Bocconi

Università Commerciale Luigi Bocconi

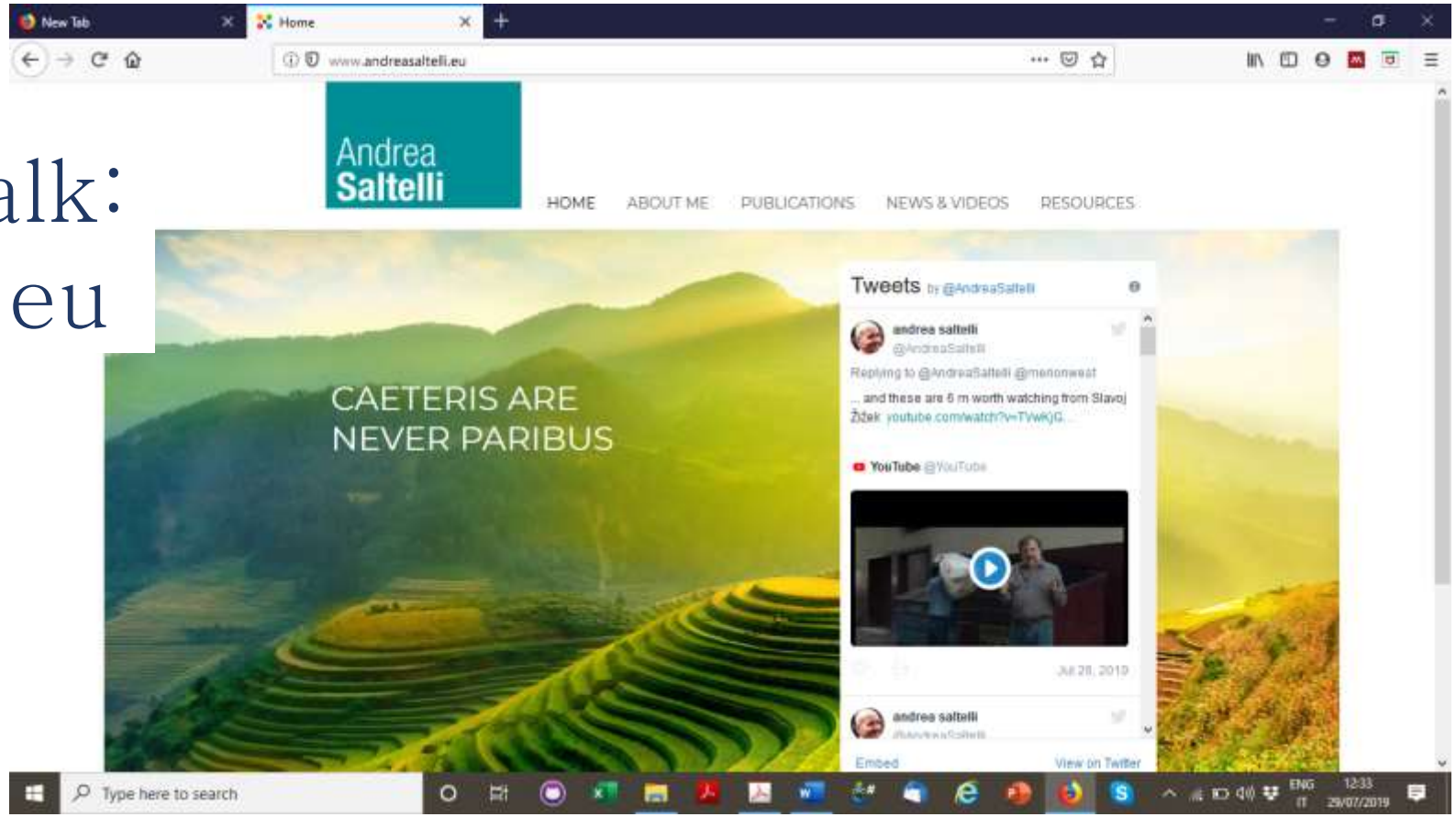
Department of Decision Sciences
Statistics Seminar

