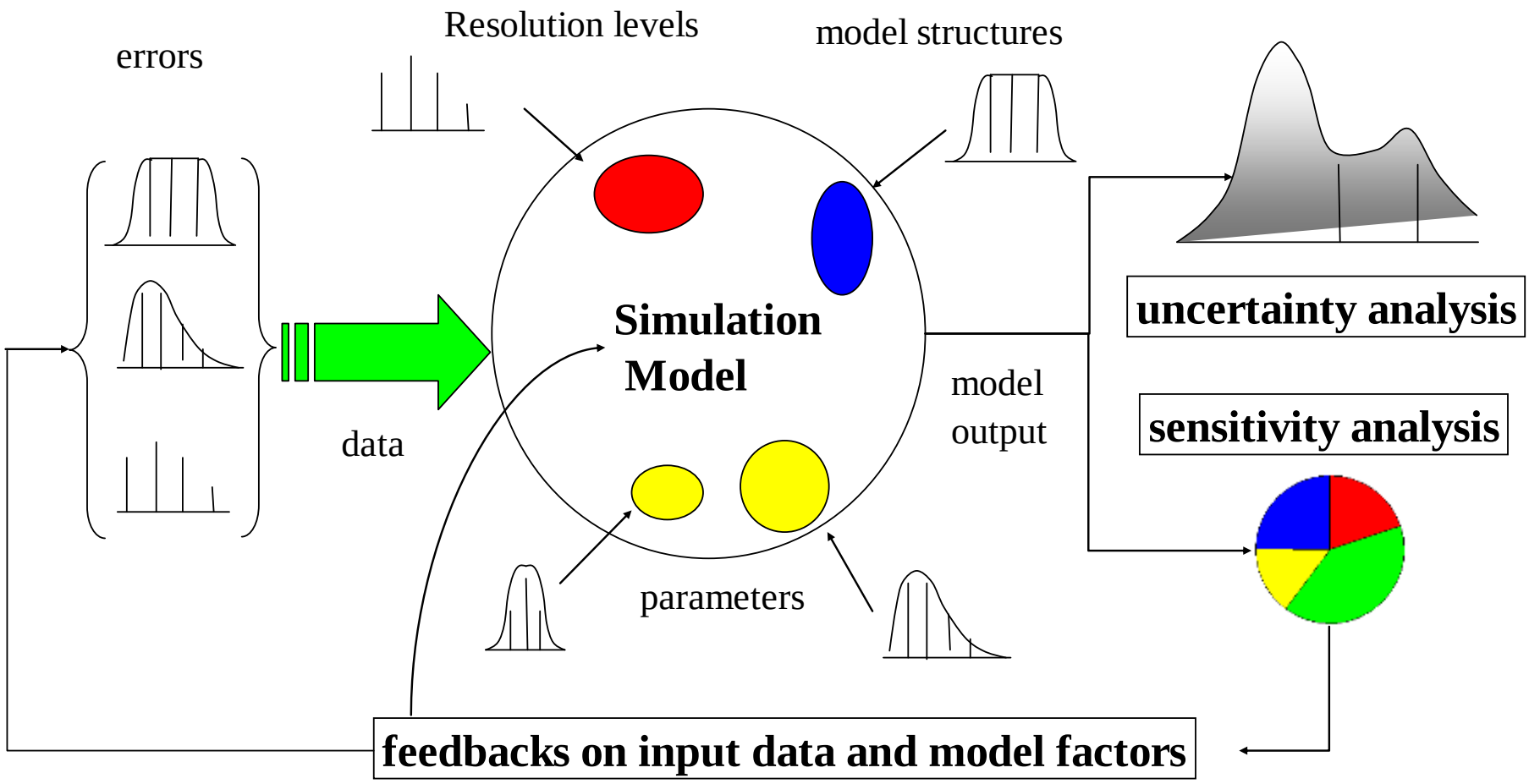
Saltelli A., 2002, Sensitivity Analysis for Importance Assessment, Risk Analysis, 22 (3), 1-12.

Suggested strategy for SA

- Modelling in a Monte Carlo framework

- All uncertainties activated simultaneously; uncertainty and sensitivity together

An engineer's vision of UA, SA

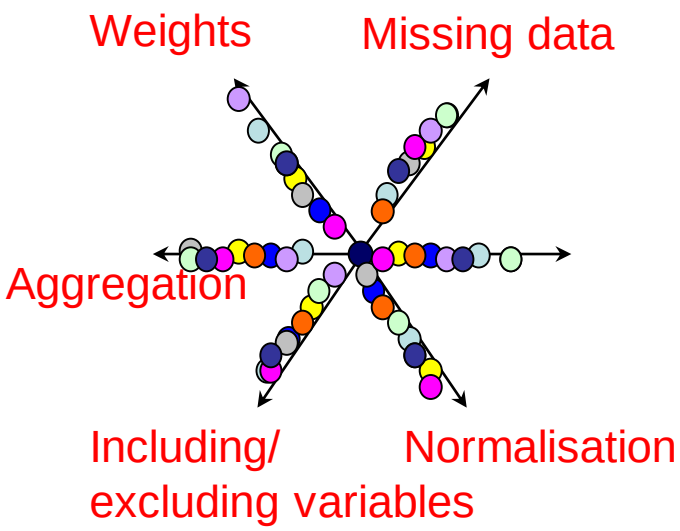


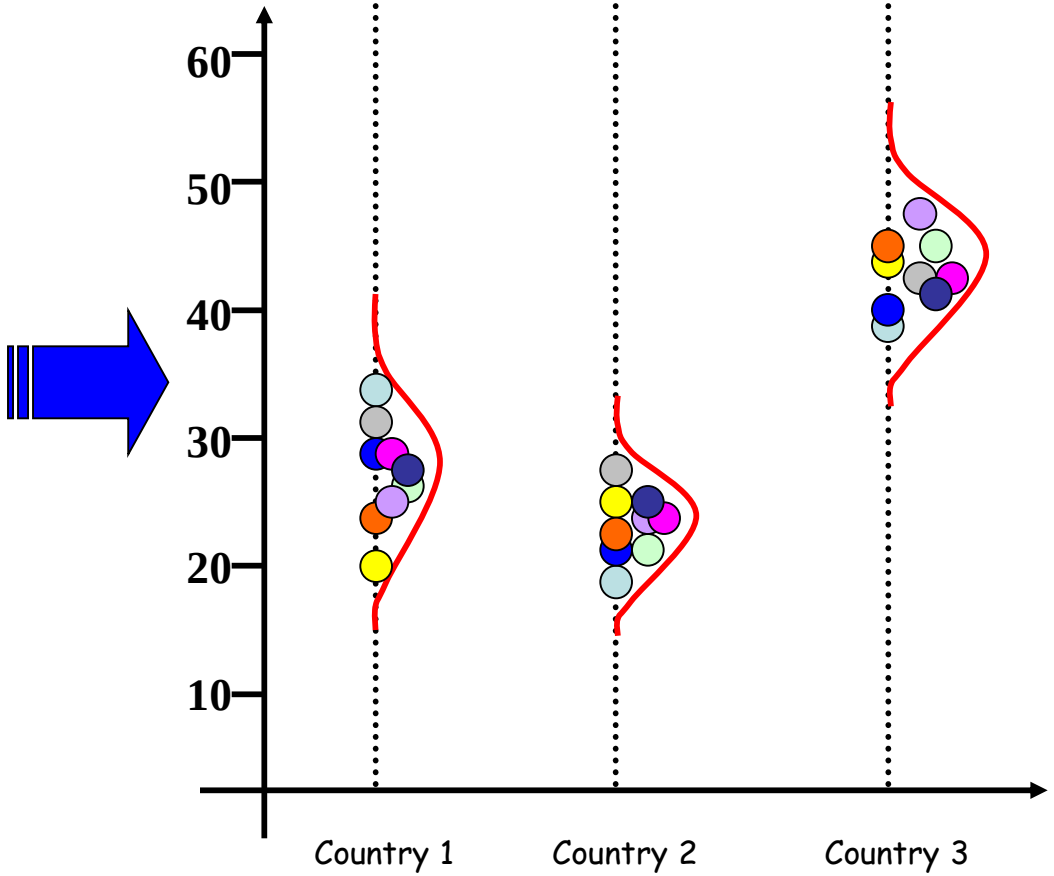
Tips

- One can sample more than just factors …
- Using triggers one can sample modelling assumptions; example: Y is a composite indicator

Assumption	**Alternatives**
Number of indicators	▪ all six indicators included or one-at-time excluded (6 options)
Weighting method	▪ original set of weights, ▪ factor analysis, ▪ equal weighting, ▪ data envelopment analysis
Aggregation rule	▪ additive, ▪ multiplicative, ▪ Borda multi-criterion

