

# How not to do a sensitivity analysis



BARCELONA  
SCHOOL OF  
MANAGEMENT

Andrea Saltelli



Course MNF 990, October 18, 2022

# Where to find this talk: [www.andreasaltelli.eu](http://www.andreasaltelli.eu)

The logo for Andrea Saltelli, featuring the name "Andrea Saltelli" in white text on a teal rectangular background.[HOME](#)[ABOUT ME](#)[PUBLICATIONS](#)[NEWS & VIDEOS](#)[RESOURCES](#)A large background image showing terraced agricultural fields on a hillside, with mountains in the distance under a hazy sky.

CAETERIS ARE  
NEVER PARIBUS

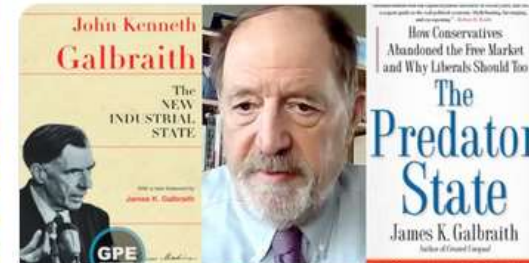
Tweets by [@AndreaSaltelli](#)



**andrea saltelli**  
[@AndreaSaltelli](#)

Worth listening all; pay heed to the bit at 31'.50".  
Why economics needs to pay heed to its  
biophysical bases [@ICTA\\_UAB](#) [@g\\_kallis](#)

Resource Limits to American Capitalism & the  
Predator State Today - % % [GPEnewsdocs.com](#)  
% [gpenewsdocs.com/resource-limit...](#)



**Resource Limits to American Capitalis...**

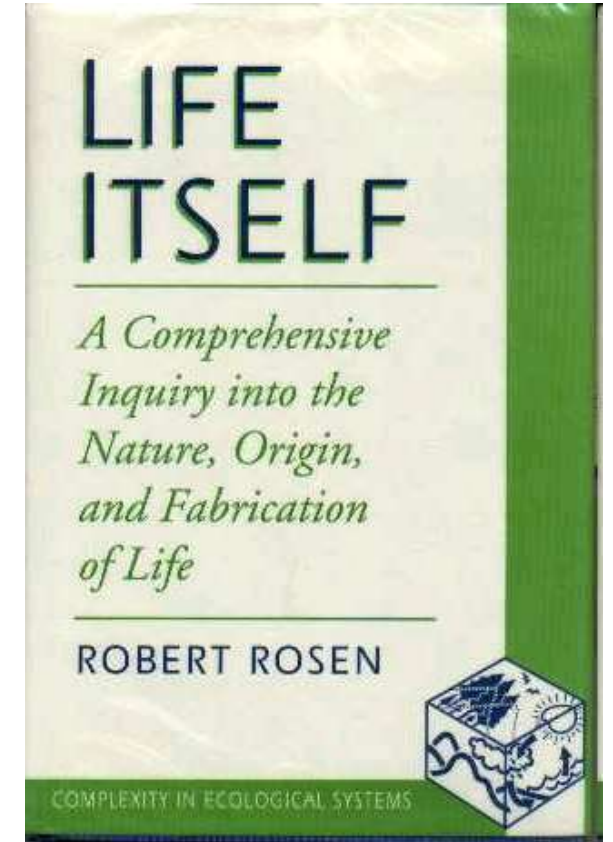
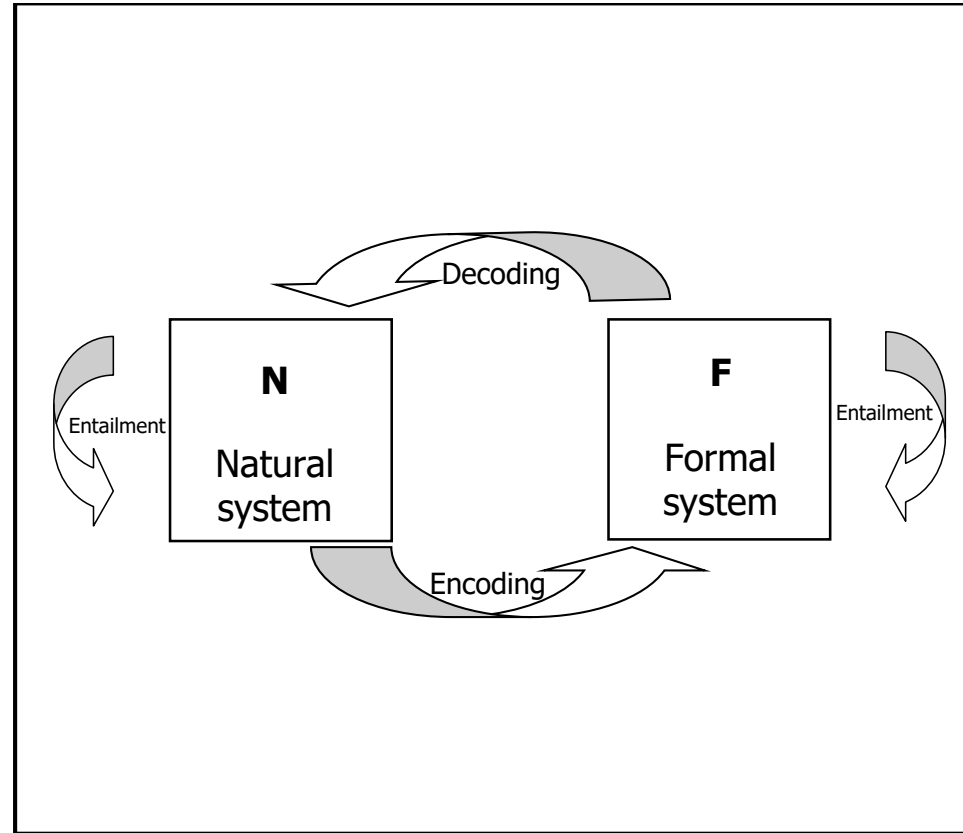
James K. Galbraith discusses the shift of ...  
[gpenewsdocs.com](#)

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Something general about  
mathematical modelling

Modelling is a  
craft more than  
a science

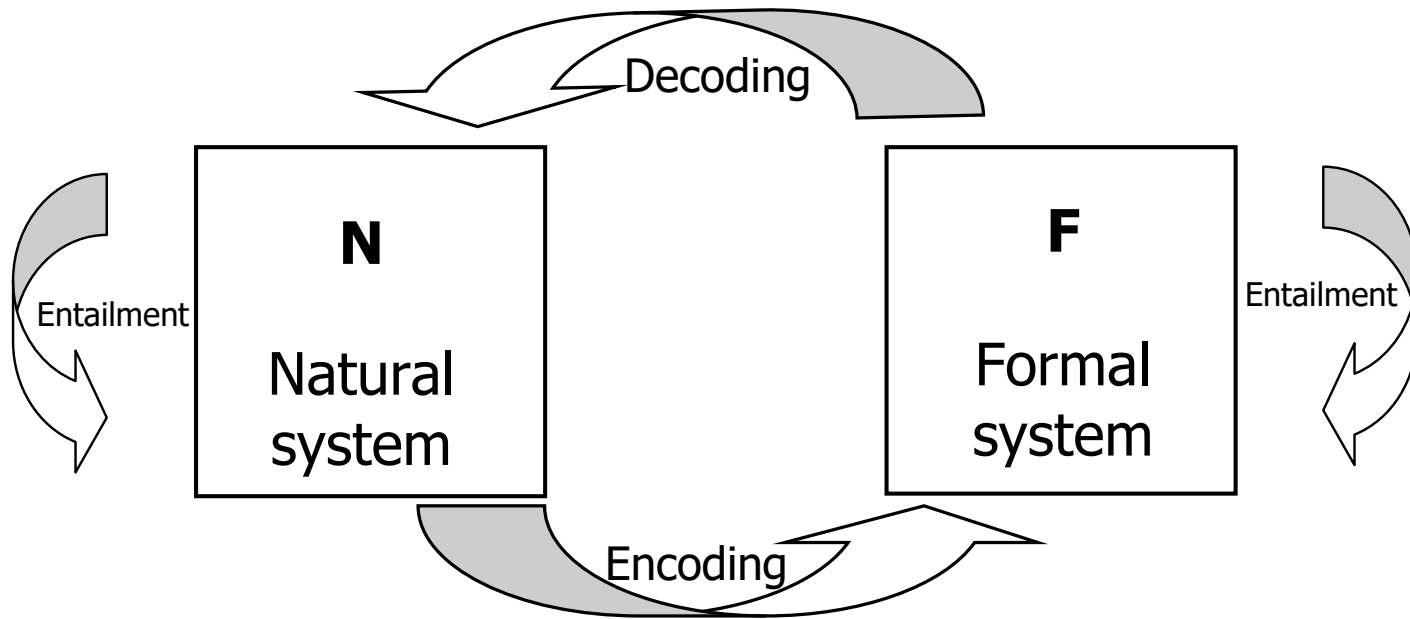
# Modelling as a craft rather than as a science for Robert Rosen



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

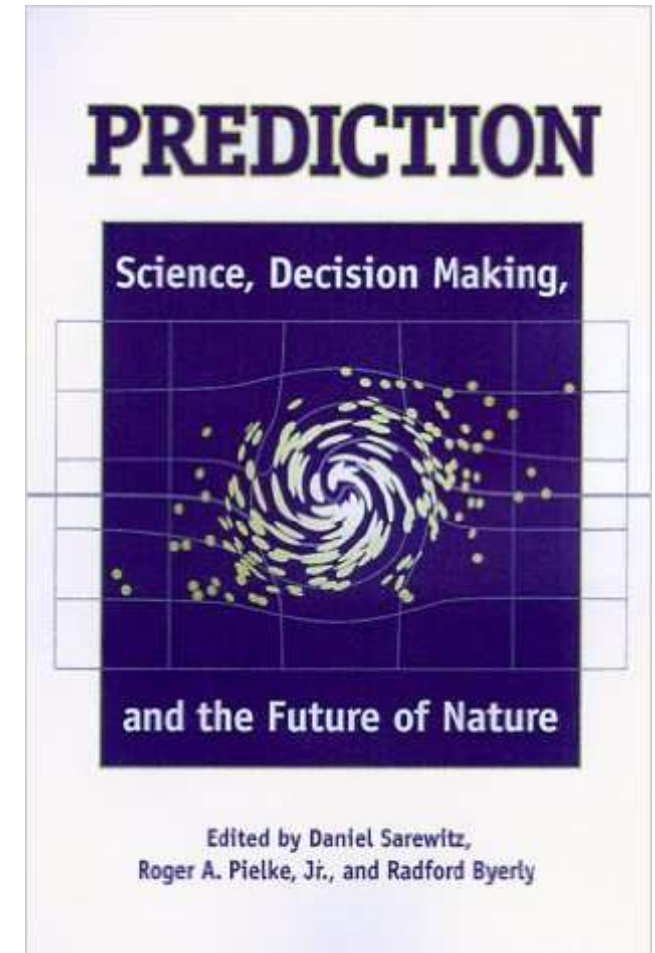
“models are most useful when they are used to challenge existing formulations, rather than to validate or verify them”



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.

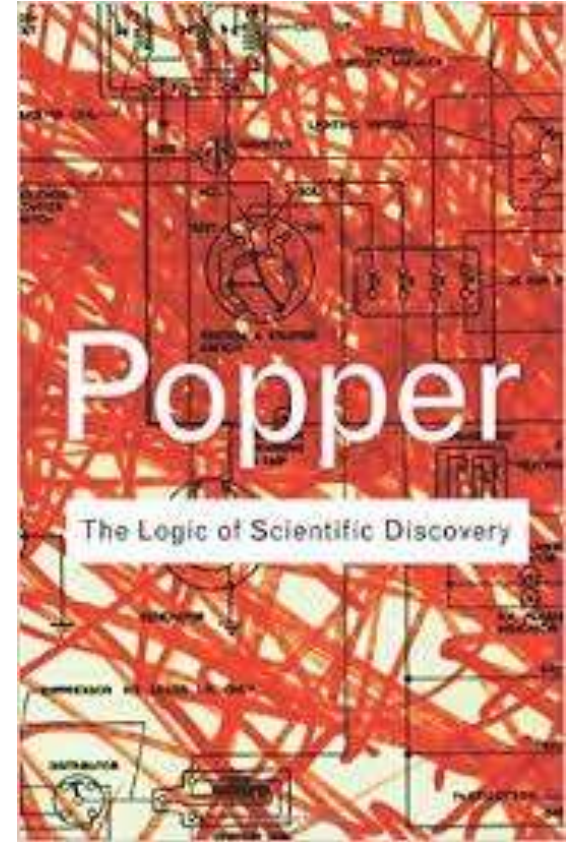
# Models are not physical laws



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 is a Latin phrase meaning "all other things being equal" or "other things held constant" or "all else unchanged" (Wikipedia)



# The case of DSGE, dynamic stochastic general equilibrium models

Rational expectations of agents  
Efficient market hypothesis

Philip Mirowski

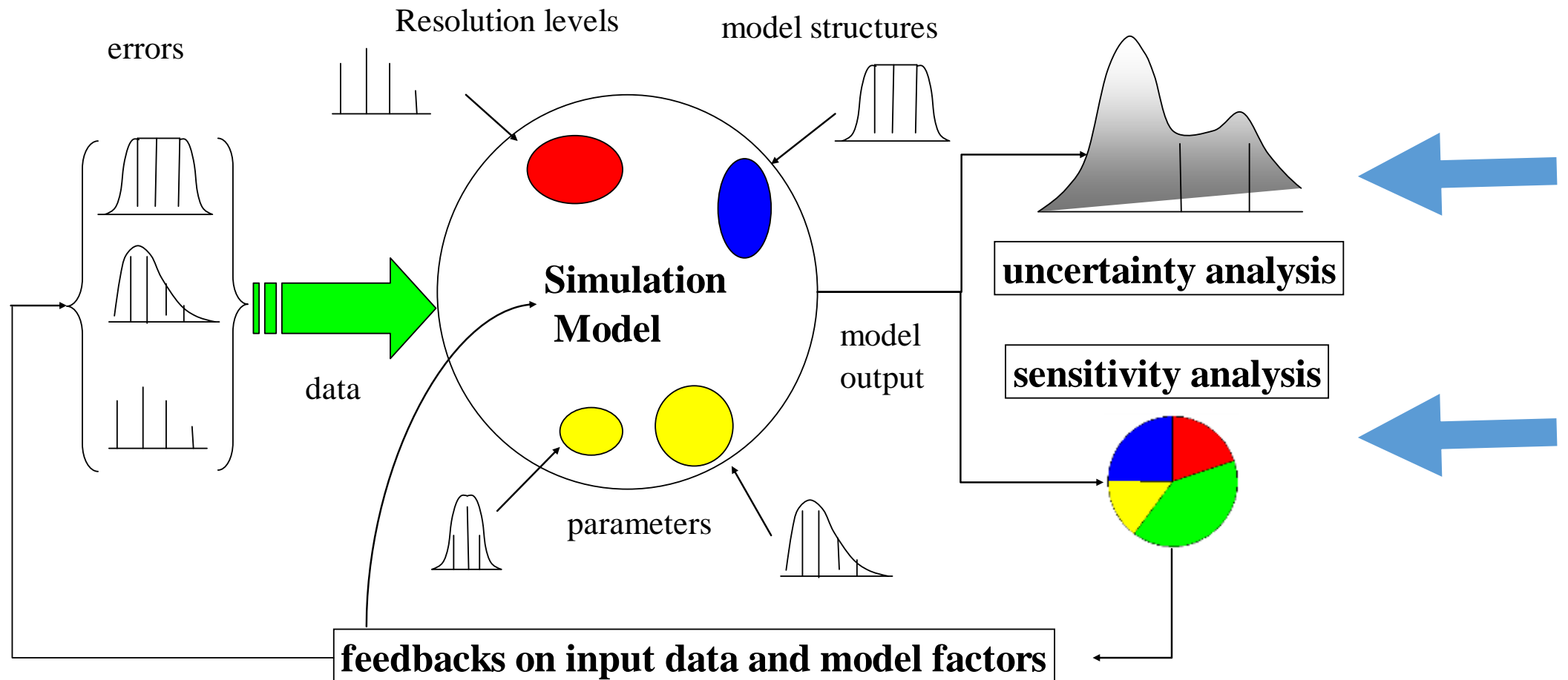


Philip Mirowski, 2013, Never let a serious crisis go wasted, Verso Books.