Sensitivity Analysis: an introduction

Andrea Saltelli
University of Bergen and Open University of Catalonia

Thursday, 7th November 2019
12:30 pm Room 3-E4-SR03 Via Roentgen 1 Milano

Where to find this talk: www.andreasaltelli.eu



UNIVERSITAS BERGENSIS

OPEN EVIDENCE

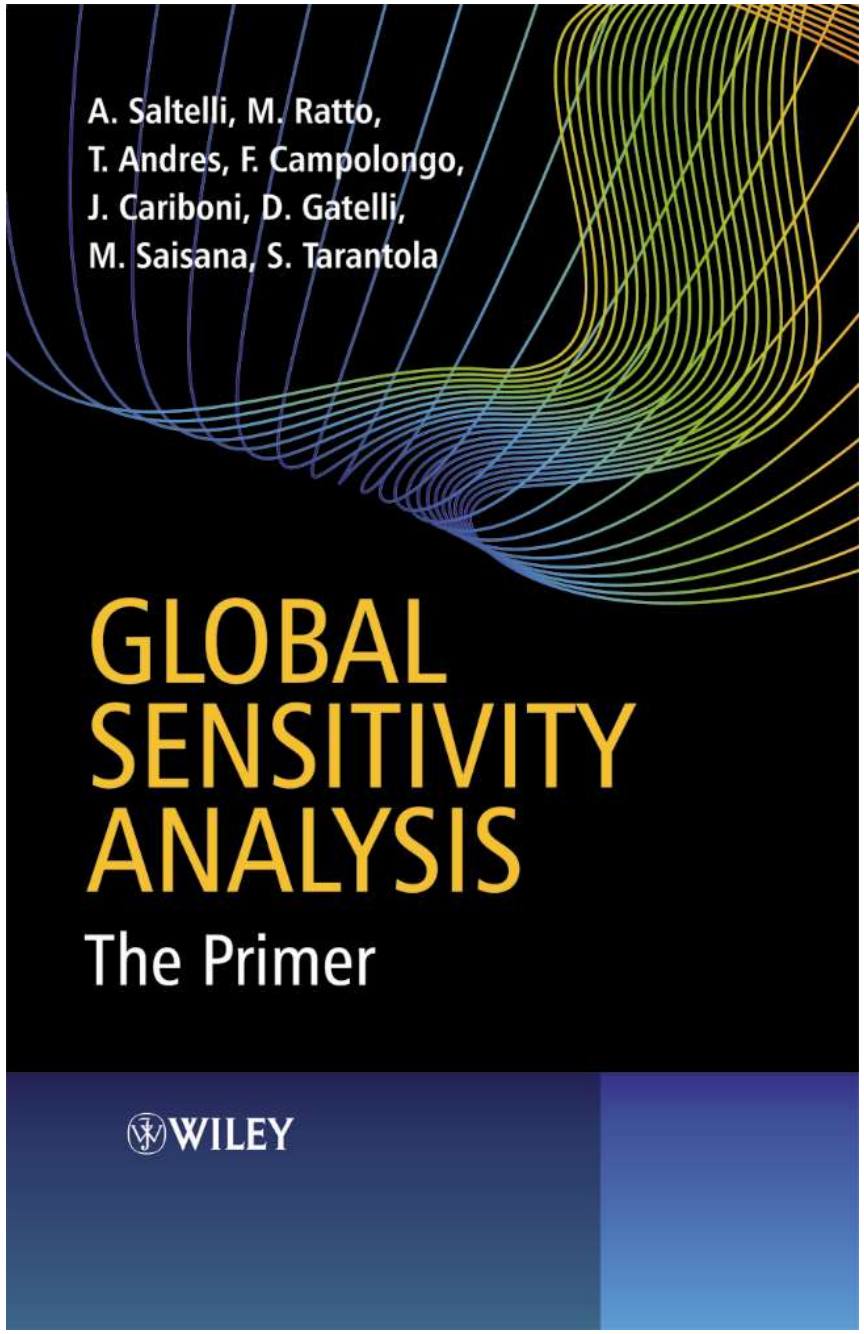
UOC Universitat Oberta de Catalunya

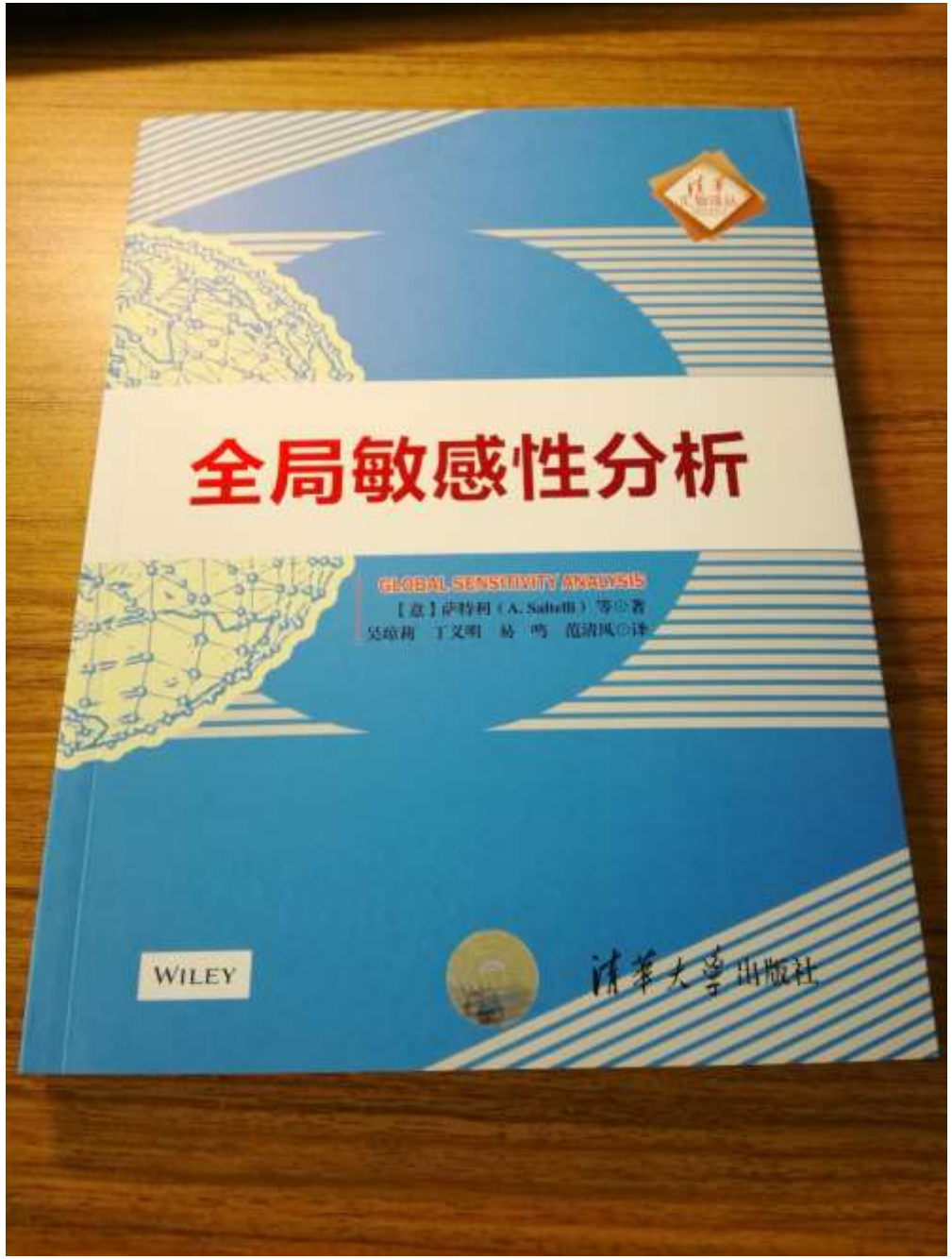
On sensitivity analysis and its take up

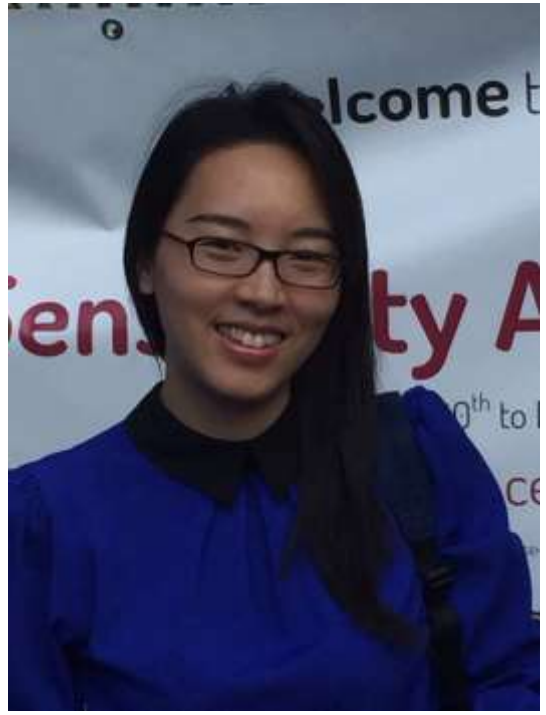
Definitions

Uncertainty analysis: Focuses on quantifying the uncertainty in model output

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







Dr. Qiongli Wu, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan, China

European Commission, 2015

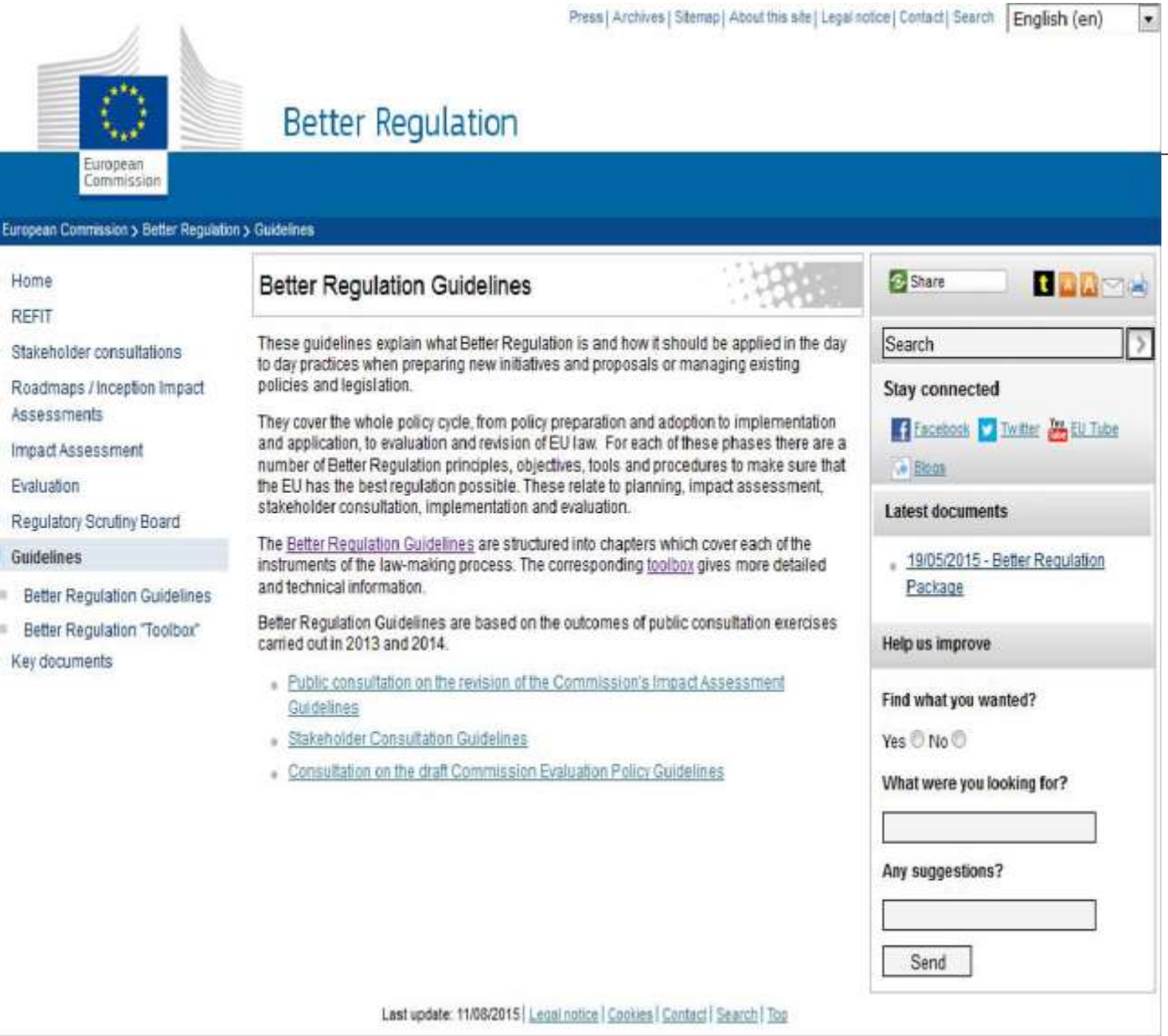
Office for the Management and Budget, 2006

Environmental Protection Agency, 2009

EPA, 2009, March. Guidance on the Development, Evaluation, and Application of Environmental Models. Technical Report EPA/100/K-09/003. Office of the Science Advisor, Council for Regulatory Environmental Modeling, http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1003E4R.PDF, Last accessed December 2015.

EUROPEAN COMMISSION, Better regulation toolbox, appendix to the Better Regulation Guidelines, Strasbourg, 19.5.2015, SWD(2015) 111 final, COM(2015) 215 final, http://ec.europa.eu/smart-regulation/guidelines/docs/swd_br_guidelines_en.pdf.

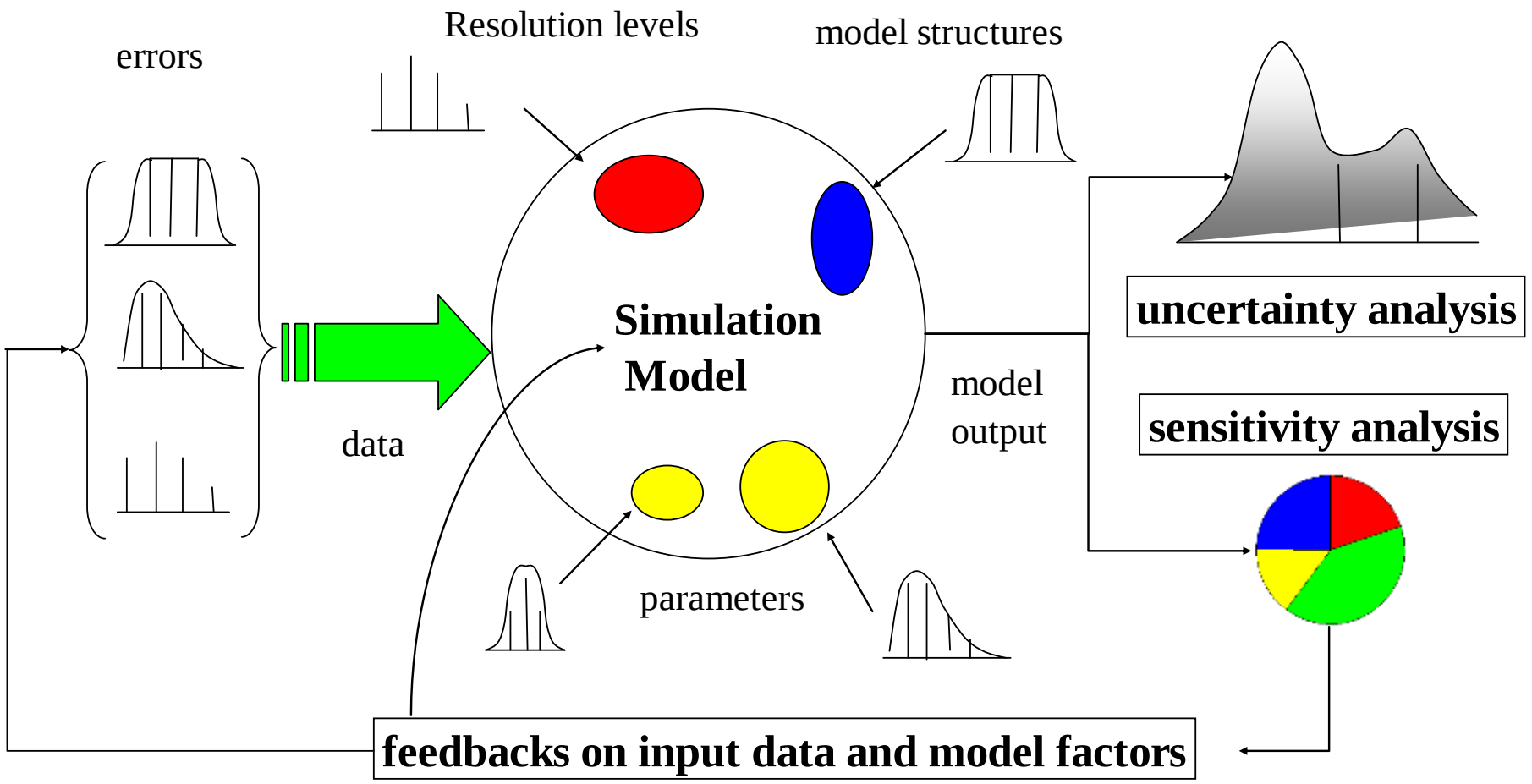
OMB, Proposed risk assessment bulletin, Technical report, The Office of Management and Budget's – Office of Information and Regulatory Affairs (OIRA), January 2006, https://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/proposed_risk_assessment_bulletin_010906.pdf, pp. 16–17, accessed December 2015.



http://ec.europa.eu/smart-regulation/

Source: IA Toolbox, p. 391

An engineer's vision of UA, SA

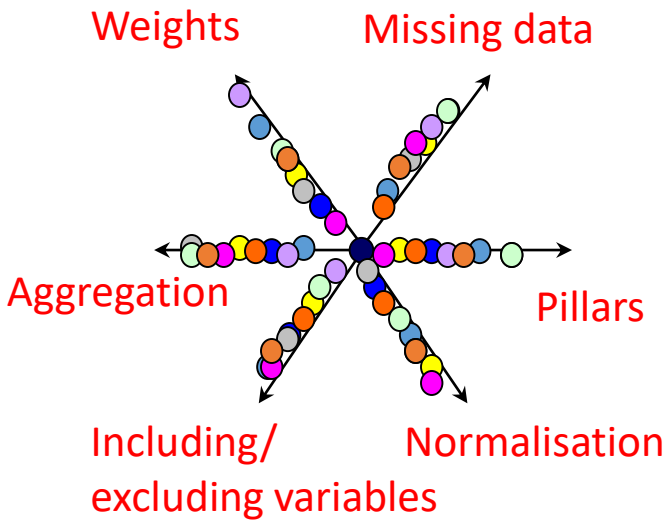


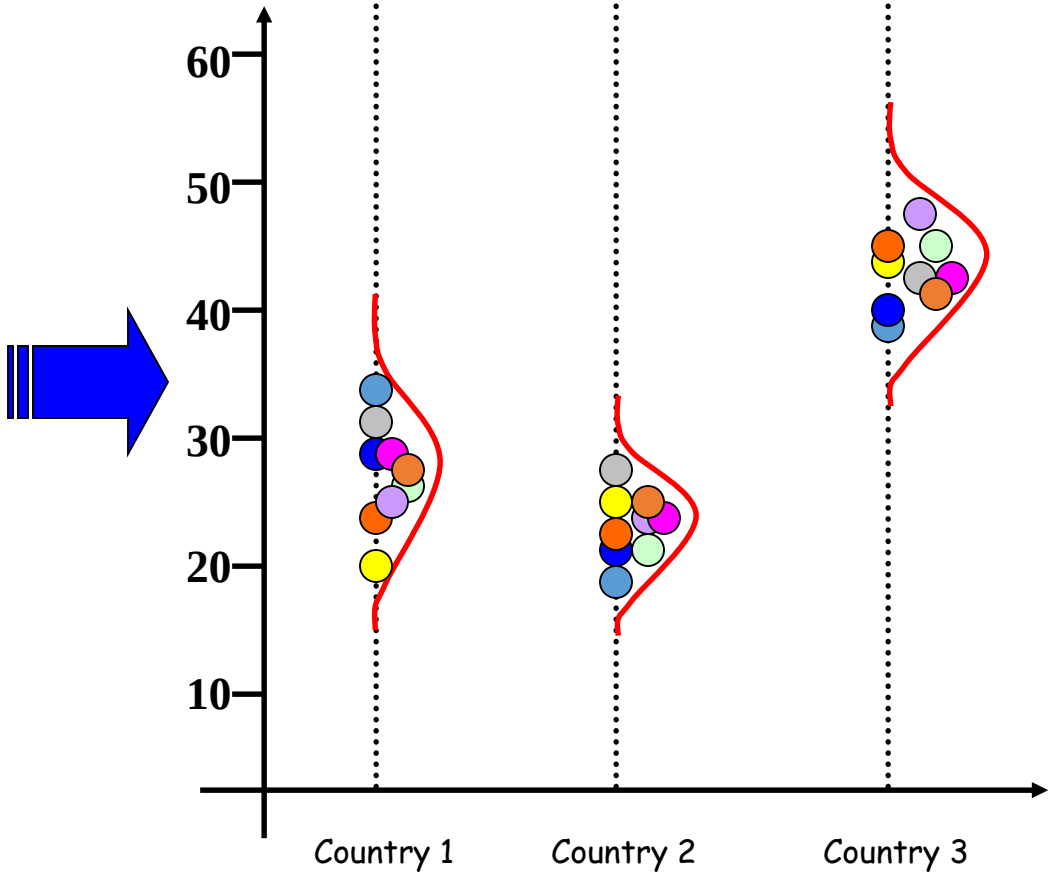
One can sample more than just factors:

- modelling assumptions,
- alternative data sets,
- resolution levels,
- scenarios …

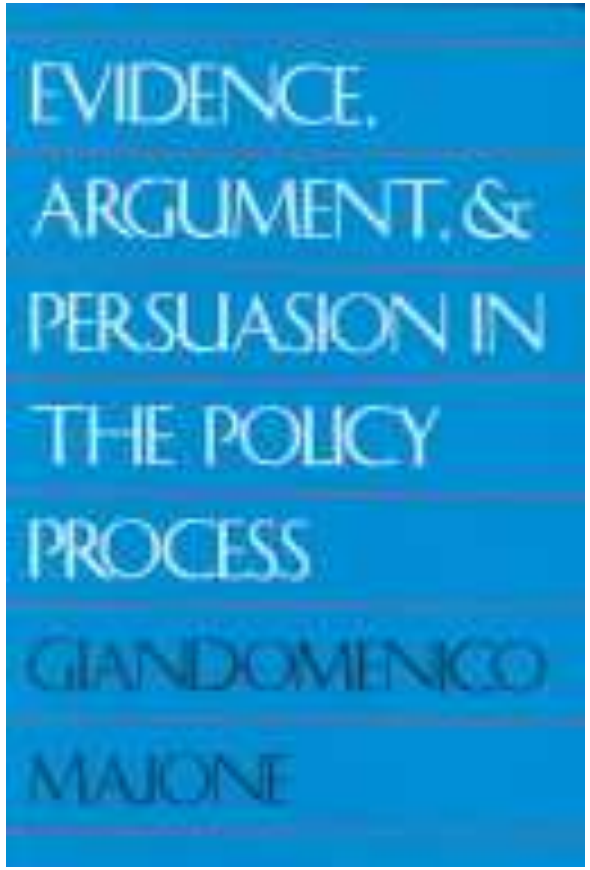
Assumption	Alternatives
Number of indicators	▪ all six indicators included or one-at-time excluded (6 options)
Weighting method	▪ original set of weights, ▪ factor analysis, ▪ equal weighting, ▪ data envelopment analysis
Aggregation rule	▪ additive, ▪ multiplicative, ▪ Borda multi-criterion

Space of alternatives



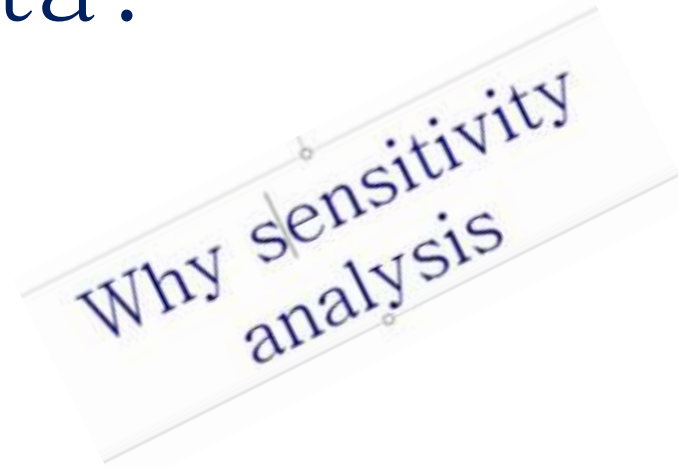


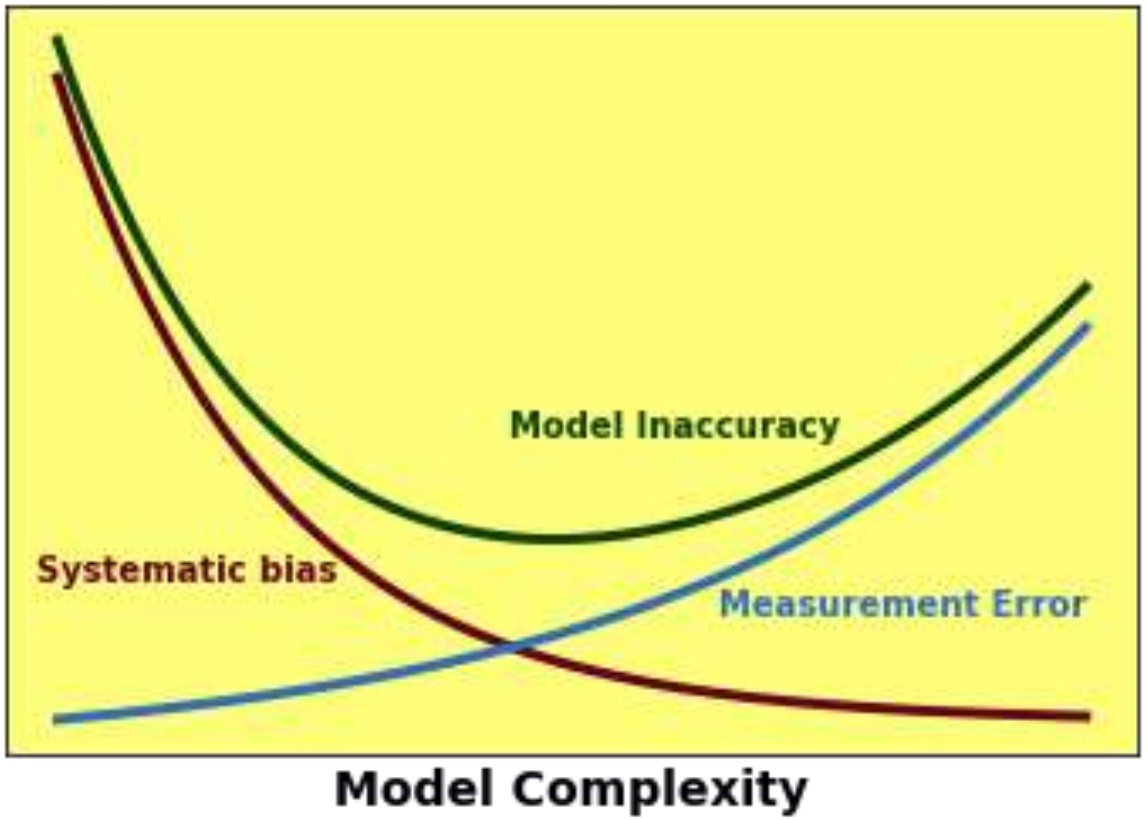
Why sensitivity analysis



"Are the results from a particular model more sensitive to changes in the model and the methods used to estimate its parameters, or to changes in the data?"

… SA can tell





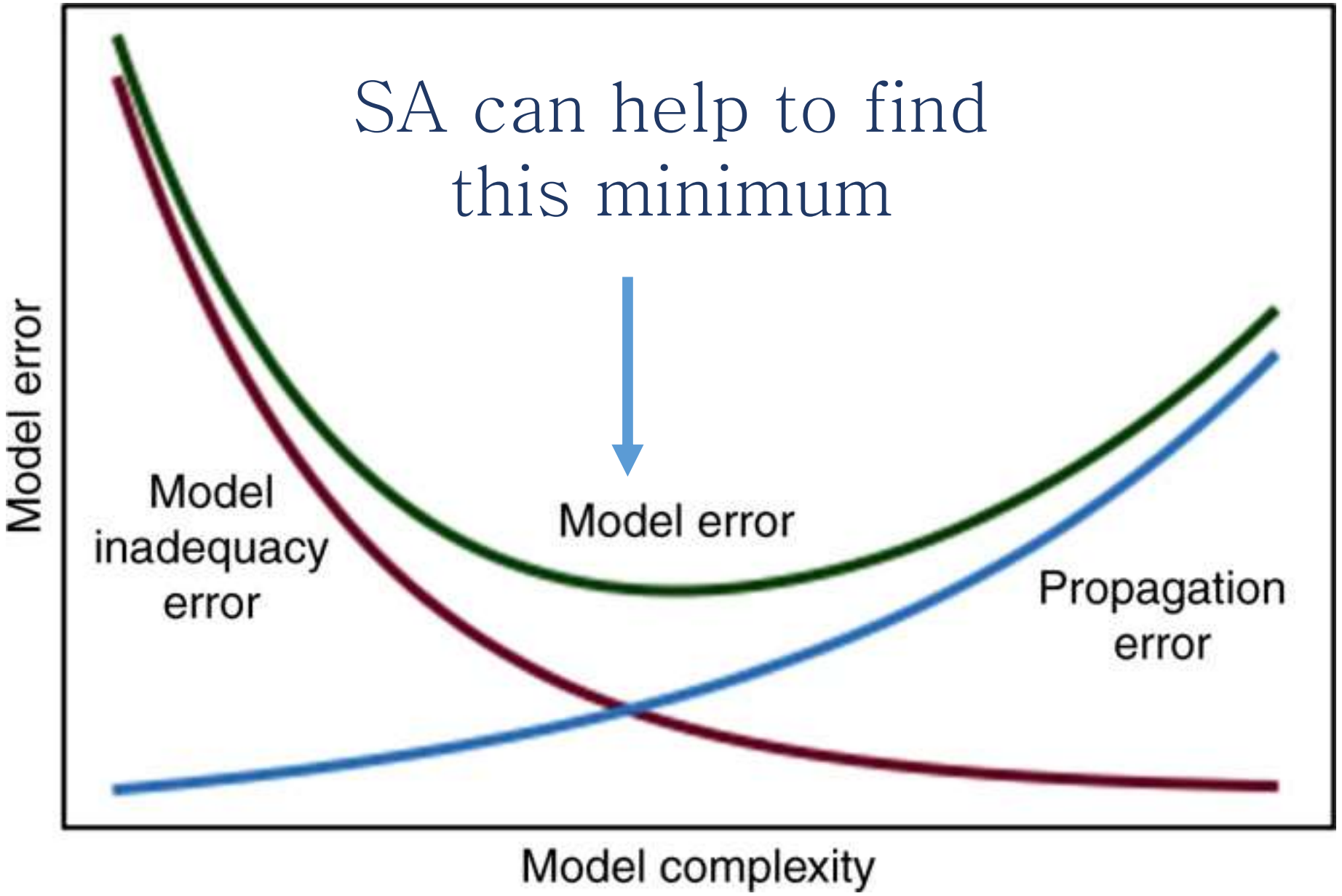
Presented as ‘Conjecture by O’Neill’

In M. G. Turner and R. H. Gardner, “Introduction to Models” in Landscape Ecology in Theory and Practice, New York, NY: Springer New York, 2015, pp. 63–95.