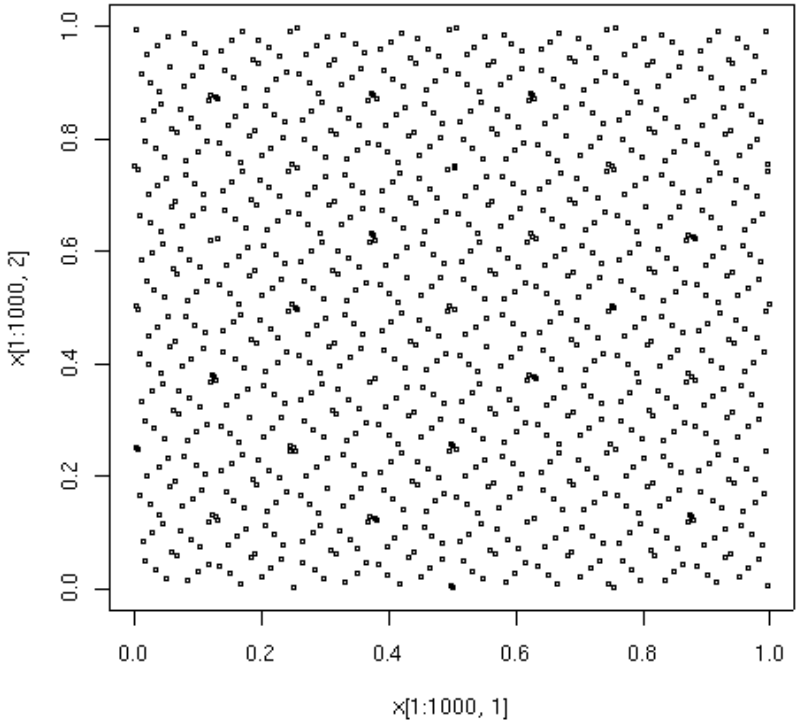
Space of alternatives





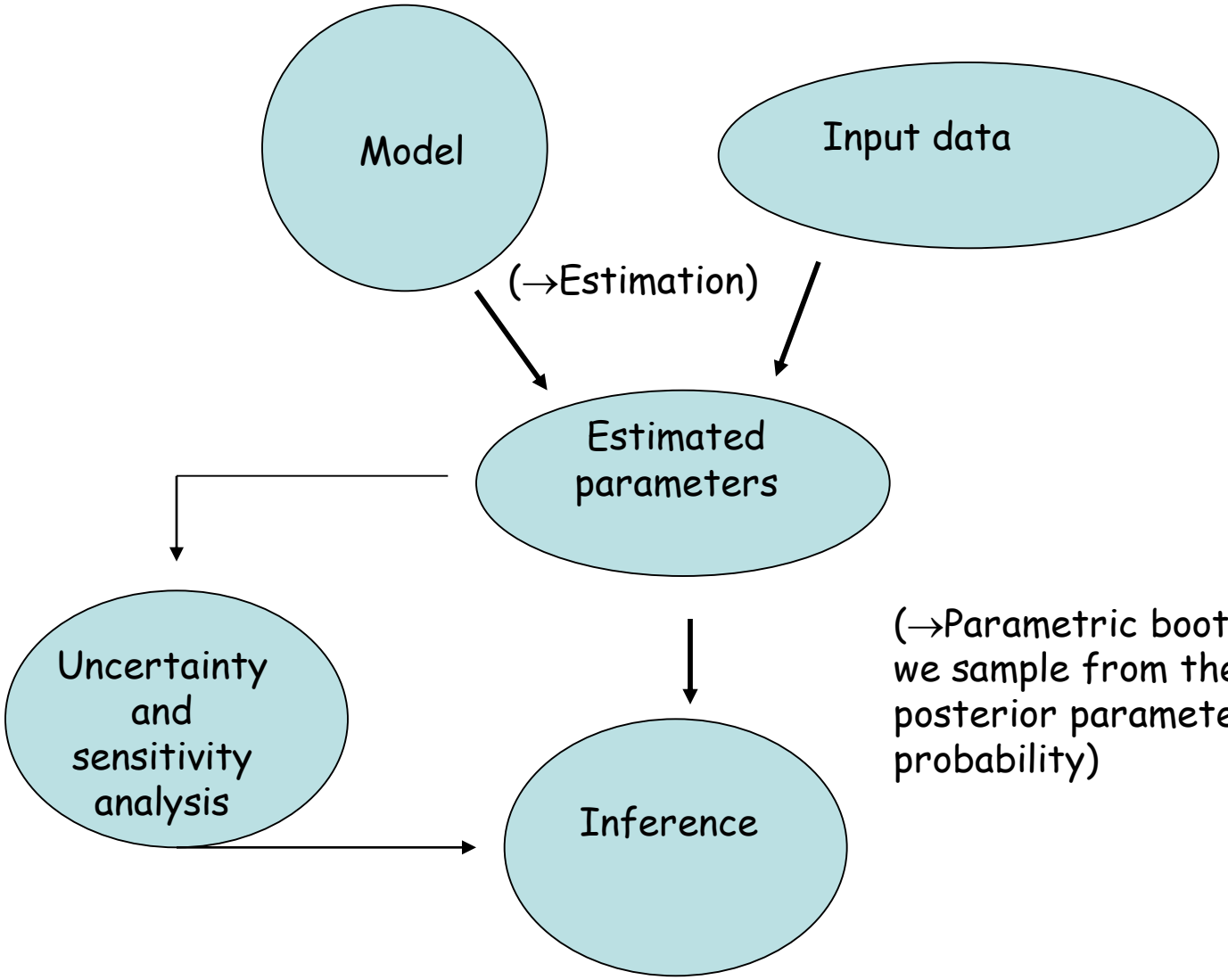
Tips

- Use quasi random numbers (LP_τ)



Ilya M. Sobol'

Models maps assumptions onto inferences (Parametric bootstrap version of UA/SA)



Sample matrix for parametric bootstrap.

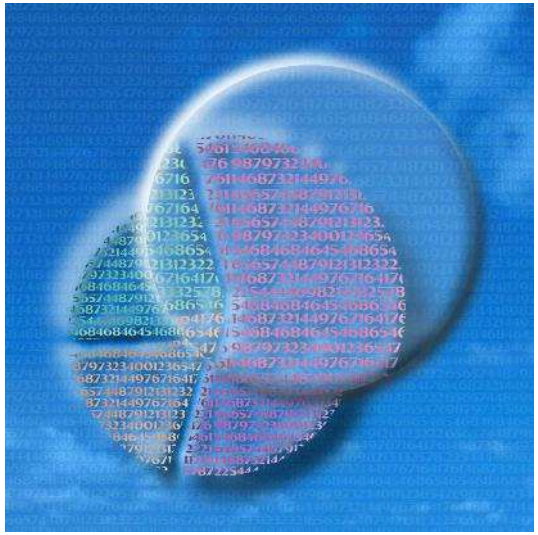
$$\begin{matrix} x_{11} & x_{12} & \dots & x_{1k} \\ x_{21} & x_{22} & \dots & x_{2k} \\ \dots & \dots & \dots & \dots \\ x_{N1} & x_{N2} & \dots & x_{Nk} \end{matrix}$$

Each row is a sample trial for one model run. Each column is a sample of size N from the marginal distribution of the parameters as generated by the estimation procedure.

Model results:

Each row is the error-free result of the model run.

