Why sensitivity analysis

(or: How not to do a sensitivity analysis)

Andrea Saltelli

Bergen, Course MNF 990, March 20 , 2024

Where to find this talk: www.andreasaltelli.eu

Andrea Saltelli

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August 25 2023: The politics of modelling is out!

Praise for the volume

"A long awaited examination of the role —and obligation —of modeling."
Nassim Nicholas Taleb , Distinguished Professor of Risk Engineering, NYU Tandon School of Engineering. Author, of the 5 -volume series Incerto.

***

"A breath of fresh air and a much needed cautionary view of the ever-widening dependence on mathematical modeling."
Orrin H. Pilkey, Professor at Duke University's Nicholas School of the Environment, co-author with Linda Pilkey-Jarvis of Useless Arithmetic: Why Environmental Scientists Can't Predict the Future, Columbia University Press 2009.

***

"The methods by which power insinuates itself into models, and facilitates their portability and

Mastodon Toots by
@AndreaSaltelli

AndreaSaltelli
2024/2/16 16:38
Are you interested in sensitivity analysis? Here a short story of it.
Open access, online in draft form:
sciencedirect.com/science/arti

Andrea

An annotated timeline of sensitivity analysis

View on mstdn.social

But the real strength of the models, in my mind at least, were in sensitivity analysis (where one could examine the response of the model to parameters or structures that were not known with precision (i.e., sensitivity analysis), and in the examination of the behavior of the model components relative to that of the real system in question (i.e., validation).

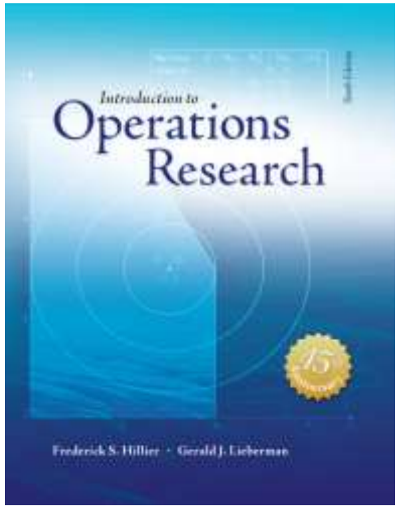
Hall, C. A. S. (2020). Systems Ecology and Limits to Growth: History, Models, and Present Status. In G. S. Metcalf, K. Kijima, & H. Deguchi, eds., *Handbook of Systems Sciences*, Singapore: Springer, , pp. 1–38.

… By undertaking sensitivity analysis and validation, a great deal can be learned about the real system, including what you do not know. (Hall, 2020)

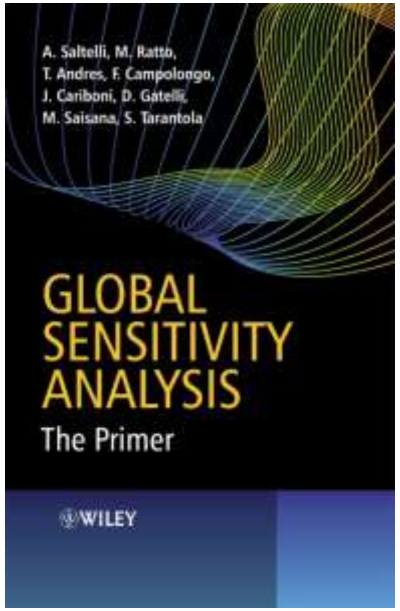
Hall, C. A. S. (2020). Systems Ecology and Limits to Growth: History, Models, and Present Status. In G. S. Metcalf, K. Kijima, & H. Deguchi, eds., *Handbook of Systems Sciences*, Singapore: Springer, , pp. 1–38.

Linear programming and sensitivity analysis

Linear programming viewpoint: testing which parameter, when changed in isolation, lead to a change in the optimal solution



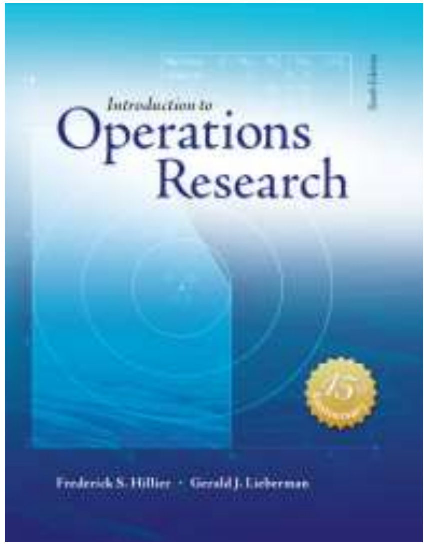
Global SA viewpoints: explore the distribution of the optimal solution when all uncertain coefficients are allowed to vary over their plausible range



We should not be surprised that the sensitivity analysis practiced in linear programming is linear!

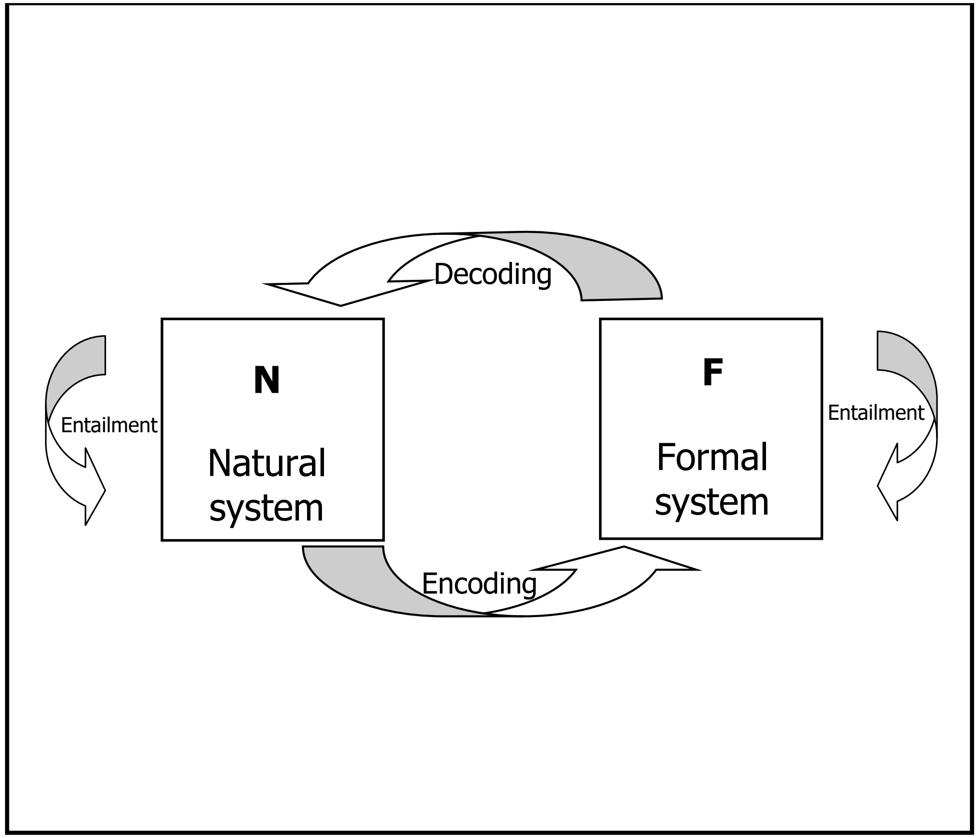
Yet so much can be lost by neglecting that part of the uncertainty that escapes linearity

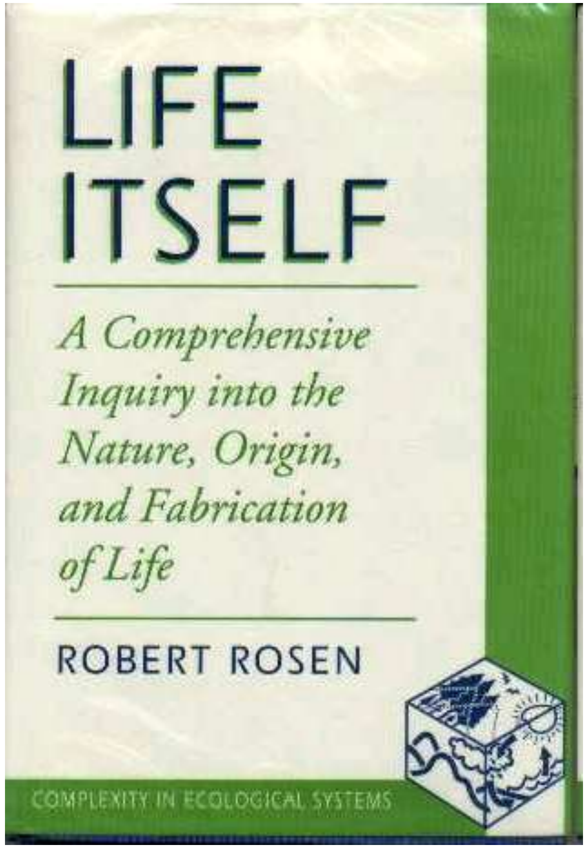
The advantages of understating global methods for uncertainty and sensitivity analysis are very large, including the possibility to test to flexibility of managerial decision when ‘all the rest’ is varying as well



Modelling is a craft more than a science

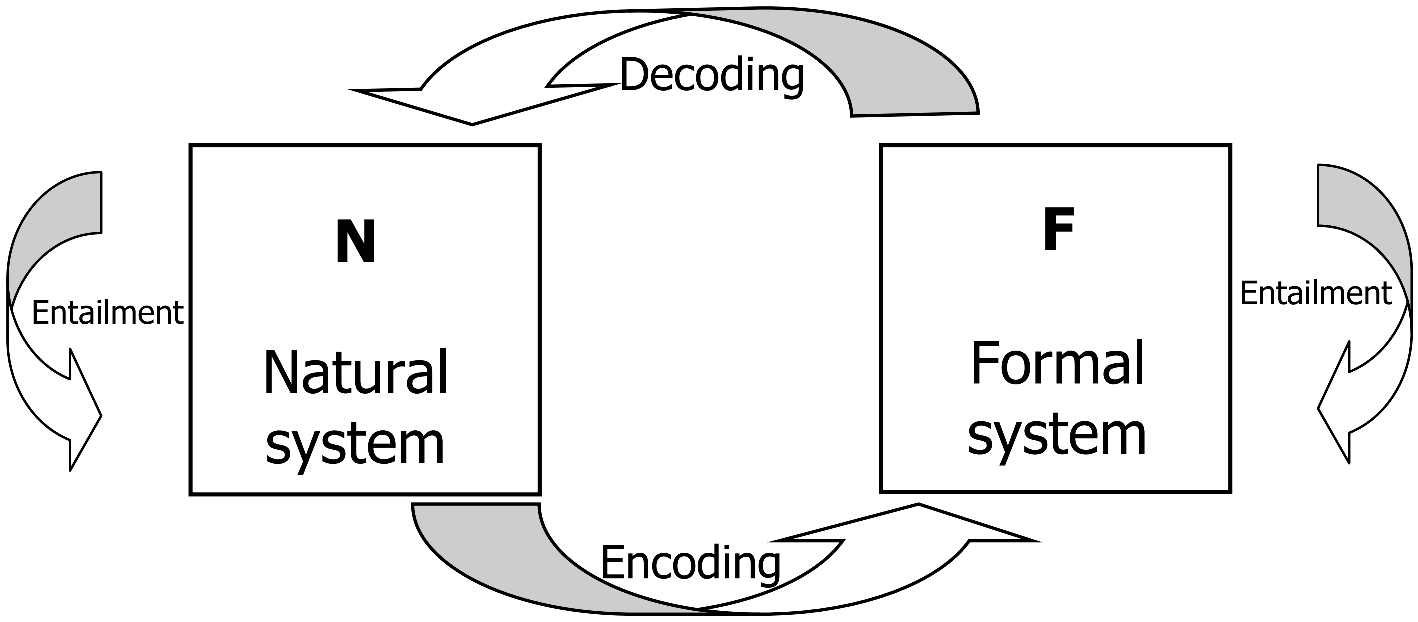
Modelling as a craft rather than as a science for Robert Rosen





R. Rosen, Life Itself: A Comprehensive Inquiry Into the Nature, Origin, and Fabrication of Life. Columbia University Press, 1991.

Louie, A.H. 2010. "Robert Rosen's Anticipatory Systems." Edited by Riel Miller. Foresight 12 (3): 18–29. https://doi.org/10.1108/14636681011049848.



What is a model ?

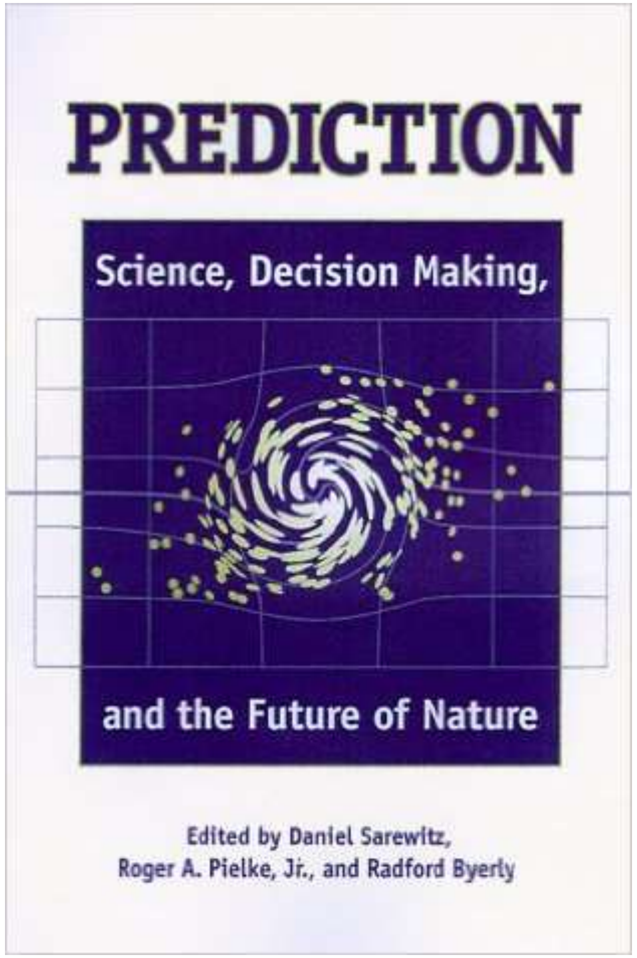
Robert Rosen
(1934–1998)

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

Naomi Oreskes

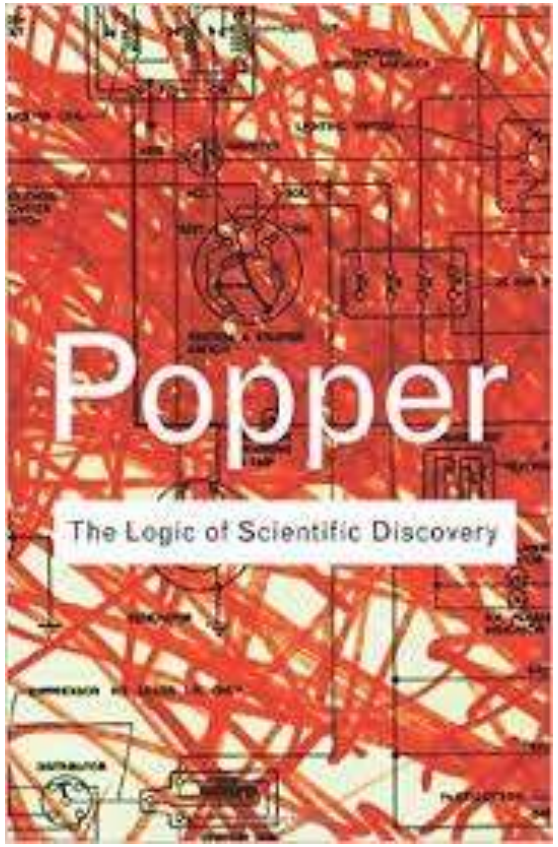
N. Oreskes, K. Shrader-Frechette, and K. Belitz, “Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences,” Science, 263, no. 5147, 1994.

Models are not physical laws

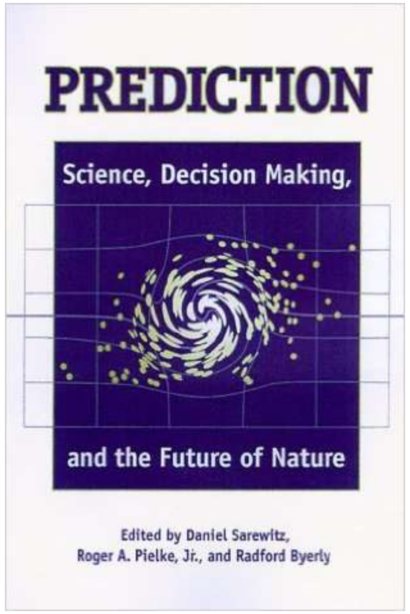


Oreskes, N., 2000, Why predict? Historical perspectives on prediction in Earth Science, in Prediction, Science, Decision Making and the future of Nature, Sarewitz et al., Eds., Island Press, Washington DC

“[⋯] to be of value in theory testing, the predictions involved must be capable of refuting the theory that generated them” (N. Oreskes)



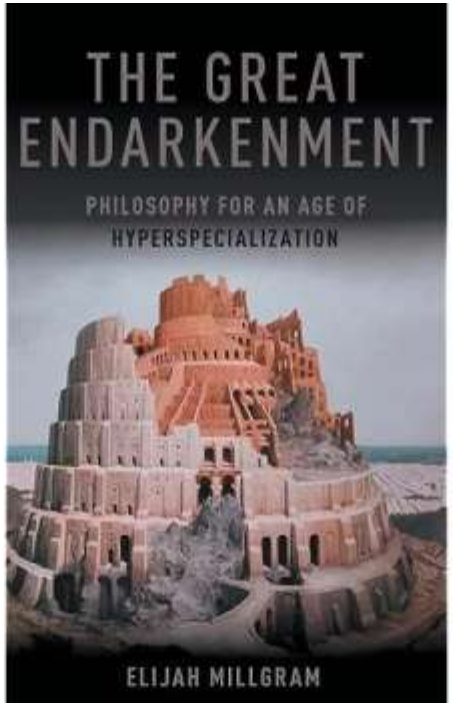
“When a model generates a prediction, of what precisely is the prediction a test? The laws? The input data? The conceptualization?



Any part (or several parts) of the model might be in error, and there is no simple way to determine which one it is”

Models have little memory

“[…] The process of constructing and validating [value-at risk] models is time consuming and detail oriented; normally even the people who produced the model will not remember many of the assumptions incorporated into it, short of redoing their work, which means that the client cannot simply ask then what went into it.”



E. Millgram The Great Endarkenment, p. 29

Caeteris are
never paribus

Ceteris paribus or caeteris paribus (Latin) = "all other things being equal" or "other things held constant" or "all else unchanged”

The case of DSGE, dynamic stochastic general equilibrium models

Rational expectations of agents
Efficient market hypothesis

Philip Mirowski

Philip Mirowski, 2013, Never let a serious crisis go wasted, Verso Books.

The US senate and Queen Elisabeth perplexed…

Philip Mirowski, 2013, Never let a serious crisis go wasted, Verso Books.

Dangers of mathematization of economics

Wolfgang Drechsler

Erik S. Reinert

Paul Romer

Philip Mirowski

W. Drechsler, “On the possibility of quantitative-mathematical social science, chiefly economics,” *J. Econ. Stud.*, vol. 27, no. 4/5, pp. 246–259, 2000.

E. S. Reinert, “Full circle: economics from scholasticism through innovation and back into mathematical scholasticism,” *J. Econ. Stud.*, vol. 27, no. 4/5, pp. 364–376, Aug. 2000.