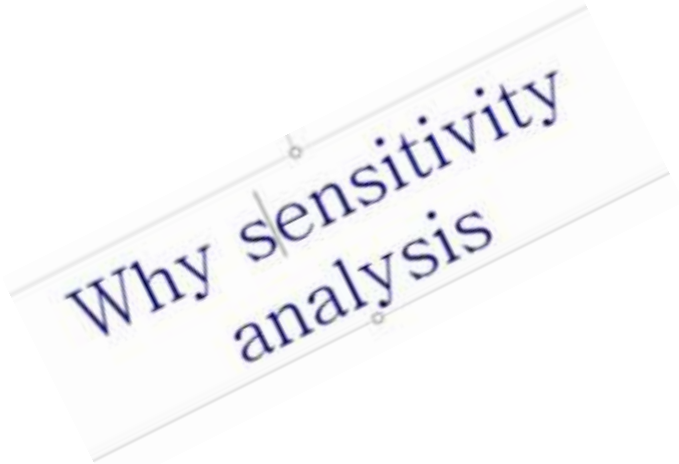
Why sensitivity analysis

Also known as Zadeh's principle of incompatibility, whereby as complexity increases "precision and significance (or relevance) become almost mutually exclusive characteristics"

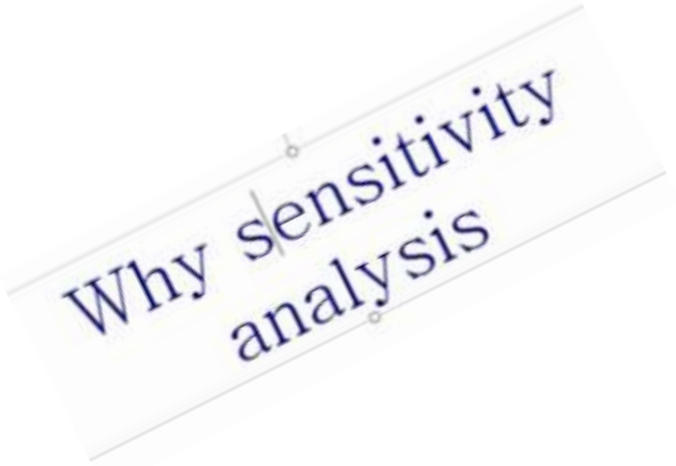
L. Zadeh, "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," IEEE Trans. Syst. Man. Cybern., vol. 3, no. 1, pp. 28–44, 1973.


SA can help to find
this minimum
Model error
Model
inadequacy
error
Model error
Propagation
error
Model complexity

Model-based knowing is conditional; SA explains this conditionality



SA can detect garbage in garbage out (GIGO)



Funtowicz & Ravetz's GIGO (Garbage In, Garbage Out) Science "where uncertainties in inputs must be suppressed least outputs become indeterminate"

Leamer's "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"

S. Funtowicz and J. R. Ravetz, *Uncertainty and Quality in Science for Policy*. Dordrecht: Kluwer, 1990; E. E. Leamer, "Sensitivity Analyses Would Help," *Am. Econ. Rev.*, vol. 75, no. 3, pp. 308–313, 1985.

Global Environmental Change 20 (2010) 298–302

Contents lists available at ScienceDirect

Global Environmental Change

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

Sensitivity analysis didn't help. A practitioner's critique of the Stern review

Andrea Saltelli *, Beatrice D'Hombres

Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy

The case of Stern's Review – Technical Annex to postscript

Nicholas Stern, London School of Economics

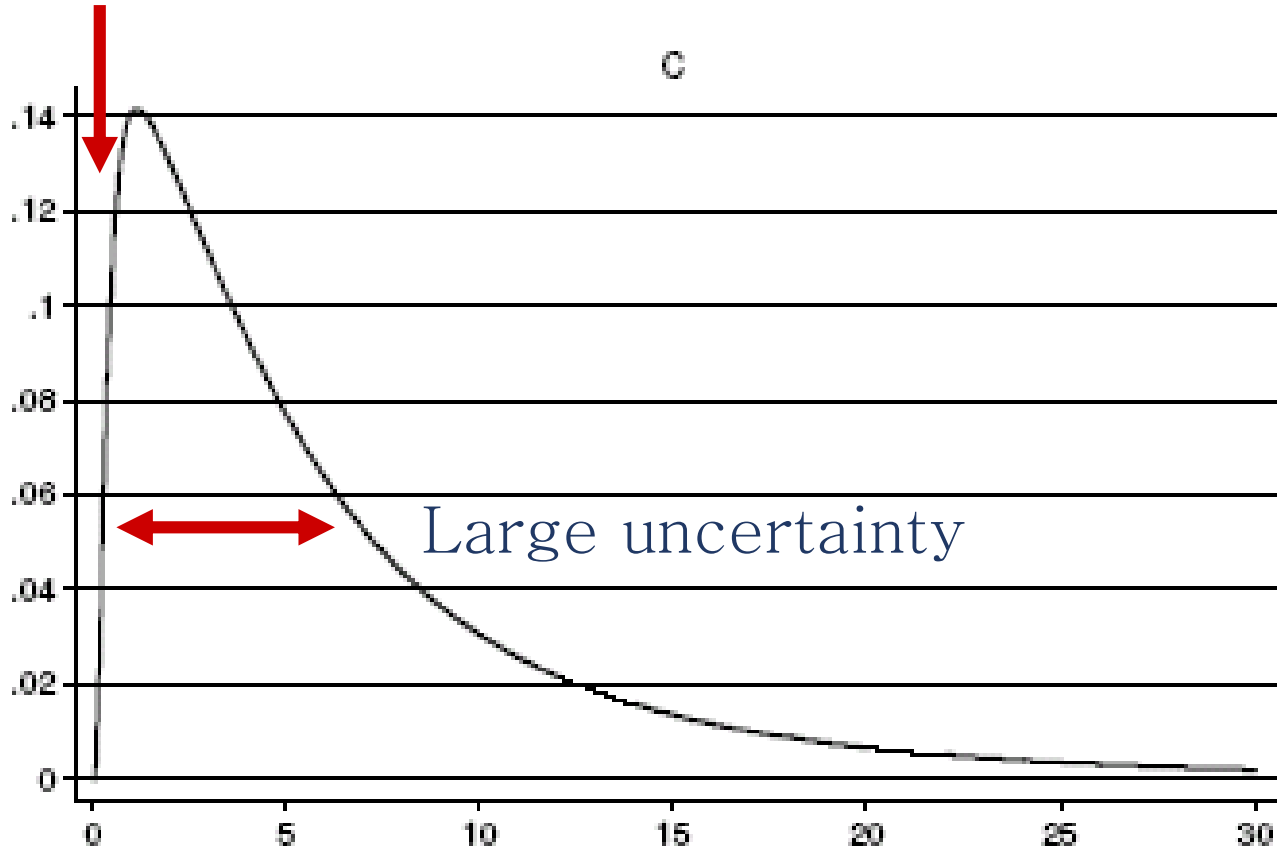
William Nordhaus, University of Yale Nobel 'Economics' 2018

Stern, N., Stern Review on the Economics of Climate Change. UK Government Economic Service, London, www.sternreview.org.uk.

Nordhaus W., Critical Assumptions in the Stern Review on Climate Change, SCIENCE, 317, 201-202, (2007).

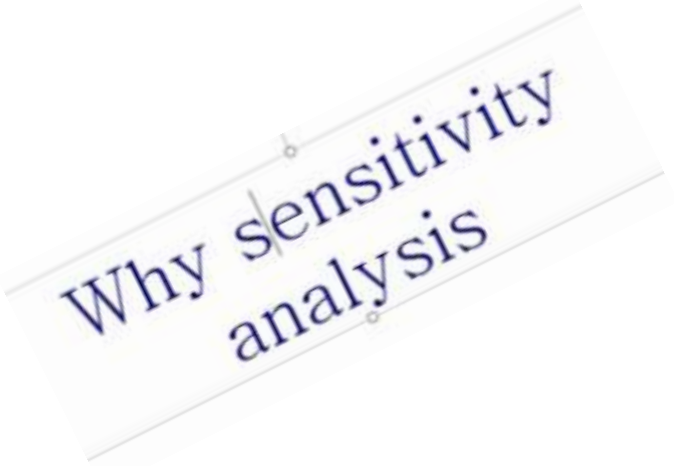
How was it done? A reverse engineering of the analysis

Missing points



% loss in GDP per capita

Finding all sorts of surprises



Journal of the Royal Statistical Society
SERIES A Statistics in Society

J. R. Statist. Soc. A (2013)
176, *Part* 3, *pp.* 609–634

Ratings and rankings: voodoo or science?

Paolo Paruolo

University of Insubria, Varese, Italy

and Michaela Saisana and Andrea Saltelli

European Commission, Ispra, Italy

Why sensitivity analysis

Cornell University

the Si

arXiv.org > stat > arXiv:1401.5617

Search...

Help | Advar

Statistics > Computation

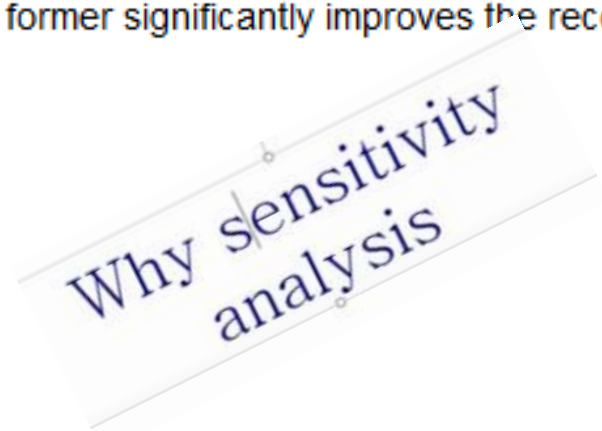
Exploring Hoover and Perez's experimental designs using global sensitivity analysis

William Becker, Paolo Paruolo, Andrea Saltelli

(Submitted on 22 Jan 2014)

This paper investigates variable-selection procedures in regression that make use of global sensitivity analysis. The approach is combined with existing algorithms and it is applied to the time series regression designs proposed by Hoover and Perez. A comparison of an algorithm employing global sensitivity analysis and the (optimized) algorithm of Hoover and Perez shows that the former significantly improves the recovery rates of original specifications.

Being revised for Journal of Time Series Econometrics



Why using variance-based sensitivity analysis methods

Advantages with variance based methods:

- graphic interpretation scatterplots
- statistical interpretation
- expressed plain English
- working with sets
- relation to settings such as factor fixing and factor prioritization

Without forgetting other methods

- Moment independent
- Shapley coefficients (also for correlated inputs)
- …

…forgetting Morris …

Computer Physics Communications 182 (2011) 978–988

Contents lists available at ScienceDirect

Computer Physics Communications

www.elsevier.com/locate/cpc

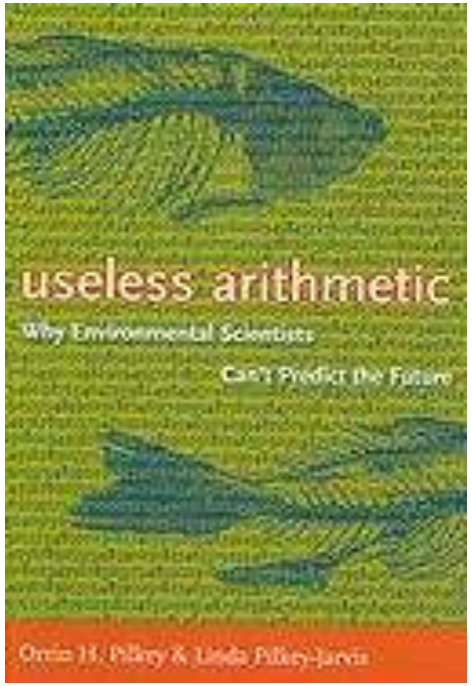
From screening to quantitative sensitivity analysis. A unified approach

Francesca Campolongo *, Andrea Saltelli, Jessica Cariboni

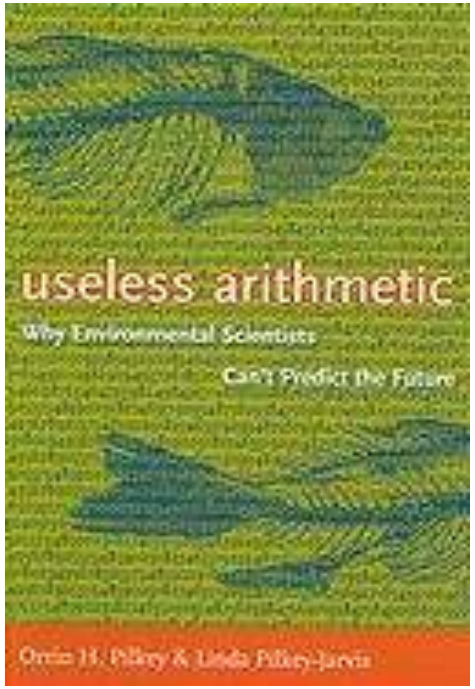
Joint Research Centre, Institute for the Protection and Security of the Citizen, Ispra, Italy

Limit of SA: The map is not the territory

Orrin H.
Pilkey



Useless Arithmetic: Why Environmental Scientists Can't Predict the Future by Orrin H. Pilkey and Linda Pilkey-Jarvis, Columbia University Press, 2009.