The US senate and Queen Elisabeth perplexed...



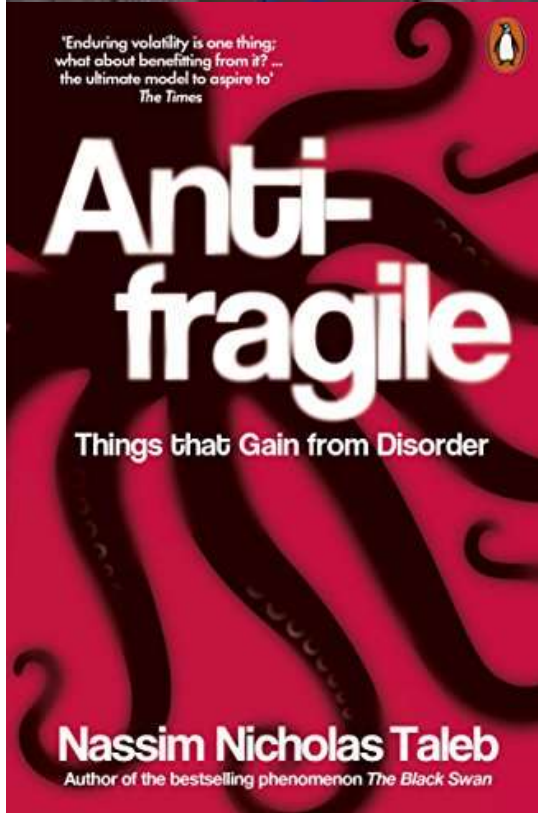
Philip Mirowski, 2013, Never let a serious crisis go wasted, Verso Books.







# A short trip through sensitivity analysis borrowing N. N. Taleb's *via negativa*



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 <sup>a, b</sup>  , Ksenia Aleksankina <sup>c</sup>, William Becker <sup>d</sup>, Pamela Fennell <sup>e</sup>, Federico Ferretti <sup>d</sup>,  
Niels Holst <sup>f</sup>, Sushan Li <sup>g</sup>, Qiongli Wu <sup>h</sup>

# Don't use just any method

Use the method appropriate to context and purpose



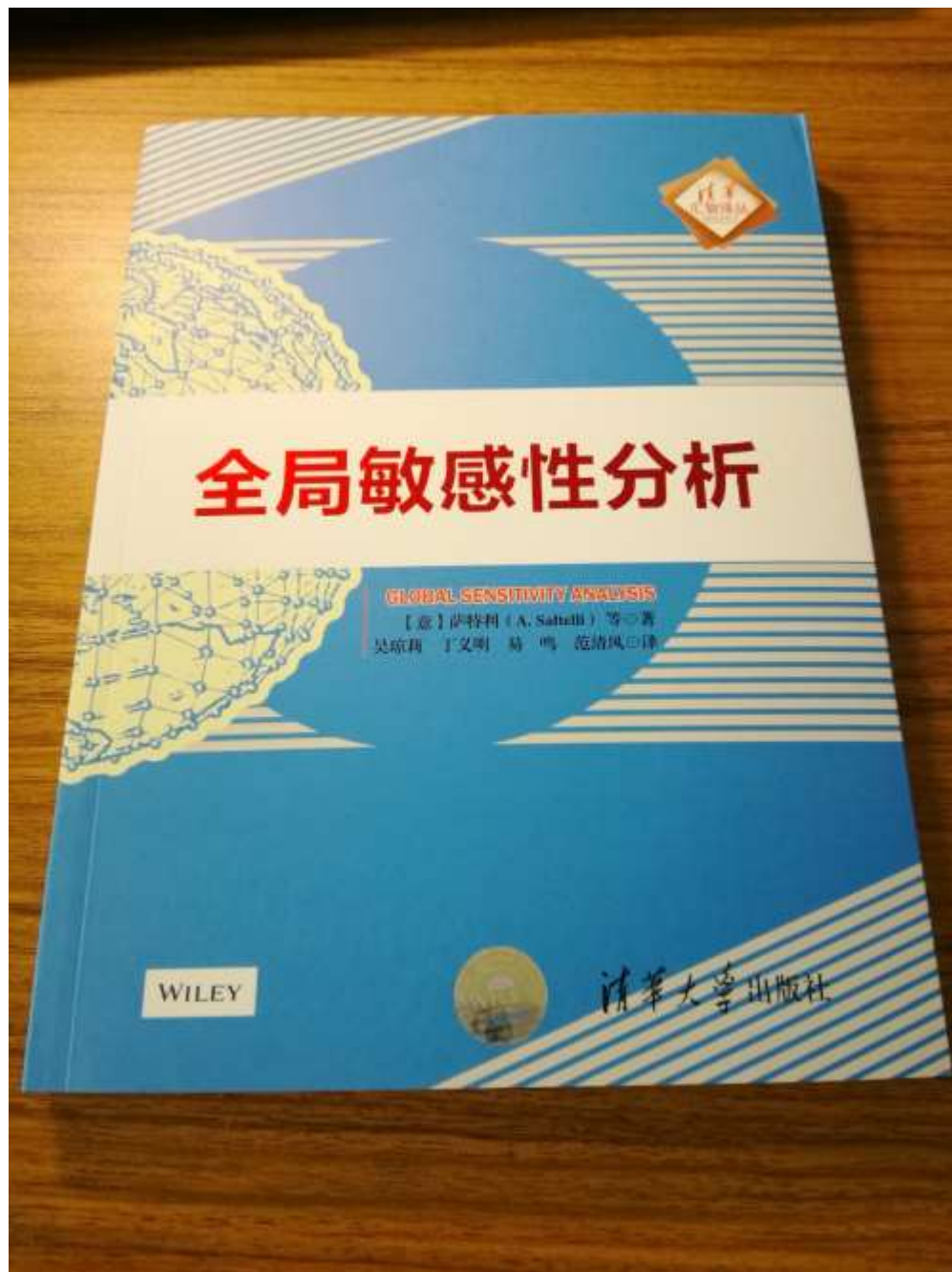
# An introduction to variance based methods

A. Saltelli, M. Ratto,  
T. Andres, F. Campolongo,  
J. Cariboni, D. Gatelli,  
M. Saisana, S. Tarantola

# GLOBAL SENSITIVITY ANALYSIS

The Primer

 WILEY





A. Saltelli, M. Ratto,  
T. Andres, F. Campolongo,  
J. Cariboni, D. Gatelli,  
M. Saisana, S. Tarantola

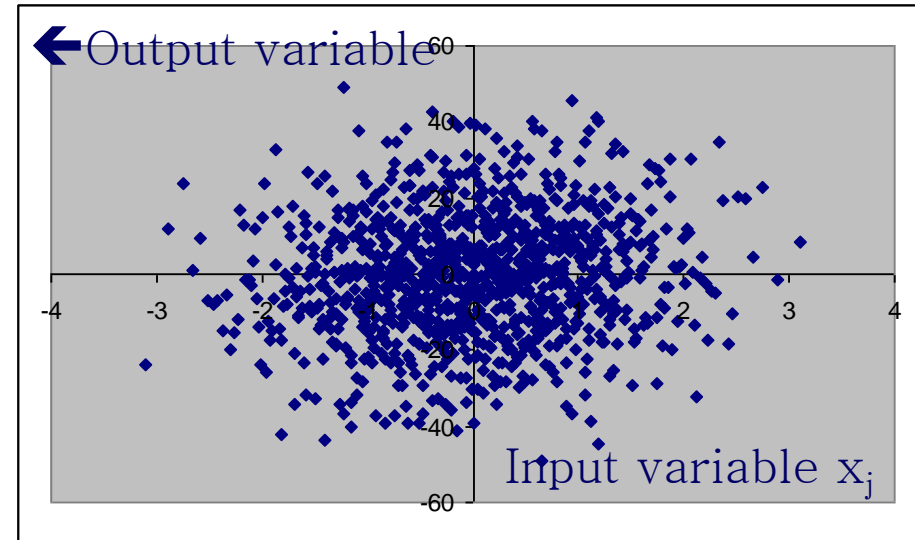
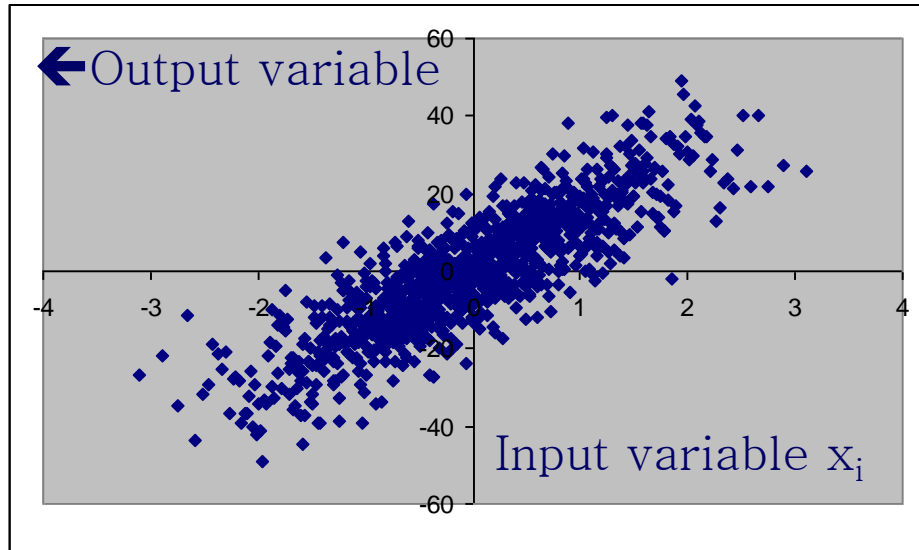
# GLOBAL SENSITIVITY ANALYSIS

The Primer

 WILEY

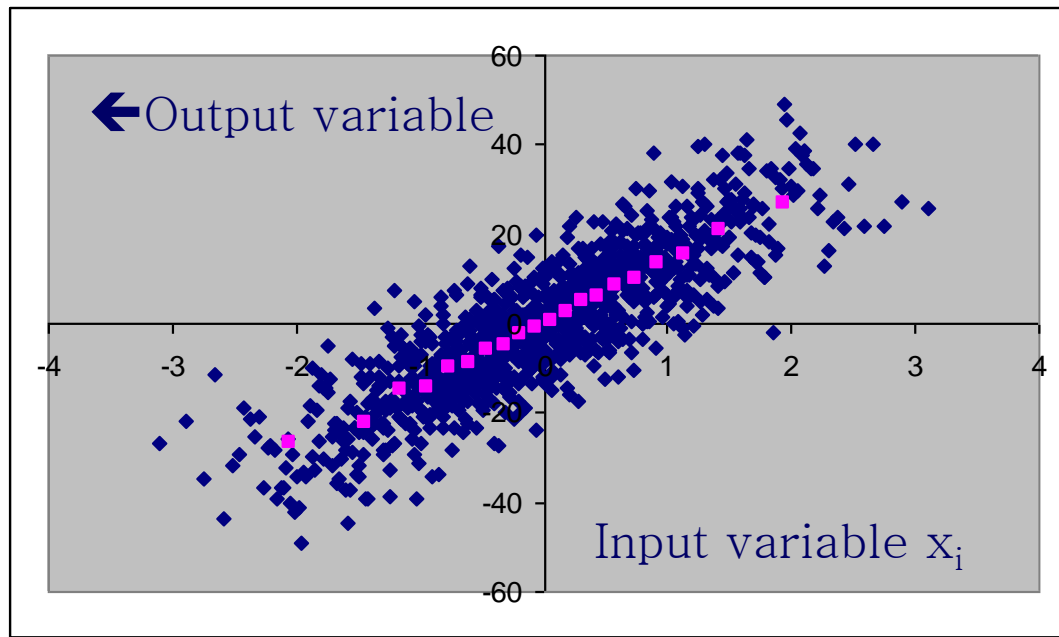
Available for free at

<http://www.andreasaltelli.eu>



Plotting the output as a function of two different input factors

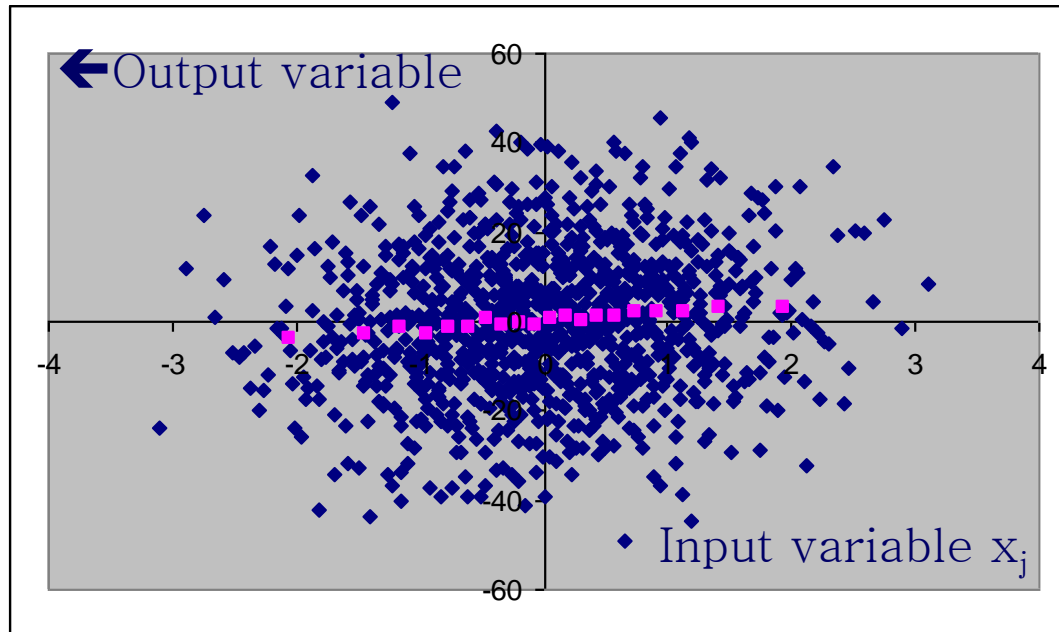
Which factor is more important?