P. Romer, “Mathiness in the Theory of Economic Growth,” *Am. Econ. Rev.*, vol. 105, no. 5, pp. 89–93, May 2015.

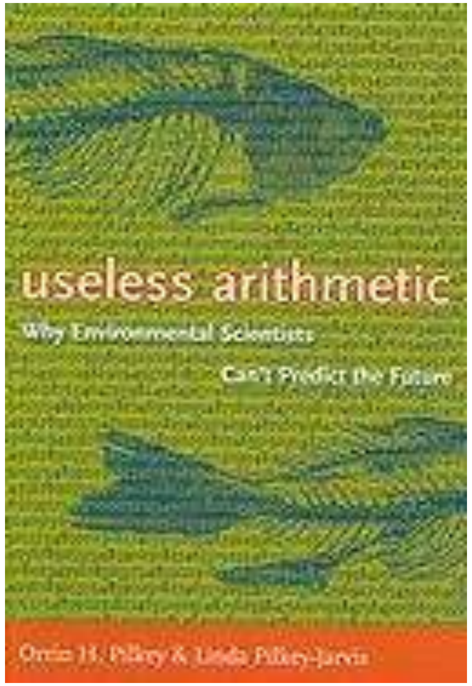
Mirowski, Philip. 2013. Never Let a Serious Crisis Go to Waste: How Neoliberalism Survived the Financial Meltdown. Verso.

Don’t confuse the map with the territory

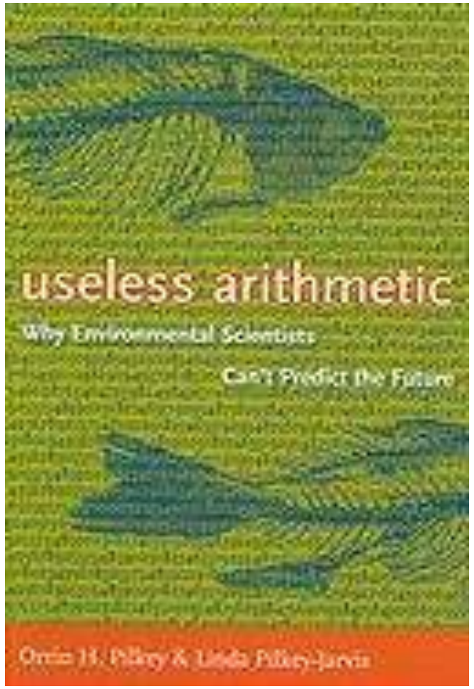
If you do, sensitivity analysis will not save you

<<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>>

Orrin H. Pilkey



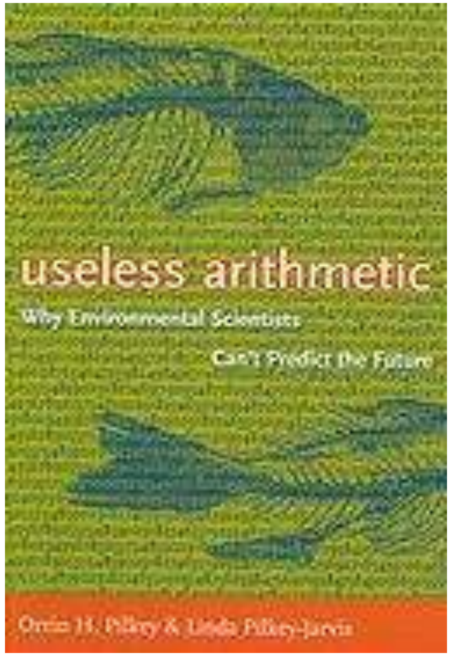
Useless Arithmetic: Why Environmental Scientists Can't Predict the Future
by Orrin H. Pilkey and Linda Pilkey-Jarvis, Columbia University Press, 2009.

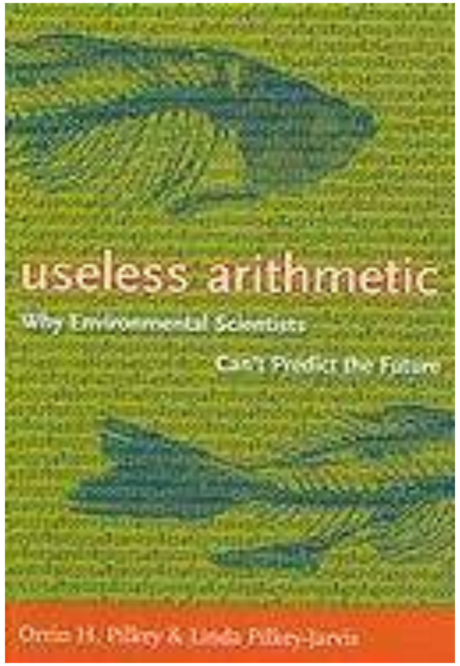


<<…If the model is wrong or if it is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit>>

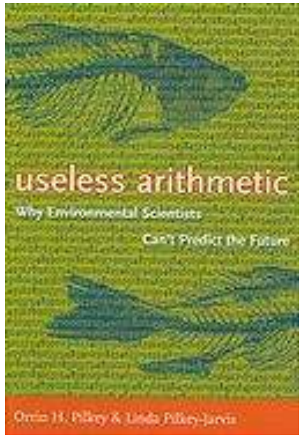
One of the examples discussed concerns the Yucca Mountain repository for radioactive waste. TSPA model (for total system performance assessment) for safety analysis.

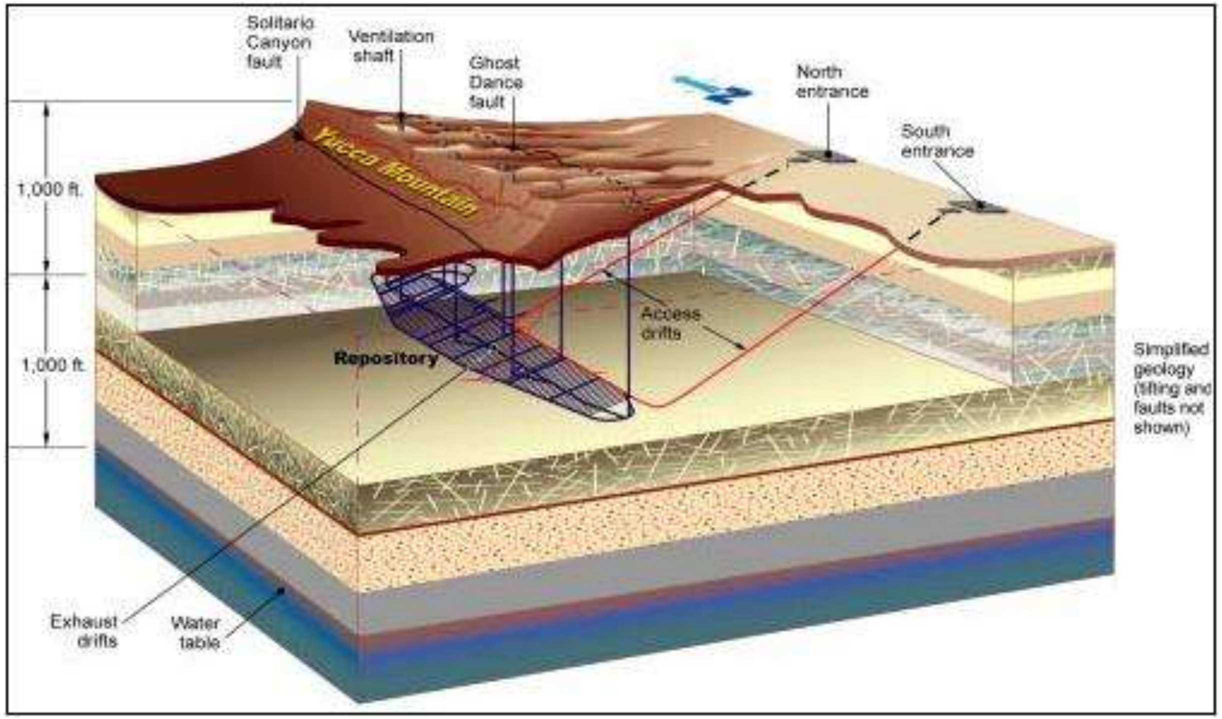
TSPA is Composed of 286 sub-models.





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



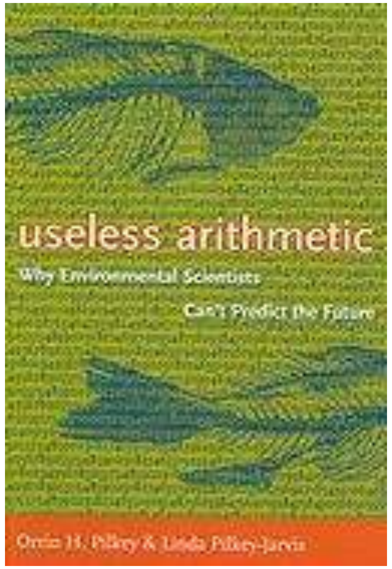


The confidence of the stakeholders in TSPA was not helped when evidence was produced which could lead to an upward revision of 4 orders of magnitude of this parameter

(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.



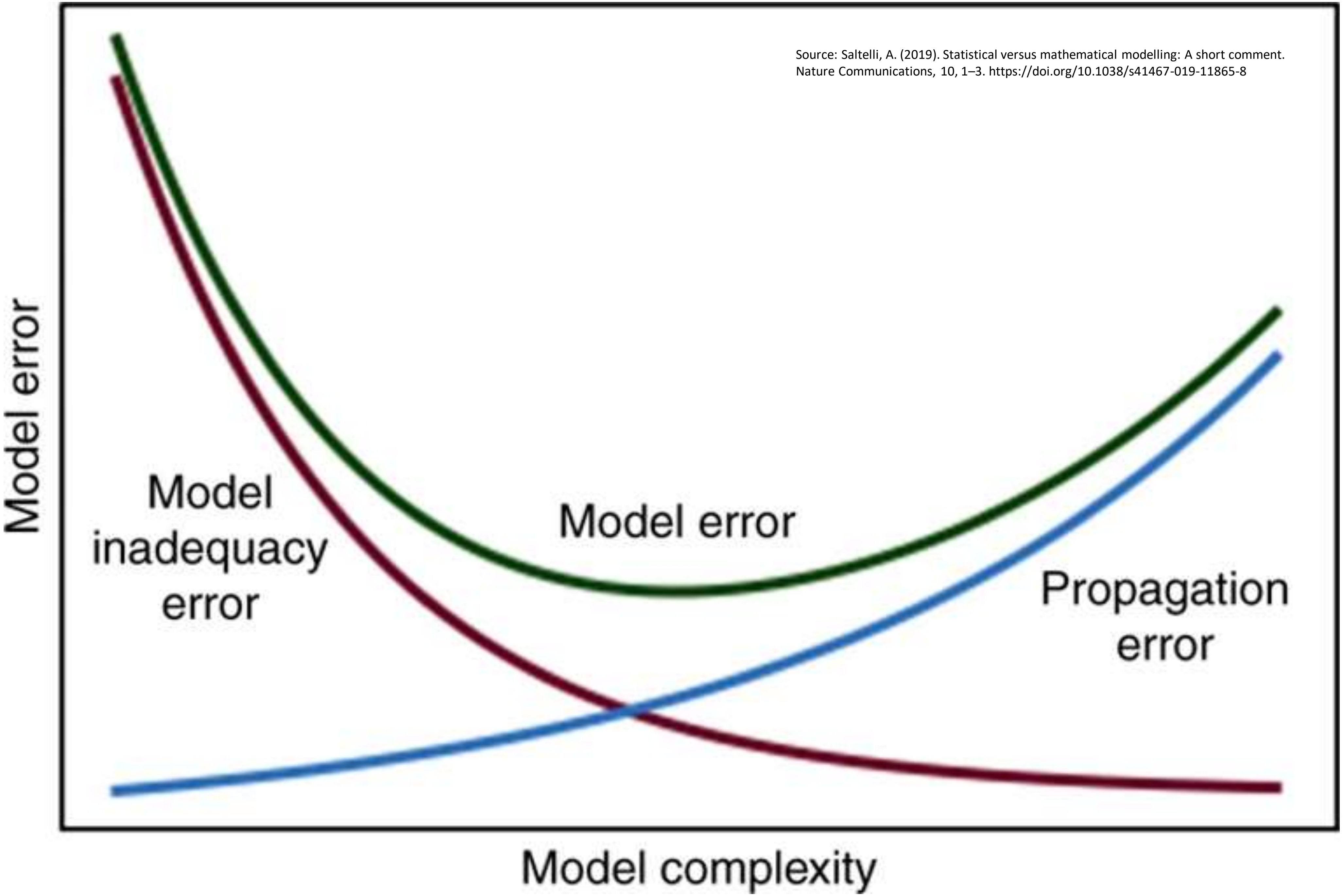
"Scientific mathematical modelling should involve constant efforts to falsify the model"

➔ Organized skepticism (as per CUDOS)

Communalism, **U**niversalism, **D**isinterestedness, **O**rganized **S**kepticism, from sociology of science, Robert K. Merton.

Beware the size of your model

Mind the conjecture of O'Neil



Source: Saltelli, A. (2019). Statistical versus mathematical modelling: A short comment. Nature Communications, 10, 1–3. https://doi.org/10.1038/s41467-019-11865-8

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

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.

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.

Puy, Arnald, Pierfrancesco Beneventano, Simon A. Levin, Samuele Lo Piano, Tommaso Portaluri, and Andrea Saltelli. 2022. "Models with Higher Effective Dimensions Tend to Produce More Uncertain Estimates." Science Advances 8 (eabn9450).

Simple principles of responsible modelling

Mind the assumptions

Assess uncertainty and sensitivity

Mind the hubris

Complexity can be the enemy of relevance

Mind the framing

Match purpose and context

Mind the consequences

Quantification can backfire.

Mind the unknowns

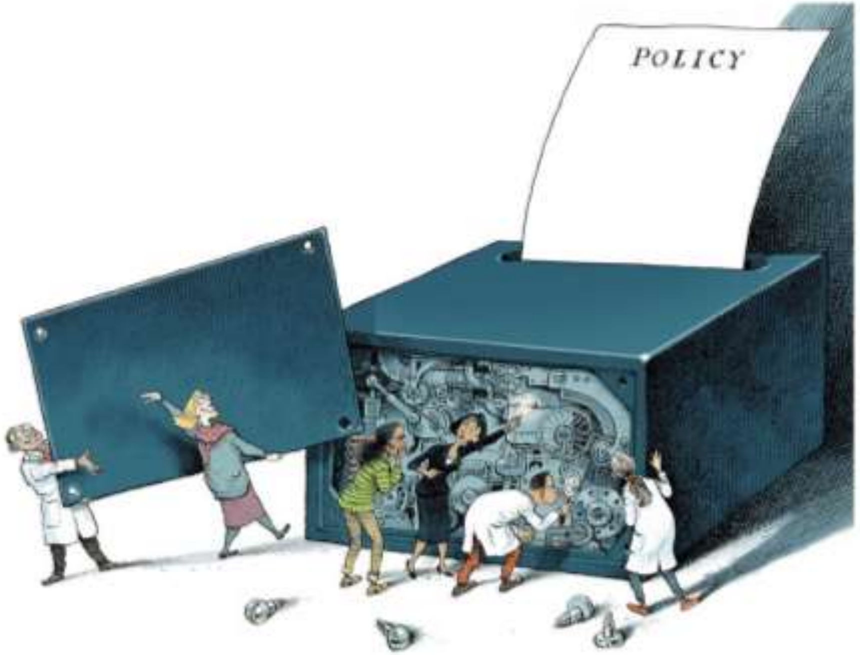
Acknowledge ignorance

Source: A. Saltelli, G. Bammer, I. Bruno, et al., Five ways to ensure that models serve society: a manifesto, Nature 582 (2020) 482–484.

Mind the assumptions

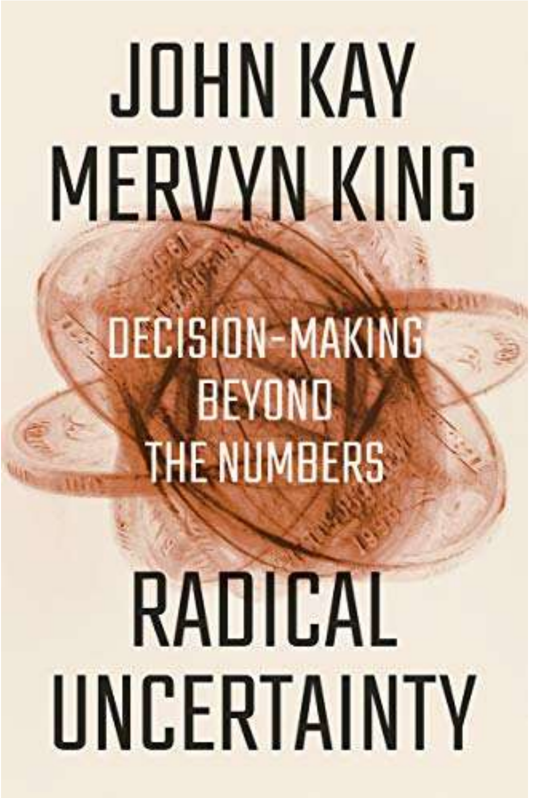
Assess uncertainty and sensitivity

… models require input values for which there is no reliable information…



Source: A. Saltelli, G. Bammer, I. Bruno, et al., Five ways to ensure that models serve society: a manifesto, Nature 582 (2020) 482–484.

Models ask as input information which we don’t have – The case of WEBTAG



John Kay

WebTAG: Annual Percentage Change in Car Occupancy (% pa) up to 2036

Journey Purpose	Weekday					Weekend	All Week
	7am-10am	10am-4pm	4pm-7pm	7pm-7am	Weekday Average		
Work	-0.48	-0.4	-0.62	-0.5	-0.44	-0.48	-0.45
Non - Work (commuting and other)	-0.67	-0.65	-0.53	-0.47	-0.59	-0.52	-0.56

Source: J. A. Kay, "Knowing when we don't know," 2012, https://www.ifs.org.uk/docs/john_kay_feb2012.pdf

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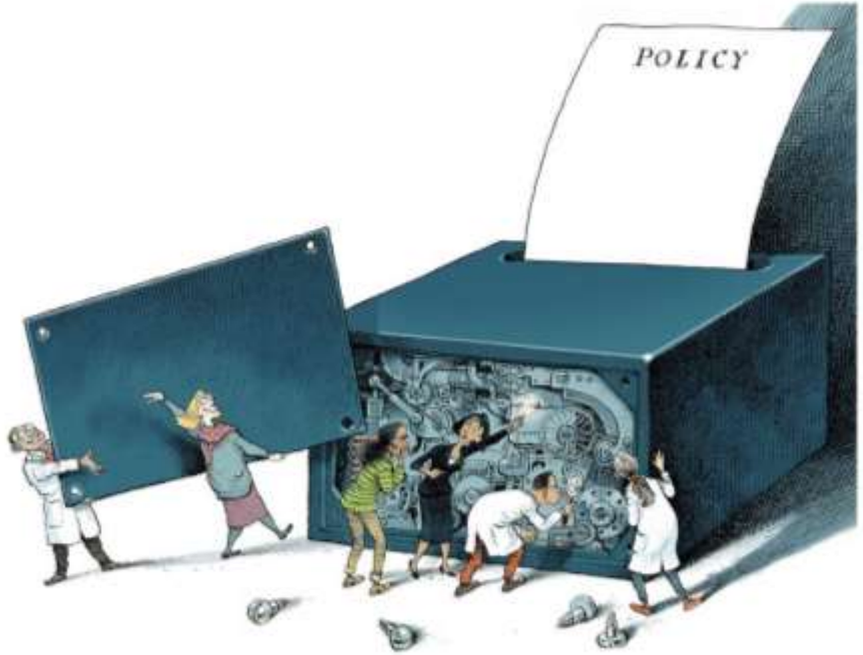

Source: A. Saltelli, G. Bammer, I. Bruno, et al., Five ways to ensure that models serve society: a manifesto, Nature 582 (2020) 482–484.