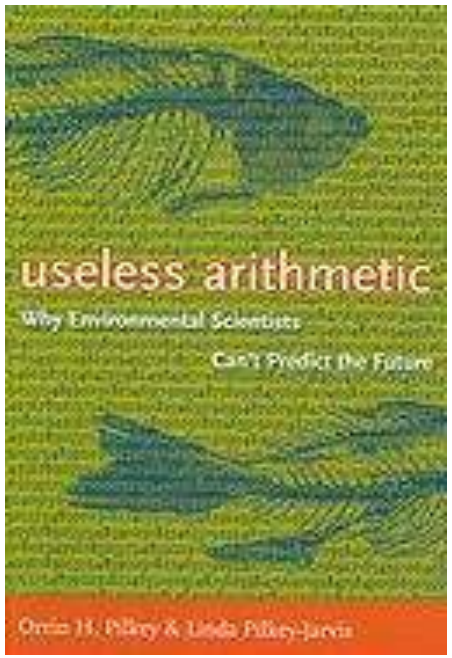


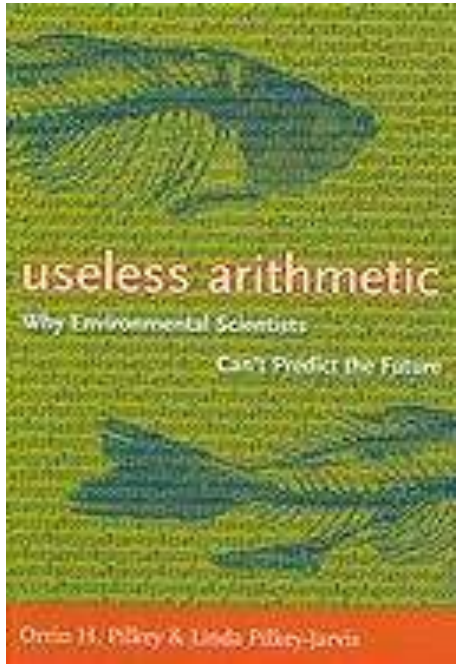
<<It is important to recognize that the sensitivity of the parameter in the equation is what is being determined, not the sensitivity of the parameter in nature.

[…] 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.>>

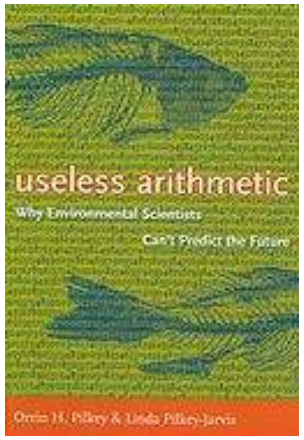
One of the examples discussed concerns the Yucca Mountain repository for radioactive waste. TSPA model (for total system performance assessment) for safety analysis.

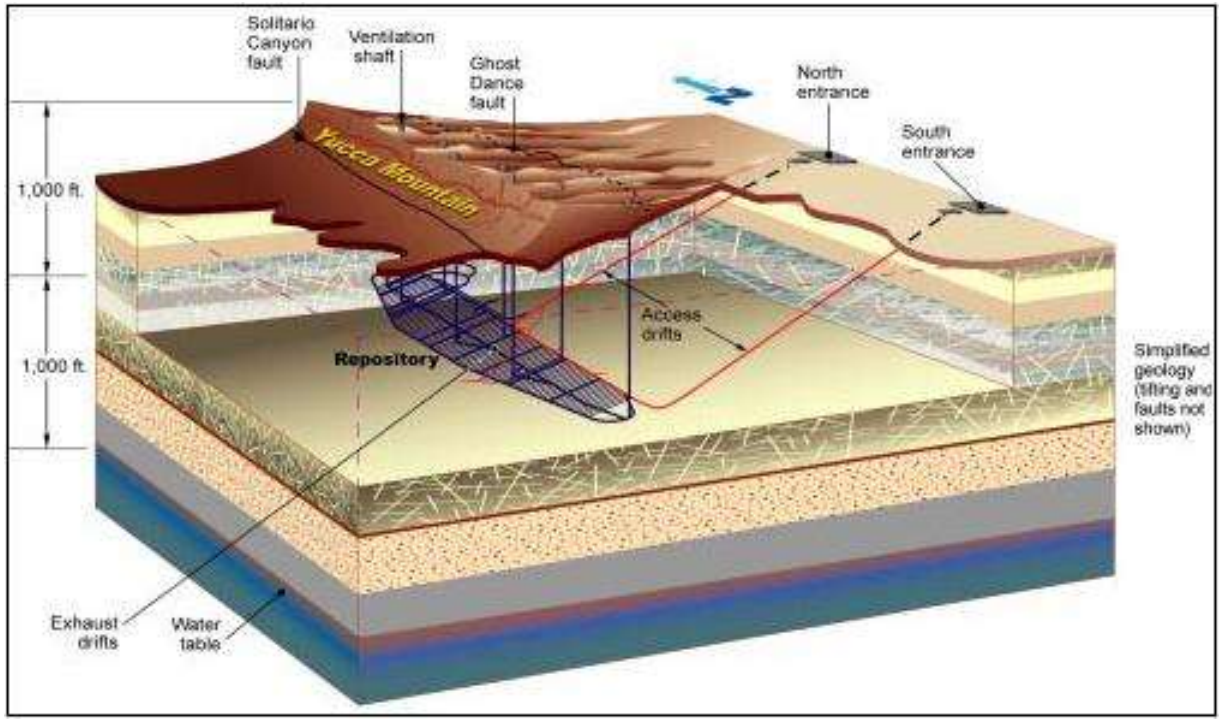
TSPA is Composed of 286 sub-models.





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.



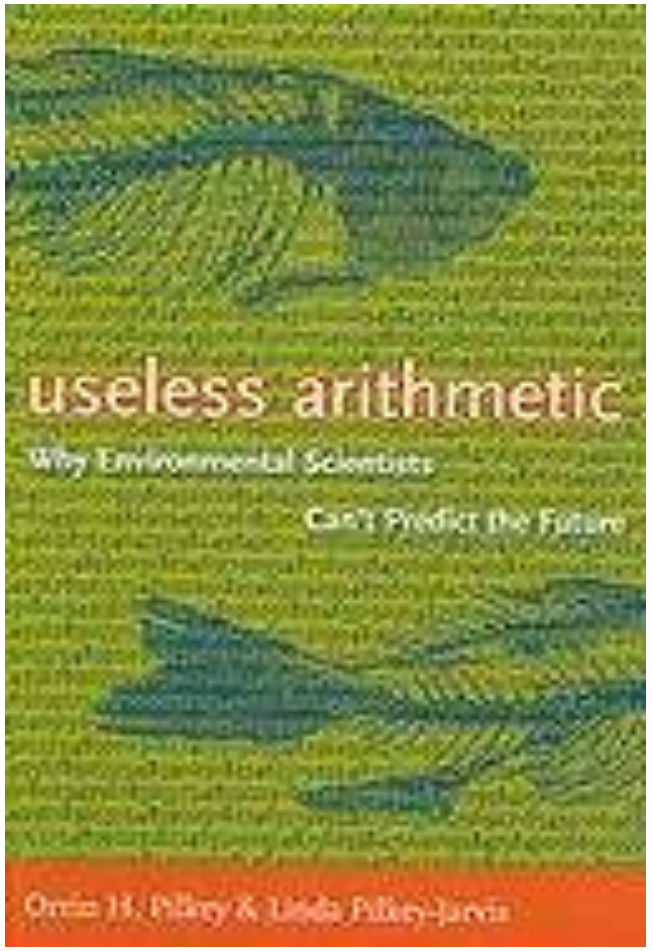


Evidence was produced leading to an upward revision of 4 orders of magnitude of this parameter (the ^{36}Cl story)

In the model 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"
(Pilkey and Pilkey-Jarvis)



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

CUDOS

Communalism – the common ownership of scientific according to which scientists give up intellectual pr exchange for recognition and esteem (Merton actua term Communism, but had this notion of communali Marxism);

Universalisı terms of un race, class, ruth a not o

Disinterestedness – according to which scientists ar acting in ways that outwardly appear to be selfless;

Robert K. Merton

Organized **S**kepticism – all ideas must be tested and are subject to rigorous, structured community scrutiny.

Limit of SA: Often no SA (SA conflated with UA e.g. in economics) or one-factor-at-a-time SA seen in the literature

Environmental Modelling & Software 25 (2010) 1508–1517

Contents lists available at ScienceDirect

Environmental Modelling & Software

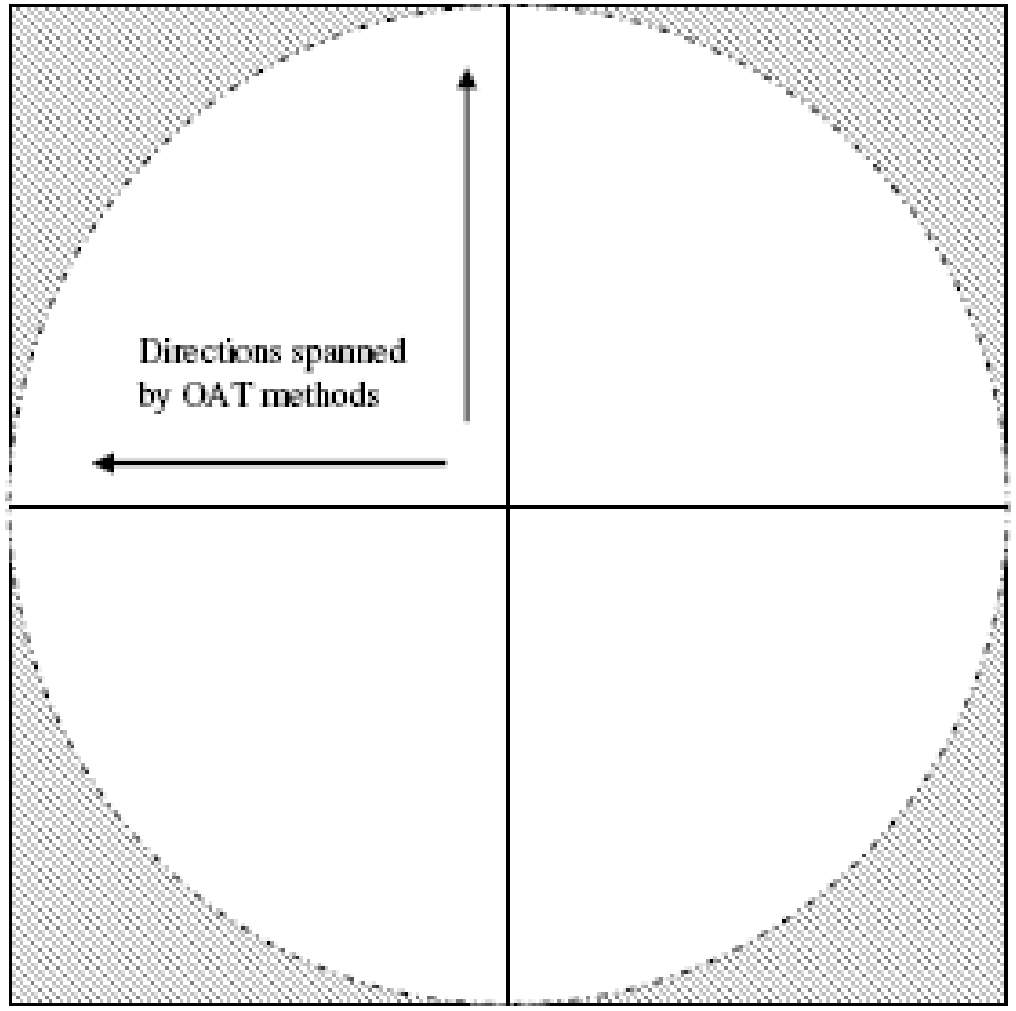
journal homepage: www.elsevier.com/locate/envsoft