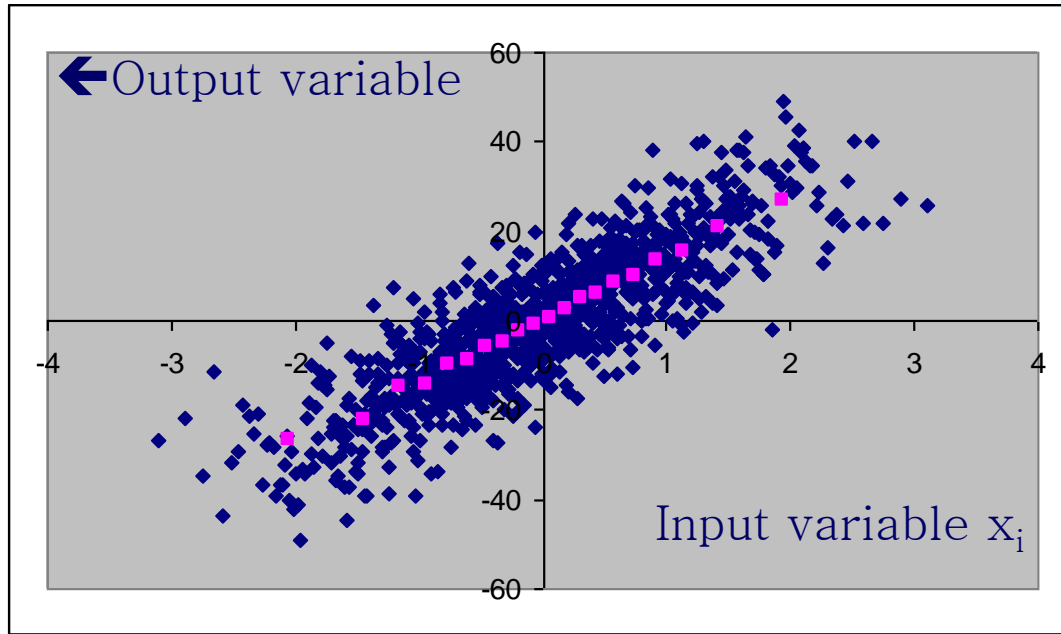
~1,000 blue points

Divide them in 20 bins of ~ 50 points

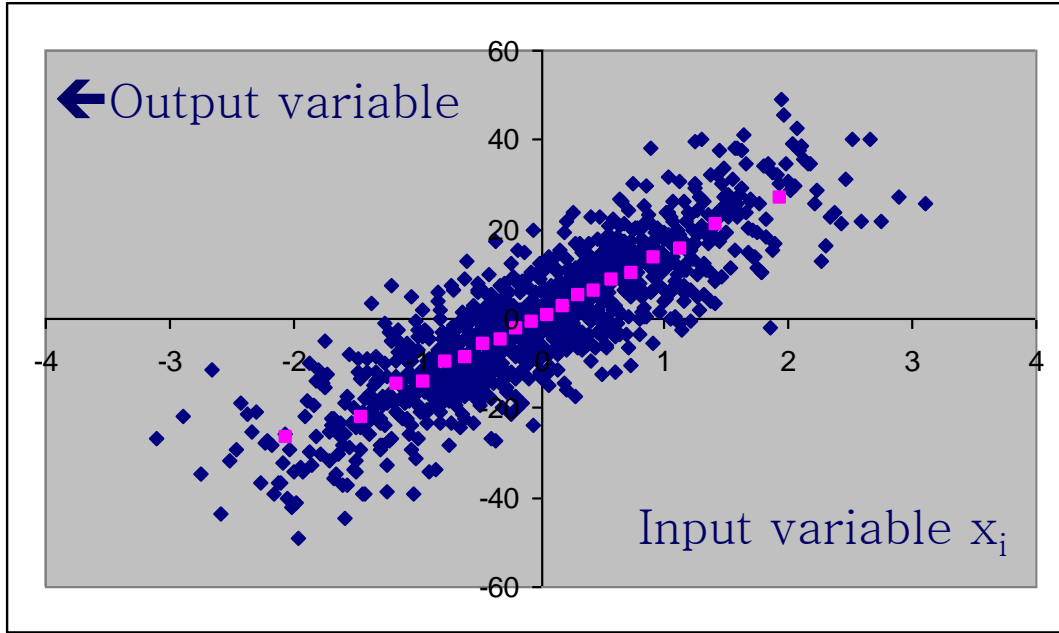
Compute the bin's average (pink dots)





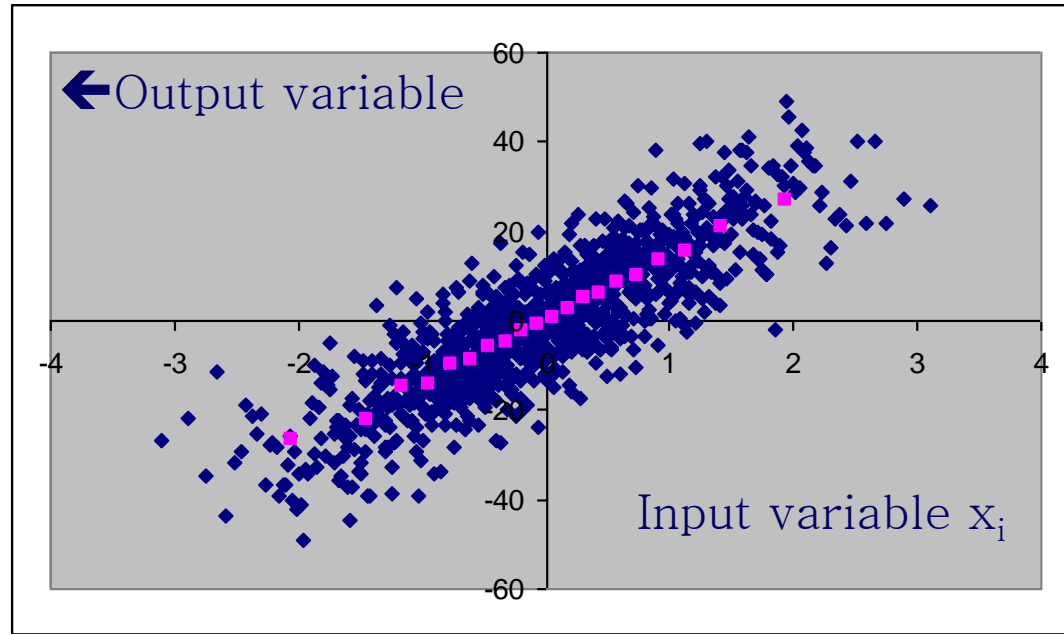


Each pink point is  $\sim E_{\mathbf{x}_{\sim i}}(Y|X_i)$

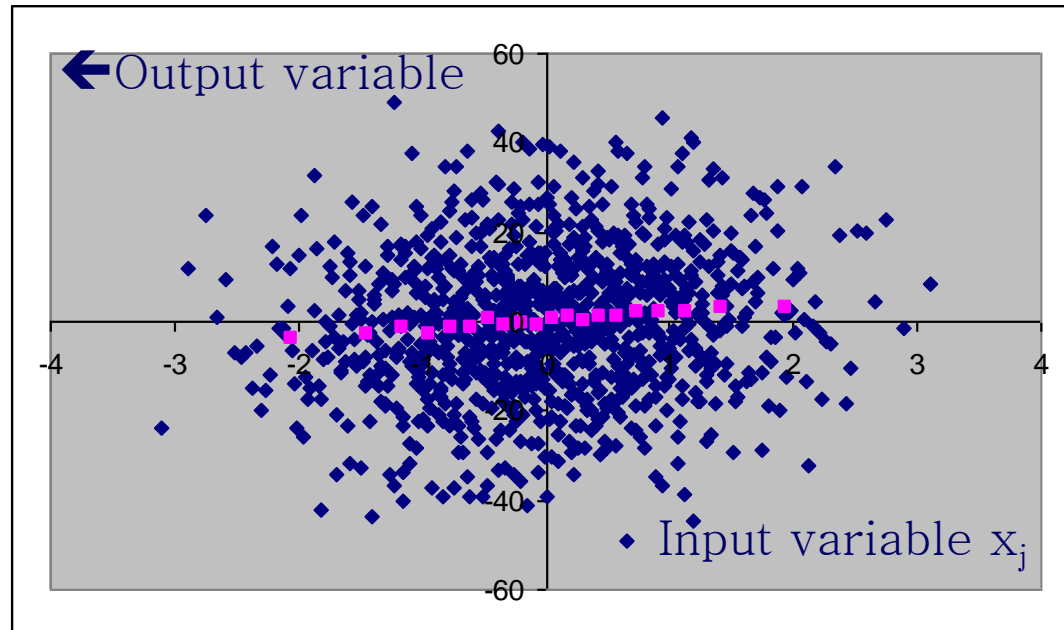


Take the variance of  
the pink points one  
obtains a sensitivity  
measure

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



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



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

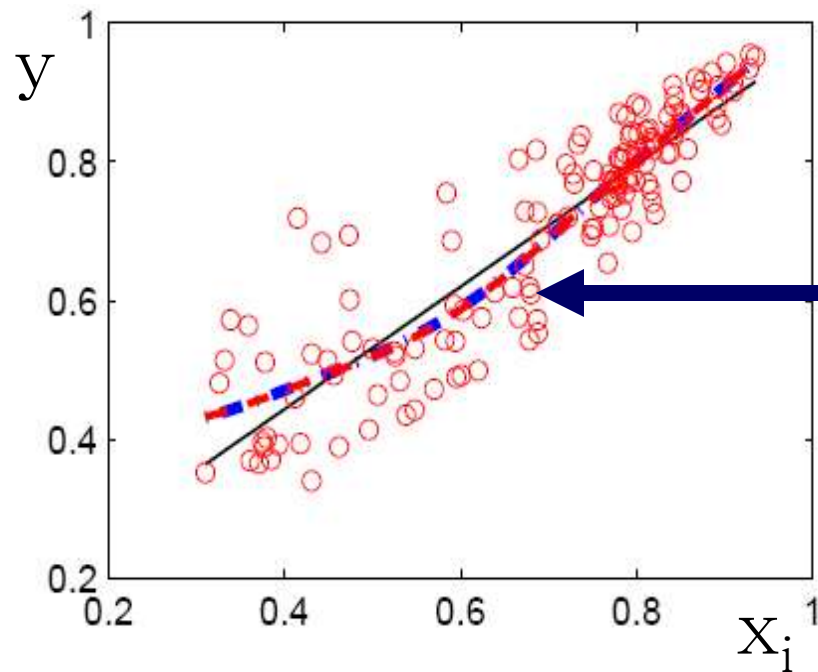
$$\sum_i V_{X_i} \left( E_{\mathbf{X}_{\sim i}} (Y | X_i) \right) \approx V(Y)$$

... which is also how additive models are defined

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

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:

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

First order  
sensitivity index:

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

Pearson's correlation  
ratio

Smoothed curve

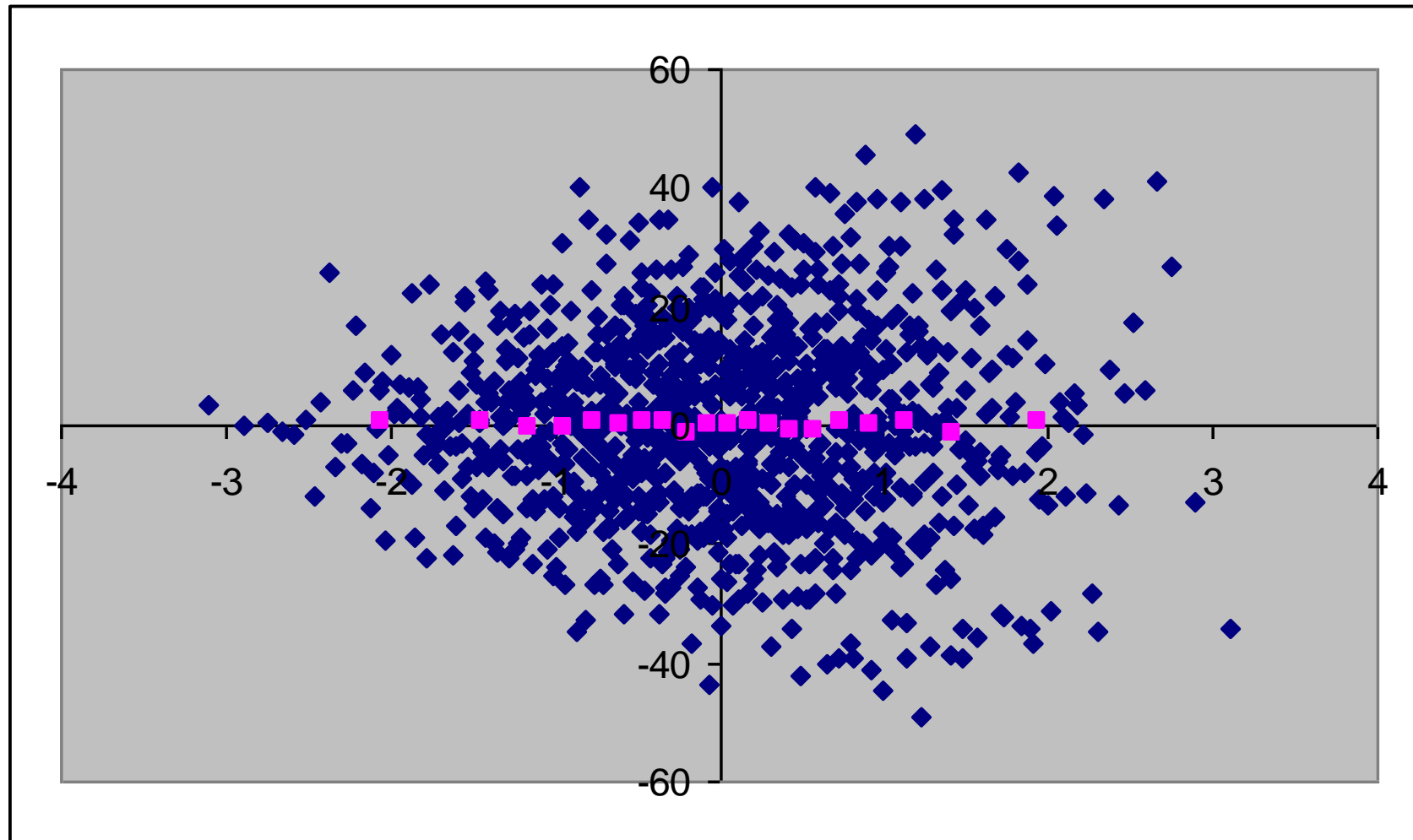
$$S_i \equiv \eta_i^2 := \frac{V_{x_i} (\mathbf{E}_{\mathbf{x}_{\sim i}} (y \mid x_i))}{V(y)}$$

First order sensitivity index

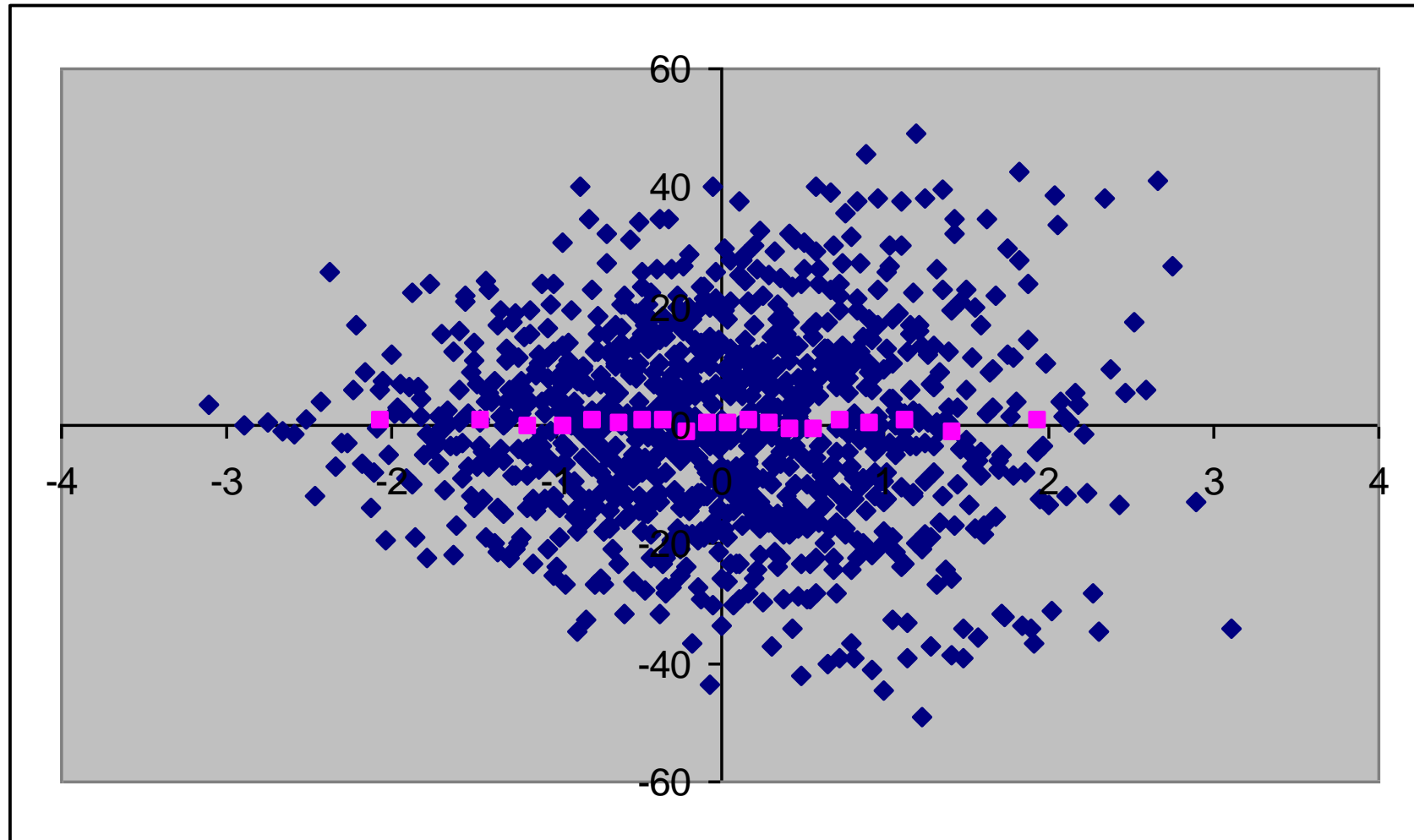
Unconditional  
variance

Non additive models

Is  $S_i = 0$ ?