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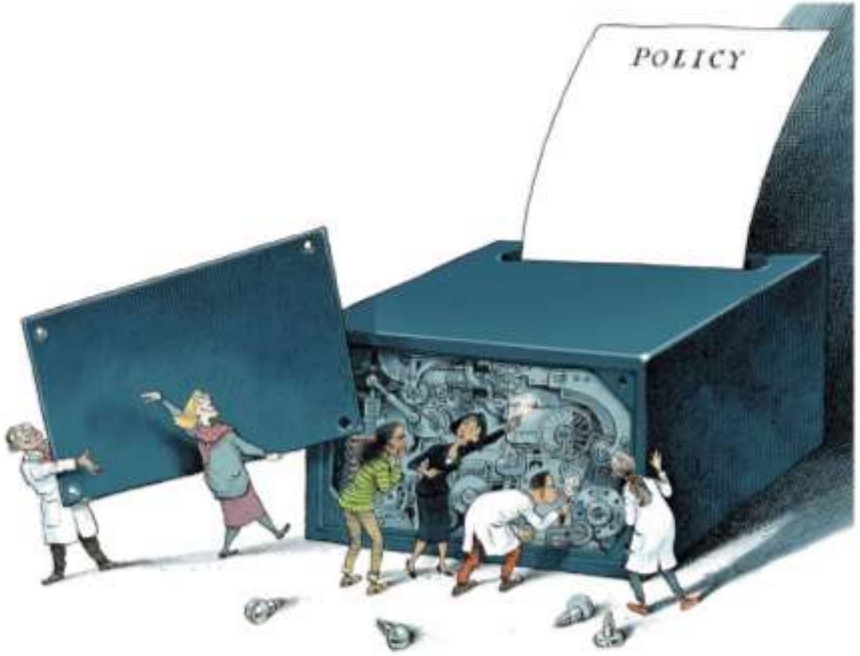

<< Back to Article

WIRED MAGAZINE: 17.03

Recipe for Disaster: The Formula That Killed Wall Street

By Felix Salmon 02.23.09

$$\Pr[T_A<1, T_B<1] = \phi_2(\phi^{-1}(F_A(1)), \phi^{-1}(F_B(1)), \gamma)$$

Here's what killed your 401(k) *David X. Li's Gaussian copula function as first published in 2000. Investors exploited it as a quick—and fatally flawed—way to assess risk. A shorter version appears on this month's cover of Wired.*

Here is what killed your 401(k)…

Li's Gaussian copula function …

Nassim Nicholas Taleb, hedge fund manager and author of *The Black Swan*, is particularly harsh when it comes to the copula. "People got very excited about the Gaussian copula because of its mathematical elegance, but the thing never worked," he says. "Co-association between securities is not measurable using correlation," because past history can never prepare you for that one day when everything goes south. "Anything that relies on correlation is charlatanism."

Felix Salmon, Wired, February 2009

WIRED

Source: https://www.wired.com/2009/02/wp-quant/

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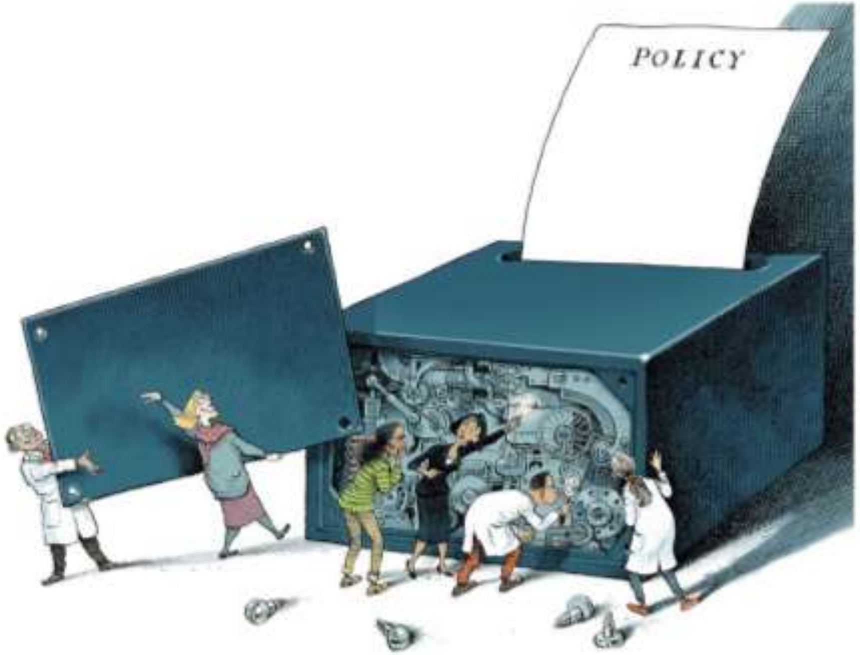
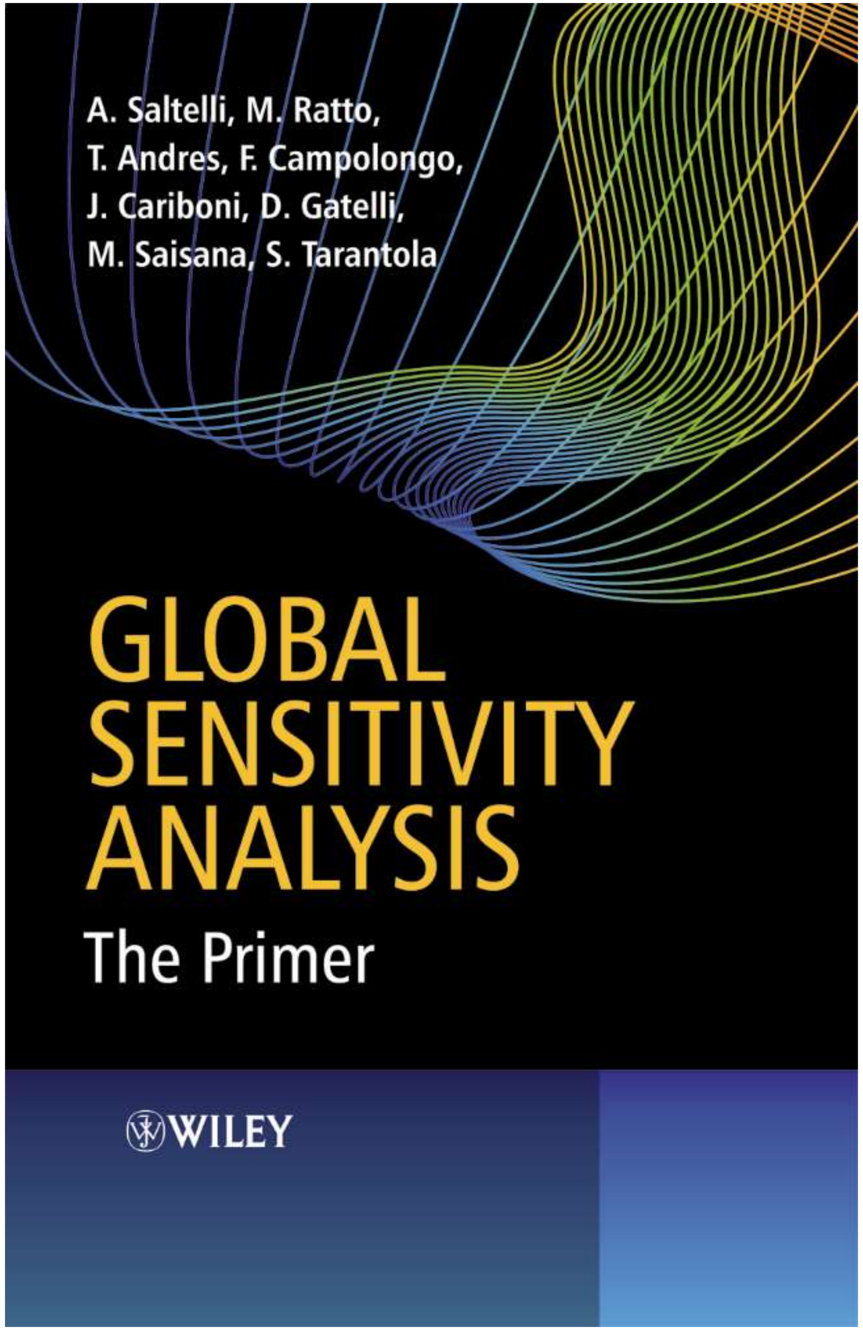
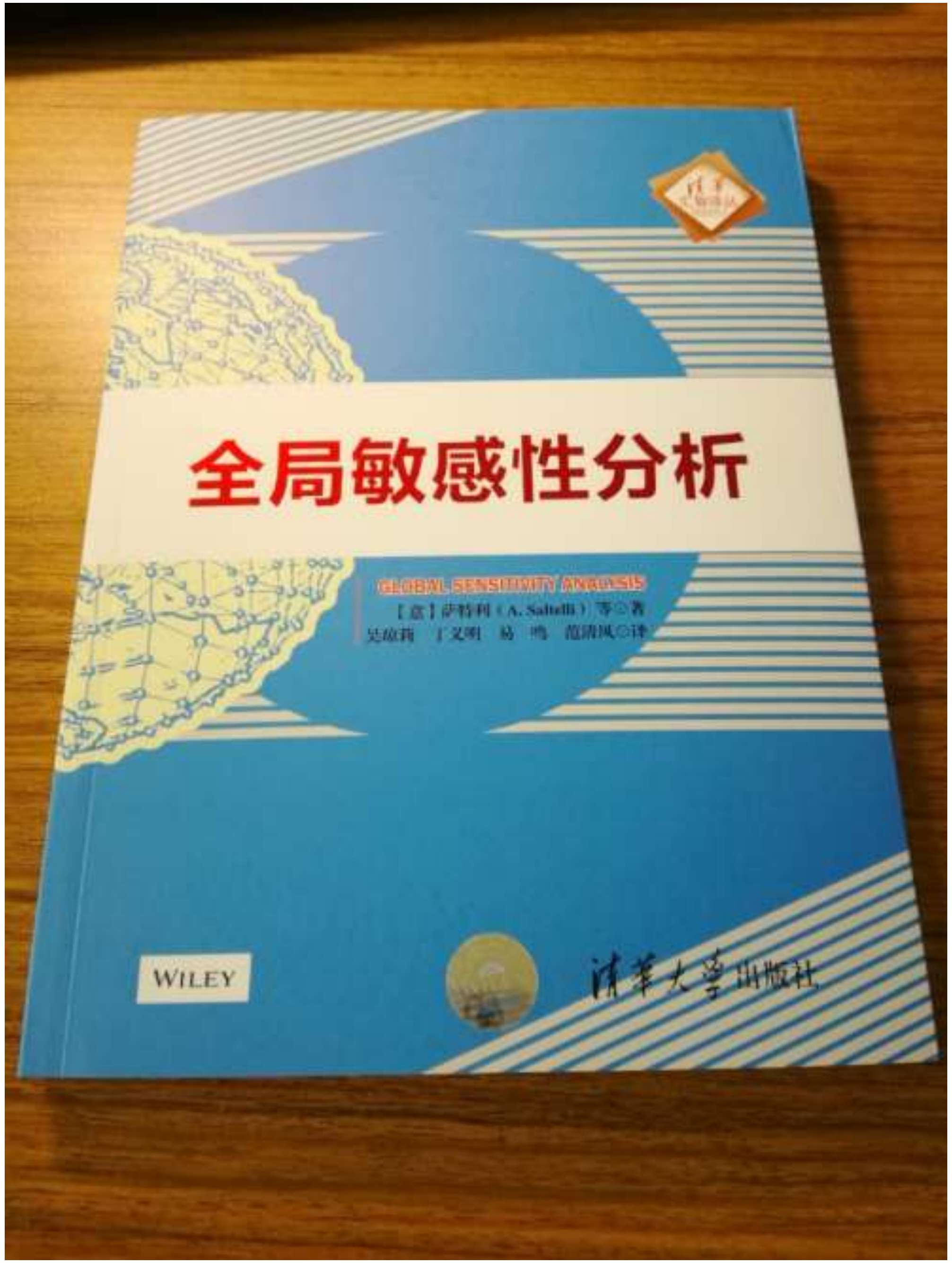


Source: A. Saltelli, G. Bammer, I. Bruno, et al., Five ways to ensure that models serve society: a manifesto, Nature 582 (2020) 482–484.

From Socrates's "knowing of not knowing" to Nicolaus Cusanus' Docta Ignorantia, ignorance was a virtue until Descartes


A. Saltelli, M. Ratto,
T. Andres, F. Campolongo,
J. Cariboni, D. Gatelli,
M. Saisana, S. Tarantola
GLOBAL SENSITIVITY ANALYSIS
The Primer
WILEY


全局敏感性分析
GLOBAL SENSITIVITY ANALYSIS
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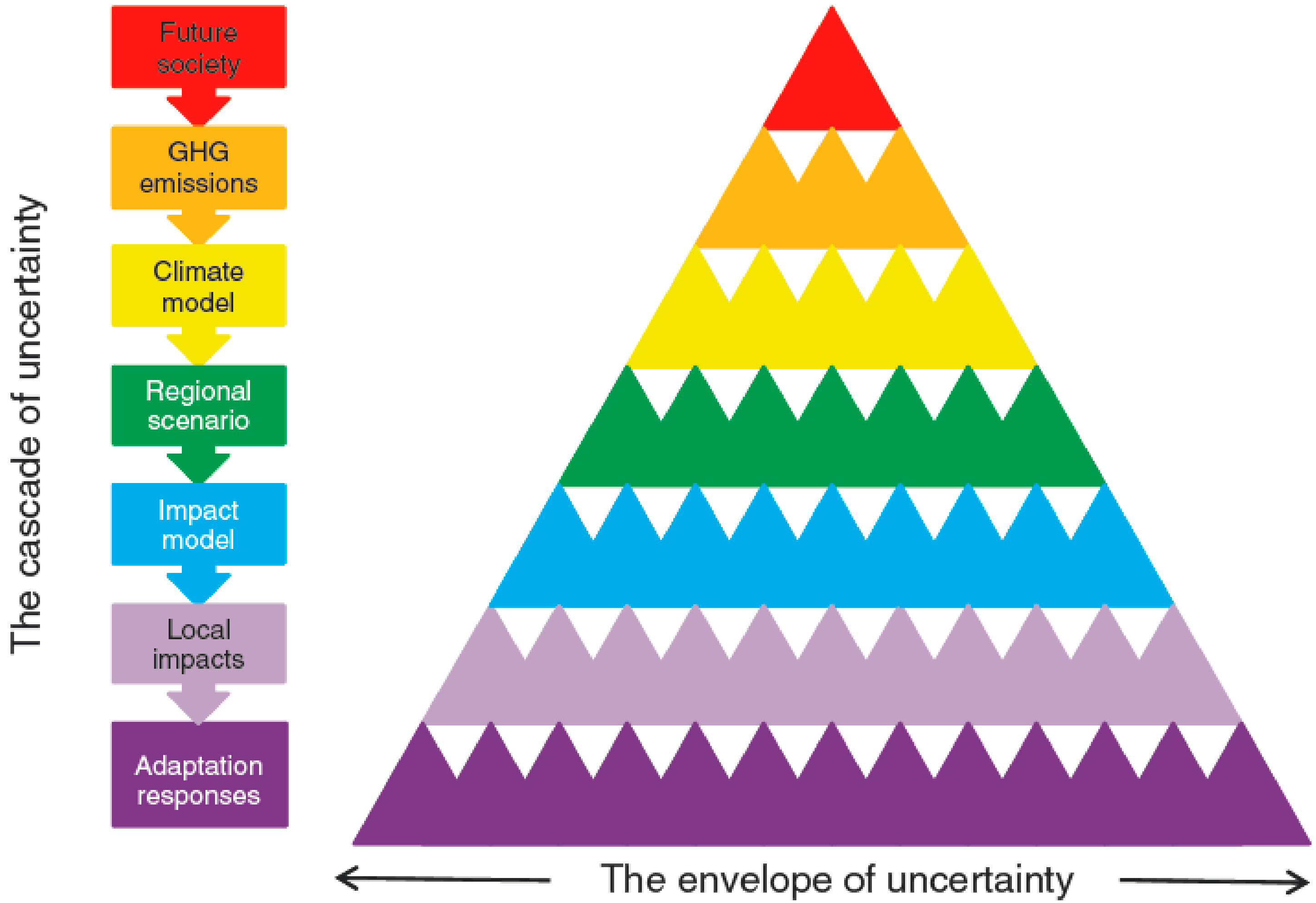
Uncertainty analysis: the study of the uncertainty in model output—see also uncertainty cascade



Source: https://www.climate-lab-book.ac.uk/2014/cascade-of-uncertainty/

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

Sensitivity analysis can:

- surprise the analyst,
- uncover technical errors in the model,
- identify critical regions in the space of the inputs,

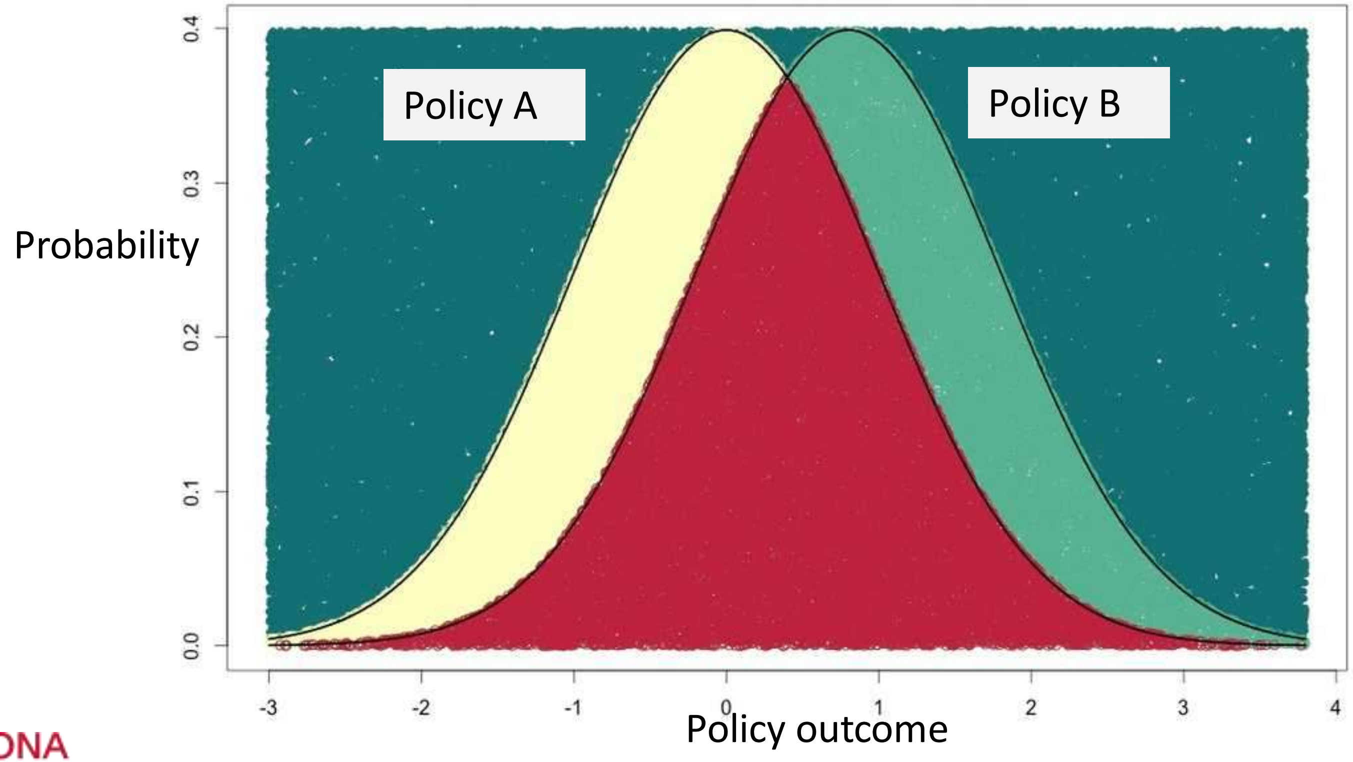
Source: The Simpson, 20th Television Animation
(The Walt Disney Company)

Sensitivity analysis can :

- surprise the analyst,
- uncover technical errors in the model,
- identify critical regions in the space of the inputs,
- establish priorities for research,
- simplify models
- falsify models (show that a model is false or irrelevant)
- defend against your own model being falsified

Sensitivity analysis can:

verify whether policy options (or marketing strategies) can be distinguished from one another given the uncertainties in the system, …



What method would one choose to perform sensitivity analysis?