$$y_1$$
$$y_2$$
$$\dots$$
$$y_N$$

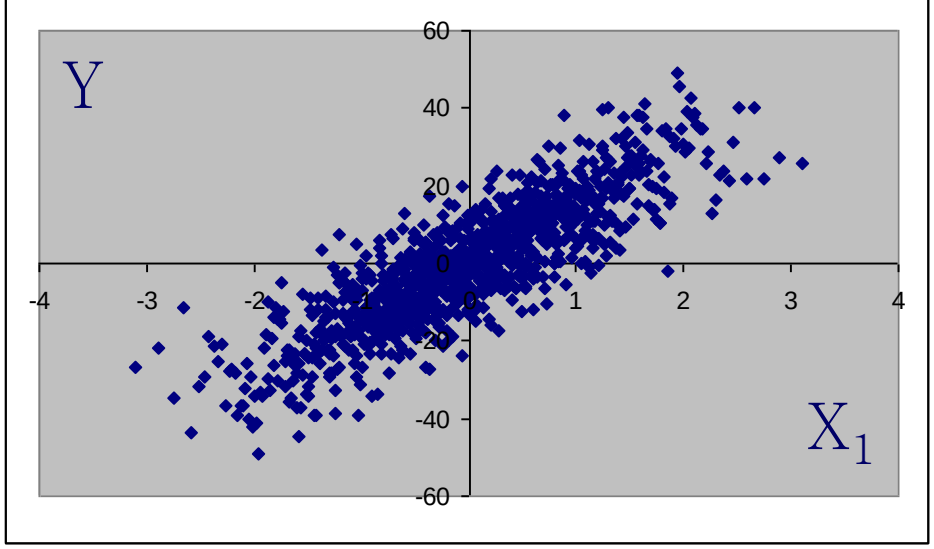


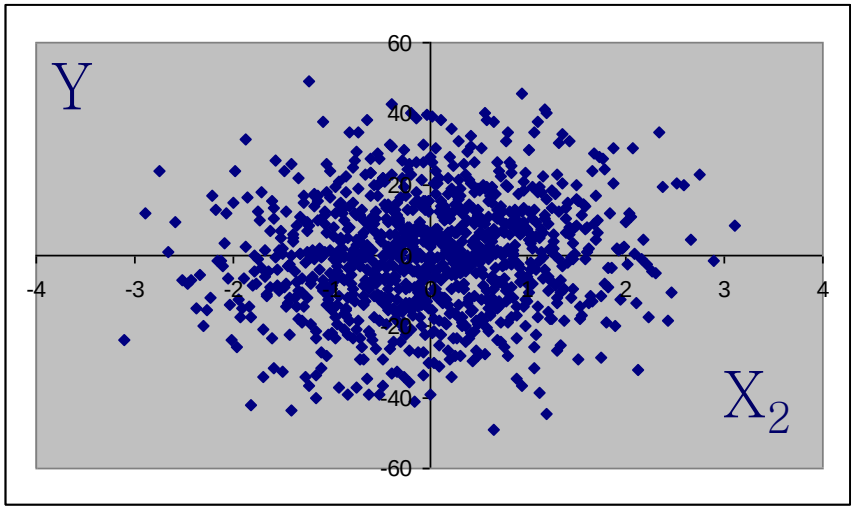
Our preferred methods for SA: variance based

An intuitive derivation of sensitivity indices

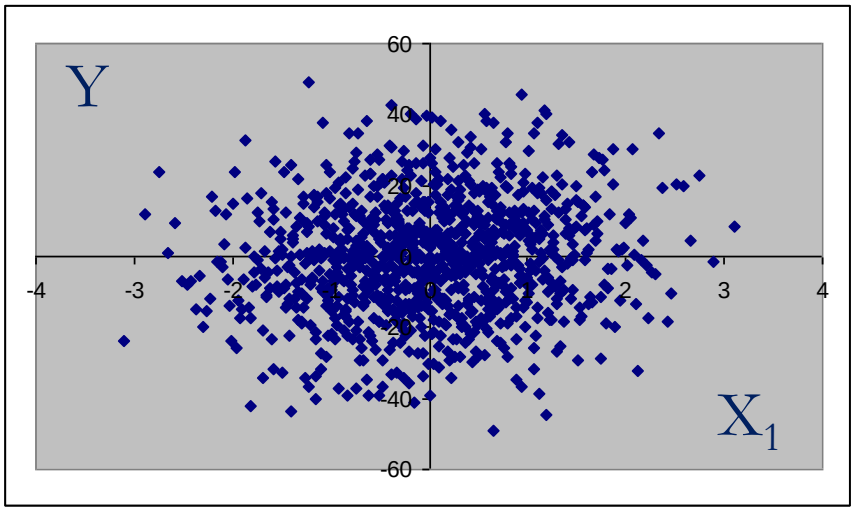
$$\begin{matrix} x_{11} & x_{12} & \dots & x_{1k} \\ x_{21} & x_{22} & \dots & x_{2k} \\ \dots & \dots & \dots & \dots \\ x_{N1} & x_{N2} & \dots & x_{Nk} \end{matrix}$$

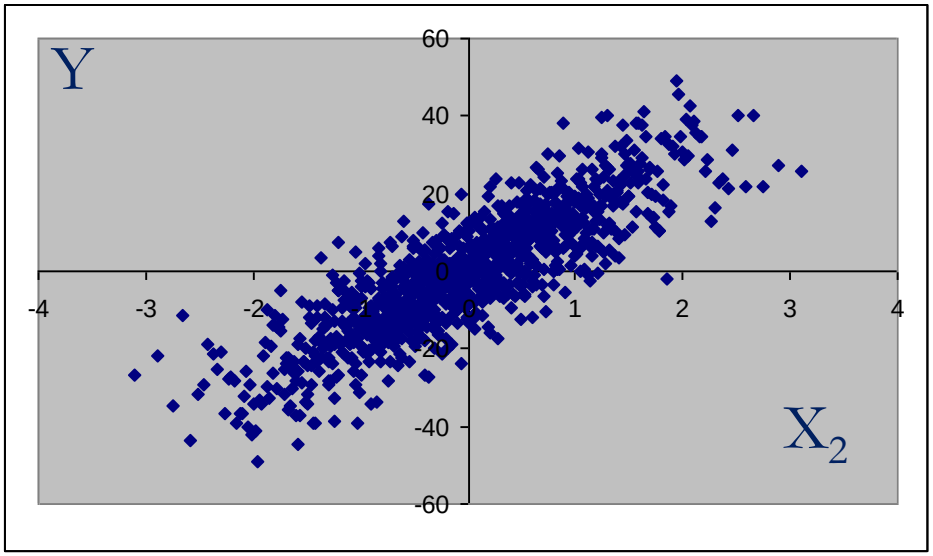
$$\begin{matrix} y_1 \\ y_2 \\ \dots \\ y_N \end{matrix}$$





Scatterplots of y versus sorted factors

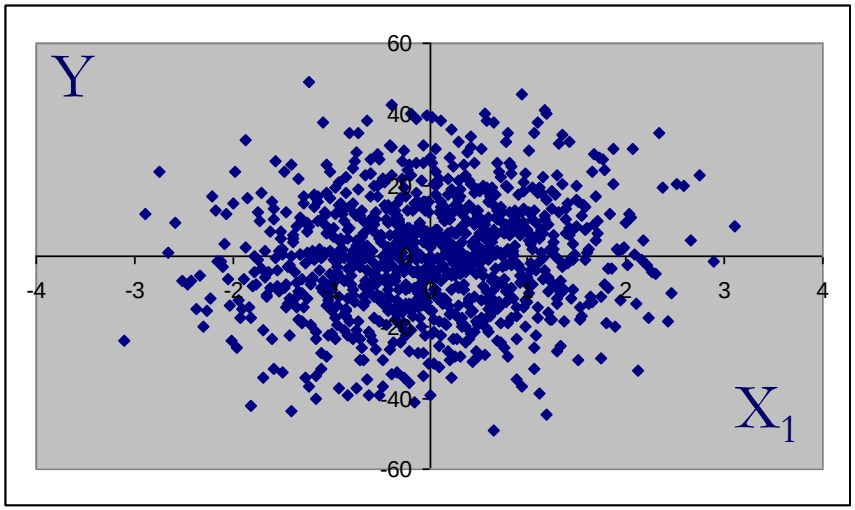


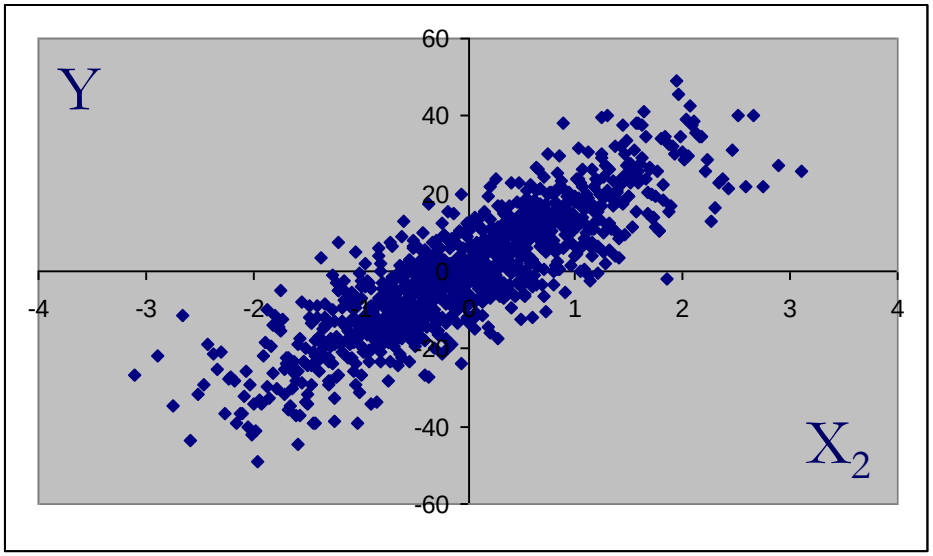


The ordinate axis is always Y

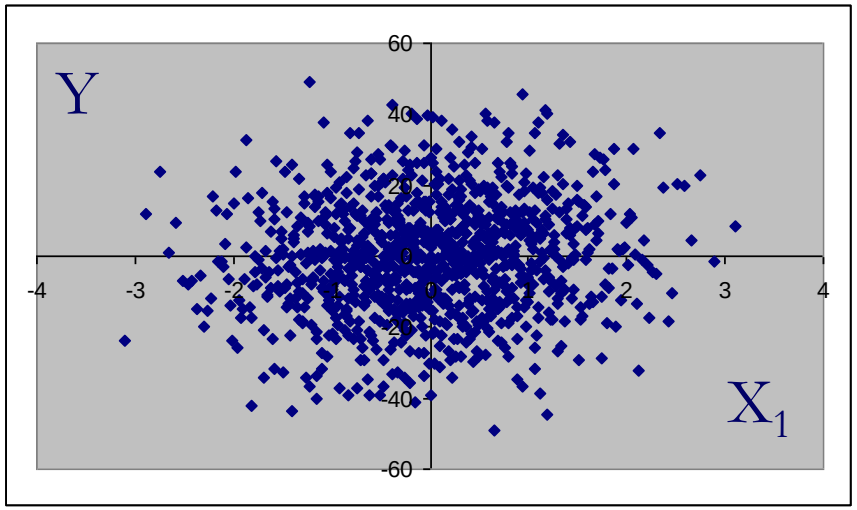
The abscissa are the various factors X_i in turn.