Is this factor non-important?



There are terms which capture  
two-way, three way,  $\cdots$  interactions  
among variables

All these terms are linked by a  
formula



# Variance decomposition (ANOVA)

$$V(Y) =$$

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

# 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  $k(k-1)/2 \dots$

(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  $f(X_1, X_2, \dots, X_3)$

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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979

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CrossRef citations  
to date

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Altmetric

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)





# Making best use of model evaluations to compute sensitivity indices

Andrea Saltelli  

Computing the  
indices  
efficiently

## 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 Python



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

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



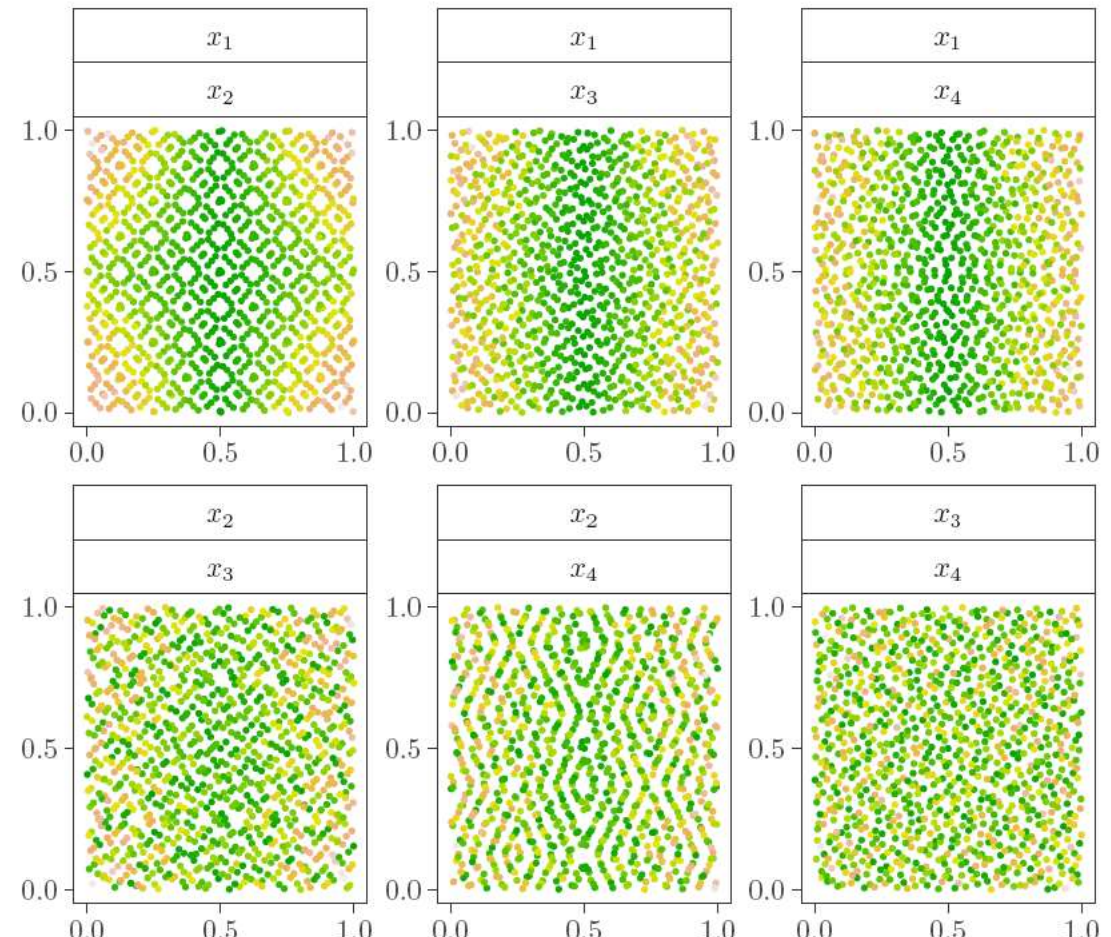
<https://www.uqlab.com/> (in MatLab, by Bruno Sudret and his team)



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

## sensobol: An R Package to Compute Variance-Based Sensitivity Indices

Arnald Puy , Samuele Lo Piano , Andrea Saltelli , Simon A. Levin 



Model's effective dimension



ACADEMIC  
PRESS

Available at  
**WWW.MATHEMATICSWEB.ORG**  
POWERED BY SCIENCE @ DIRECT•

Journal of Complexity 19 (2003) 101–124

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*Journal of*  
**COMPLEXITY**

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<http://www.elsevier.com/locate/jco>

# The effective dimension and quasi-Monte Carlo integration<sup>☆</sup>

Xiaoqun Wang<sup>a,b,\*</sup> and Kai-Tai Fang<sup>c</sup>

<sup>a</sup>*Department of Mathematical Sciences, Tsinghua University, Beijing 100084, China*

<sup>b</sup>*School of Mathematics, University of New South Wales, Sydney 2052, Australia*

<sup>c</sup>*Department of Mathematics, Hong Kong Baptist University, Hong Kong, China*

Received 12 February 2002; accepted 6 November 2002



The difficulty of a function/model is not in its number of dimensions but in the number of effective dimensions, either in the **truncation** or **superposition** sense

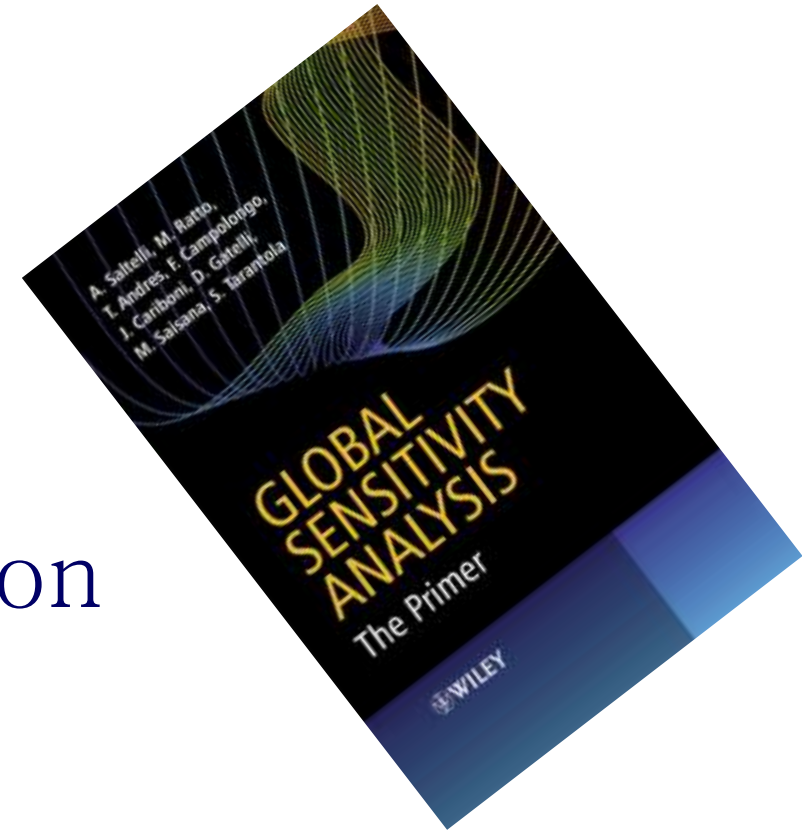
**truncation** sense = how many factors are important?

**superposition** sense=how high is the highest interaction?

Why using variance-based  
sensitivity analysis methods

# Advantages with variance based methods:

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



Chapter 1 its  
exercises



... anyone developing a  
new method tests it against  $S_i, T_i$



## Water Resources Research

### RESEARCH ARTICLE

10.1002/2015WR017558

Companion to  
*Razavi and Gupta* [2016],  
doi:10.1002/2015WR017559.

#### Key Points:

- The VARS framework enables

## A new framework for comprehensive, robust, and efficient global sensitivity analysis: 1. Theory

**Saman Razavi<sup>1,2</sup> and Hoshin V. Gupta<sup>3</sup>**

<sup>1</sup>Global Institute for Water Security & School of Environment and Sustainability, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, <sup>2</sup>Department of Civil and Geological Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, <sup>3</sup>Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, USA

$S_i, T_i$  can be used to do a sensitivity analysis of a sensitivity analysis...



## Environmental Modelling & Software

Volume 137, March 2021, 104960

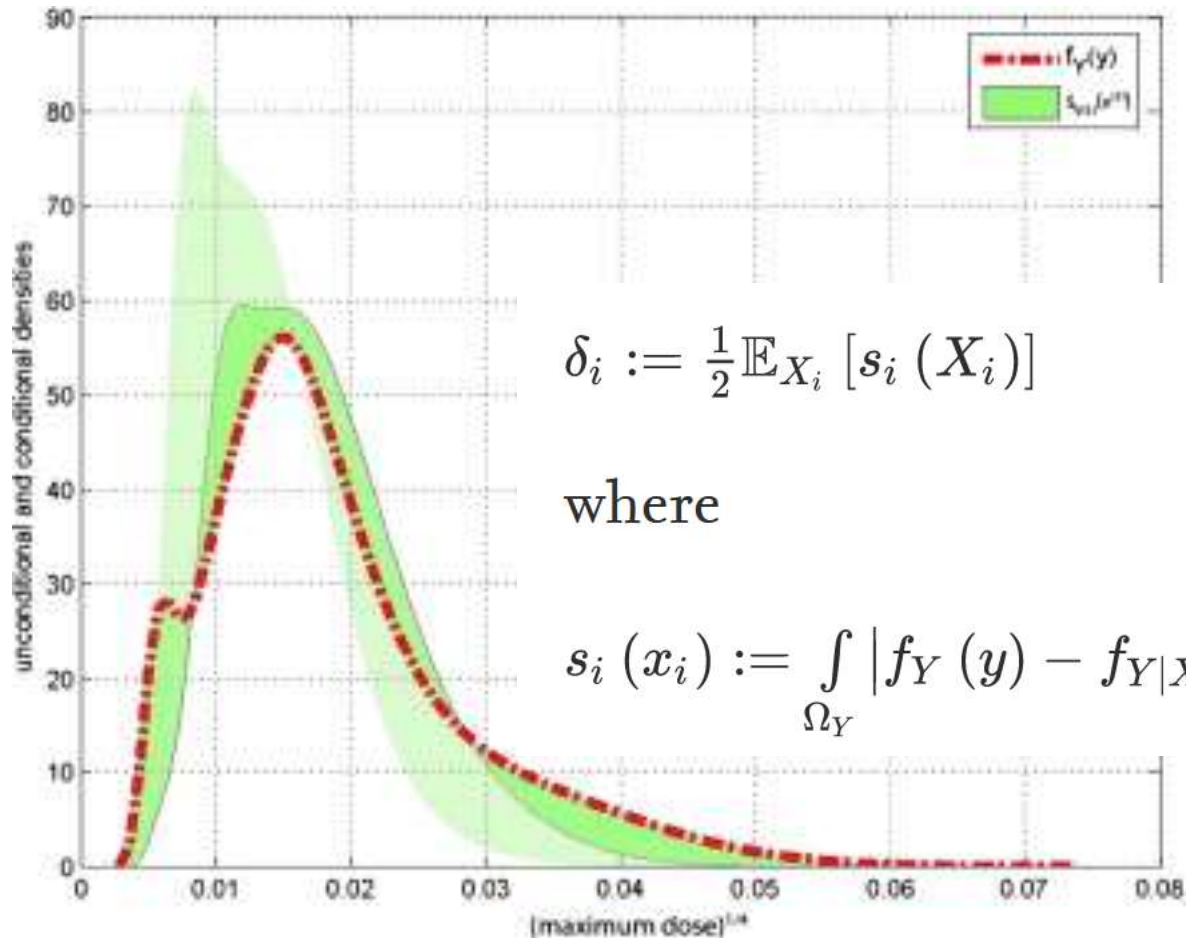


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# Is VARS more intuitive and efficient than Sobol' indices?