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

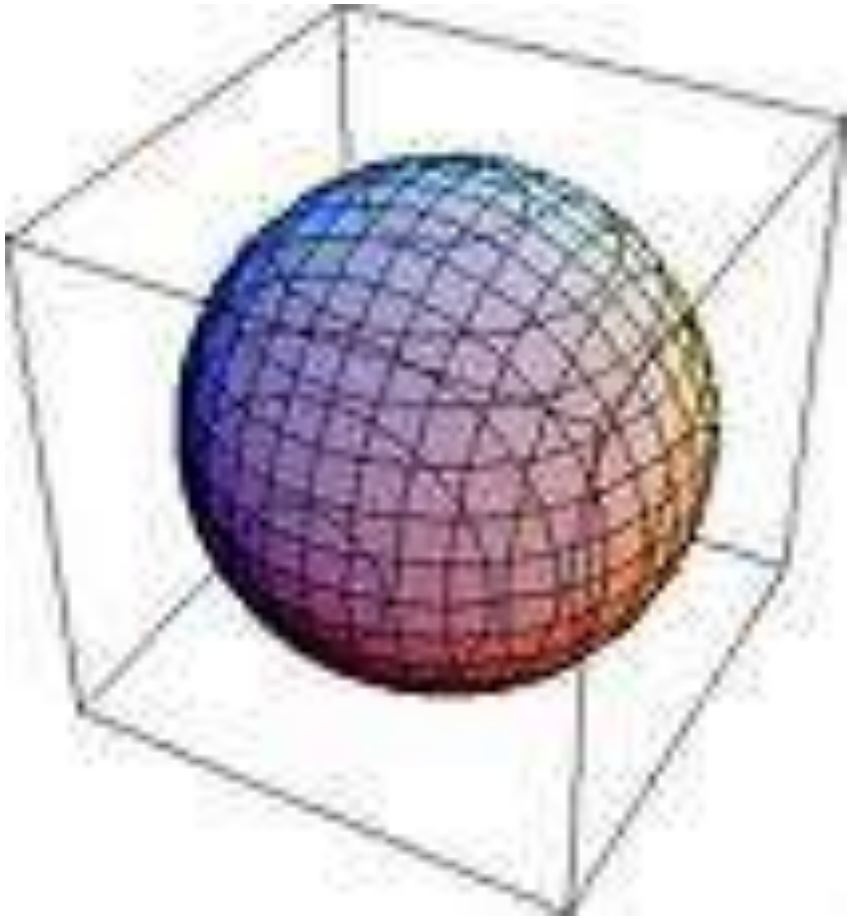
OAT in 2 dimensions



Area circle / area square =?

~ 3/4

OAT in 3 dimensions

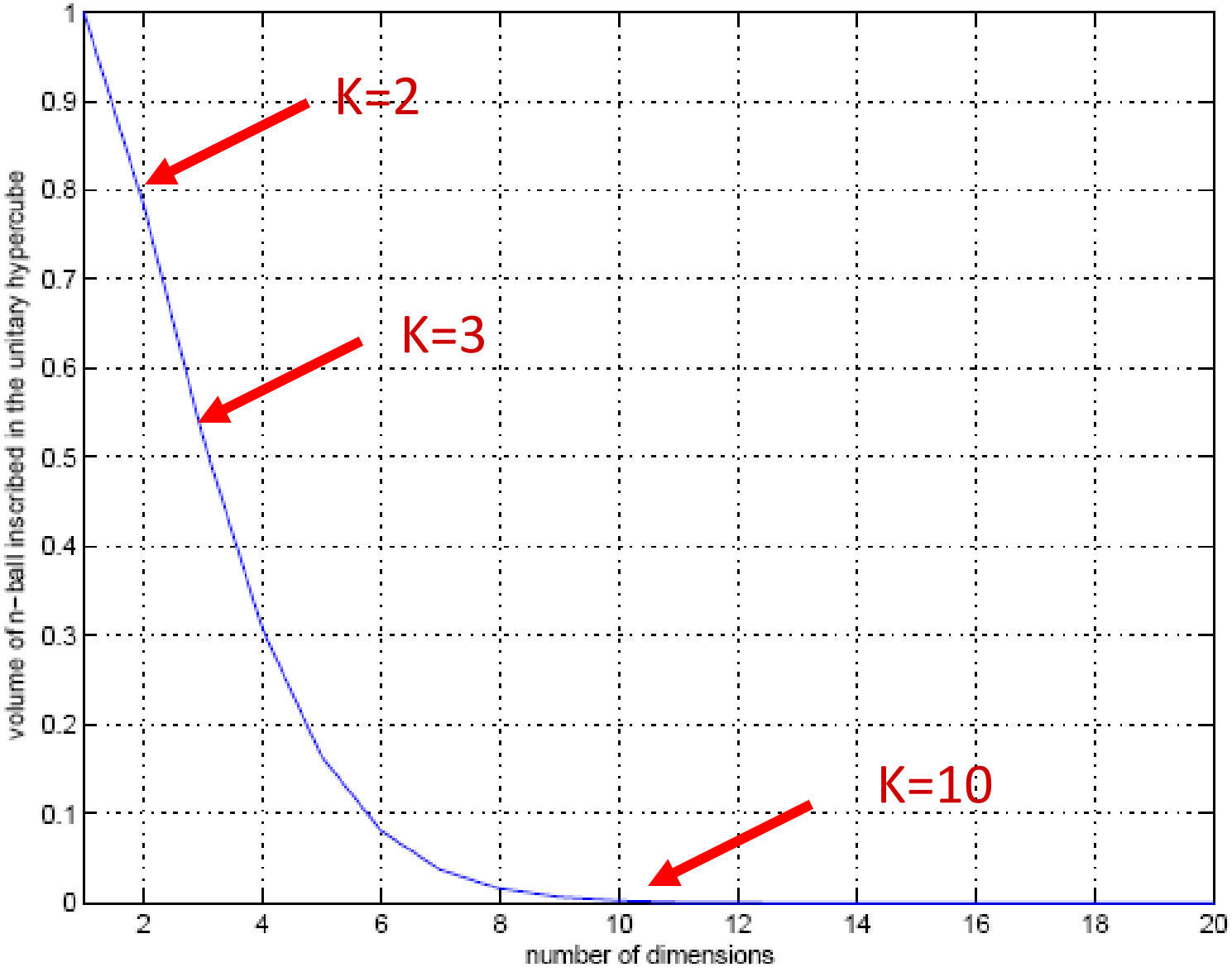


Volume sphere / volume cube =?

~ 1/2

OAT in 10 dimensions; Volume hypersphere / volume ten dimensional hypercube =? ~ 0.0025

OAT in k dimensions



Environmental Modelling & Software

Volume 114, April 2019, Pages 29-39

Why so many published sensitivity analyses are false: A systematic review of sensitivity analysis practices

Andrea Saltelli [a, b], Ksenia Aleksankina [c], William Becker [d], Pamela Fennell [e], Federico Ferretti [d], Niels Holst [f], Sushan Li [g], Qiongli Wu [h]

A systematic review of 280 scientific papers mentioning sensitivity analysis, focusing on highly cited works

42% of highly cited papers present a SA of poor quality

Literature search in Scopus

Query: “sensitivity analysis” & “model/modelling” & “uncertainty”; years 2012–2017; journal articles; in English

➔ 6000 articles

- AgrBioSci (Agricultural and Biological Sciences)
- BiochemGenMBio (Biochemistry, Genetics and Molecular Biology)
- BusManAcc (Business, Management and Accounting)
- Chemi (Chemistry)
- ChemEng (Chemical Engineering)
- CompSci (Computer Science)
- DecSci (Decisional Science)
- EarthSci (Earth and Planetary Sciences)
- EconFin (Economy and Finance)
- Energy (Energy)
- Engineering (Engineering)
- EnvSci (Environmental Science)
- ImmunMicrobio (Immunology and Microbiology)
- MatSci (Material Science)
- Math (Math)
- Medicine (Medicine)
- PharTox (Pharmacology and Toxicology)
- PhysAstro (Physics and Astronomy)
- SocSci (Social Science)

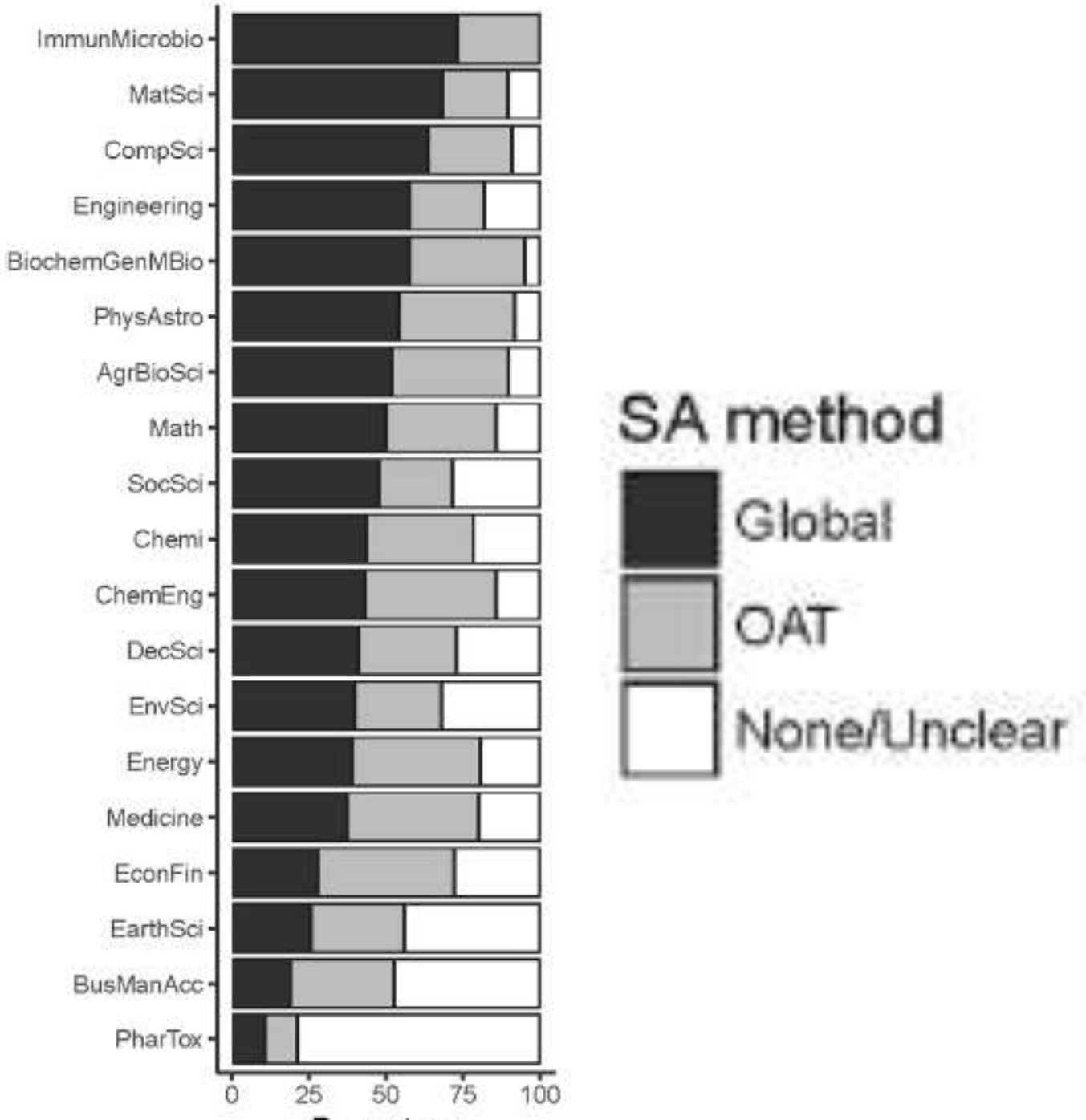
subject areas >100 articles

Taking the top twenty most-cited papers in each subject area:

➔ 324 articles, divided among authors

Cleansing manually irrelevant articles:

➔ 280 articles



Still many papers apply an OAT SA: 65%

What if the model is truly linear?