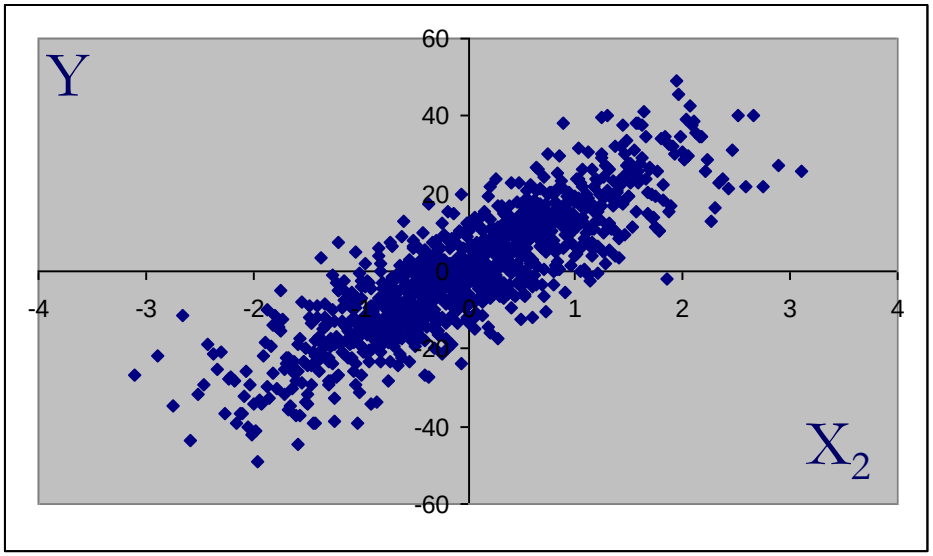
The points are always the same





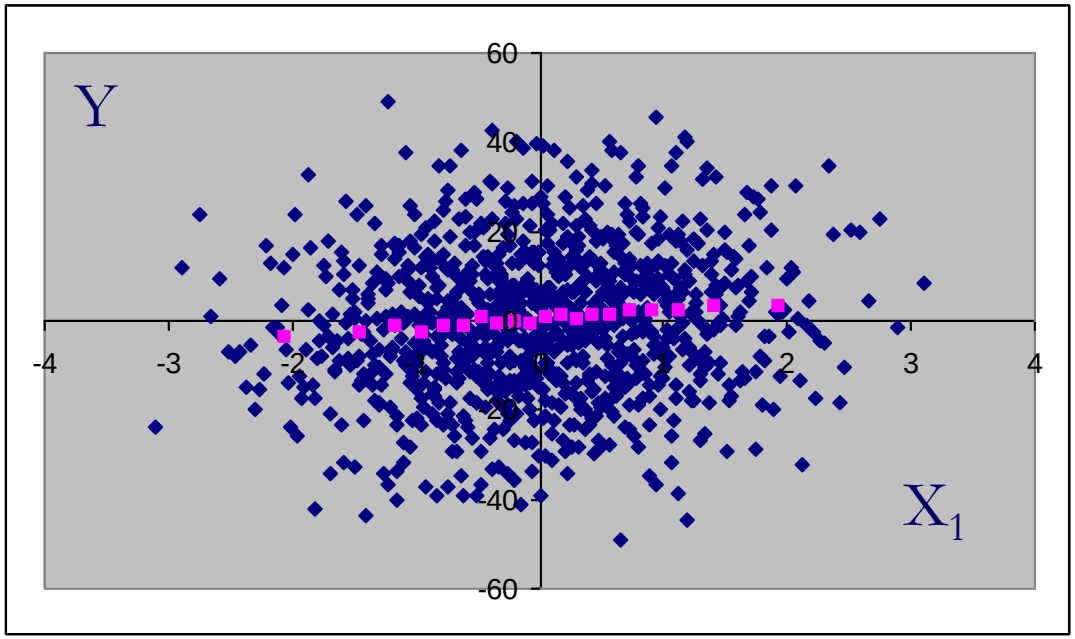
Which factor is more important?