Arnald Puy <sup>a, b</sup>  , Samuele Lo Piano <sup>c</sup>, Andrea Saltelli <sup>d</sup>

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



Environmental Modelling & Software

Volume 34, June 2012, Pages 105-115



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

E. Borgonovo <sup>a</sup>, W. Castaings <sup>b, c</sup>, S. Tarantola <sup>d</sup>  

Don't use One factor At a  
Time (OAT)

A geometric proof



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journal homepage: [www.elsevier.com/locate/envsoft](http://www.elsevier.com/locate/envsoft)

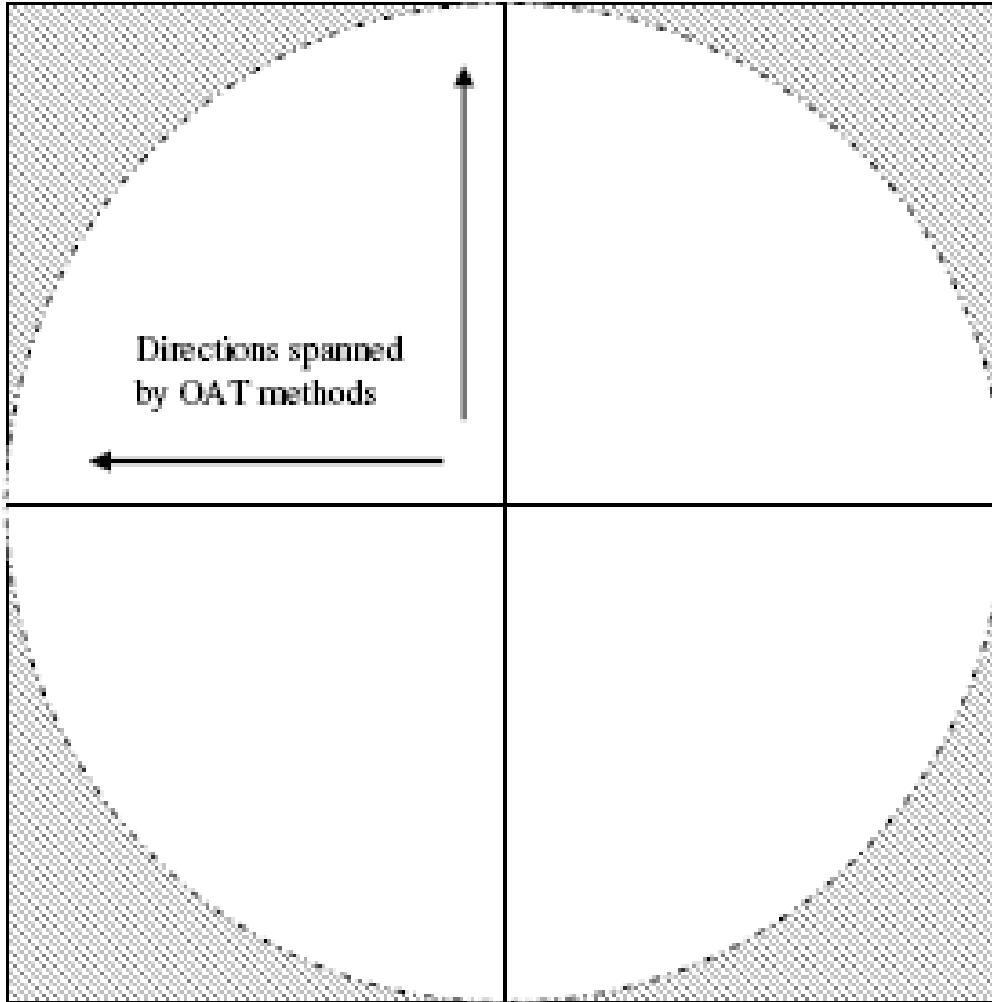


## How to avoid a **perfunctory** sensitivity analysis

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

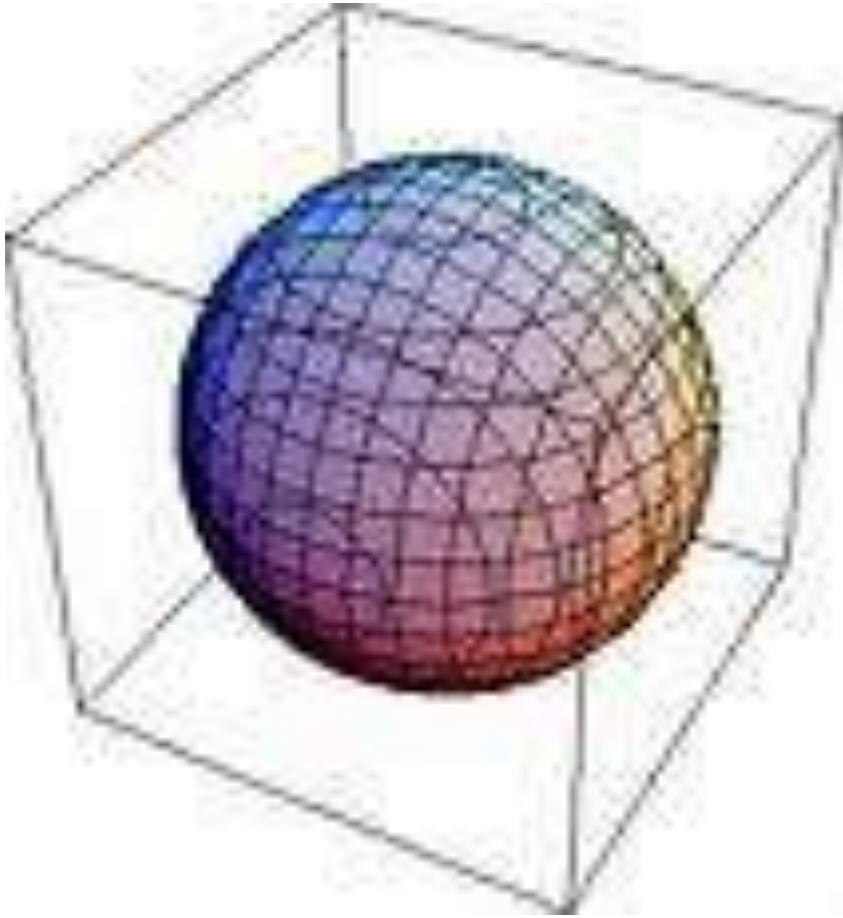


Area circle  
/ area  
square = ?

$\sim 3/4$



# OAT in 3 dimensions



Volume sphere /  
volume cube = ?

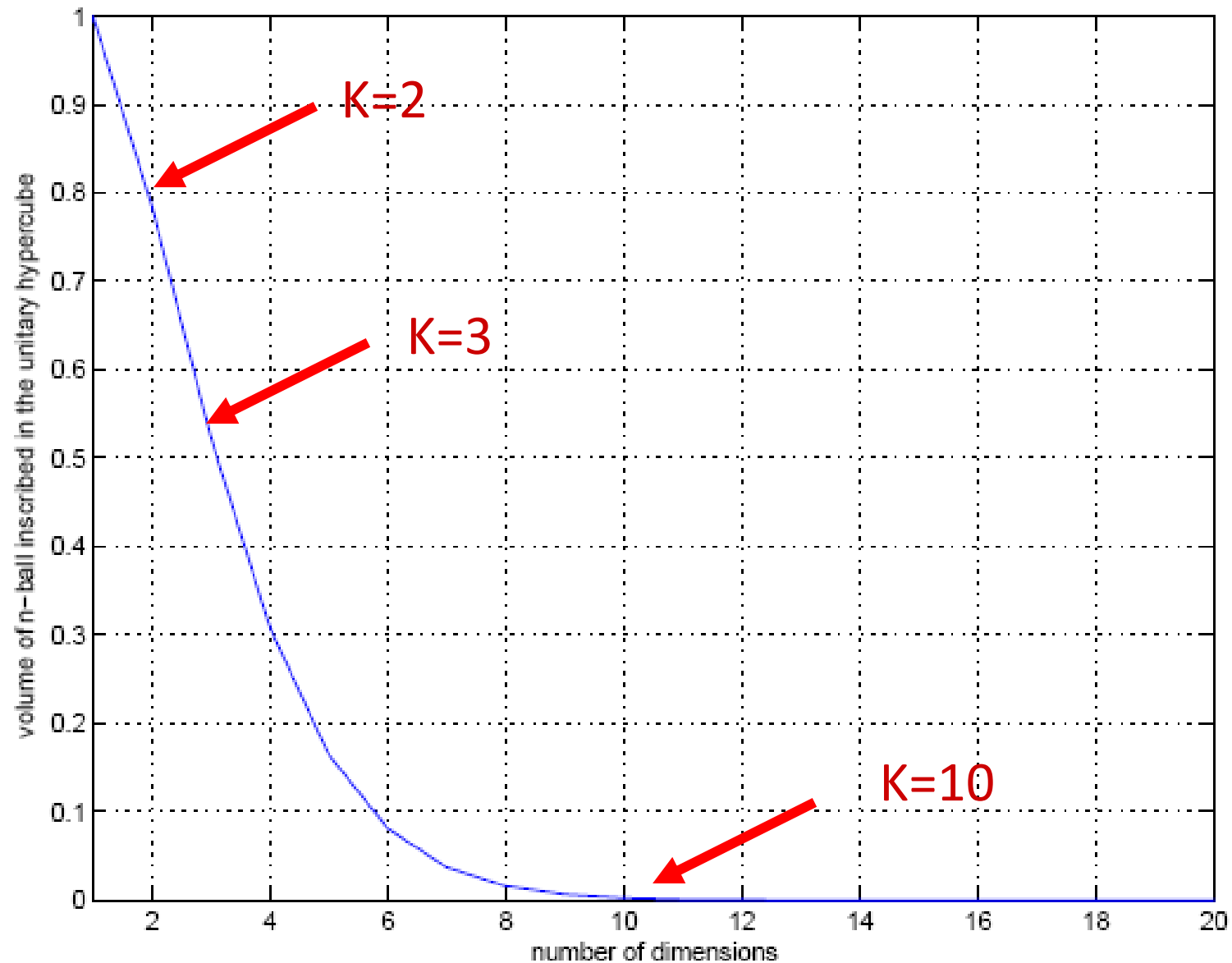
$\sim 1/2$

OAT in 10 dimensions; Volume  
hypersphere / volume ten dimensional  
hypercube =?  $\sim 0.0025$





# OAT in k dimensions



OAT does not capture interactions

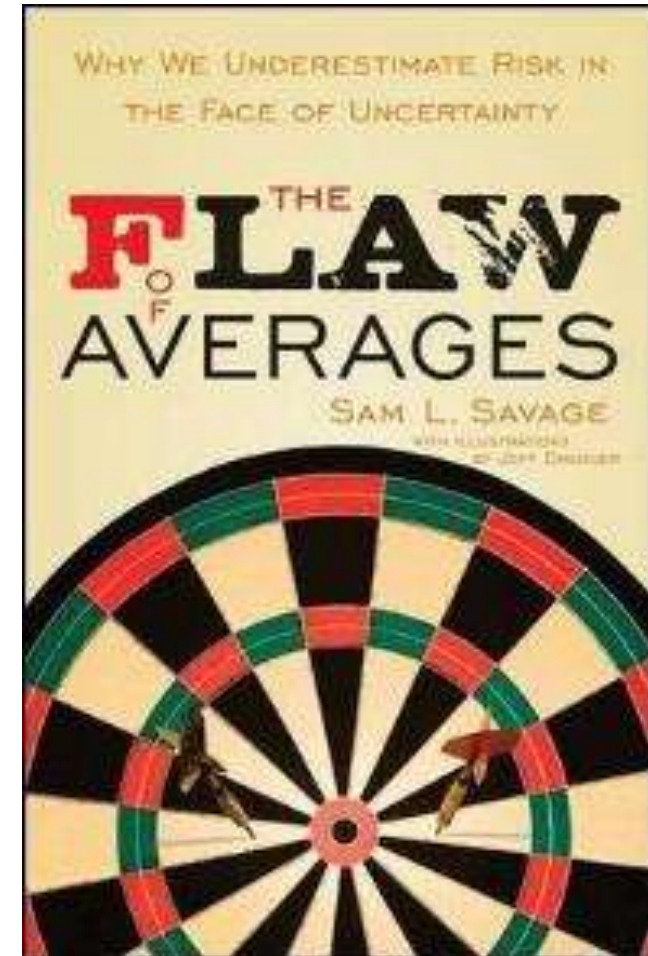
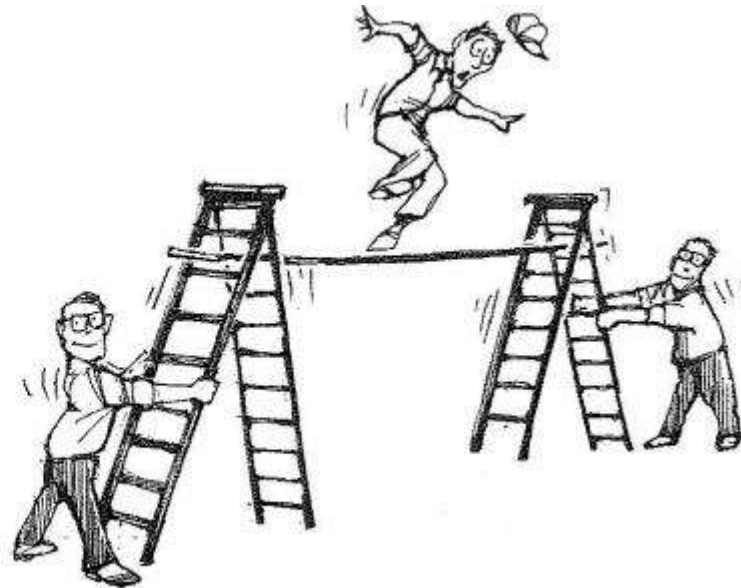
➔ The resulting analysis is non conservative

# How would you test the scaffolding?

How coupled ladders are shaken in most of available literature



How to shake coupled ladders







# 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 <sup>a, b</sup>  , Ksenia Aleksankina <sup>c</sup>, William Becker <sup>d</sup>, Pamela Fennell <sup>e</sup>, Federico Ferretti <sup>d</sup>, Niels Holst <sup>f</sup>, Sushan Li <sup>g</sup>, Qiongli Wu <sup>h</sup>

Don't use method that are  
not model-independent  
(such as PCC, PRCC)

Use model-free methods

# Why not using correlation-regression based techniques?

## PCC, PRCC, SRC, SRRC



Reliability Engineering & System Safety

Volume 28, Issue 2, 1990, Pages 229-253



Non-parametric statistics in sensitivity analysis for model output: A comparison of selected techniques

A. Saltelli, J. Marivoet



Computational Statistics & Data Analysis

Volume 13, Issue 1, January 1992, Pages 73-94



Sensitivity analysis for model output: Performance of black box techniques on three international benchmark exercises

A. Saltelli, T. Homma

➔ They assume linearity (PCC) or monotonicity (PRCC), which is difficult to know *ex-ante*



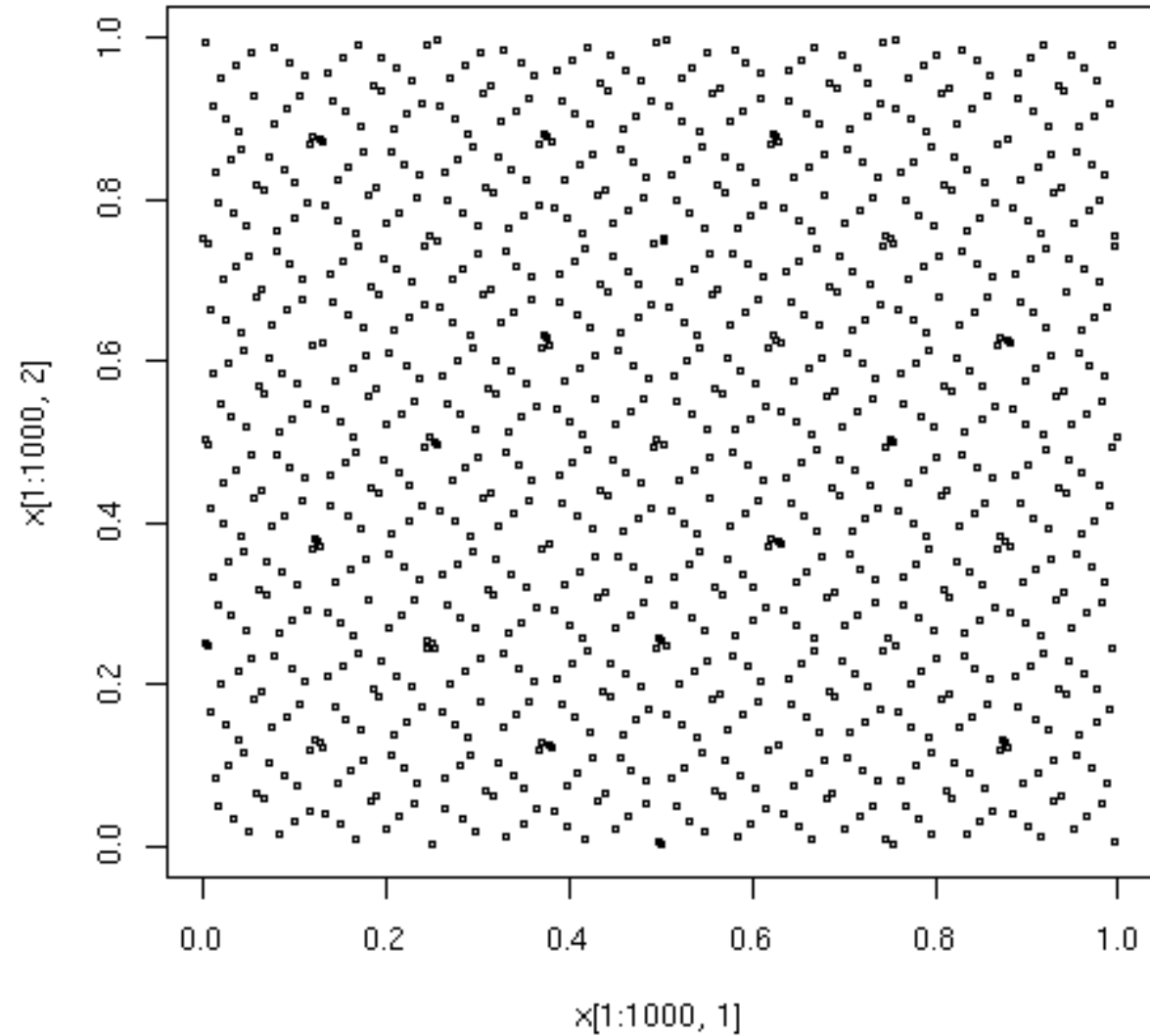
Don't use either LHS or  
optimized LHS

Quasi-random sequences perform better

# Quasi random sequences



Ilya M. Sobol'