Source: iStock by Getty images

What method would one choose to perform sensitivity analysis?

Most of the sensitivity analysis found in the literature are local or otherwise OAT (One factor At a Time)

$$y = f(x_1, x_2, \dots x_k)$$

$$\left.\frac{\partial y}{\partial x_i}\right|_{x_i = x_i^0} \longleftarrow \text{Local}$$

What method would one choose to perform sensitivity analysis?

Most of the sensitivity analysis found in the literature are local or otherwise OAT (One factor At a Time)

$$y = f(x_1, x_2, \dots x_k)$$

$$\left.\frac{x_i^0}{y^0}\frac{\partial y}{\partial x_i}\right|_{x_i = x_i^0} \longleftarrow \text{Local}$$

What method would one choose to perform sensitivity analysis?

Most of the sensitivity analysis found in the literature are local or otherwise OAT (One factor At a Time)

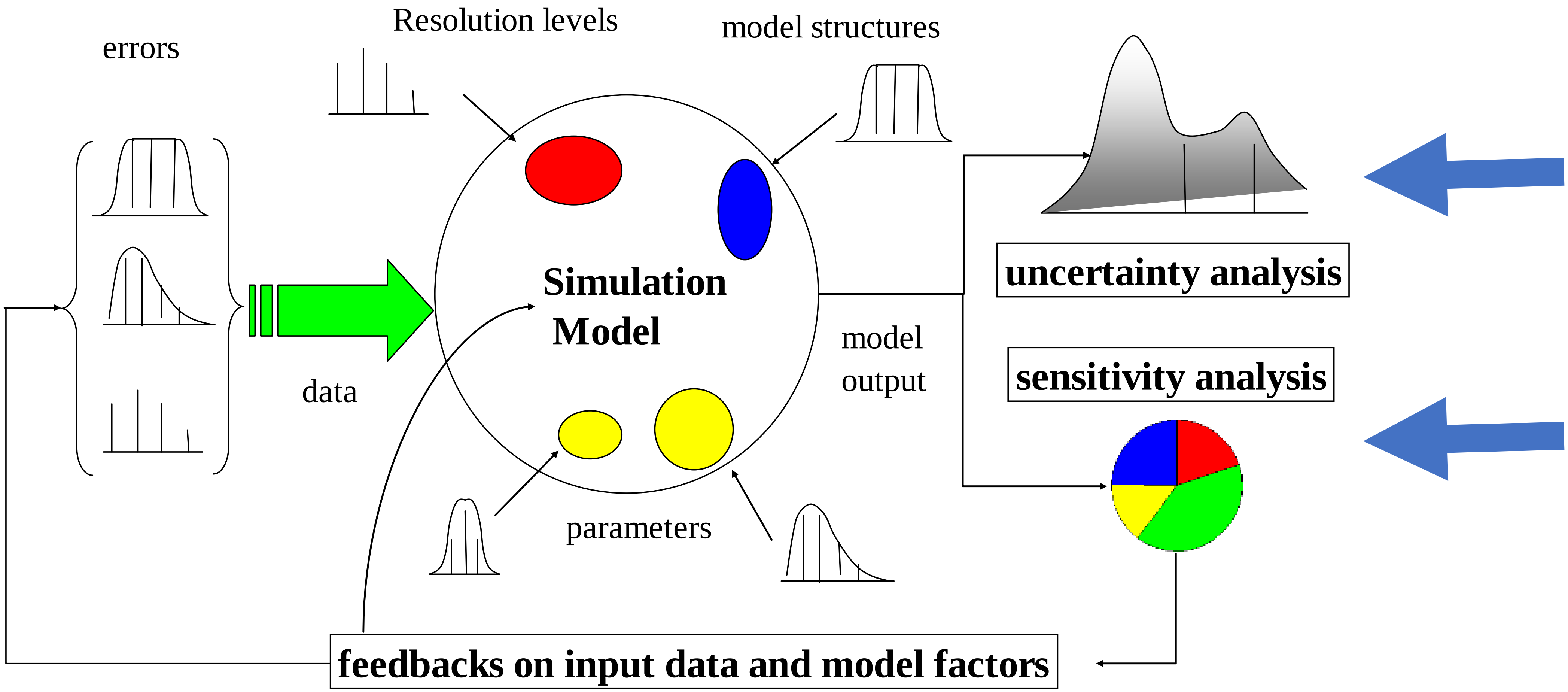
$$y = f(x_1, x_2, \ldots x_k)$$

$$\frac{std(x_i)}{std(y)} \frac{\partial y}{\partial x_i}\bigg|_{x_i = x_i^0} \longleftarrow \text{Hybrid}$$

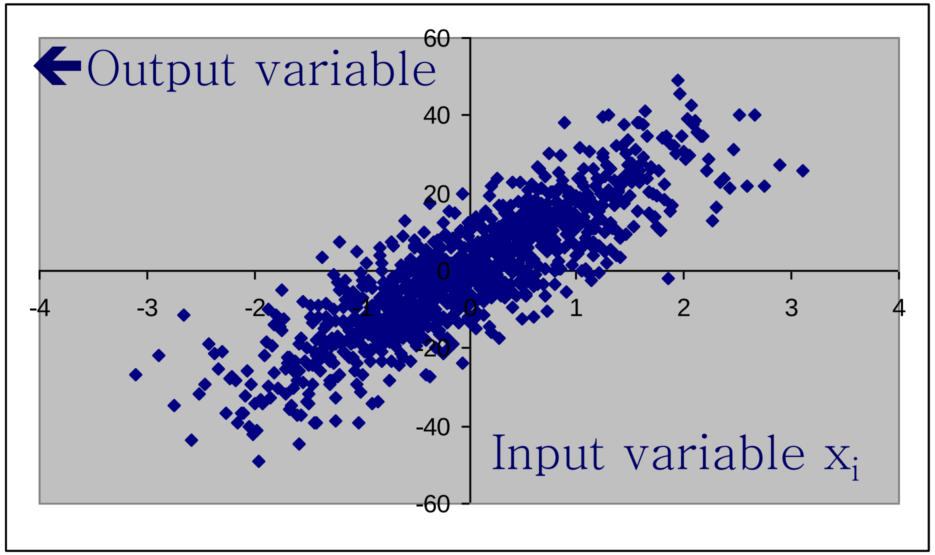
$$\left.\frac{\partial y}{\partial x_i}\right|_{x_i=x_i^0}$$ ⟵ Relative effect on y of perturbing x_i around its nominal value

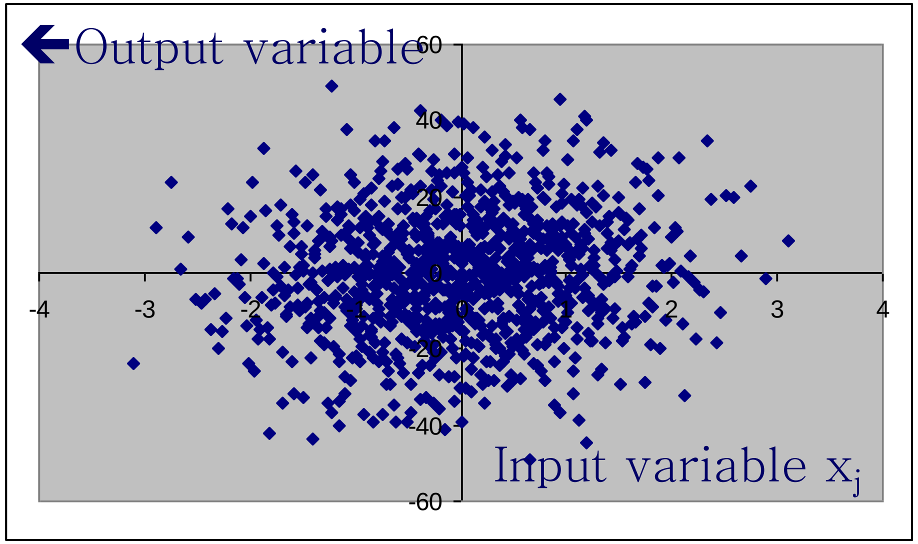
$$\left.\frac{x_i^0}{y^0}\frac{\partial y}{\partial x_i}\right|_{x_i=x_i^0}$$ ⟵ Relative effect on y of perturbing x_i by a fixed fraction of its nominal value

$$\left.\frac{std(x_i)}{std(y)}\frac{\partial y}{\partial x_i}\right|_{x_i=x_i^0}$$ ⟵ Relative effect on y of perturbing x_i by a fixed fraction of its standard deviation


errors
Resolution levels
model structures
Simulation Model
data
model output
parameters
uncertainty analysis
sensitivity analysis
feedbacks on input data and model factors

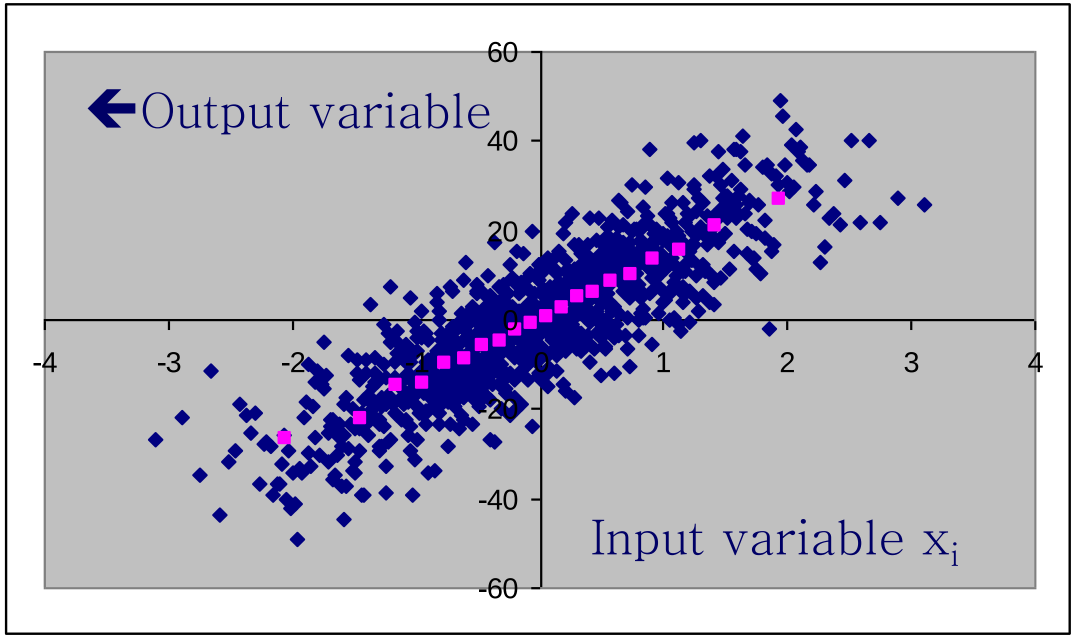
An introduction to variance based methods

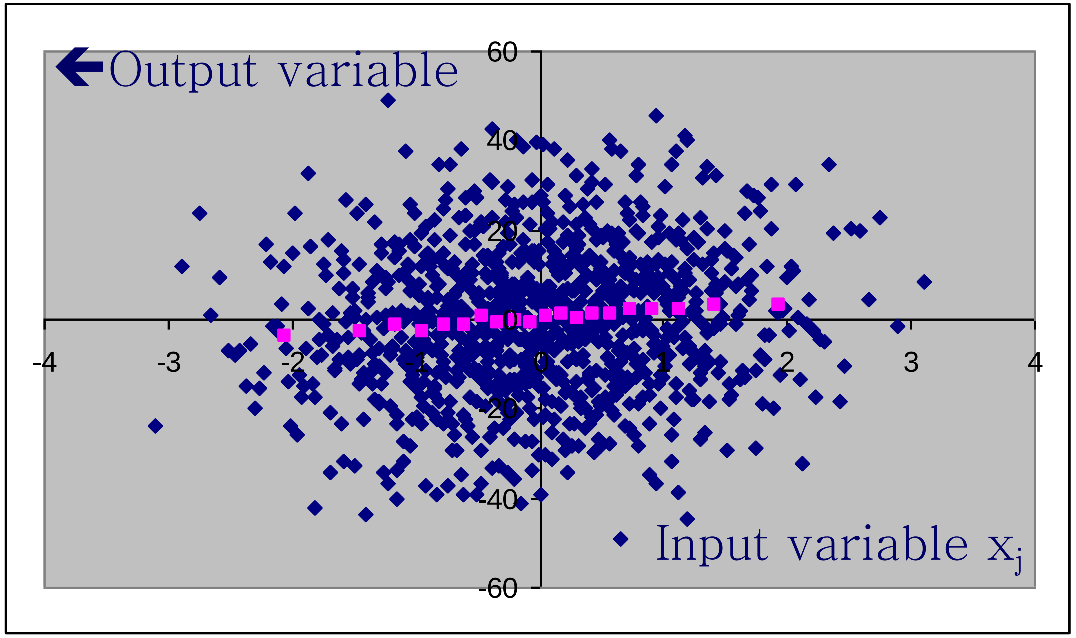




Plotting the output as a function of two different input factors

Which factor is more important?

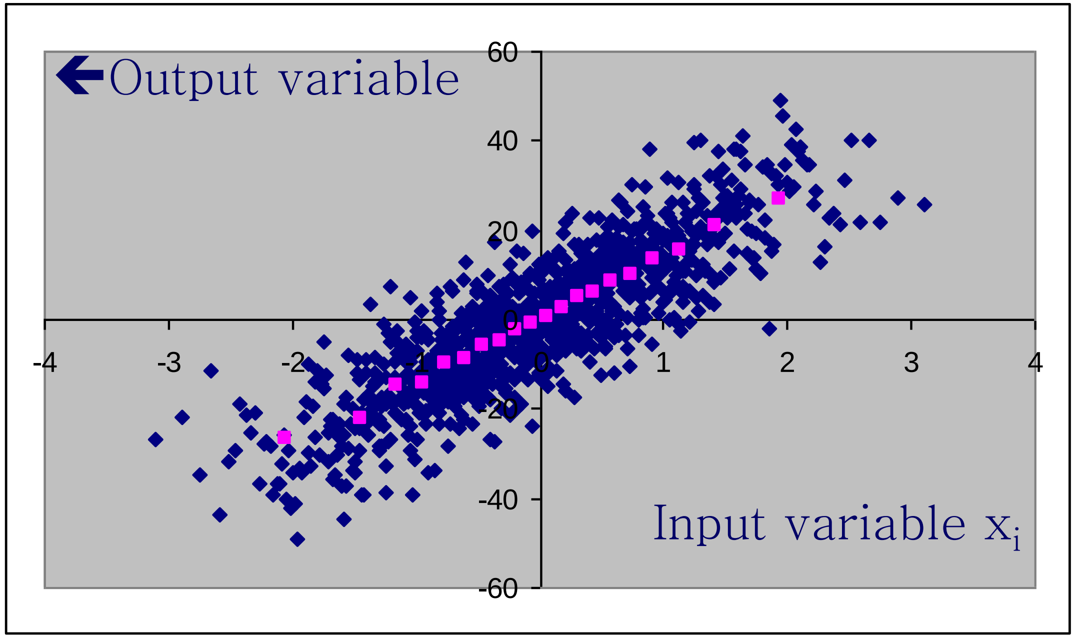




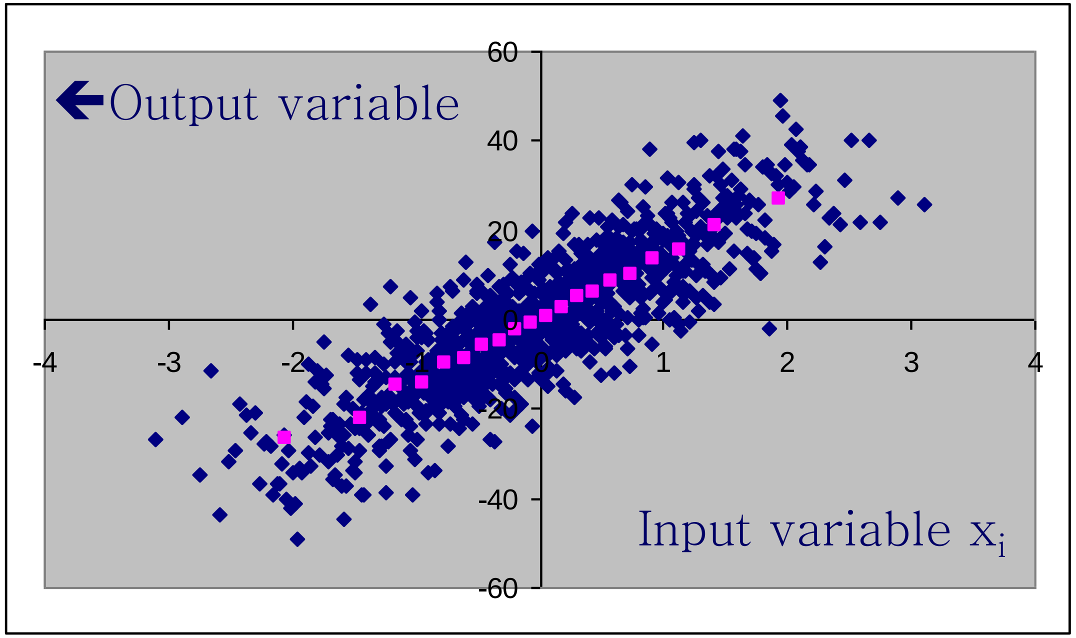
~1,000 blue points

Divide them in 20 bins of ~ 50 points

Compute the bin's average (pink dots)