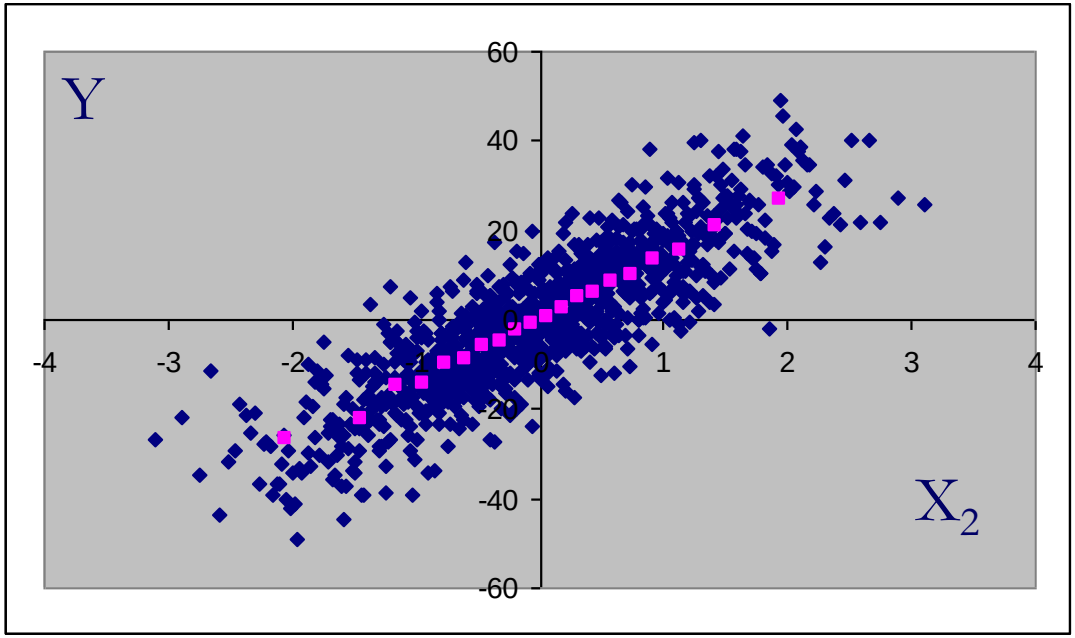




These are ~1,000 points

Divide them in 20 bins of ~ 50 points

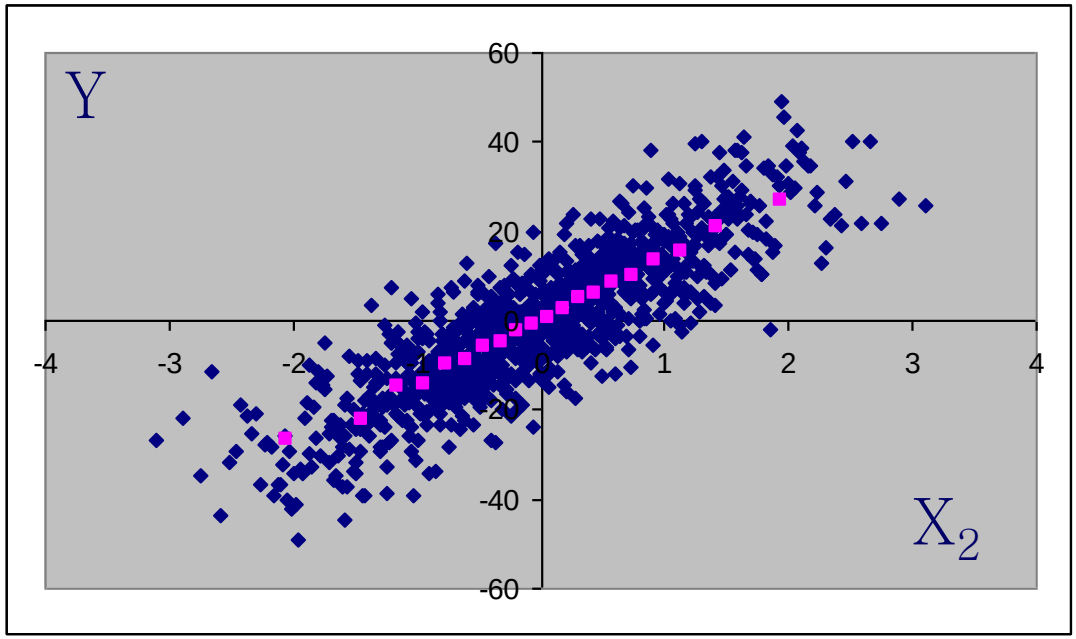




~1,000 blue points

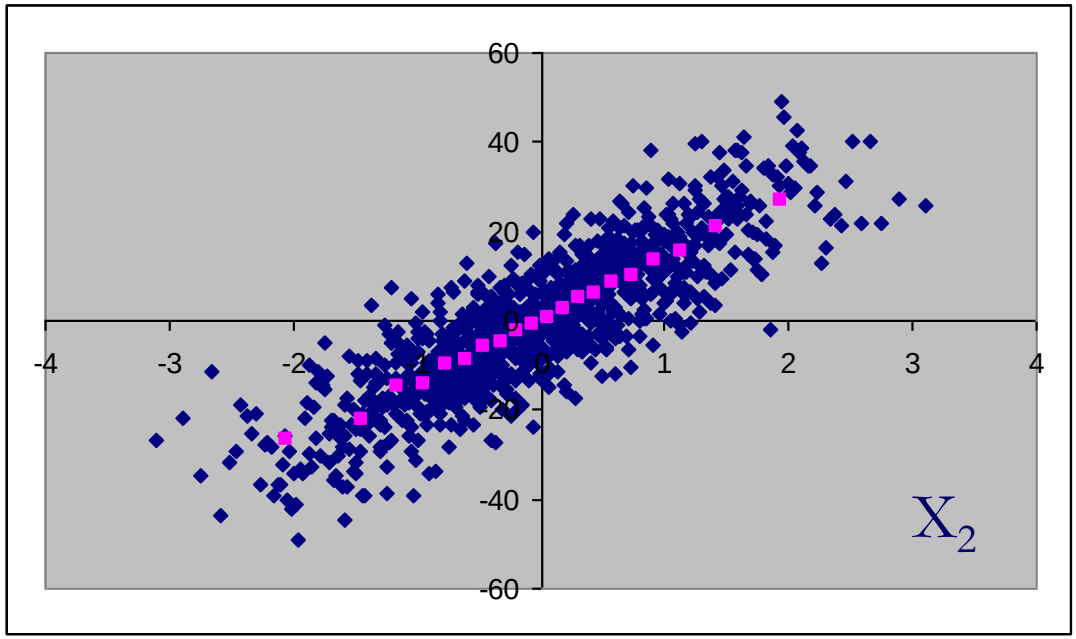
Divide them in 20 bins of ~ 50 points

Compute the bin's average (pink dots)



Each pink point is ~ $E_{\mathbf{x}_{\sim i}}\left(Y \middle| X_i\right)$

Y



Take the variance of the pinkies

$$V_{X_i}\left(E_{\mathbf{X}_{\sim i}}\left(Y|X_i\right)\right)$$

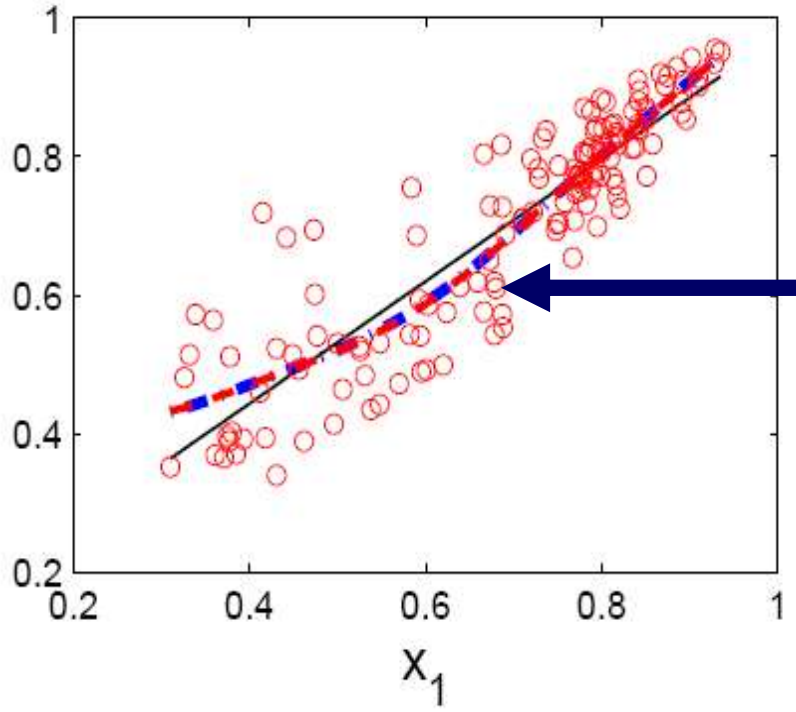
Pearson's correlation ratio

Smoothed curve

$$S_i \equiv \eta_i^2 := \frac{\mathrm{V}_{x_i}\left(\mathrm{E}_{\mathbf{x}_{\sim i}}\left(y \mid x_i\right)\right)}{\mathrm{V}\left(y\right)}$$

First order sensitivity index

Unconditional variance



Smoothed curve

$$\mathrm{E}_{\mathbf{x}_{\sim i}}\left(y \mid x_i\right)$$

First order sensitivity index:

$$\frac{\mathrm{V}_{x_i}\left(\mathrm{E}_{\mathbf{x}_{\sim i}}\left(y \mid x_i\right)\right)}{\mathrm{V}\left(y\right)}$$

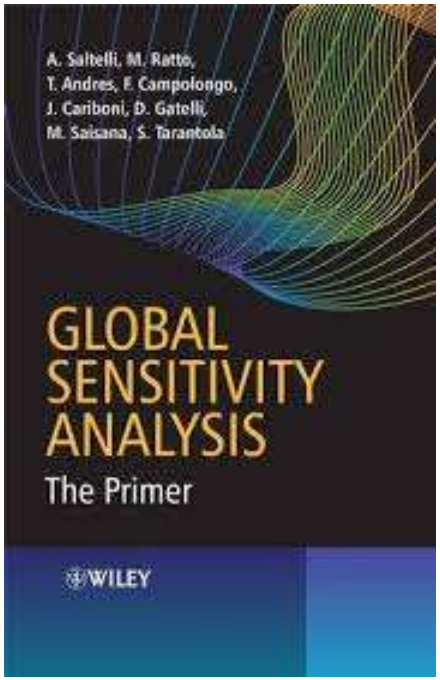
$$V_{X_i}\left(E_{\mathbf{X}_{\sim i}}\left(Y|X_i\right)\right)$$

First order effect, or top marginal variance=

= the expected reduction in variance than would be achieved if factor Xi could be fixed.

Why? See

this book



First secret: The most important question is the question.

Corollary 1: Sensitivity analysis is not “run” on a model but on a model once applied to a question.

First secret: The most important question is the question.

Corollary 2: The best setting for a sensitivity analysis is one when one wants to prove that a question cannot be answered given the model

It is better to be in a setting of falsification than in one of confirmation (Oreskes et al., 1994).

[Normally the opposite is the case]

Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences, Naomi Oreskes, Kristin Shrader-Frechette, Kenneth Belitz, Science, New Series, Vol. 263, No. 5147 (Feb. 4, 1994), pp. 641-646.

Second secret: Sensitivity analysis should not be used to hide assumptions [it often is]

Third secret: If sensitivity analysis shows that a question cannot be answered by the model one should find another question/model which can be treated meaningfully.