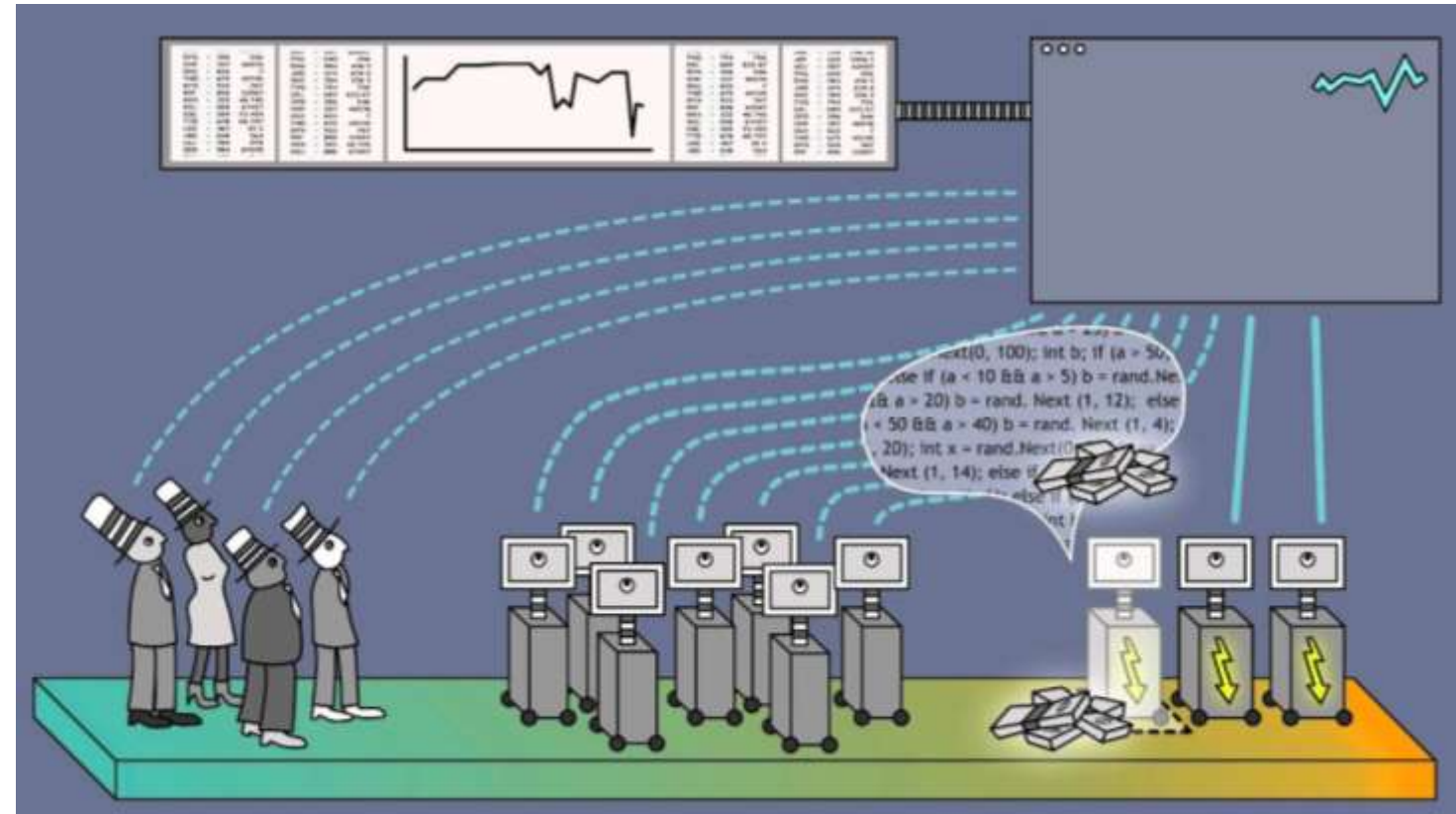


[Submitted on 10 May 2015]

# 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



# 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

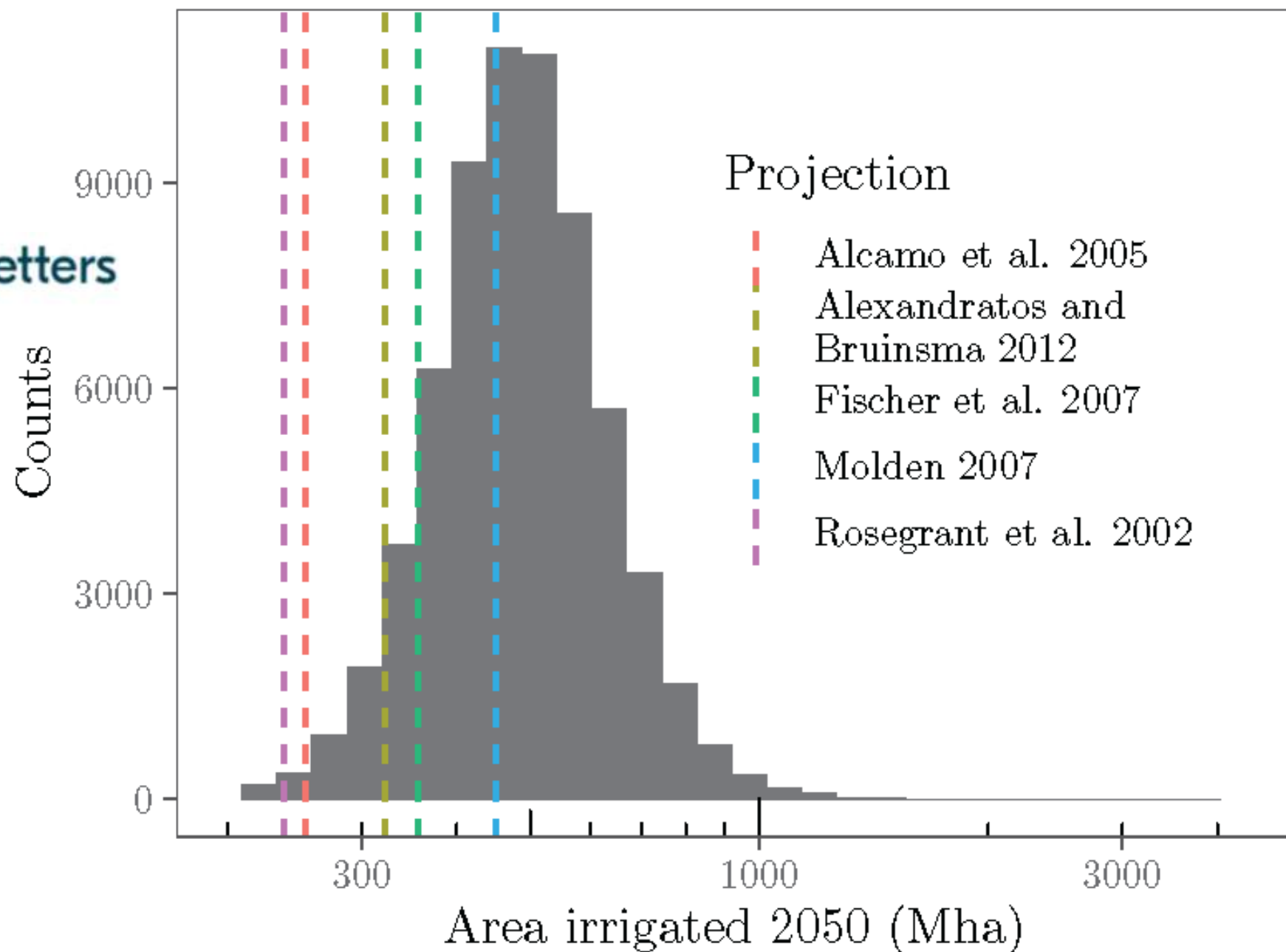
# Current Models Underestimate Future Irrigated Areas

## Geophysical Research Letters

A. Puy✉, S. Lo Piano, A. Saltelli

### 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>






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## The delusive accuracy of global irrigation water withdrawal estimates

[Arnald Puy](#) , [Razi Sheikholeslami](#), [Hoshin V. Gupta](#), [Jim W. Hall](#), [Bruce Lankford](#), [Samuele Lo Piano](#), [Jonas Meier](#), [Florian Pappenberger](#), [Amilcare Porporato](#), [Giulia Vico](#) & [Andrea Saltelli](#)

[Nature Communications](#) **13**, Article number: 3183 (2022) | [Cite this article](#)

**3022** Accesses | **102** Altmetric | [Metrics](#)

**Miscalculating the volumes of water withdrawn for irrigation, the largest consumer of freshwater in the world, jeopardizes sustainable water management. Hydrological models quantify water withdrawals, but their estimates are unduly precise. Model imperfections need to be appreciated to avoid policy misjudgements.**

Sustainable Development Goals (SDGs), from Zero Hunger (SDG 2) to Water Stress (SDG 6), will be poorly assessed if irrigation water withdrawal convey an illusion of accuracy


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## **The delusive accuracy of global irrigation water withdrawal estimates**

[Arnald Puy](#) , [Razi Sheikholeslami](#), [Hoshin V. Gupta](#), [Jim W. Hall](#), [Bruce Lankford](#), [Samuele Lo Piano](#), [Jonas Meier](#), [Florian Pappenberger](#), [Amilcare Porporato](#), [Giulia Vico](#) & [Andrea Saltelli](#)

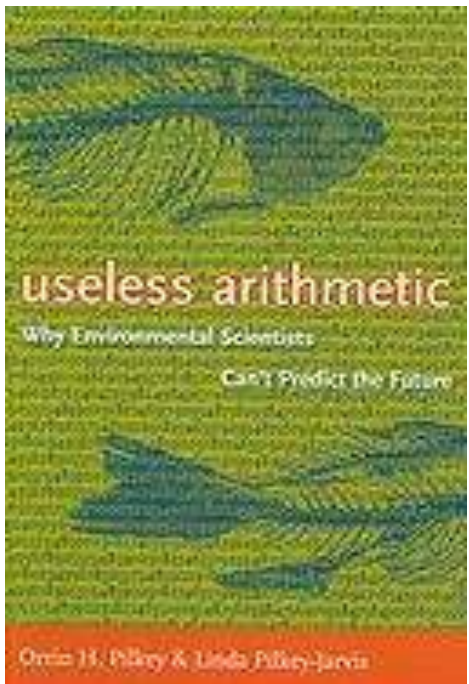
Don't confuse the map with  
the territory

If you do, sensitivity analysis will not save you

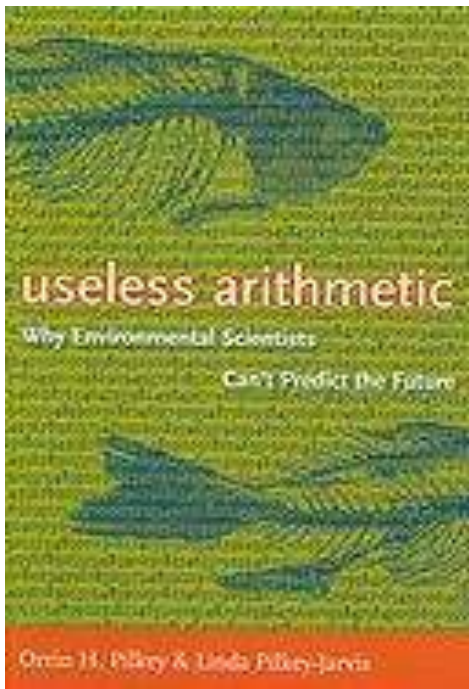




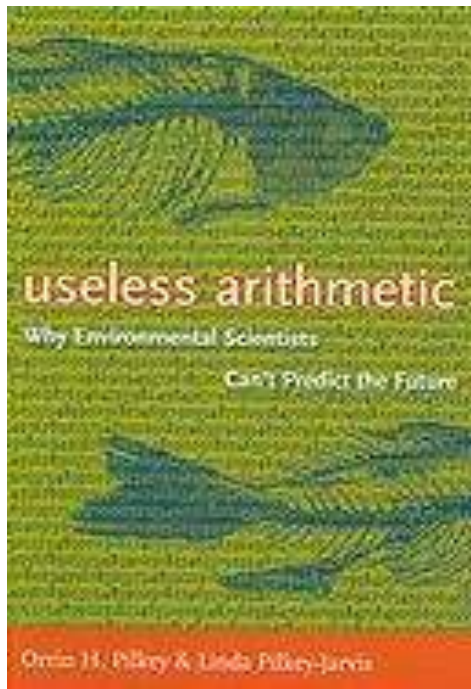
Orrin H.  
Pilkey



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



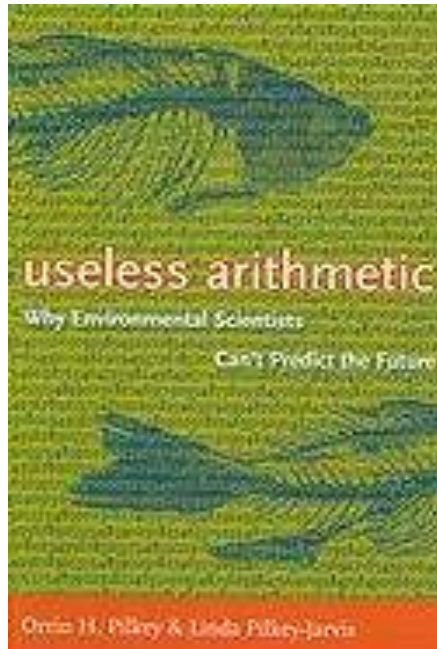
<<It is important, however, to recognize that the sensitivity of the parameter in the equation is what is being determined, not the sensitivity of the parameter in nature>>



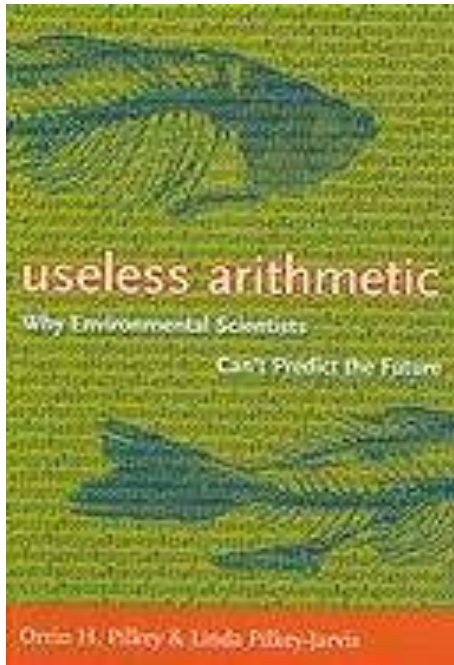
<<...If the model is wrong or if it is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit>>

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.