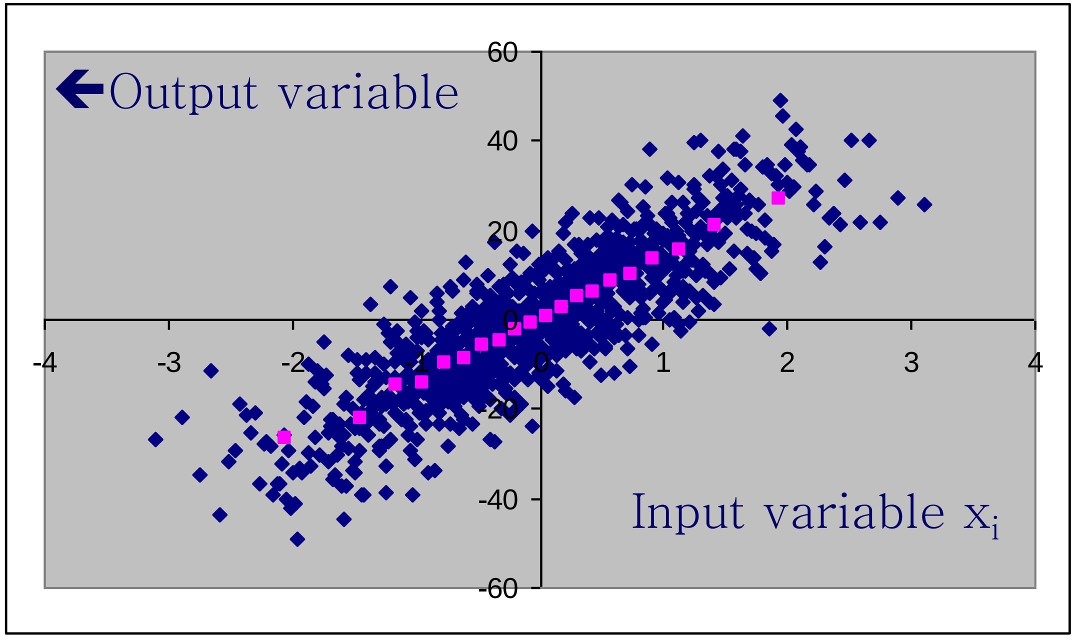


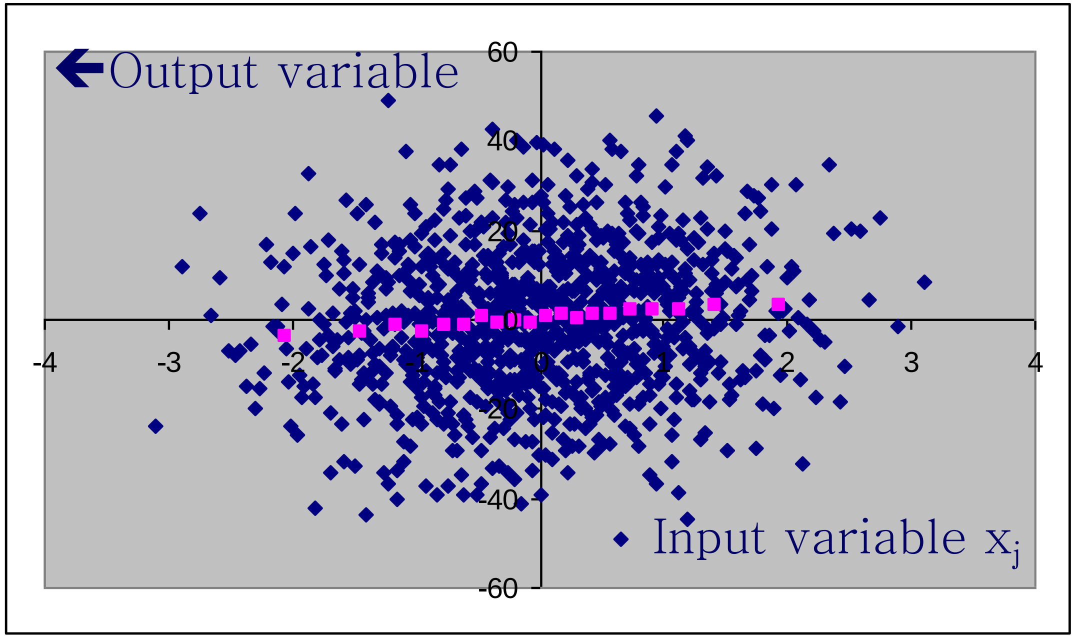
Each pink point is ~ $E_{\mathbf{X}_{\sim i}}\left(Y \middle| X_i\right)$



Taking the variance of the pink points one obtains a sensitivity measure

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





Which factor has the highest $V_{X_i}\left(E_{\mathbf{X}_{\sim i}}\left(Y \middle| X_i\right)\right)$?

$$S_i = \frac{V_{X_i}\left(E_{\mathbf{X}_{\sim i}}\left(Y \mid X_i\right)\right)}{V(Y)}$$

The partial variance divided by the total variance is the so-called sensitivity index of the first order

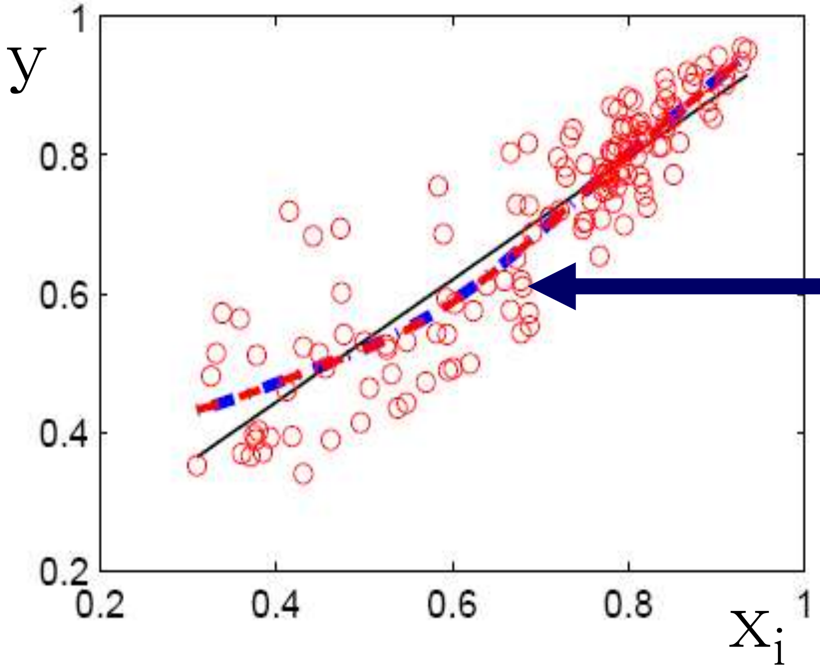
For additive models one can decompose the total variance as a sum of those partial variances

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

… which is also how additive models are defined

$$S_i = \frac{V_{X_i}\left(E_{\mathbf{X}_{\sim i}}\left(Y \middle| X_i\right)\right)}{V(Y)}$$

The partial variance divided by the total variance is the so-called sensitivity index of the first order, identical in formulation to Pearson's correlation ratio



Smoothed curve:

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

First order sensitivity index:

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

Pearson's correlation ratio

Smoothed curve

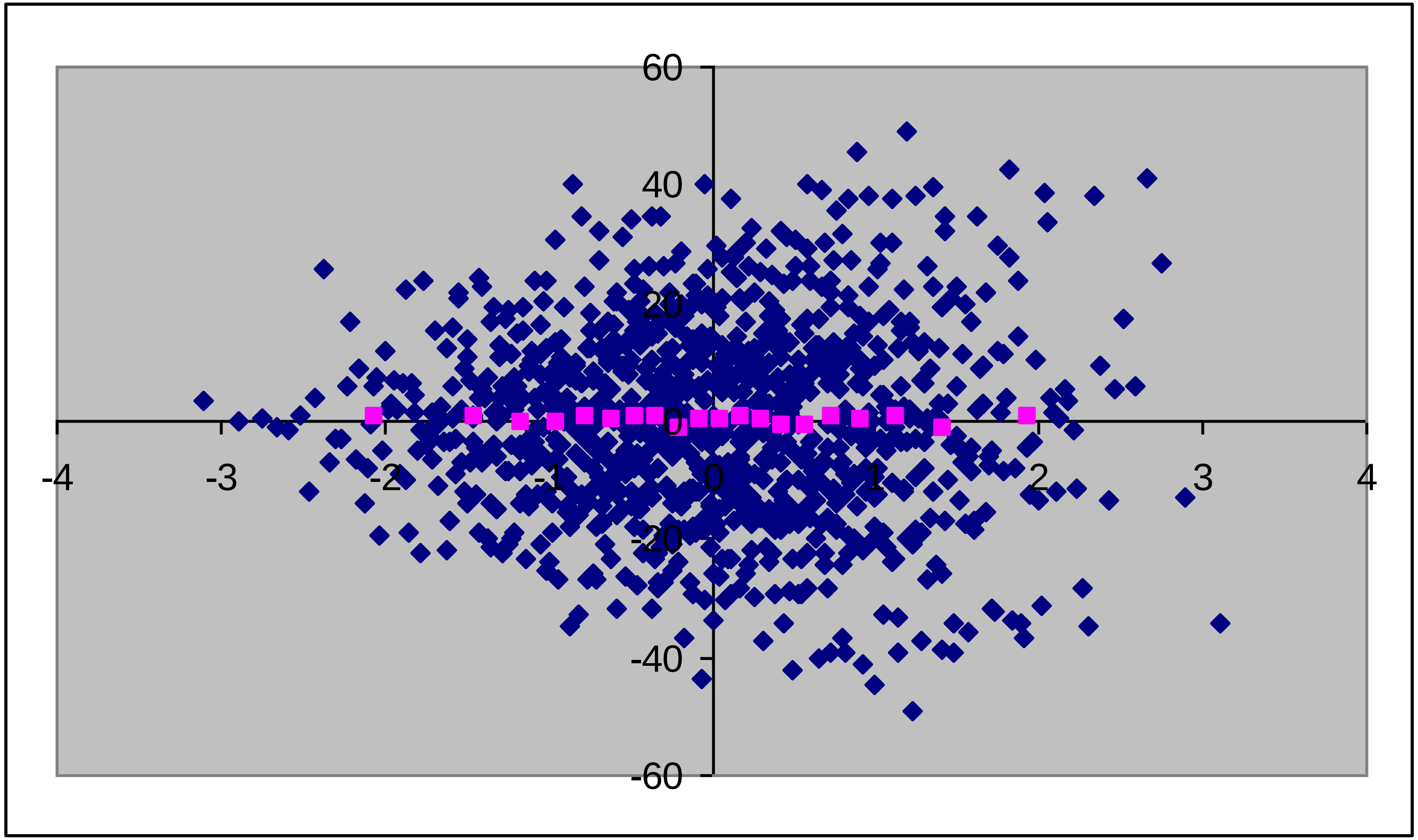
$$S_i \equiv \eta_i^2 := \frac{V_{x_i}\left(E_{\mathbf{x}_{\sim i}}\left(y \mid x_i\right)\right)}{V\left(y\right)}$$

First order sensitivity index

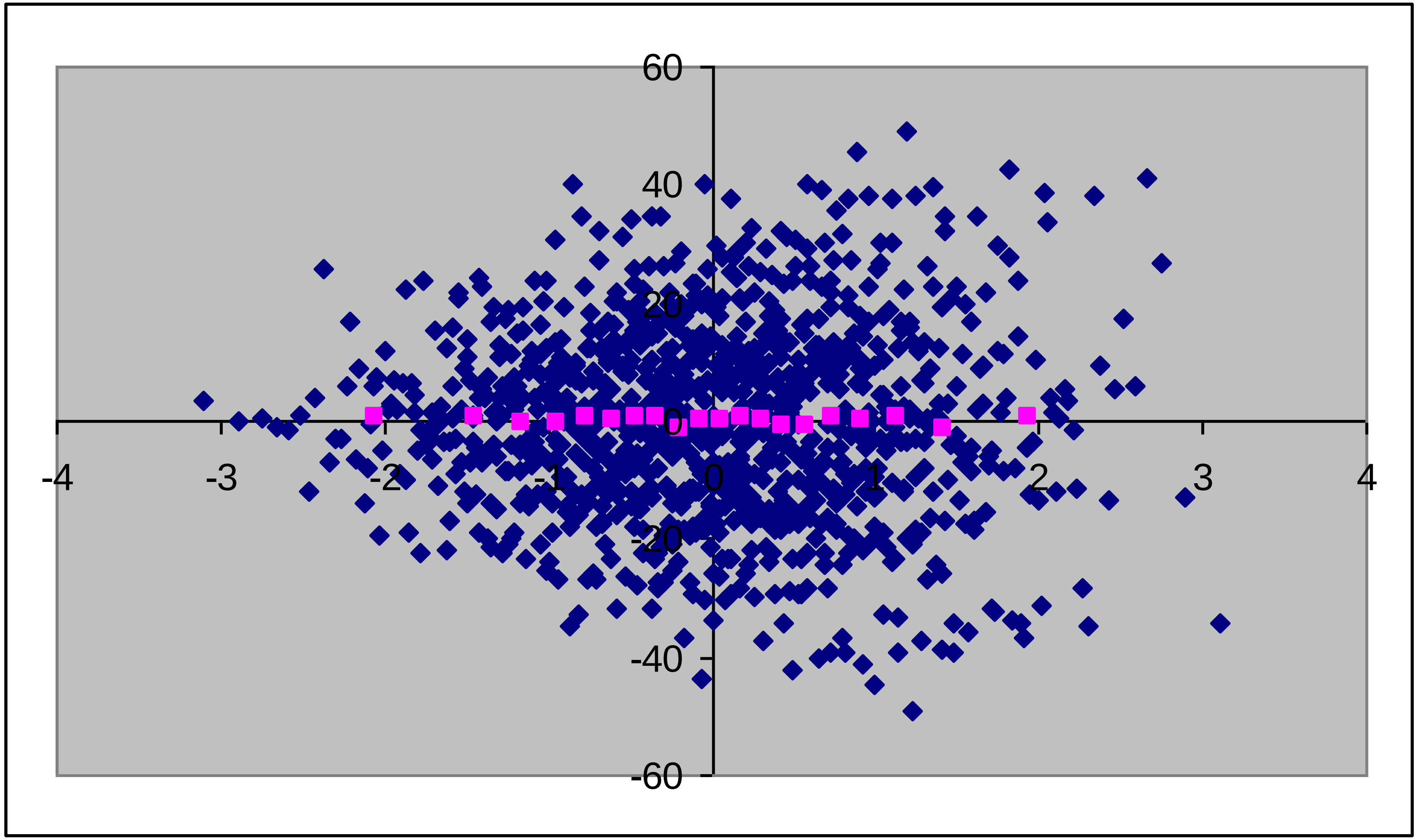
Unconditional variance

Non additive models

Is $S_i = 0$?



Is this factor non-important?



There are terms which capture two-way, three way, … interactions among variables

All these terms are linked by a formula

Variance decomposition (ANOVA)

$$V(Y) =$$

$$\sum_i V_i + \sum_{i,j>i} V_{ij} + \ldots + V_{123\ldots k}$$

Variance decomposition (ANOVA)

The total variance can be decomposed into main effects and interaction effects up to the order k, the dimensionality of the problem (only for independent factors)

If fact interactions terms are awkward to handle: **just** the **second** order terms for a model with k factors are as many as k(k−1)/2 …

(10 factors=45 second order terms)

How about a single ‘importance’ terms for all effects?

In fact such terms exist and can be computed easily, without knowledge of the individual interaction terms

Thus given a model $f(X_1, X_2, \ldots, X_3)$

Where the variance decomposition would read $1 = S_1 + S_2 + S_3 + S_{12} + S_{13} + S_{23} + S_{123}$

We compute

$$T_1 = S_1 + S_{12} + S_{13} + S_{123}$$

$$T_2 = S_2 + S_{12} + S_{23} + S_{123}$$

$$T_3 = S_3 + S_{13} + S_{23} + S_{123}$$

The measures and their 'settings' = when to use them

Journal of the American Statistical Association ›
Volume 97, 2002 - Issue 459

Enter keywords, authors, DOI, C

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Primary Article

On the Relative Importance of Input Factors in Mathematical Models

Safety Assessment for Nuclear Waste Disposal

Andrea Saltelli & Stefano Tarantola

Pages 702-709 | Published online: 31 Dec 2011
Download citation https://doi.org/10.1198/016214502388618447

The measures and their 'settings' = when to use them

First order effect	Factor prioritization (orienting research)
Total effect	Factor fixing (model simplification)

ELSEVIER

Computer Physics Communications

Volume 145, Issue 2, 15 May 2002, Pages 280-297

Computing the indices efficiently

Making best use of model evaluations to compute sensitivity indices

Andrea Saltelli

Higher order Sobol' indices

Get access >

Art B. Owen, Josef Dick, Su Chen

Information and Inference: A Journal of the IMA, Volume 3, Issue 1, March 2014, Pages 59–81, https://doi.org/10.1093/imaiai/iau001

Published: 01 March 2014 **Article history ▾**

Plenty of code available in R, MATLAB, and Phyton

https://cran.r-project.org/web/packages/sensitivity/sensitivity.pdf

https://cran.rstudio.com/web/packages/sensobol/index.html

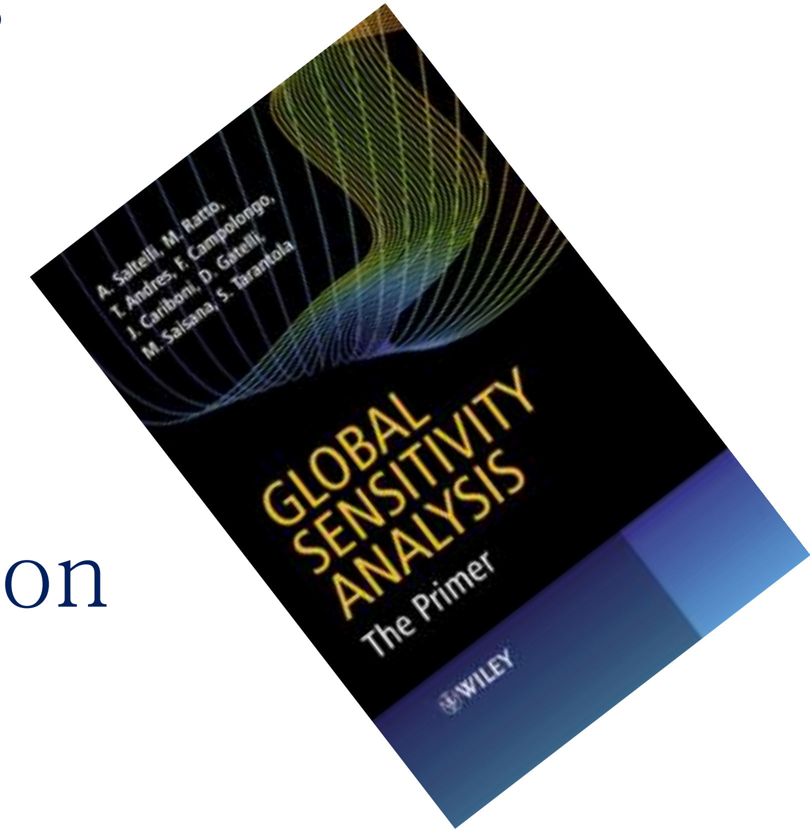
https://www.uqlab.com/ (in MatLab, by Bruno Sudret and his team)

SALib https://salib.readthedocs.io/en/latest/

…but there is more, in R, Phython, Giulia …

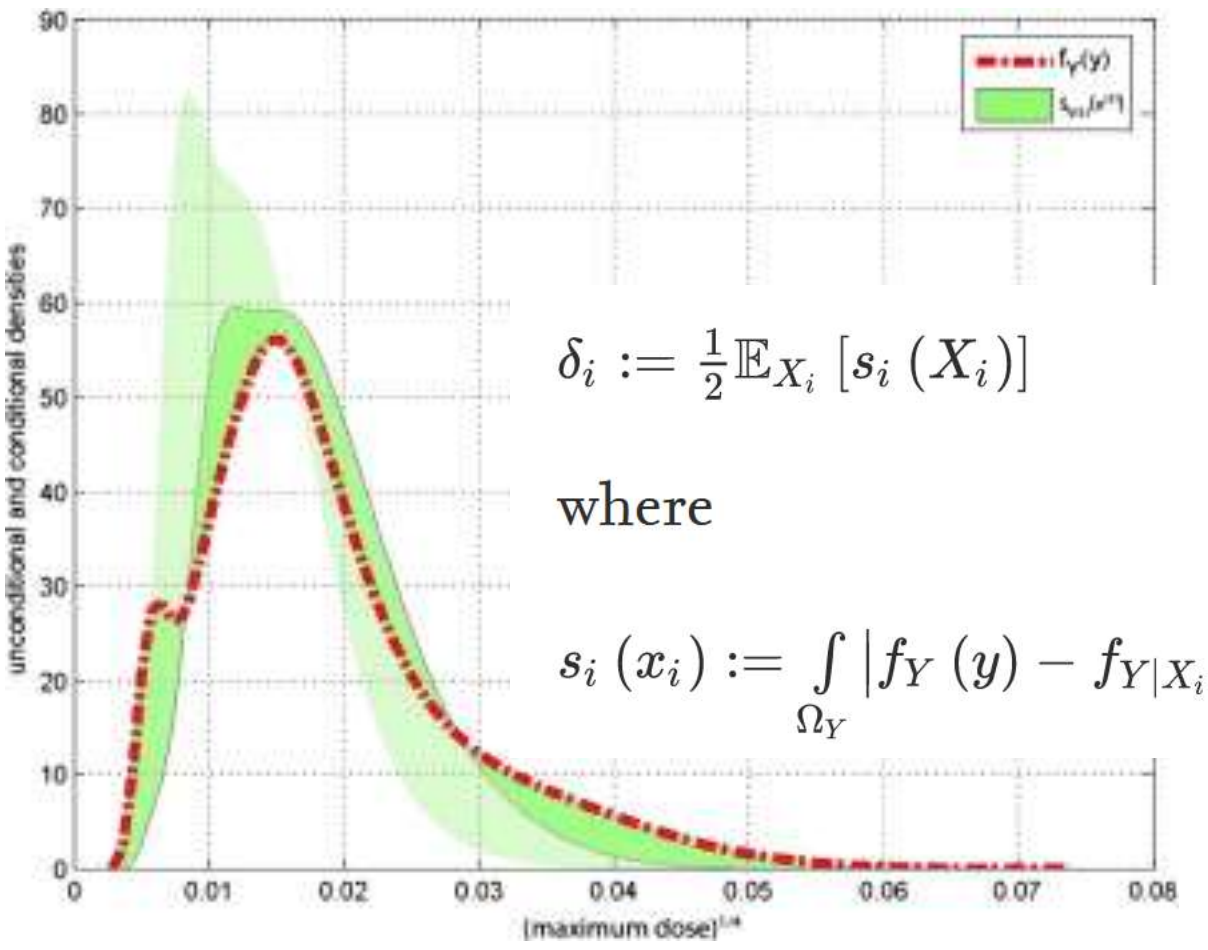
Advantages with variance based methods:

- graphic interpretation scatterplots
- statistical interpretation (ANOVA)
- expressed plain English
- working with sets
- relation to settings such as
  factor fixing and factor prioritization
- give the effective dimension



Chapter 1 and its exercises

… but there are other methods that can be used for different settings, e.g. moment independents methods, Shapley coefficients, reduced spaces, VARS …



$$\delta_i := \frac{1}{2}\mathbb{E}_{X_i}\left[s_i\left(X_i\right)\right]$$

where

$$s_i\left(x_i\right) := \int_{\Omega_Y}\left|f_Y\left(y\right) - f_{Y|X_i=x_i}\left(y\right)\right| dy$$

ELSEVIER

Environmental Modelling & Software

Volume 34, June 2012, Pages 105-115

Model emulation and moment-independent sensitivity analysis: An application to environmental modelling

E. Borgonovo [a], W. Castaings [b, c], S. Tarantola [d]

Don’t use One factor At a Time (OAT)

A geometric proof

Environmental Modelling & Software 25 (2010) 1508–1517

Contents lists available at ScienceDirect

Environmental Modelling & Software

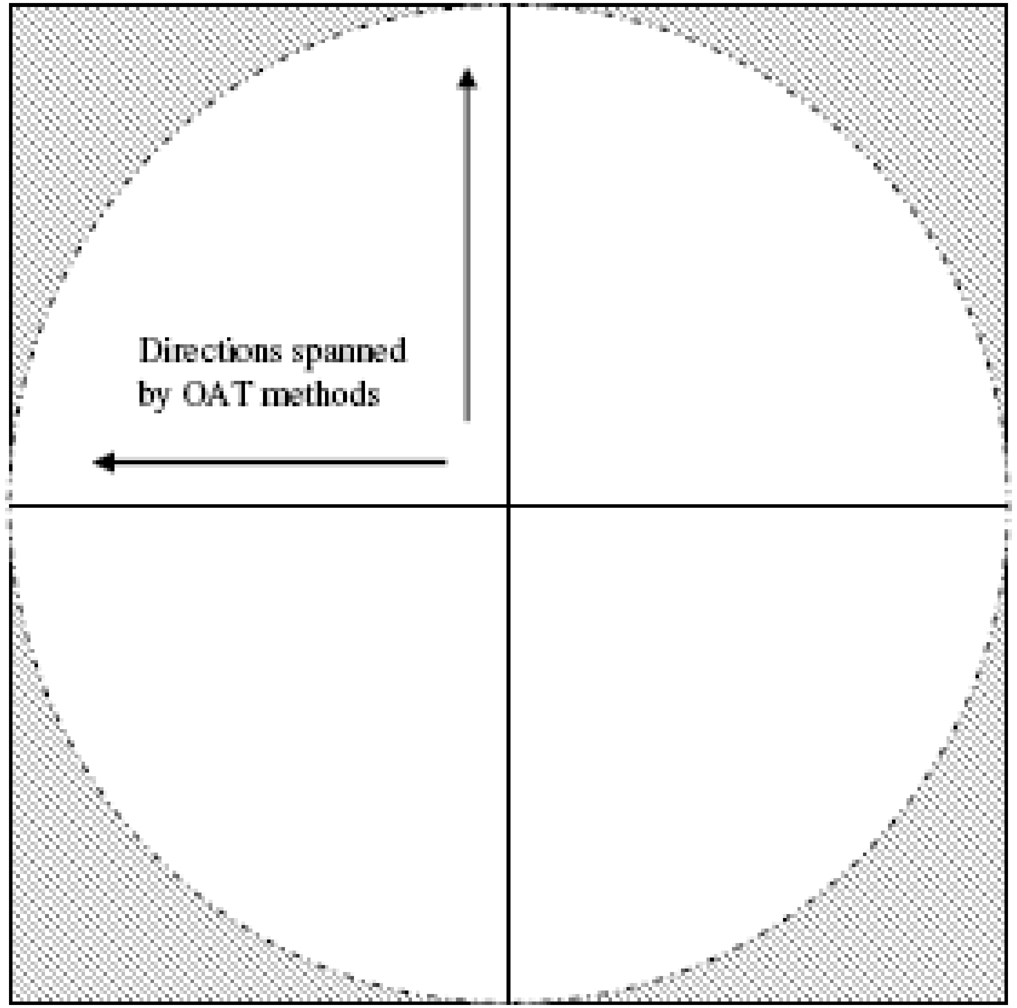
journal homepage: www.elsevier.com/locate/envsoft

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

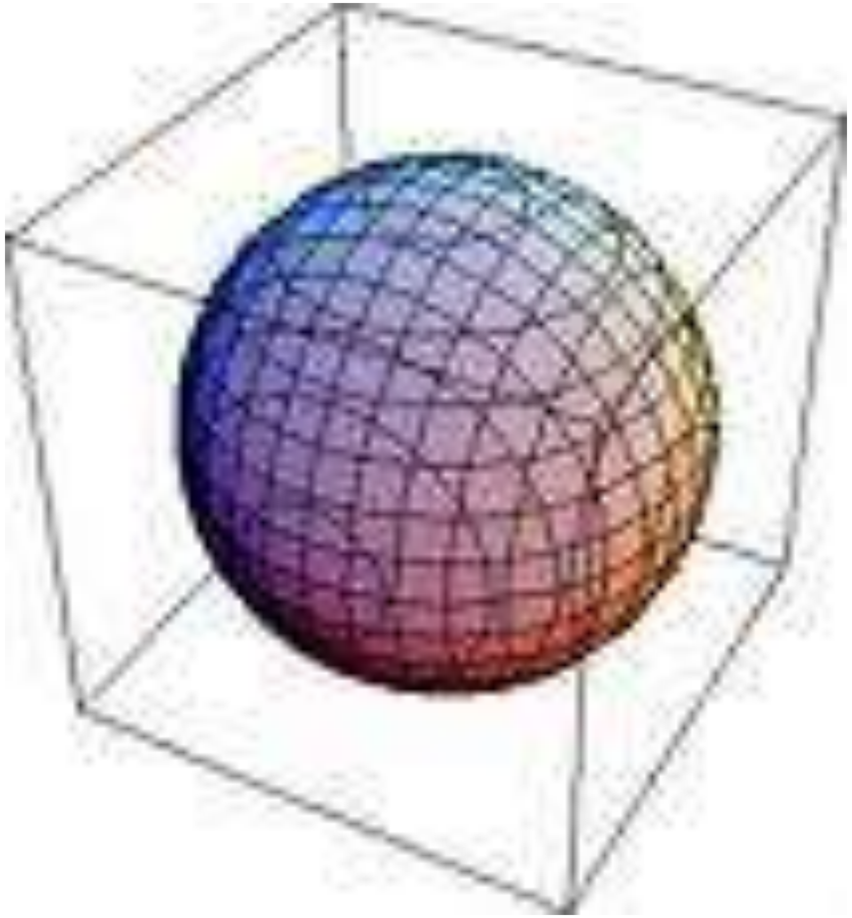
OAT in 2 dimensions



Area circle / area square =?

~ 3/4

OAT in 3 dimensions



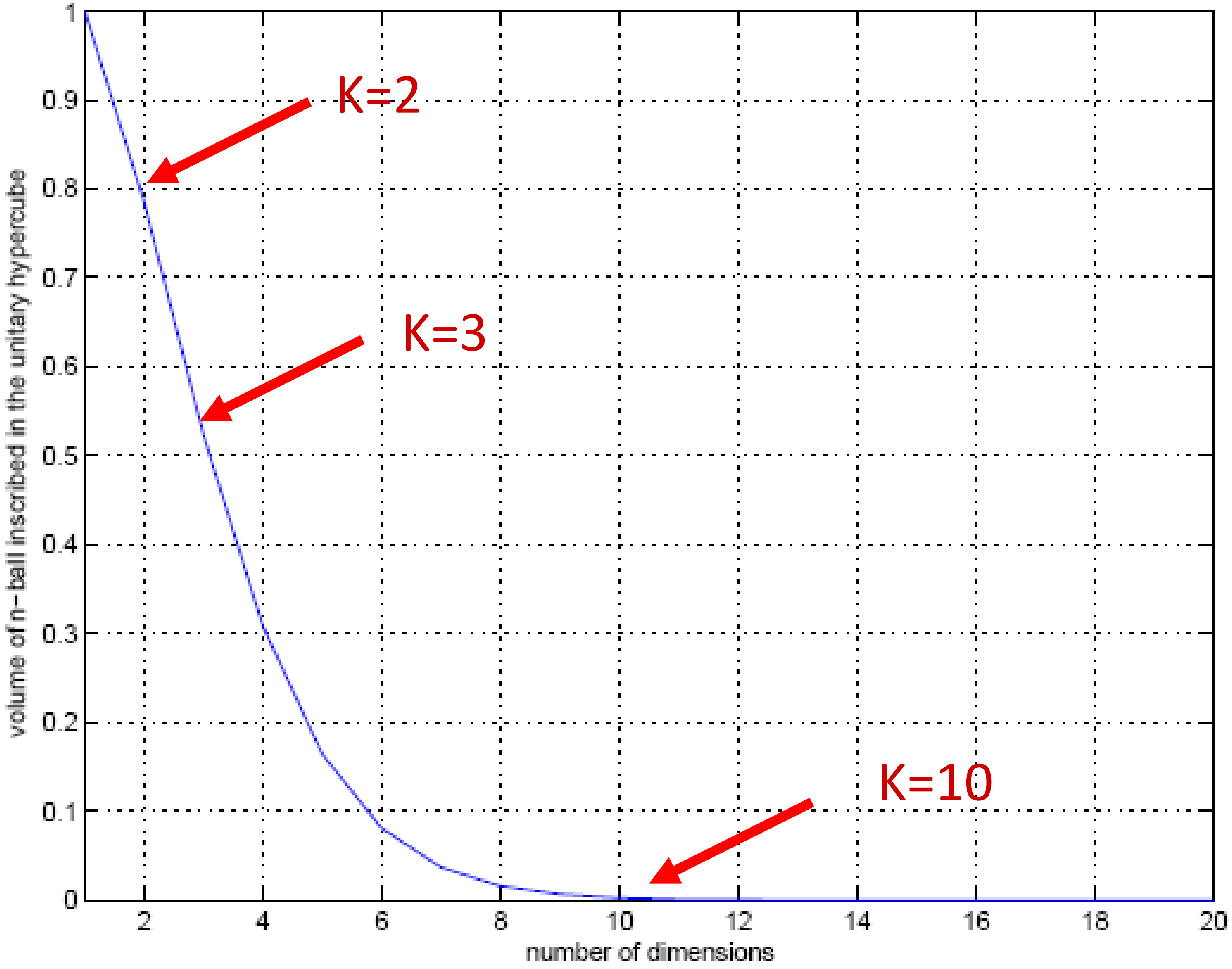
Volume sphere / volume cube =?

~ 1/2

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

~ 0.0025

OAT in k dimensions



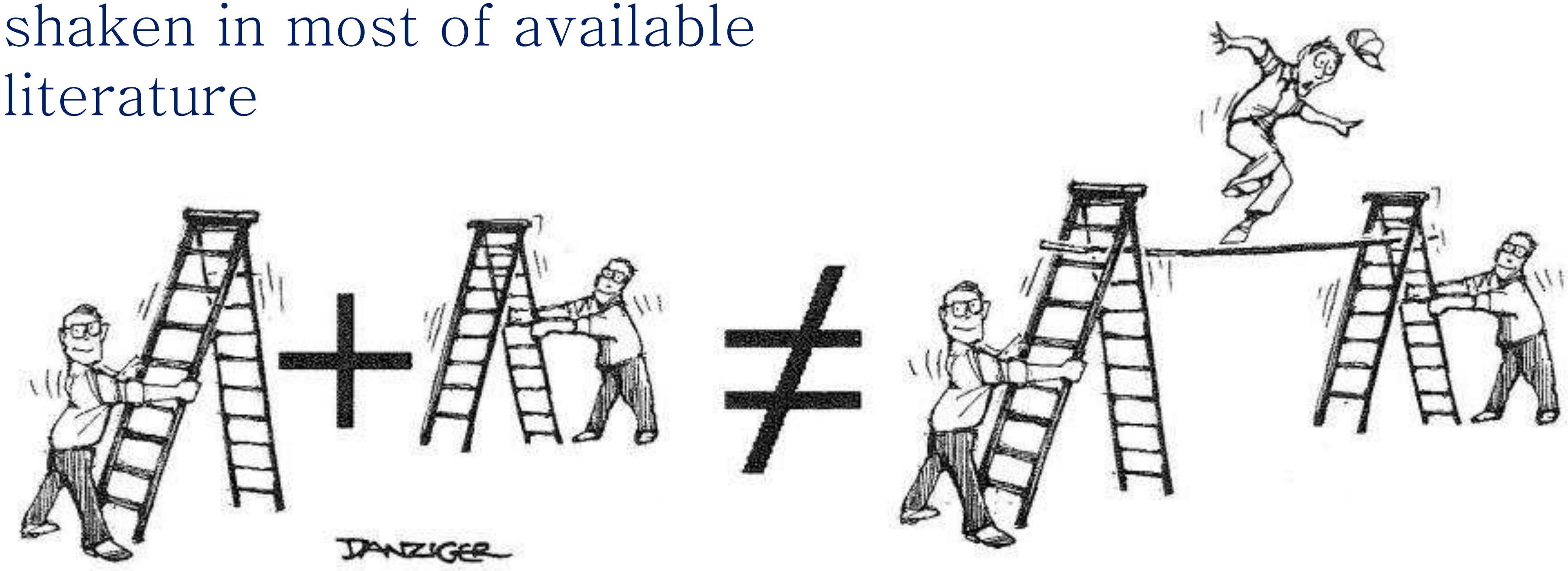
OAT does not capture interactions

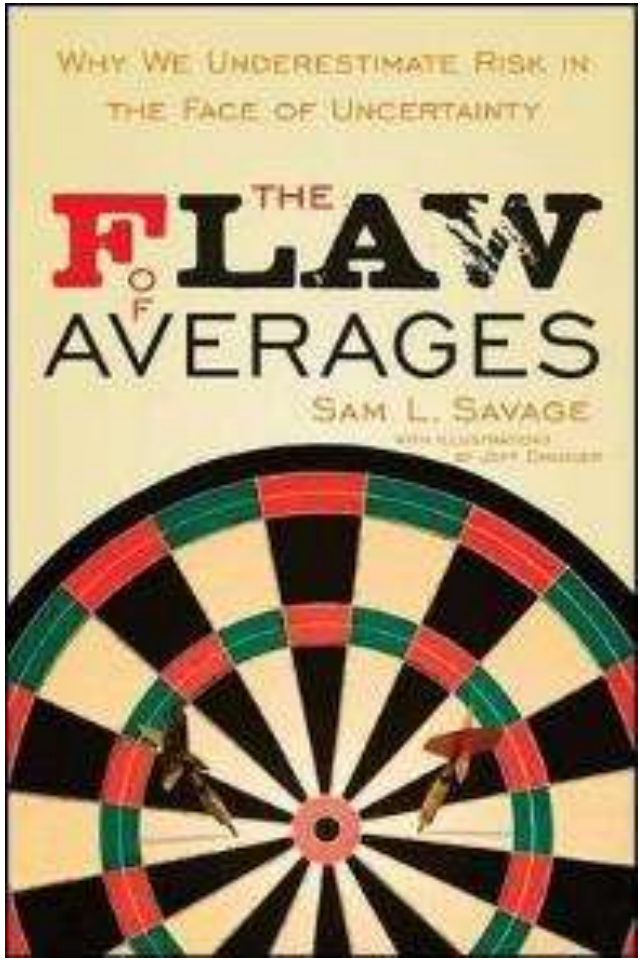
➔ The resulting analysis is non conservative

How would you test the scaffolding?

How coupled ladders are shaken in most of available literature

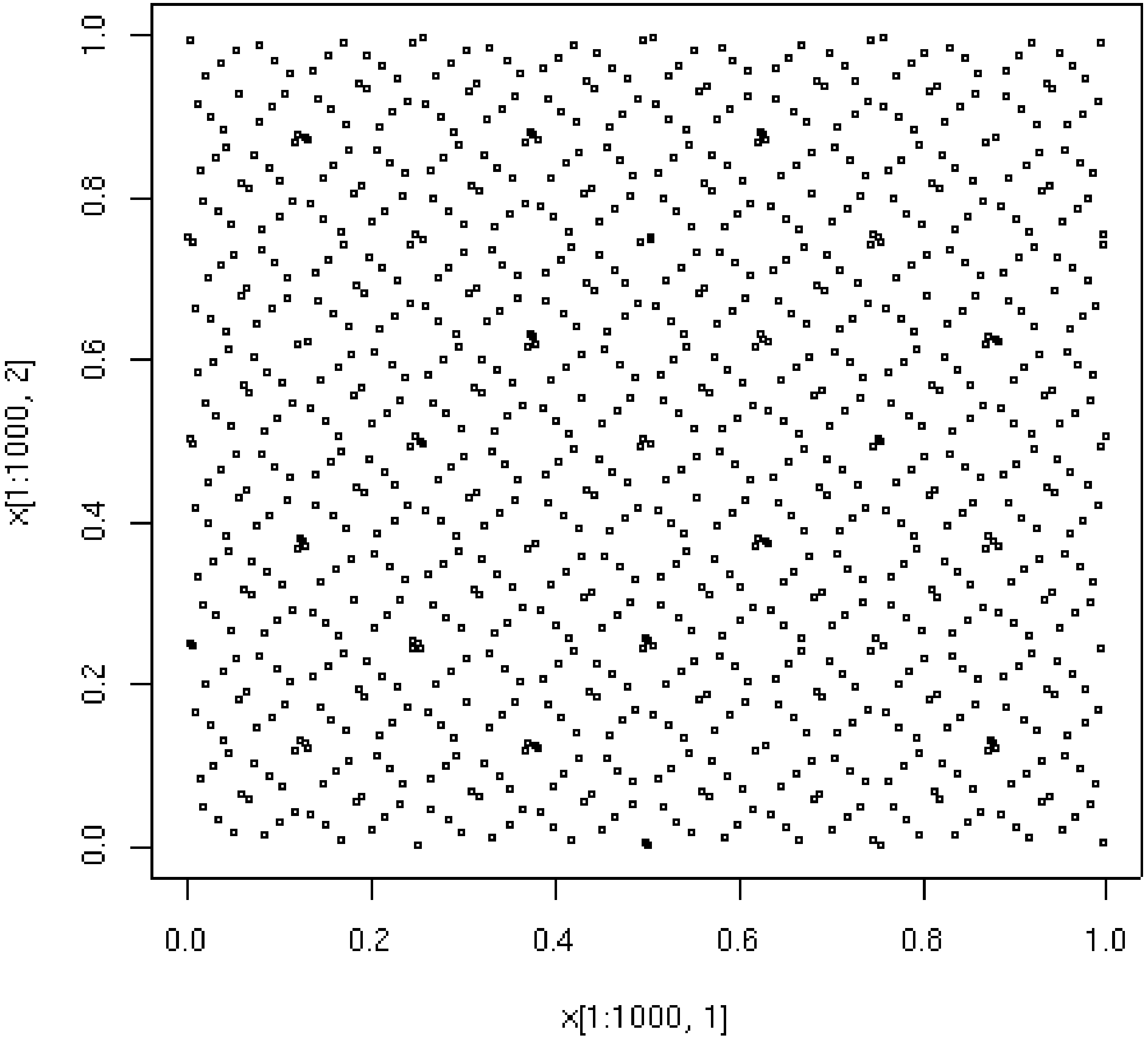
How to shake coupled ladders





Quasi random sequences

Ilya M. Sobol'



Cornell University

the

arXiv.org > stat > arXiv:1505.02350

Search...