[Often the love for the model prevails]

Badly kept secret:

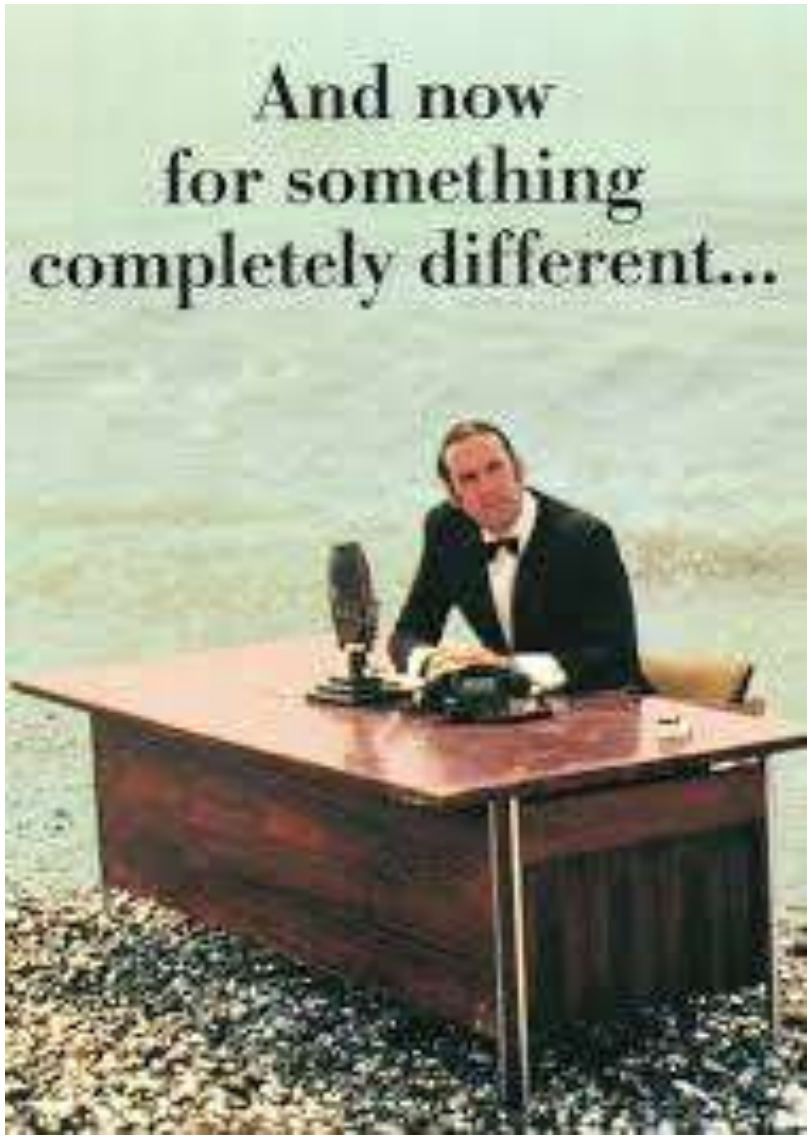
There is always one more bug!

(Lubarsky's Law of Cybernetic Entomology)

Personal note: I never run a
SA without finding more bugs

Discussion point

- Why doing a sensitivity analysis if it can undermine an laborious quantification exercise?
- What do I do if this happens to be the case?



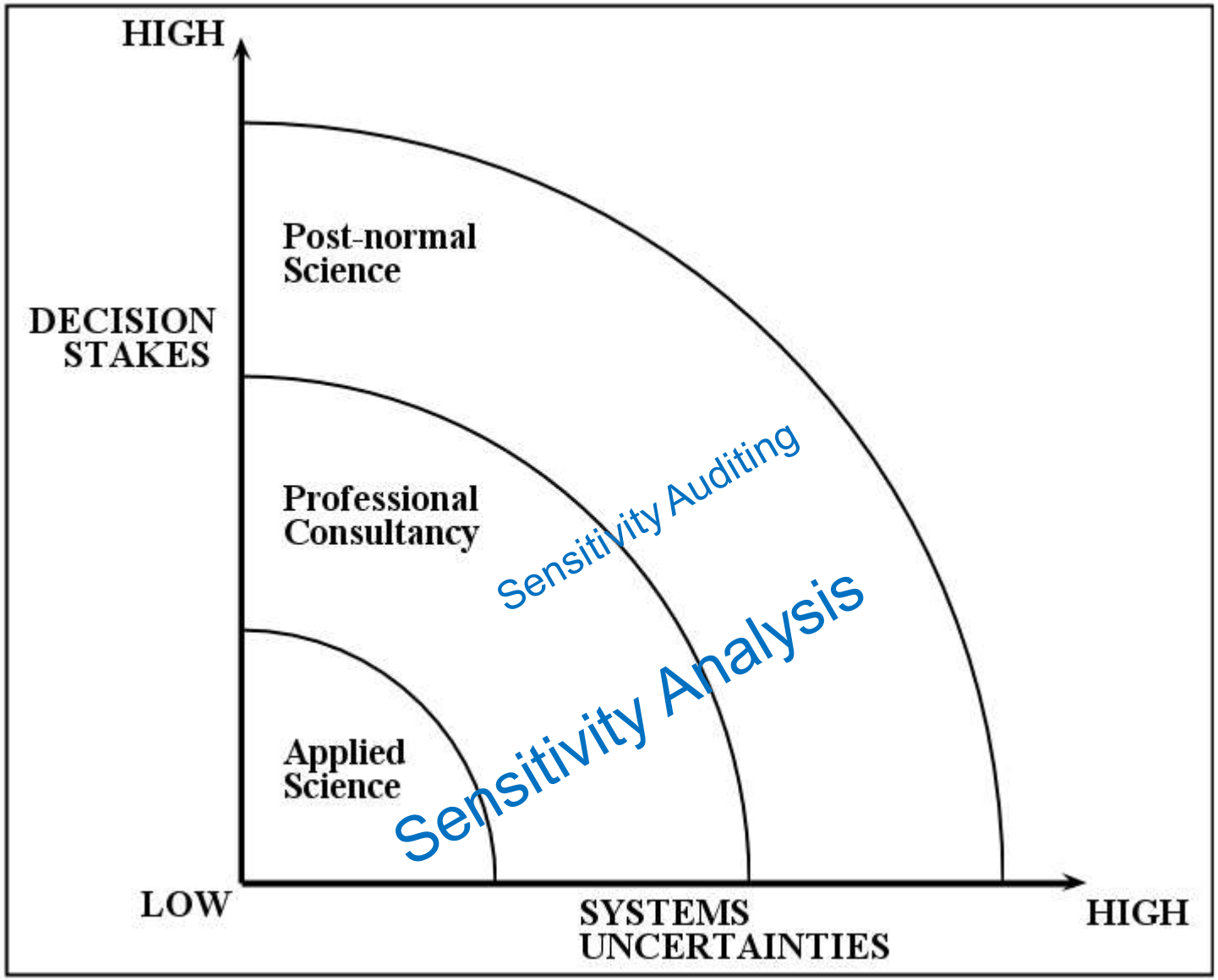
From sensitivity analysis to sensitivity auditing

Sensitivity auditing

- Originates from uncertainty & sensitivity analysis
- Addresses model-based evidence used for policy

Saltelli, A., Guimarães Pereira, Â., Van der Sluijs, J.P. and Funtowicz, S., 2013, What do I make of your latinorum? Sensitivity auditing of mathematical modelling, Int. J. Foresight and Innovation Policy, 9, 2/3/4, 213–234.

Saltelli, A., Funtowicz, S., When all models are wrong: More stringent quality criteria are needed for science-policy interface, Issues in Science and Technology, Winter 2014, 79-85.
http://issues.org/30-2/andrea/


HIGH
DECISION STAKES
Post-normal Science
Professional Consultancy
Applied Science
Sensitivity Auditing
Sensitivity Analysis
LOW
SYSTEMS UNCERTAINTIES
HIGH

RULE ONE: Check against rhetorical use of mathematical modelling

The instrumental use of mathematical modelling to advance one's agenda

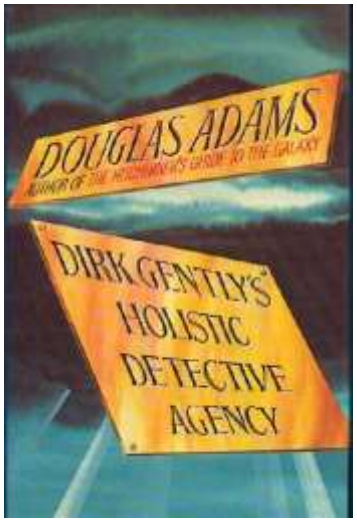
Rhetorical, or strategic

Like the use of Latin to obfuscate opponents.

RULE ONE: Check against rhetorical use of mathematical modelling

"Well, Gordon's great insight was to design a program which allowed you to specify in advance what decision you wished it to reach, and only then to give it all the facts. The program's task, […], was to construct a plausible series of logical-sounding steps to connect the premises with the conclusion."

Douglas Adam, 1987, Dirk Gently's holistic detective agency, p.69



About "All else being equal" (Caeteris paribus)

Models by their nature are like blinders. In leaving out certain things, they focus our attention on other things. They provide a frame through which we see the world.

Joseph E. Stiglitz, 2011, RETHINKING MACROECONOMICS: WHAT FAILED, AND HOW TO REPAIR IT, Journal of the European Economic Association August 2011 9(4):591–645

Caeteris are never paribus!

Philip Mirowski

"…To be fair, DSGE and similar macroeconomic models were first conceived as theorists' tools. But why, then, are they being relied on as the platform upon which so much practical policy advice is formulated? And what has caused them to become, and to stay, so firmly entrenched?"

The quote reported is from Miller, B., 2010, Opening Address, The Hearing Charter of the House Committee on Science and Technology and sworn testimony of economists Sidney Winter, Scott Page, Robert Solow, David Colander and V.V. Chari. See book on this slide.