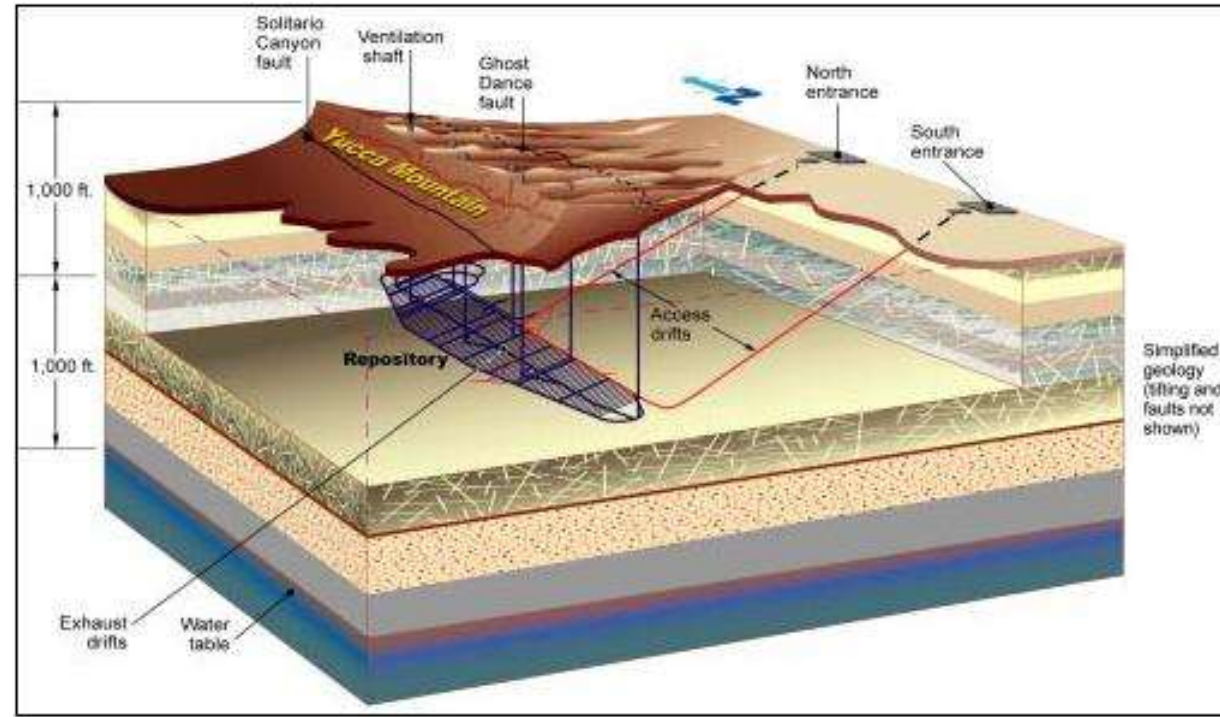
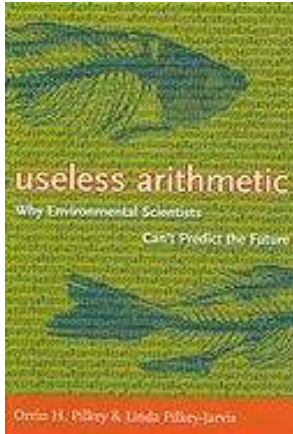






TSPA (like any other model) **relies on assumptions** → one is the low permeability of the geological formation → long time for the water to percolate from surface to disposal.





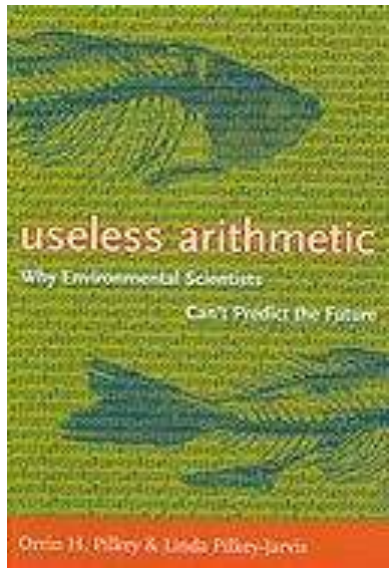
The confidence of the stakeholders in TSPA was not helped when evidence was produced which could lead to an upward revision of 4 orders of magnitude of this parameter  
(the  $^{36}\text{Cl}$  story)

## Type III error in sensitivity: Examples:

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, Universalism, Disinterestedness, Organized Skepticism, from sociology of science, Robert K. Merton.



Steve Rayner

Rayner, S., 2012, Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses, *Economy and Society*, 41:1, 107–125.

Rayner's (2012) strategies to deal with  
“uncomfortable knowledge”.

Denial, Dismissal, Diversion, Displacement



Model based

Rayner, S., 2012, Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses, *Economy and Society*, 41:1, 107–125.

Displacement: “The model we have developed tells us that real progress is being achieved” (The focus is now the model not the problem).

Rayner, S., 2012, Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses, *Economy and Society*, 41:1, 107–125.

## Example of displacement: Chesapeake Bay Program (CBP) modelling work

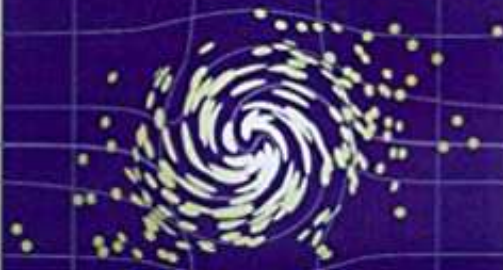
“Bay models are used to track nutrient loads to ensure the cap is not exceeded”

→ The model results – rather than the actual measurements, become the substance of use

Rayner, S., 2012, Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses, *Economy and Society*, 41:1, 107–125.

# PREDICTION

Science, Decision Making,



and the Future of Nature

Edited by Daniel Sarewitz,  
Roger A. Pielke, Jr., and Radford Byerly

Model GENESIS for beach  
erosion



**US Army Corps  
of Engineers®**

Manipulated to support coastal-engineering  
projects

It neglected the role of extreme event

Sarewitz, D., Pielke, R. A. & Byerly, R. *Prediction: Science, Decision Making, and the Future of Nature* (Island Press, 2000).

Beware the size of your  
model

Mind the conjecture of O'Neil





Comment

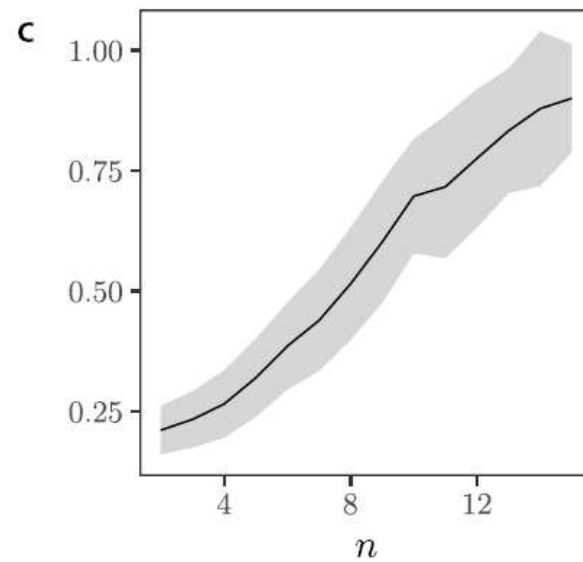
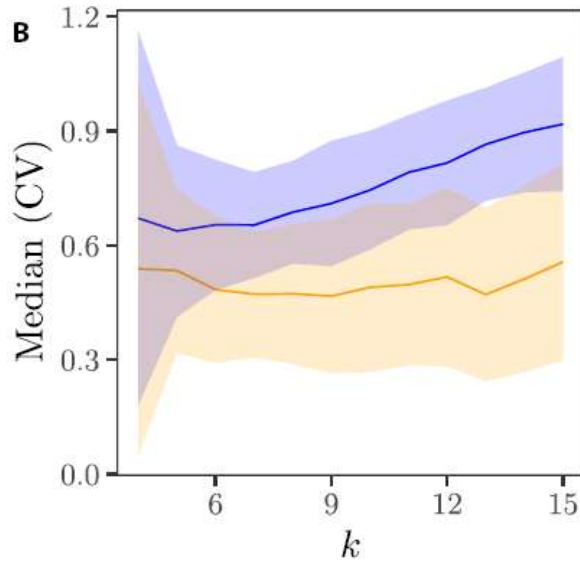
Open Access

Published: 27 August 2019

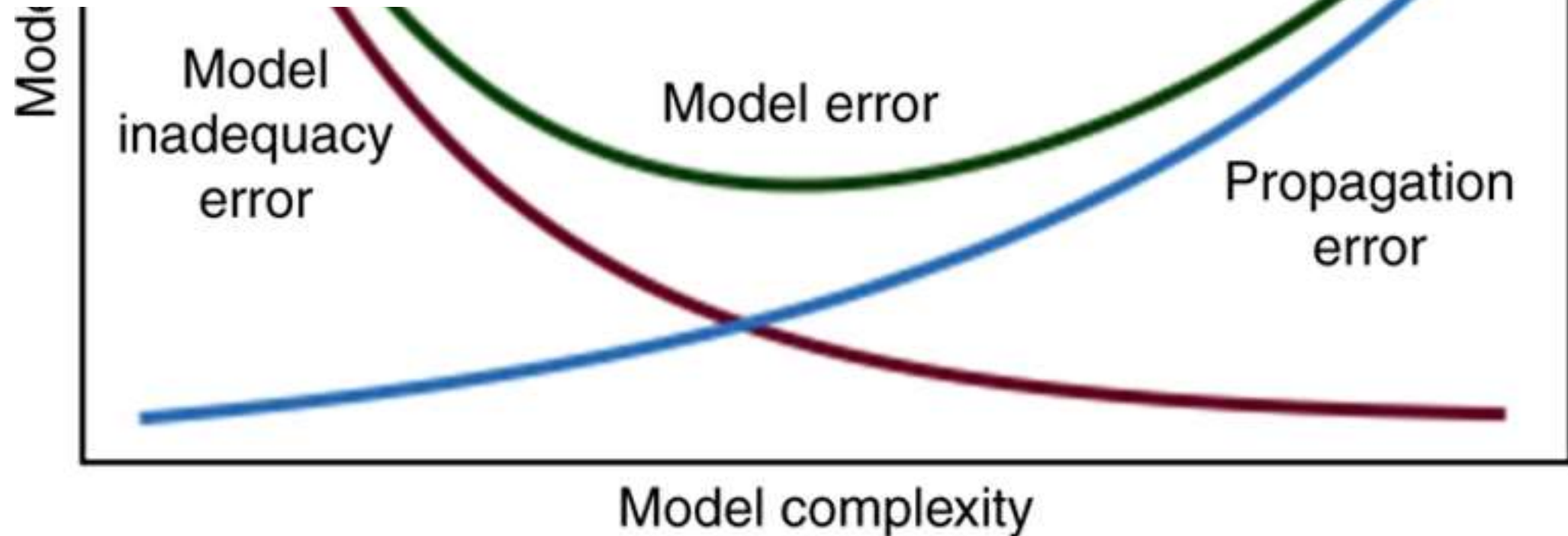
# A short comment on statistical versus mathematical modelling

Andrea Saltelli 

Interactions — Up to the  $k$ th order — Up to the  $n$ th order for  $k = 15$



Empirical test using the SA-based  
concept of effective dimension  
(forthcoming Science Advances  
online October 20)



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.

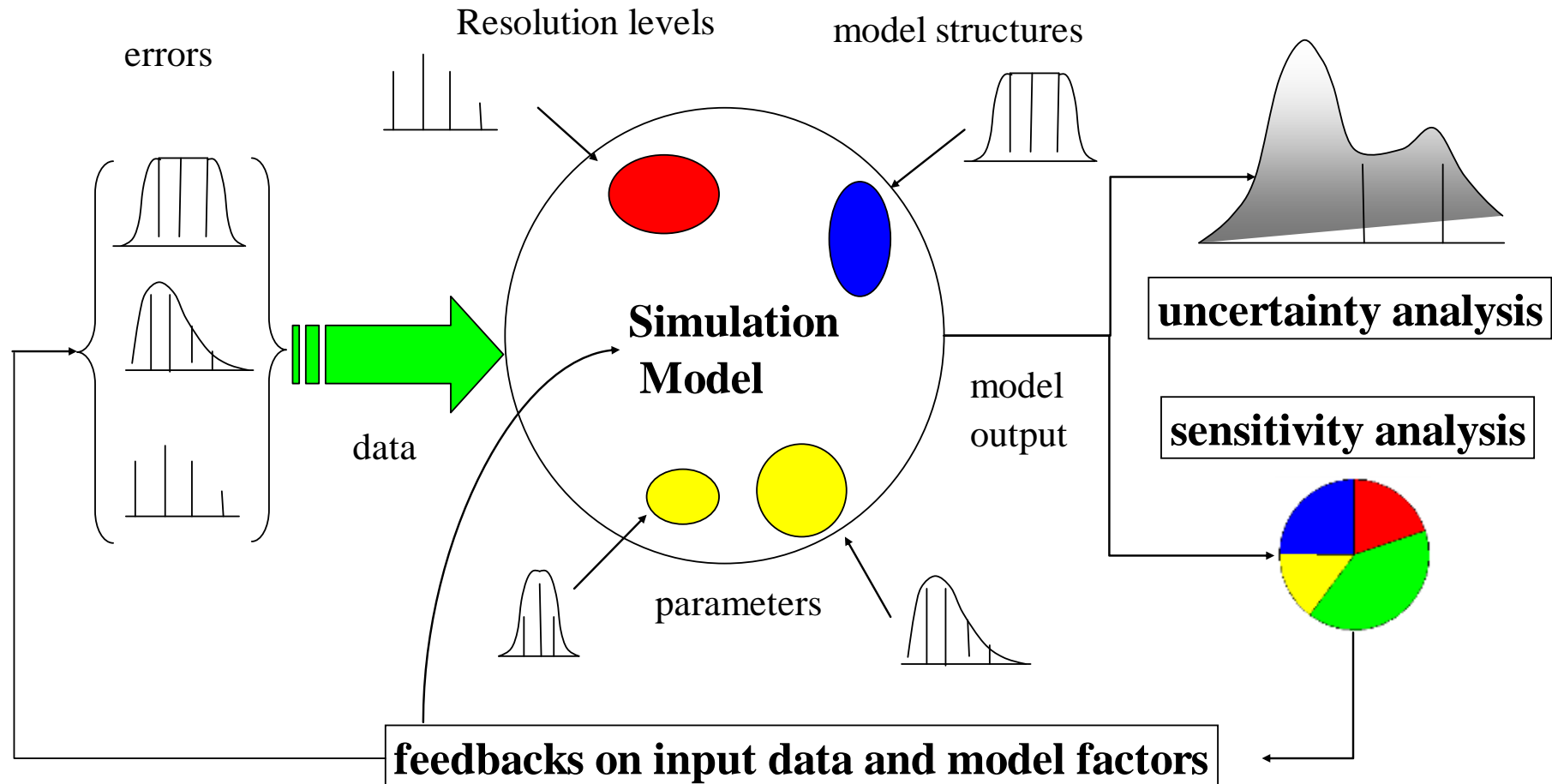
L. Zadeh, "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," *IEEE Trans. Syst. Man. Cybern.*, vol. 3, no. 1, pp. 28–44, 1973.

Don't sample just  
parameters and boundary  
conditions

Explore thoroughly the space of the  
assumptions

Remember?