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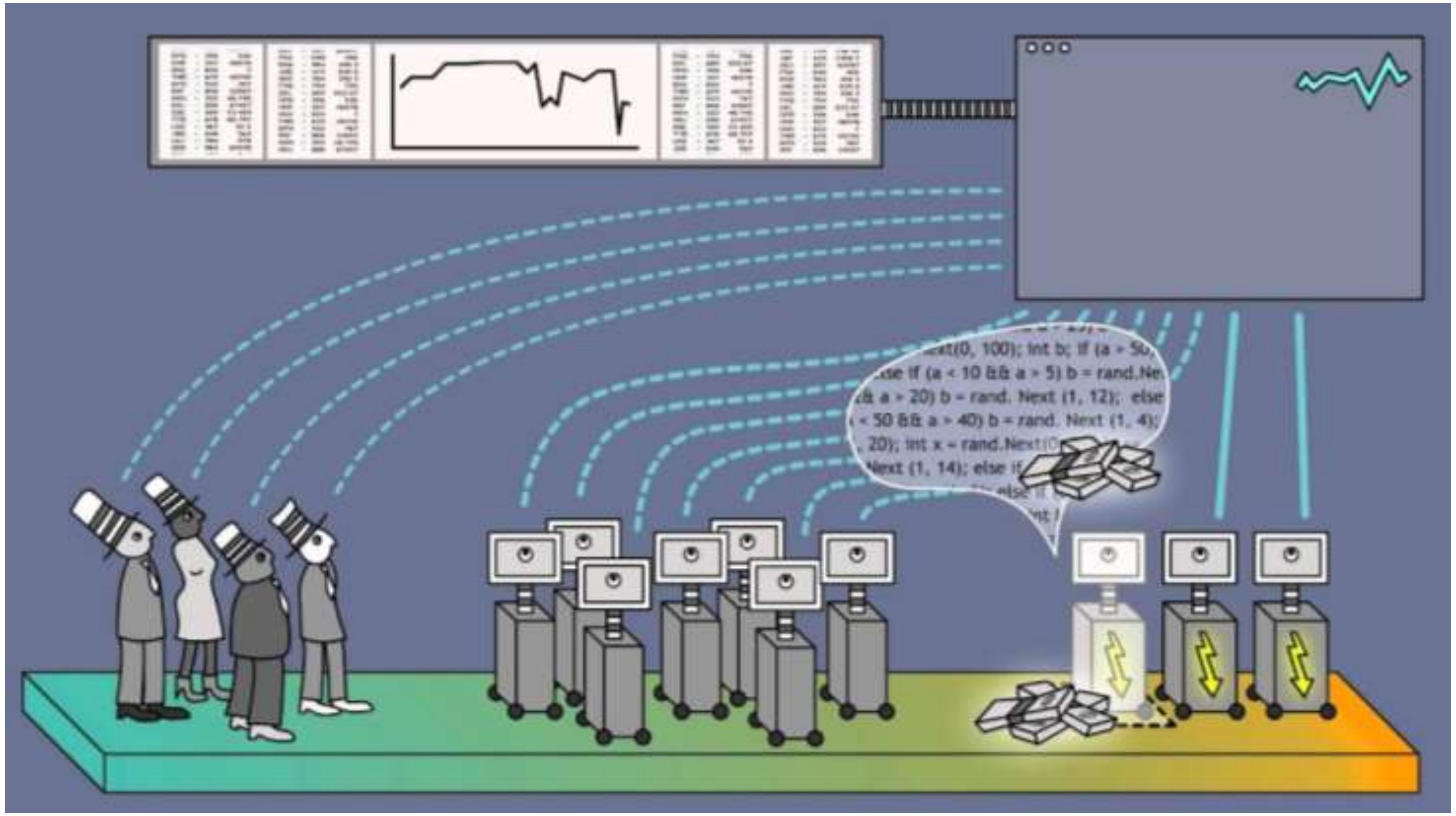
Statistics > Applications

[Submitted on 10 May 2015]

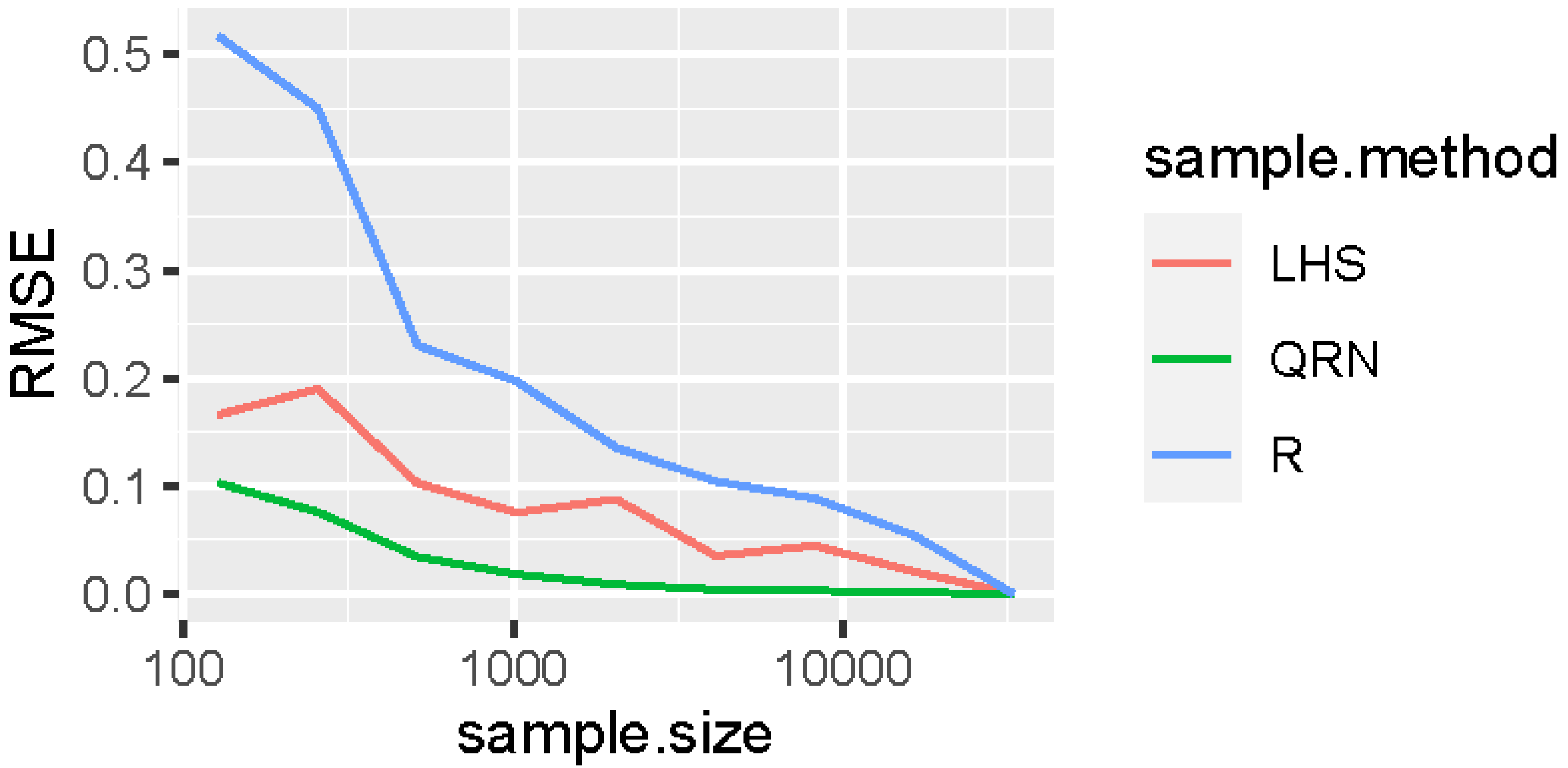
Exploring multi-dimensional spaces: a Comparison of Latin Hypercube and Quasi Monte Carlo Sampling Techniques

Sergei Kucherenko, Daniel Albrecht, Andrea Saltelli

Sobol' LP-TAU are used in high frequency trading



Source: https://www.youtube.com/watch?v=z4nCTdQlH8w



Root mean square error with different designs

Sensitivity analysis made easy

Cornell University

arXiv > stat > arXiv:2206.13470

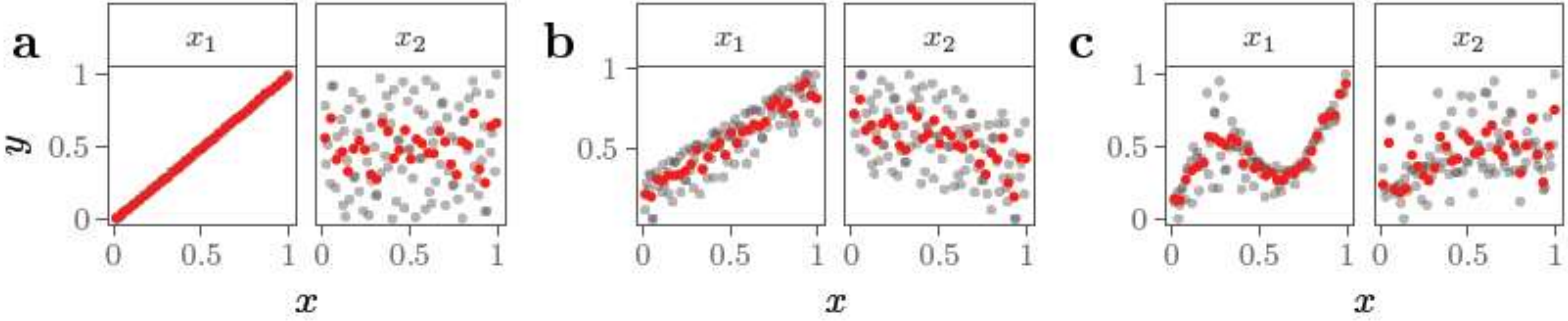
Statistics > Applications

[Submitted on 27 Jun 2022 (v1), last revised 17 Mar 2023 (this version, v2)]

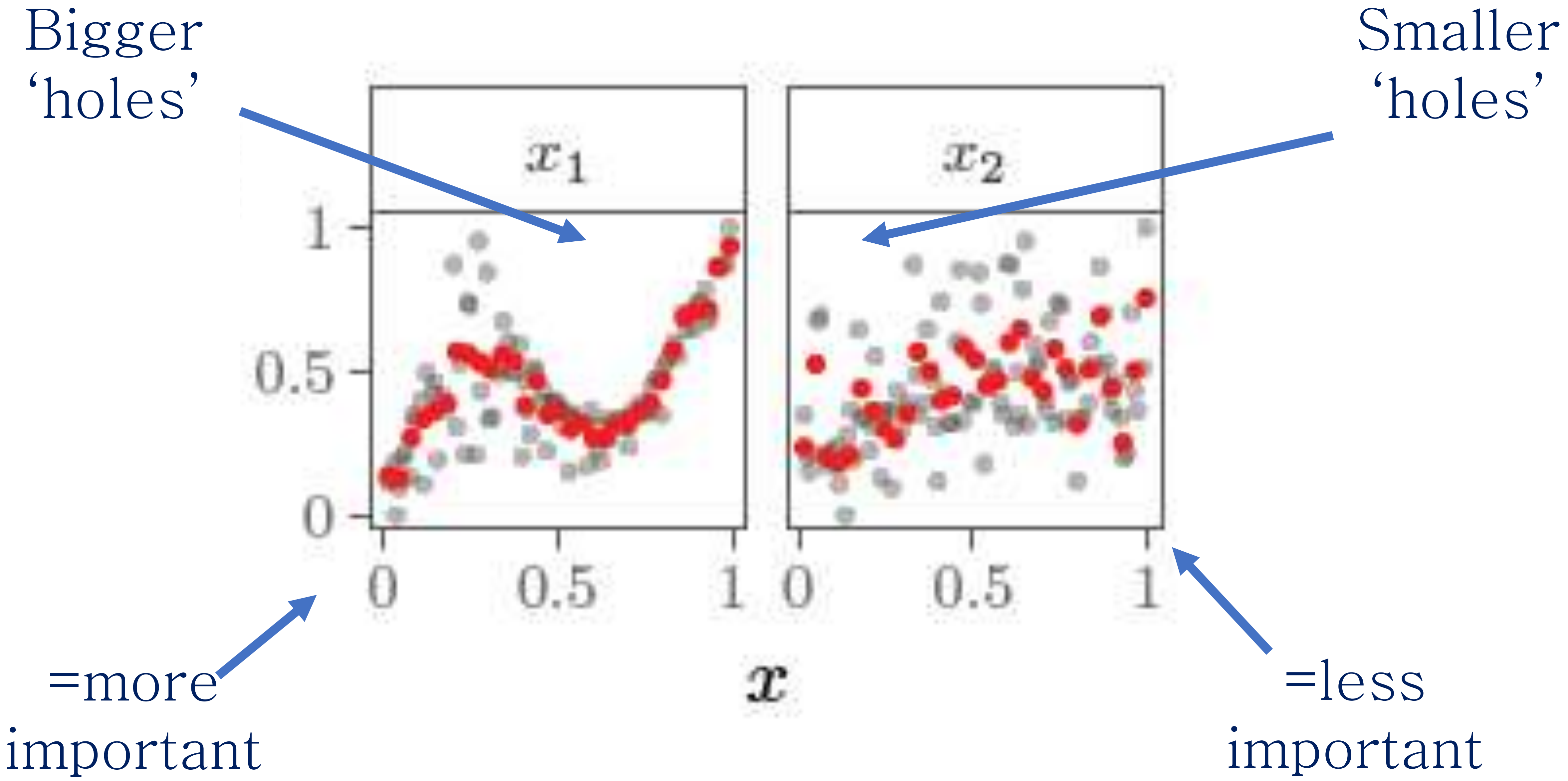
Discrepancy measures for sensitivity analysis

Arnald Puy, Pamphile T. Roy, Andrea Saltelli

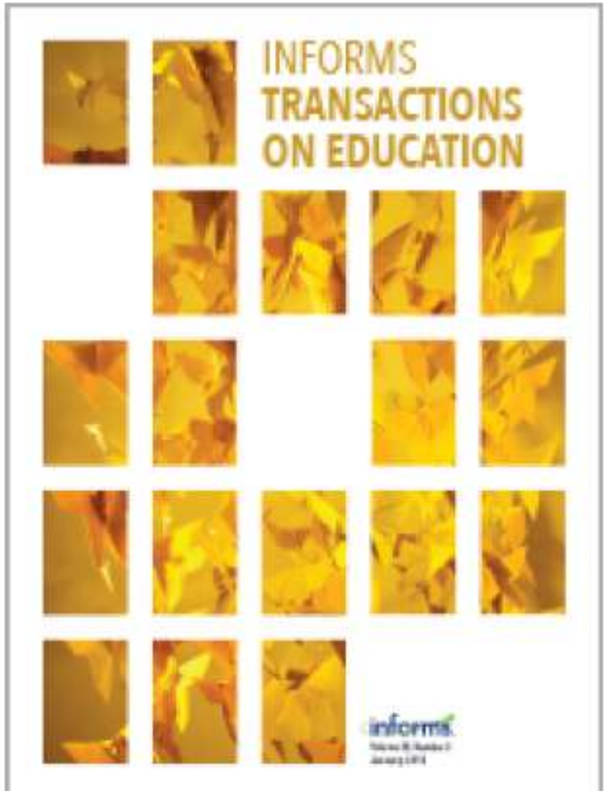
Do we need to compute indices?
Can we do without statistics and calculus using the histograms we have met already?



'Stupid' histograms in the
x_i, y plane, both in [0,1], for different $y = f(x_i)$


Bigger 'holes'
Smaller 'holes'
x_1
x_2
1
0.5
0
0
0.5
1
0
0.5
1
x
=more important
=less important

Another way to bypass statistics and calculus



INFORMS Transactions on Education

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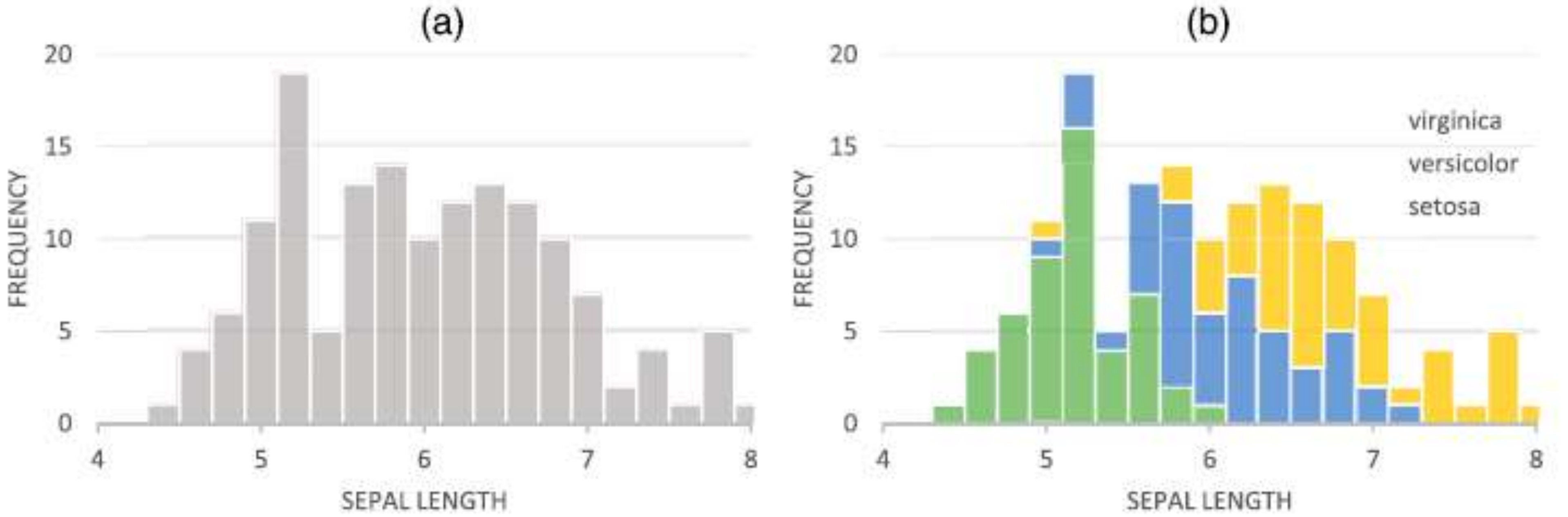
http://pubsonline.informs.org