Linear	7%
Nonlinear	61%
Unclear	32%

Linear	7%
Nonlinear	61%
Unclear	32%

65% highly cited articles are OAT

Taking all unclear = linear ➔ still over 20% of papers wrong

(OAT & non-linear model)

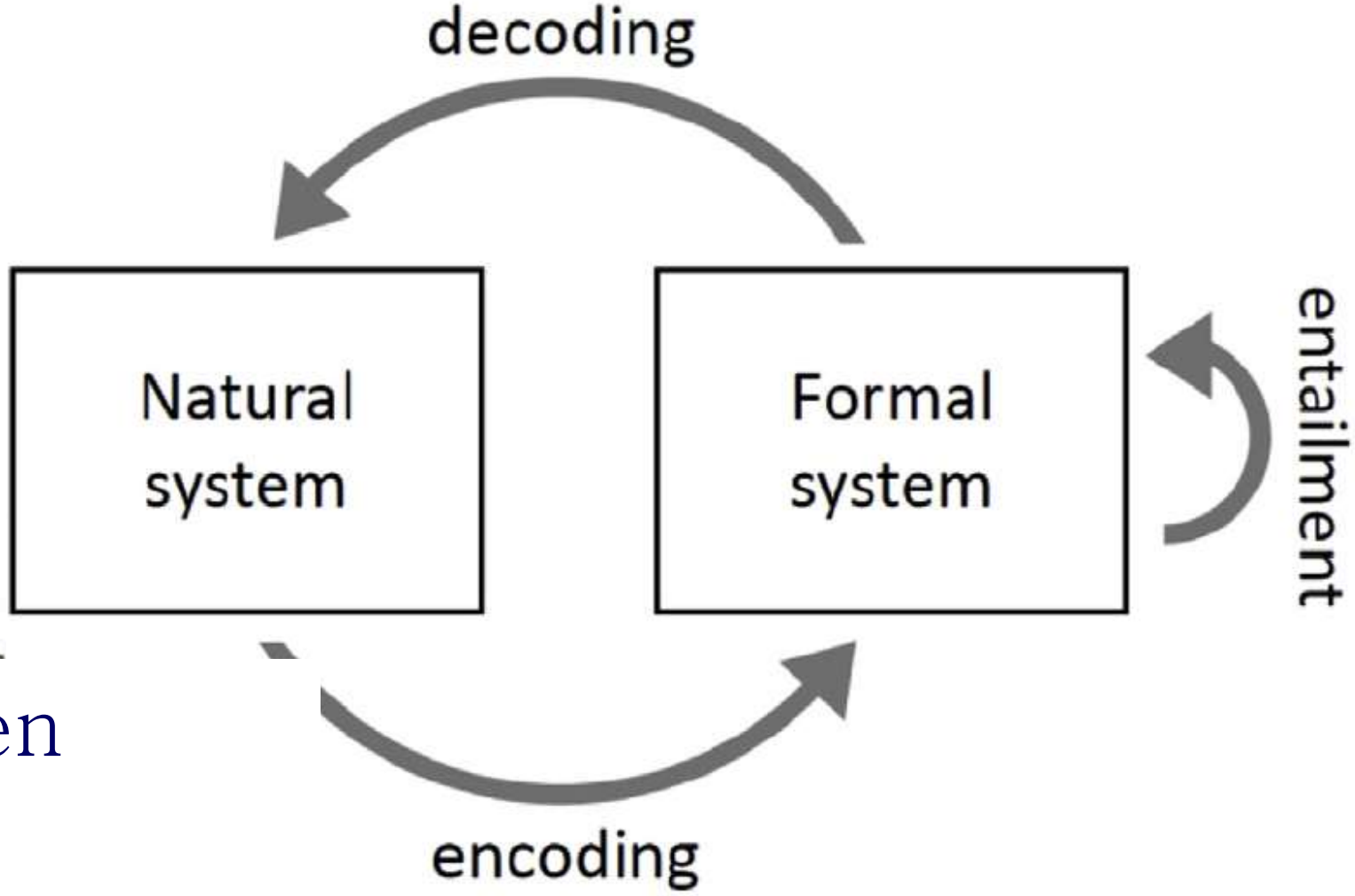
Why?

5. Discussion

5.1. Reasons for bad practice

Why? ➔ 1. Modelling as a craft

Robert Rosen



Why? ➔ 2. Each discipline going about modelling on its own separate way; pockets of SA practitioners (out of our 280 papers, 35 were methodological, of which 24 suggest global SA)

Why? ➔ 3. Good practices require training in statistics

Why? ➔ 4. More time is needed; researchers tend to emulate methods found in highly cited papers (assuming that they are best practice)

Why? 5. Unlike statistics, modelling is not a discipline …

… mathematical modelling cannot do this:

Wasserstein, R.L. and Lazar, N.A., 2016. 'The ASA's statement on p-values: context, process, and purpose', The American Statistician, Volume 70, 2016 - Issue 2, Pages 129-133.

Why? ➔ 6. More time is needed; though mature global sensitivity analysis methods around for more than 25 years researchers tend to emulate methods found in highly cited papers assuming that they are best practice

Why? ➔ 7. Strategical reasons: global SA is bad if one wants to play the uncertainty game, inflating or deflating uncertainties instrumentally

Interested? Come to our 'Numbers for policy' school in November 18-20, here in Castelldefels https://www.uib.no/en/svt/127988/numbers-policy-practical-problems-quantification with Samuele Lo Piano, Jeroen van der Sluijs and myself.

Solutions? 1. Statistics as a discipline takes responsibility for statistical methods for model validation and verification

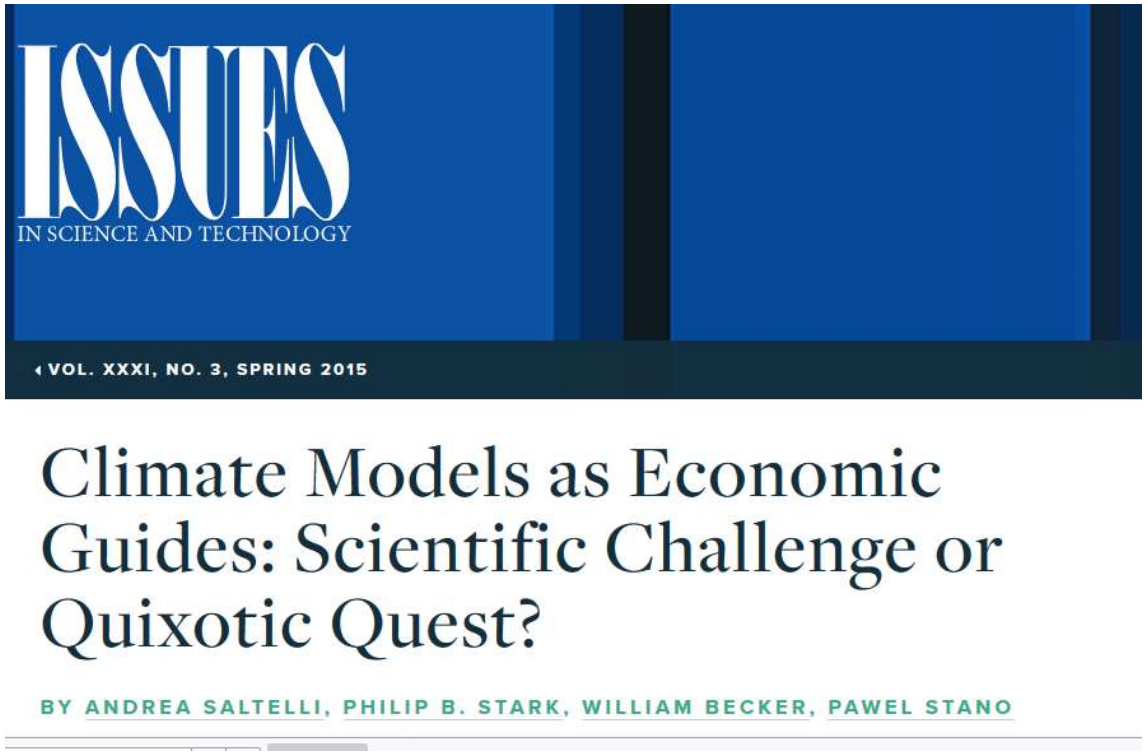
Example: who can authoritatively suggest to modellers not to overinterpret results form multi-model ensembles?

ISSUES
IN SCIENCE AND TECHNOLOGY

VOL. XXXI, NO. 3, SPRING 2015

Climate Models as Economic Guides: Scientific Challenge or Quixotic Quest?

BY ANDREA SALTELLI, PHILIP B. STARK, WILLIAM BECKER, PAWEL STANO



A plea against audacious risk or cost-benefit analysis running over centennial time scales; example: crime rate as modified by climate change at US county level in 2100

Solutions? 2. Learn from what happens in statistics where the p-test crisis is being tackled head on

SIGNIFICANCE

Business Culture Politics

IN PRACTICE

Cargo-cult statistics and scientific crisis

The mechanical, ritualistic application of statistics is contributing to a crisis in science. Education, software and peer review have encouraged poor practice – and it is time for statisticians to fight back. By **Philip B. Stark** and **Andrea Saltelli**

Solutions? 3. Use models *via negativa*

Nassim Taleb, Black Swan, Antifragile,…

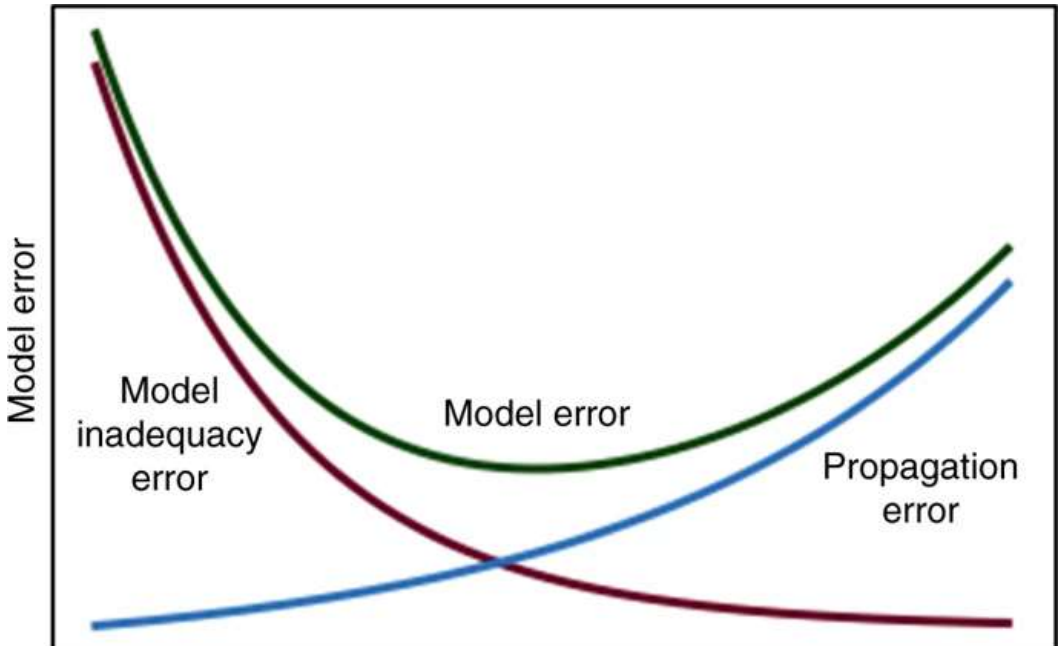
“models are most useful when they are used to challenge existing formulations, rather than to validate or verify them”

Naomi Oreskes

N. Oreskes, K. Shrader-Frechette, and K. Belitz, “Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences,” Science, 263, no. 5147, 1994.