RULE TWO: Adopt an 'assumption hunting' attitude;

What was 'assumed out'? What are the tacit, pre-analytic, possibly normative assumptions underlying the analysis?

Bogus Quantification: Uses and Abuses of Models

John Kay uncovers that the UK transport WebTAG model needs as input 'Annual Percentage Change in Car Occupancy up to 2036.'

John Kay, London School Economics, Columnist Financial Times

John Kay, Financial Times

Watch the videos from the workshop 'Significant digits. Responsible Use of Quantitative Information', Brussels, 11,9-10 June 2015.

https://ec.europa.eu/jrc/en/event/conference/use-quantitative-information

Philip Stark,
University of Berkeley

Contents lists available at ScienceDirect

Energy Policy

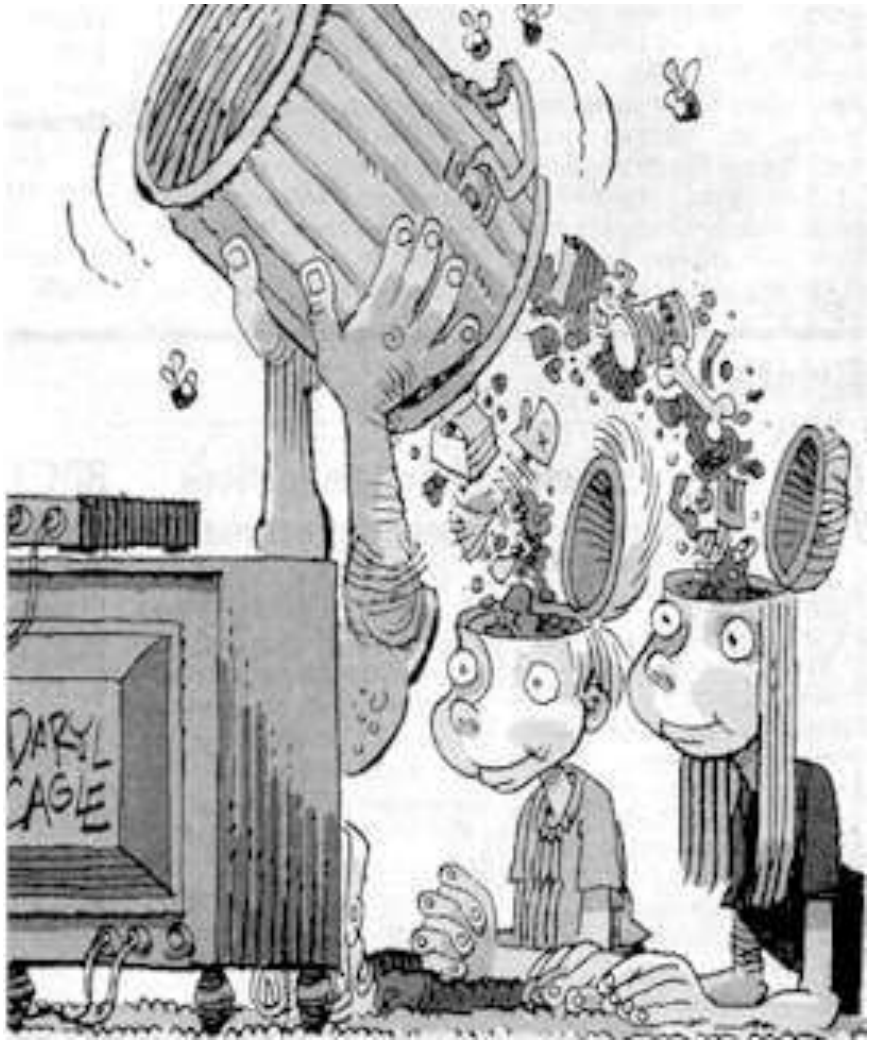
journal homepage: www.elsevier.com/locate/enpol

On the contribution of external cost calculations to energy system governance: The case of a potential large-scale nuclear accident

Erik Laes [a,*], Gaston Meskens [b], Jeroen P. van der Sluijs [c]

'[…] calculation of the external costs of a potential large-scale nuclear accident […] 'An [analysis] resulted in a list of 30 calculation steps and assumptions' …

RULE THREE: detect GIGO (Garbage In, Garbage Out)
Science or pseudo-science

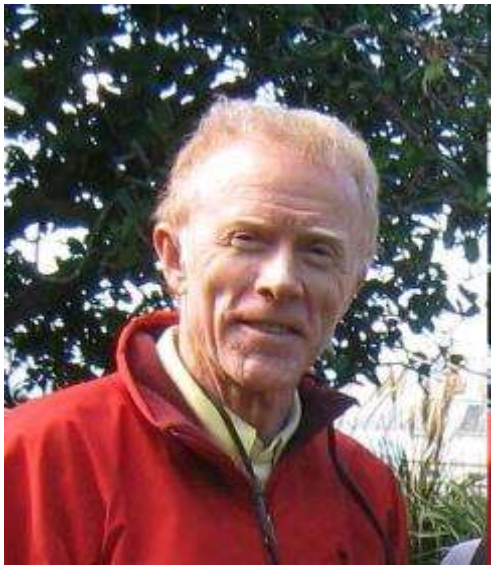


What is GIGO (Garbage In, Garbage Out) Science or pseudo-science "where uncertainties in inputs must be suppressed lest outputs become indeterminate"

From: Uncertainty and Quality in Science for Policy, by Silvio Funtowicz and Jerry Ravetz, Springer 1990.

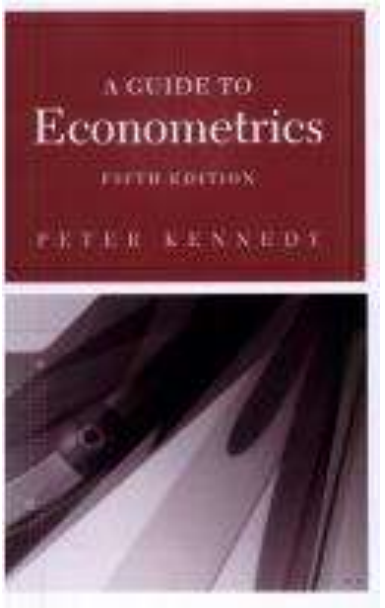
RULE FOUR: find sensitivities before sensitivities find you;

RULE FOUR: find sensitivities before sensitivities find you;



Peter Kennedy, A Guide to Econometrics.
Anticipating criticism by applying sensitivity analysis. This is one of the ten commandments of applied econometrics:

<<Thou shall confess in the presence of sensitivity.
Corollary: Thou shall anticipate criticism >>



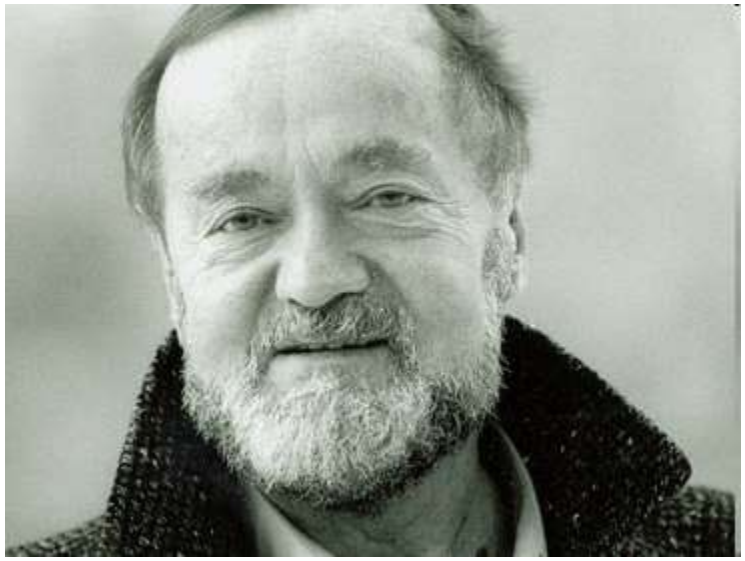
RULE FIVE: aim for transparency

[models should be made available to a third party so that it can] use the same data, computer model or statistical methods to replicate the analytic results reported in the original study.