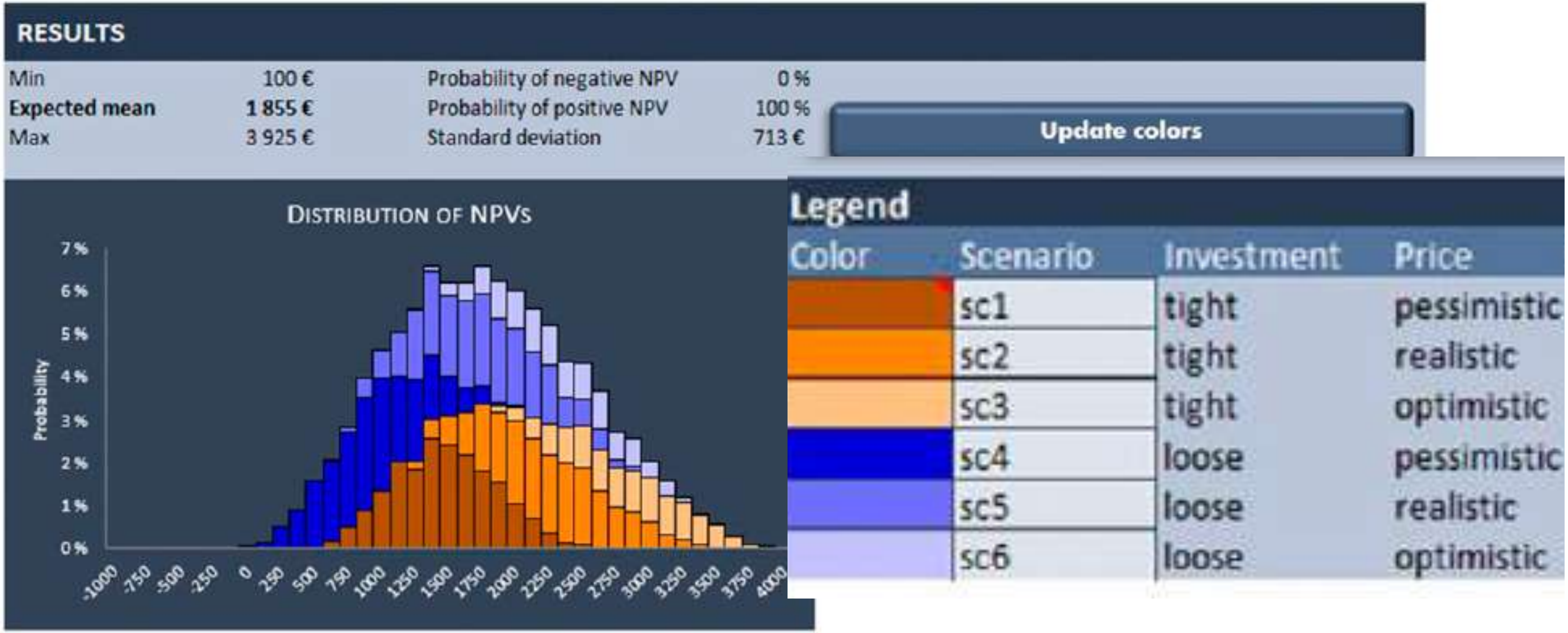
Monte Carlo Enhancement via Simulation Decomposition: A "Must-Have" Inclusion for Many Disciplines

Mariia Kozlova, Julian Scott Yeomans

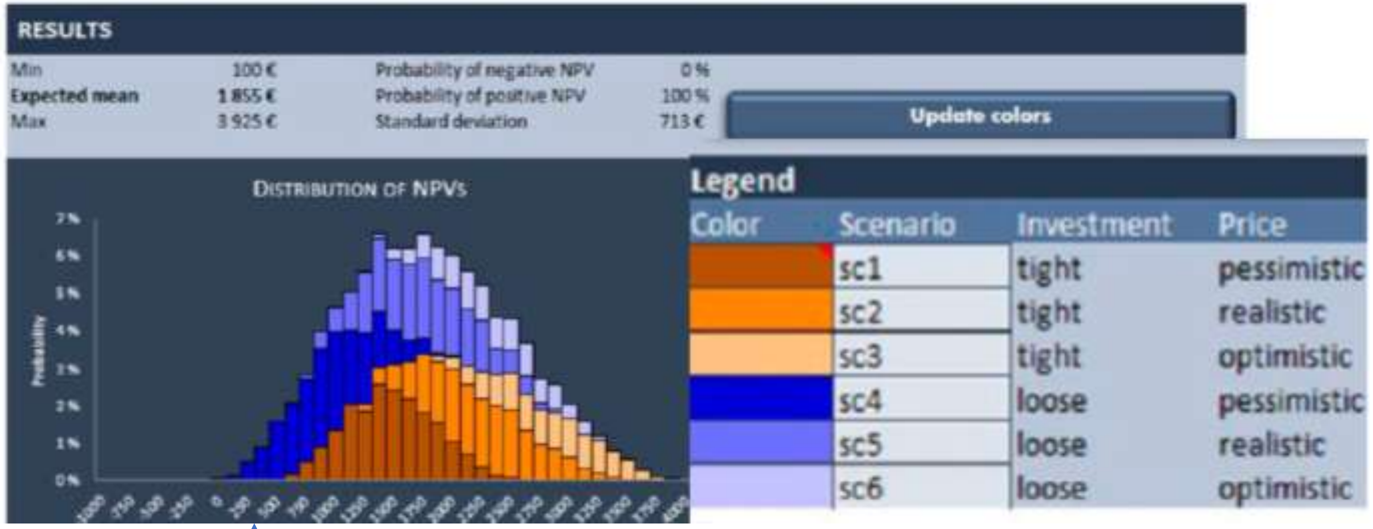
Colouring the output histogram can give sensitivity insights …



··· without computing sensitivity indices



… without computing sensitivity indices



What is done here? We have two variables / options:

- Investment= 'tight' or 'loose'
- Price='pessimistic', 'realistic' or 'optimistic'

Combing the 2 levels of investment with the three levels of price gives 2*3=6 'scenarios'

➔ The possibility of very low returns (dark blue) corresponds to loose investment and pessimistic prices

Don't run the model just once

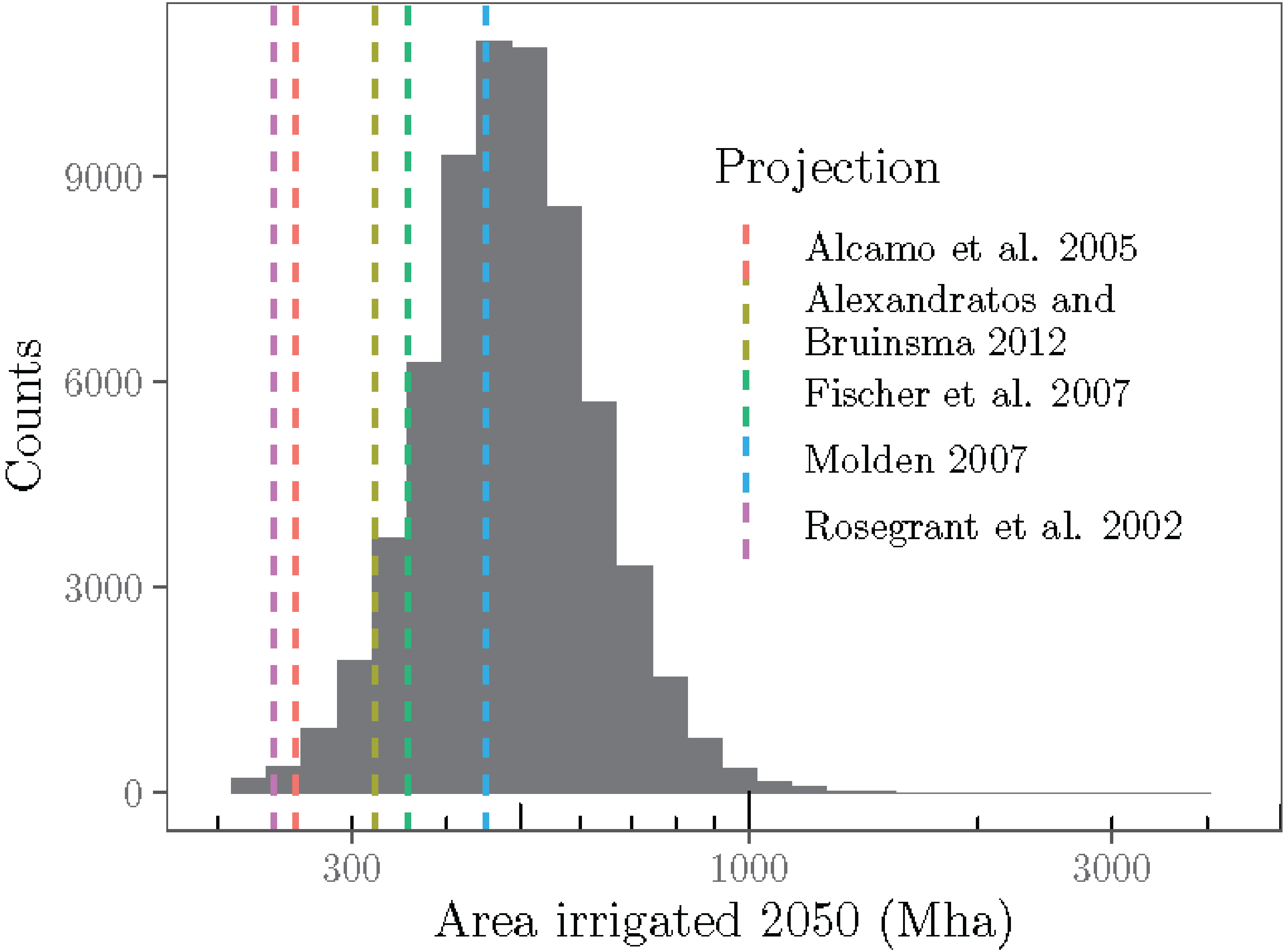
There is much to learn by running the model a few times, especially during model building

Lubarsky's Law of Cybernetic Entomology: there is always one more bug!

Model routinely used to produce point estimates may becomes non conservative when the uncertainty is plugged in

Current Models Underestimate Future Irrigated Areas

- How much land will need to be irrigated by the year 2050?
- Here the dashed lines represent deterministic model predictions from different models and datasets (from FAO & others organizations);
- An uncertainty analysis (grey histogram) reveals that the models are non-conservative: the need might be much larger



Citation:
Puy, A., Lo Piano, S., & Saltelli, A. (2020). Current models underestimate future irrigated areas. *Geophysical Research Letters*, *47*, e2020GL087360. https://doi.org/10.1029/2020GL087360

Don’t sample just parameters and boundary conditions

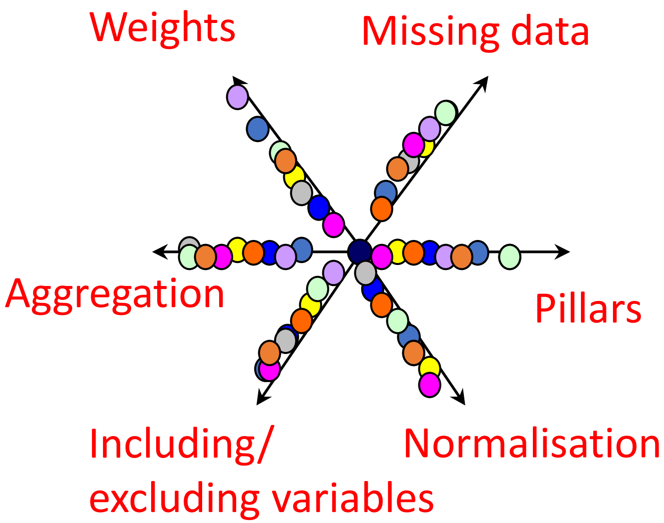
Explore thoroughly the space of the assumptions

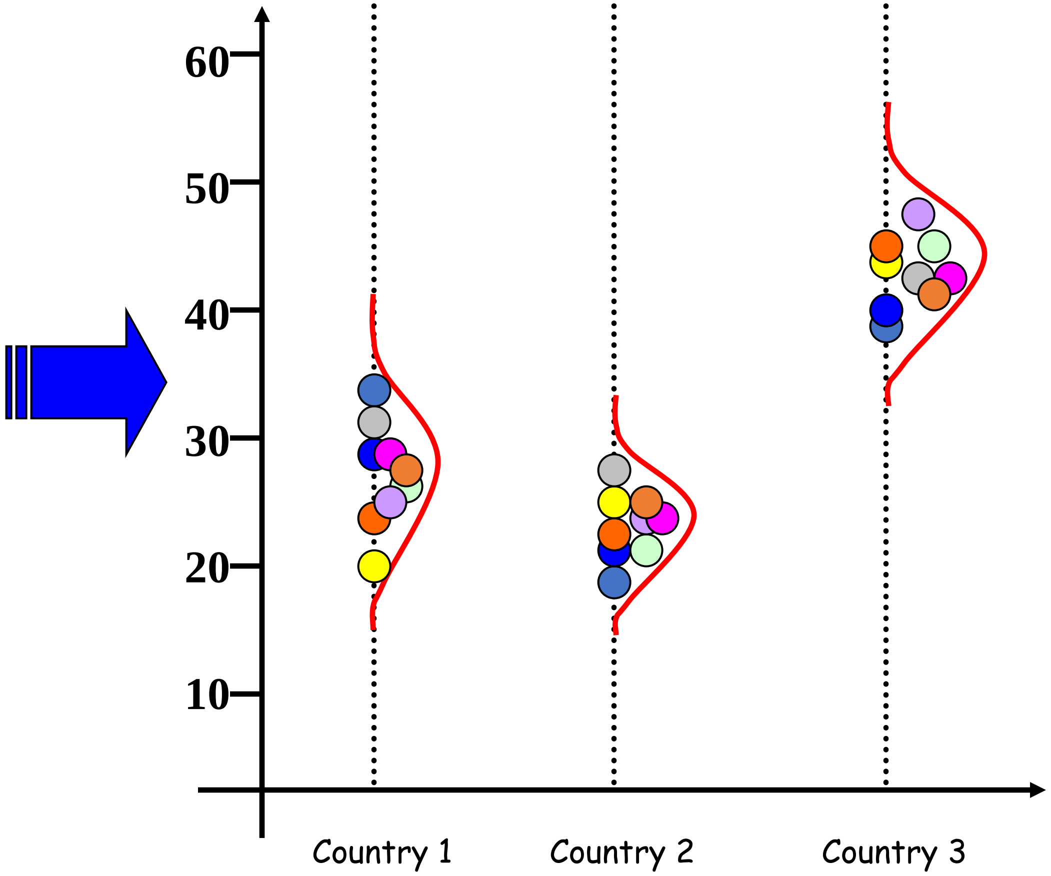
One can sample more than just factors:

- 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



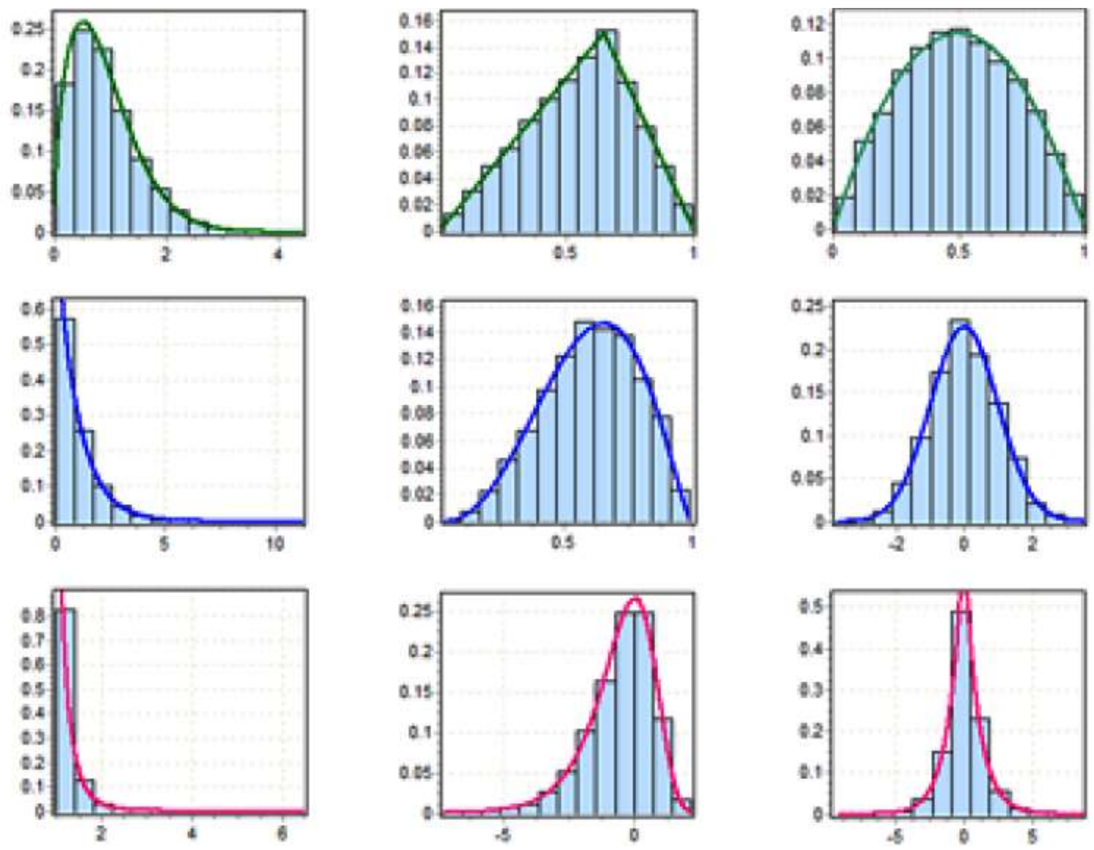


Building a Monte Carlo analysis

$$
\begin{array}{ccc}
x_{11} & x_{12\ldots} & x_{1k} \\
x_{21} & x_{22\ldots} & x_{2k} \\
\ldots & \ldots & \ldots \\
x_{N1} & x_{N2} & x_{Nk1}
\end{array}
$$

Input matrix: each column is a sample of size N from the distribution of a factor

Each row is a sample trial of size k to generate a value of y



Examples of distributions of input factors

upf. BARCELONA SCHOOL OF MANAGEMENT

NEVER vary all factors of the same amount

Be it 5%, 10%, or 20%

New WHO estimates: Up to 190 000 people could die of COVID-19 in Africa if not controlled

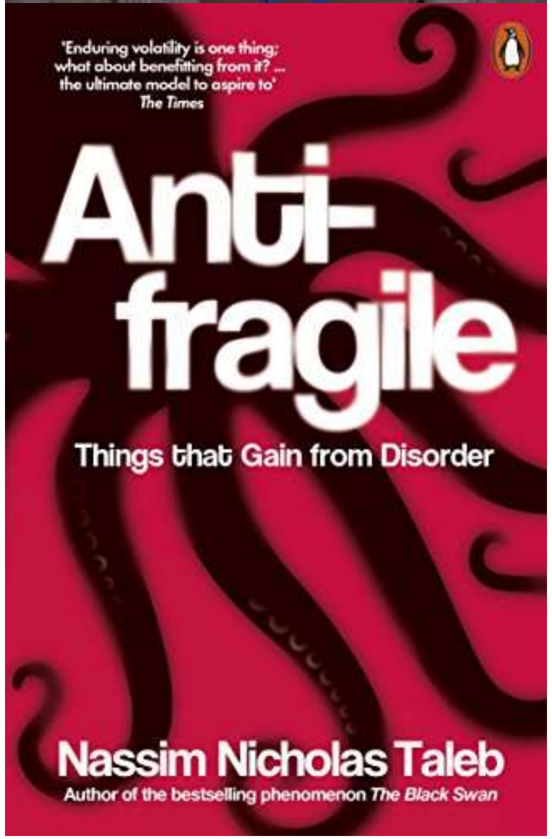
07 May 2020

Brazzaville – Eighty-three thousand to 190 000 people in Africa could die of COVID-19 and 29 million to 44 million could get infected in the first year of the pandemic if containment measures fail, a new study by the World Health Organization (WHO) Regional Office for Africa finds. The research, which is based on prediction modelling, looks at 47 countries in the

World Health Organization
REGIONAL OFFICE FOR Africa

Speculative scenario in which ten uncertain input probabilities are increased by an arbitrary 10% — as if they were truly equally uncertain — with no theoretical or empirical basis for such a choice

In a numerical experiment relating to a real-life application the range of uncertainty of each input is crucial input to the analysis, and often the most expensive to get



Suggested reading:

- Nassim N. Taleb's books, and his *via negativa,* the science of what is not;
- A paper on why most sensitivity analyses fail

ELSEVIER
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]

The End

https://mstdn.social/@AndreaSaltelli/