Lessons for sensitivity analysis

- Global SA
- UA and SA coupled
- Purpose- & context-specific
- The map is not the territory
- Memento



Ninth International Conference on Sensitivity Analysis of Model Output

Paula Rego, Self portrait in red (1962), detail, MNAC, Barcelona

Watch out for two special issues:

Reliability Engineering and System Safety (RESS)

Guest editors: Bertrand Iooss and Bruno Sudret

Environmental Modelling and Software (EMS)

Guest Editors: Saman Razavi, Andrea Saltelli, Quiongli Wu and Tony Jakeman

Beyond sensitivity analysis: sensitivity auditing

Sensitivity auditing

EC guidelines on impact assessment 2015, and SAPEA report 2019

SAPEA

Science Advice for Policy by European Academies

ISSUES
IN SCIENCE AND TECHNOLOGY

VOL. XXX, NO. 2, WINTER 2014

When All Models Are Wrong

BY ANDREA SALTELLI, SILVIO FUNTOWICZ

The rules of sensitivity auditing

1. Check against rhetorical use of mathematical modelling;
2. Adopt an “assumption hunting” attitude; focus on unearthing possibly implicit assumptions;
3. Check if uncertainty been instrumentally inflated or deflated.

4. Find sensitive assumptions before these find you; do your SA before publishing;
5. Aim for transparency; Show all the data;
6. Do the right sums, not just the sums right;
7. Perform a proper global sensitivity analysis.

nature COMMUNICATIONS

Comment | Open Access | Published: 27 August 2019

A short comment on statistical versus mathematical modelling

Andrea Saltelli

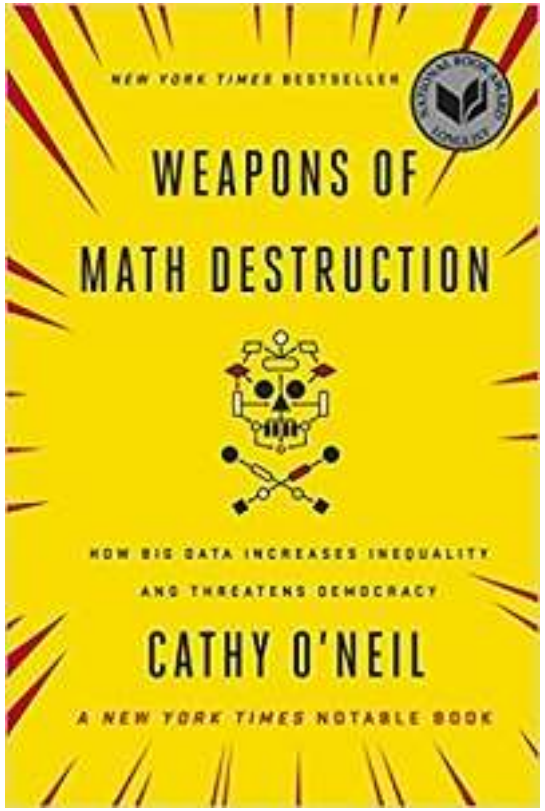
Is there a broader problem affecting different instances of quantification?

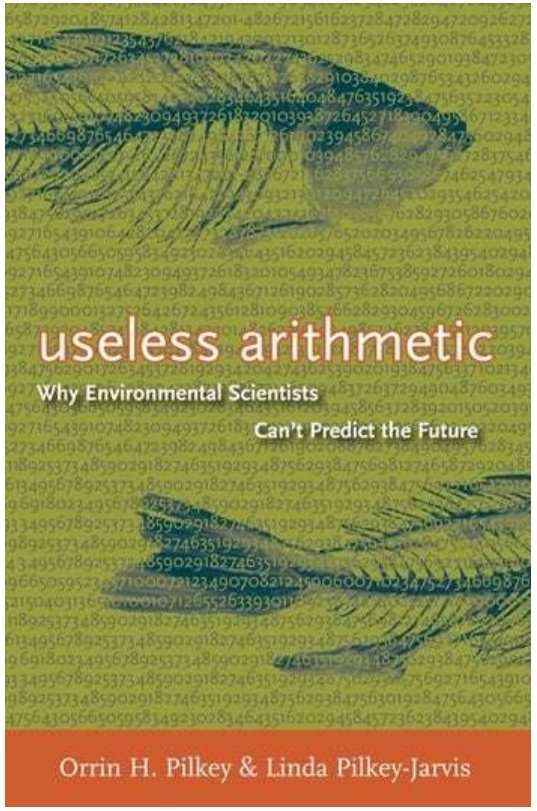
“what qualities are specific to rankings, or indicators, or models, or algorithms?”

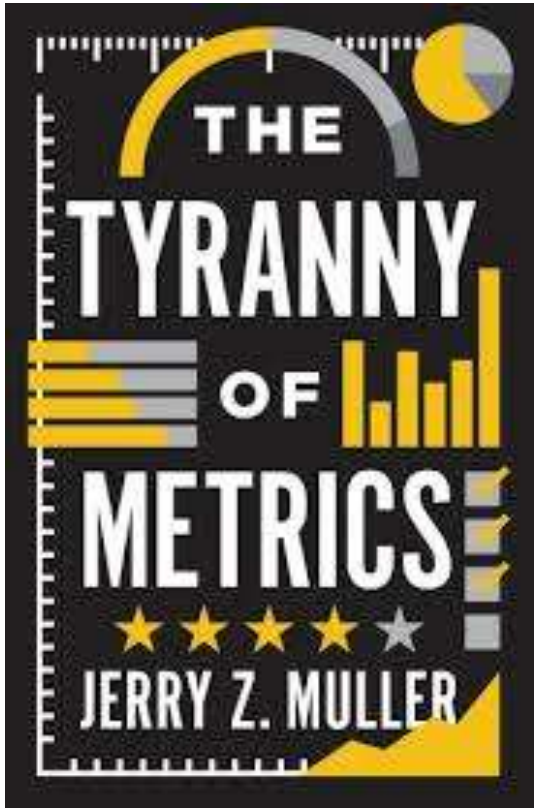
E. Popp Berman

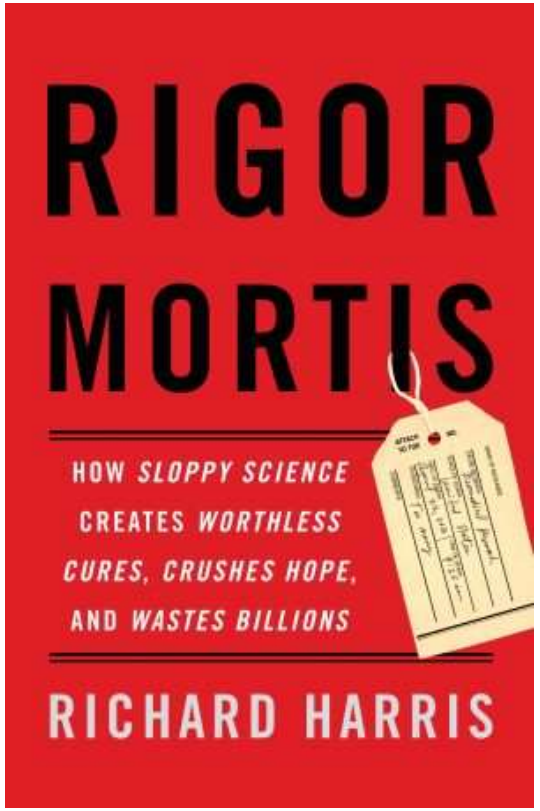
Popp Berman, E. & Hirschman, D. The Sociology of Quantification: Where Are We Now? Contemp. Sociol. 47, 257–266 (2018).

Algorithms, models, metrics, statistics

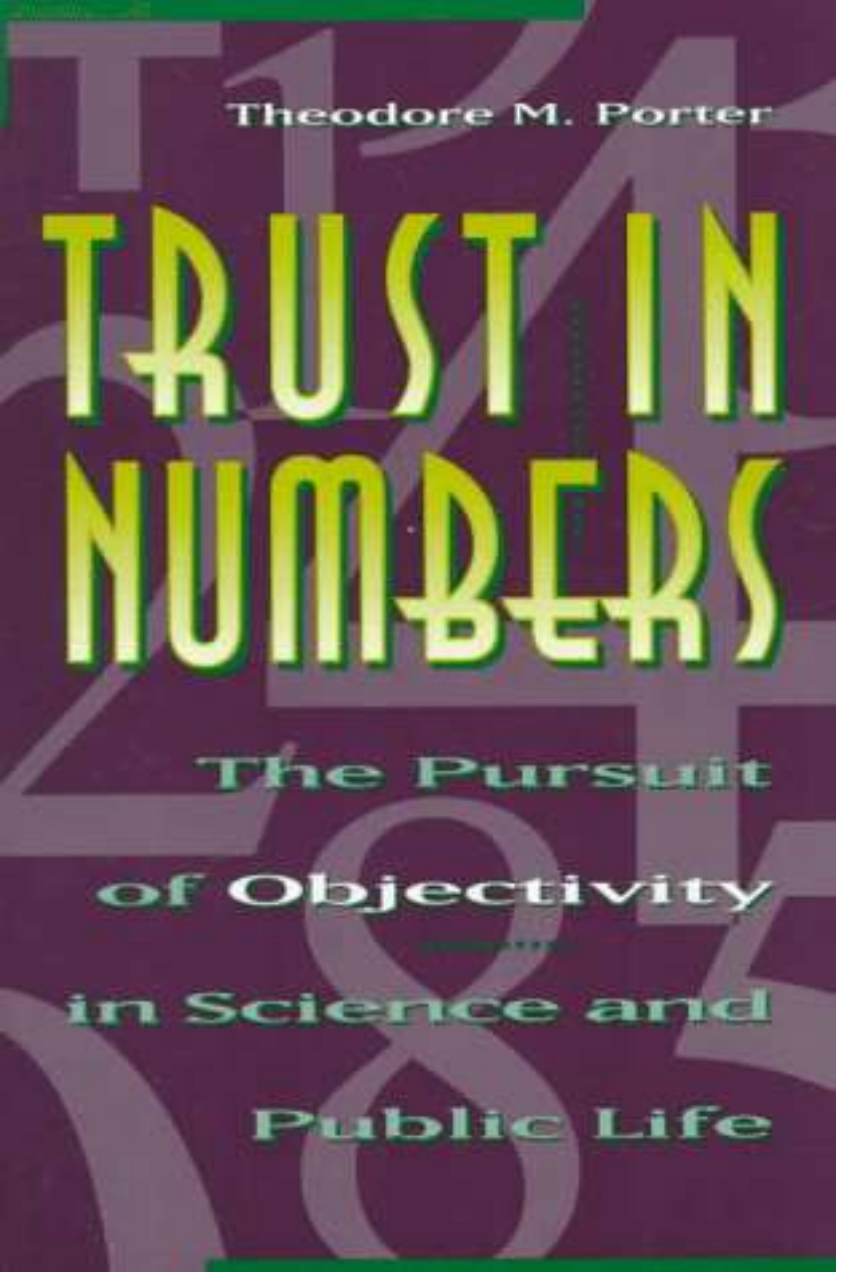








Common root causes?



Can we learn something from sociology of numbers?

Centre for the Study of the Sciences and the Humanities

Photo: 123RF

Ethics of quantification

2019 Symposium of the UIB Senter for vitenskapsteori, December 5 and 6, Bergen, opening talk by Theodor Porter

END

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