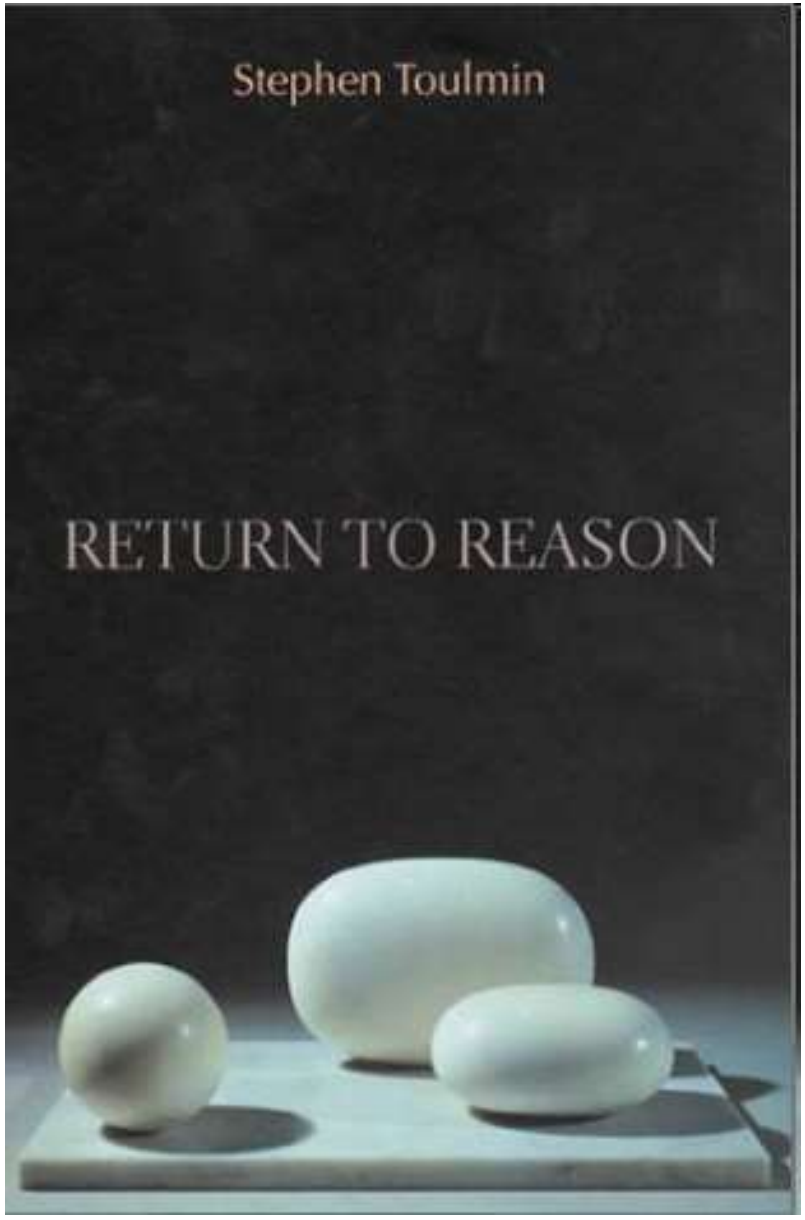
[…] The more important benefit of transparency is that the public will be able to assess how much an agency's analytic result hinges on the specific analytic choices made by the agency.

Friday, February 22, 2002
Graphic - Federal Register, Part IX
Office of Management and Budget
Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies; Notice; Republication
http://www.whitehouse.gov/omb/inforeg/

RULE SIX: Do the right sums



Do the sum right
Versus
Do the right sums
(Stephen Toulmin)
A plea for reasonableness versus rationality



RULE SIX: Do the right sums

Peter Kennedy's commandment of applied econometrics: 'Thou shall answer the right question', Kennedy 2007

Expertise and responsibility Rule 6

- Most analyses offered as input to policy are framed as cost benefit analysis or risk analyses.

Langdon Winner

Winner, L., 1986. The Whale and the Reactor: a Search for Limits in an Age of High Technology. The University of Chicago Press, 1989 edition.

RULE SEVEN: Explore diligently the space of the assumptions

Environmental Modelling & Software 25 (2010) 1508–1517

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

How to avoid a perfunctory sensitivity analysis

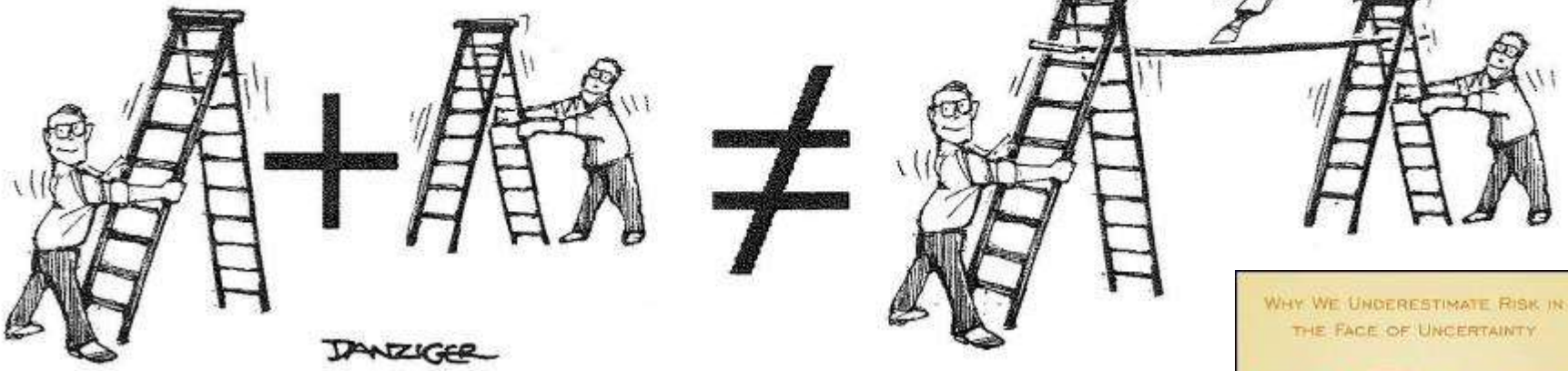
Andrea Saltelli*, Paola Annoni

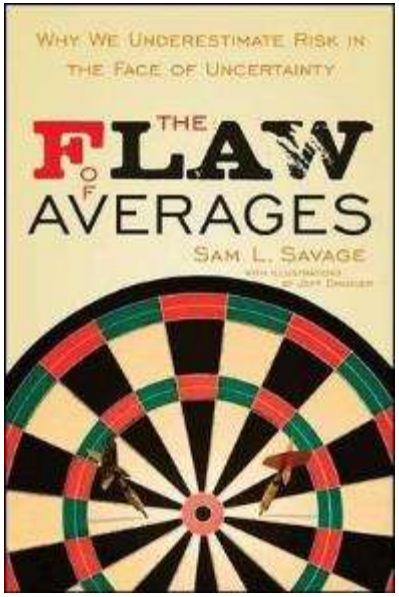
Joint Research Center, Institute for the Protection and Security of the Citizen, via E.Fermi, 2749, Ispra VA 21027, Italy

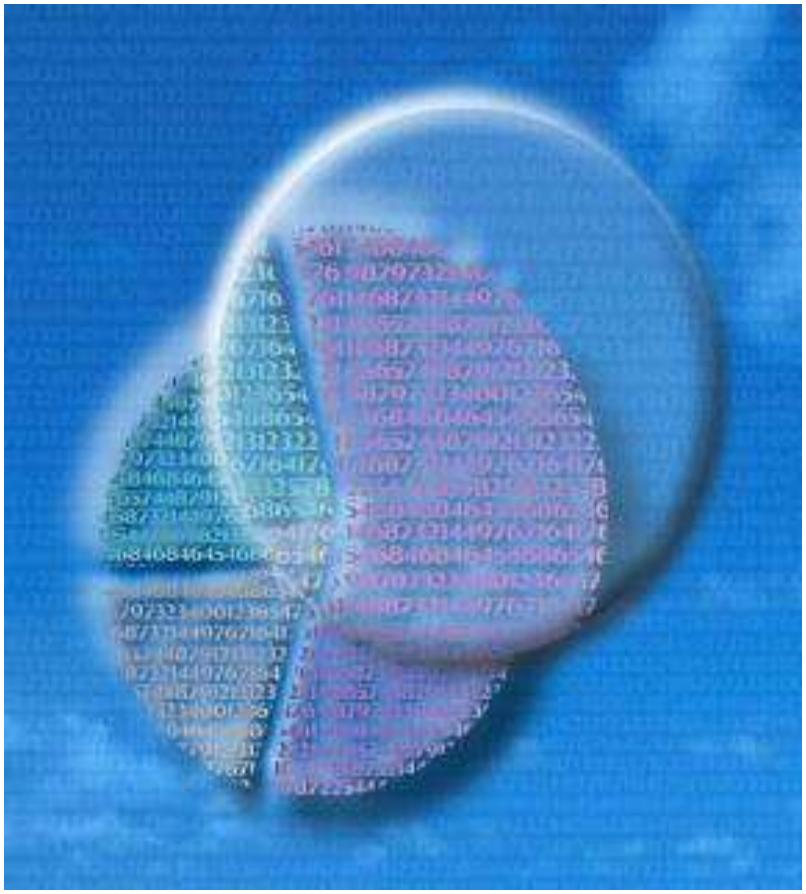
RULE SEVEN: Explore diligently the space of the assumptions

How coupled ladders are shaken in most of available literature

How to shake coupled ladders







END

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