# An engineer's vision of UA, SA



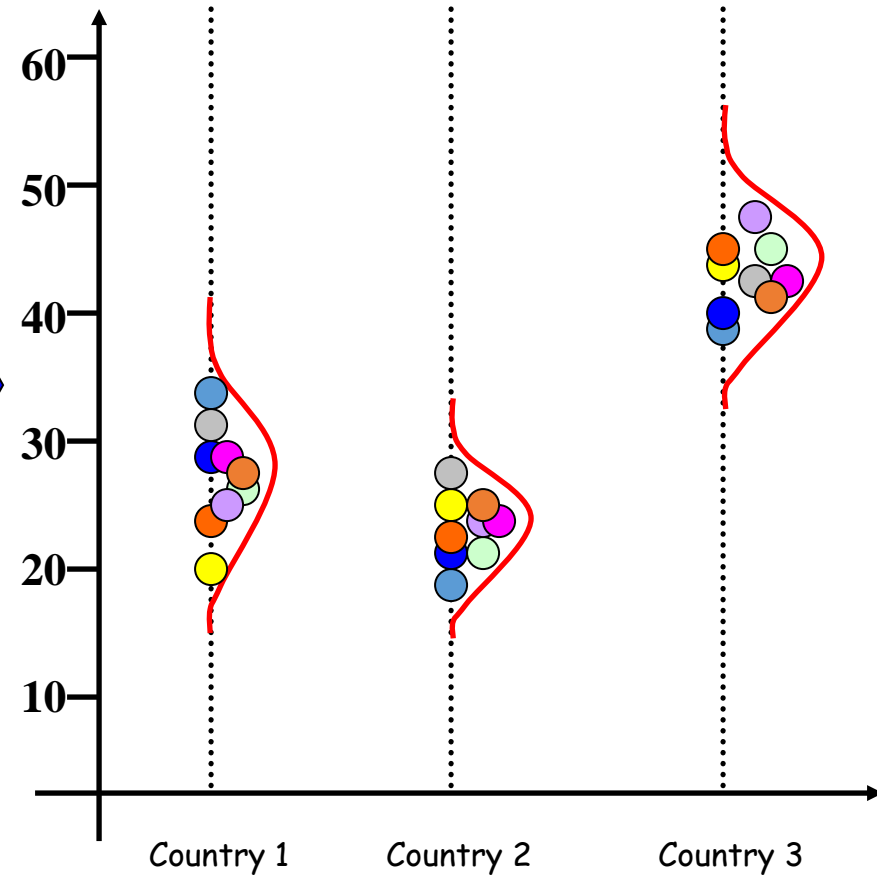
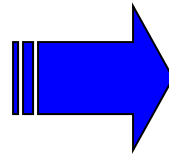
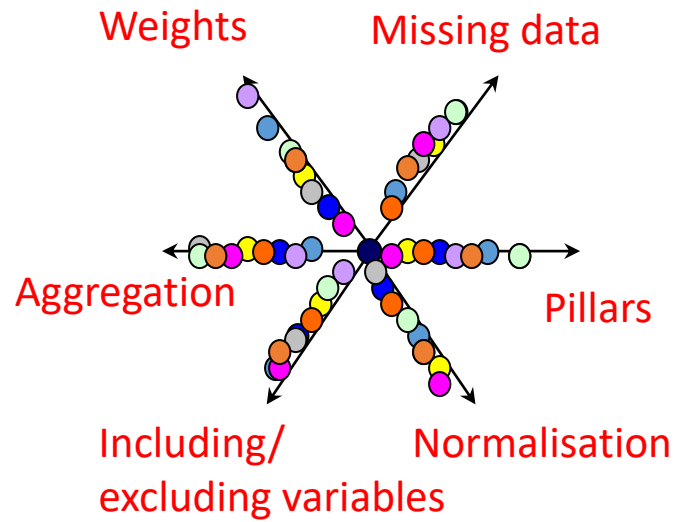
One can sample more than just factors:

- 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

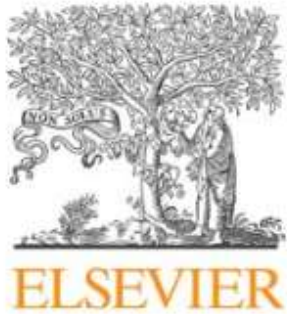


Don't go public  
with your results  
without having  
seen your SA

Find SA before SA finds you

Try to Find God  
before God Finds  
You.

Global Environmental Change 20 (2010) 298–302



Contents lists available at ScienceDirect

## Global Environmental Change

journal homepage: [www.elsevier.com/locate/gloenvcha](http://www.elsevier.com/locate/gloenvcha)



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

Andrea Saltelli<sup>\*</sup>, 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



William Nordhaus,  
University of Yale  
Nobel 'Economics'  
2018



Nicholas Stern, London School  
of Economics

Stern, N., Stern Review on the Economics of Climate Change. UK Government Economic Service, London, [www.sternreview.org.uk](http://www.sternreview.org.uk).

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

# The Stern – Nordhaus exchange on *SCIENCE*

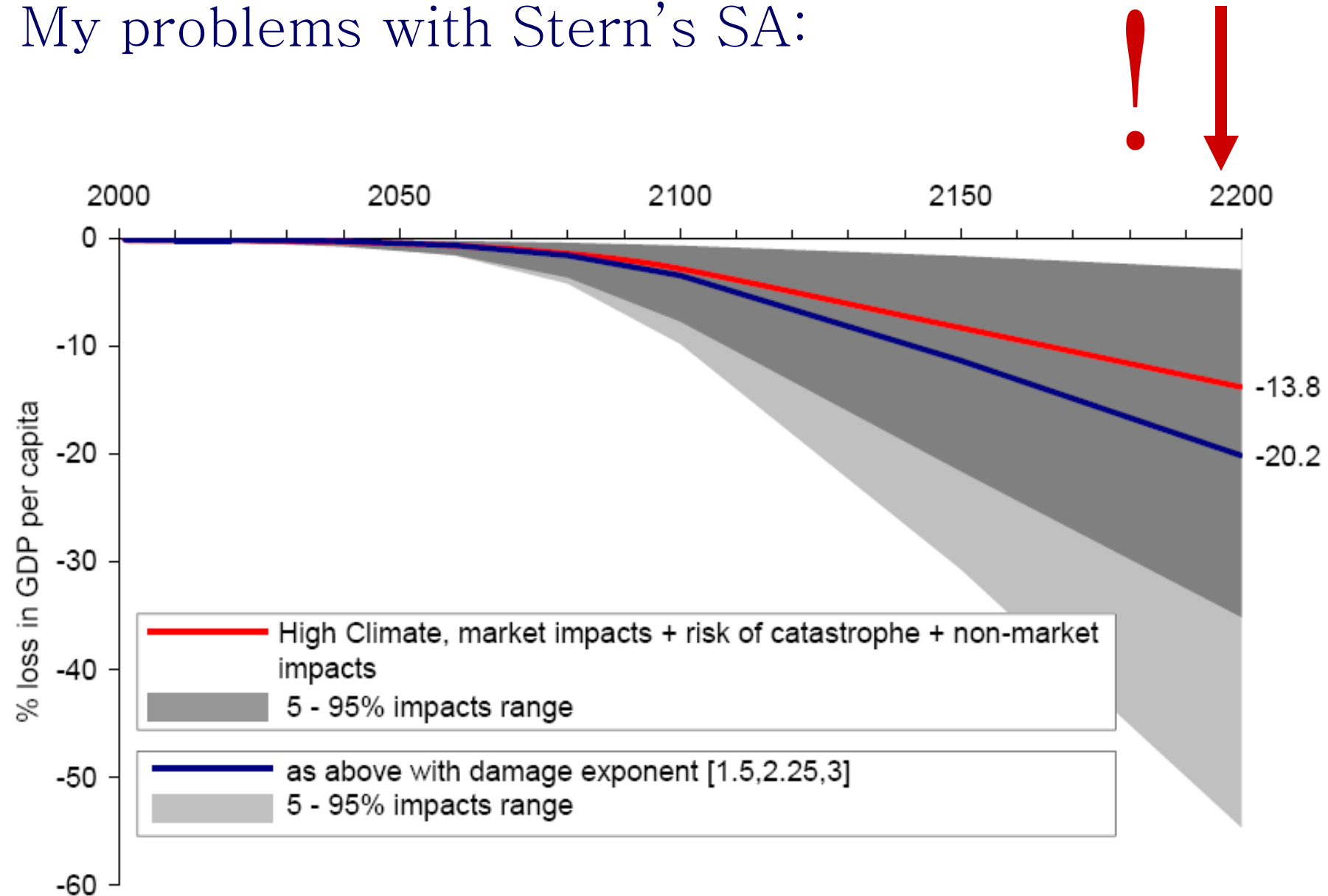


Nordhaus → attacks Stern based on ‘wrong’ range of discount rate ( $\sim$  you are GIGging)

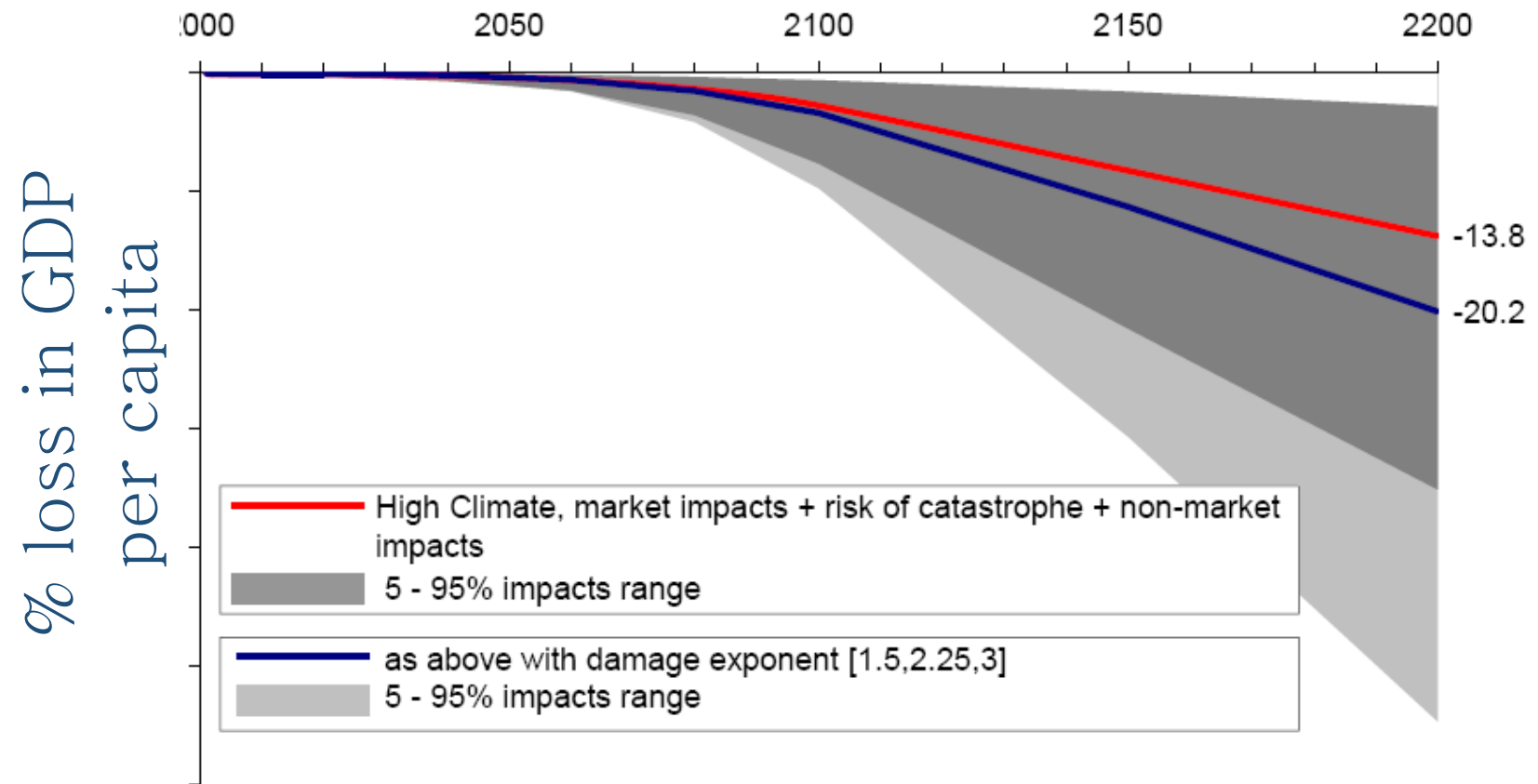


Stern → Perform a sensitivity analysis and retorts: ‘My analysis shows robustness’

# My problems with Stern's SA:



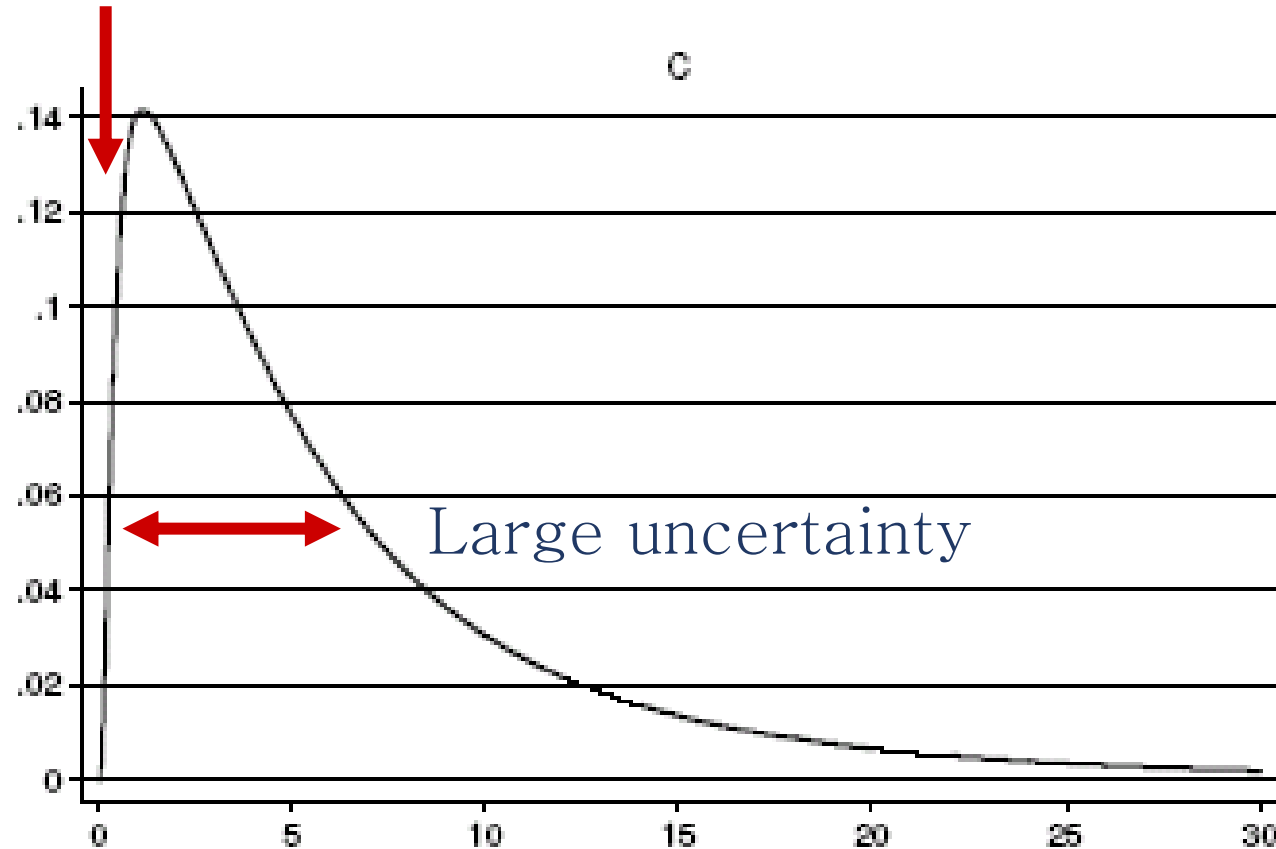
... but foremost Stern says:  
changing assumptions → important effect  
when instead he should admit that:  
changing assumptions → all changes a lot





# How was it done? A reverse engineering of the analysis

Missing points



% loss in GDP per capita

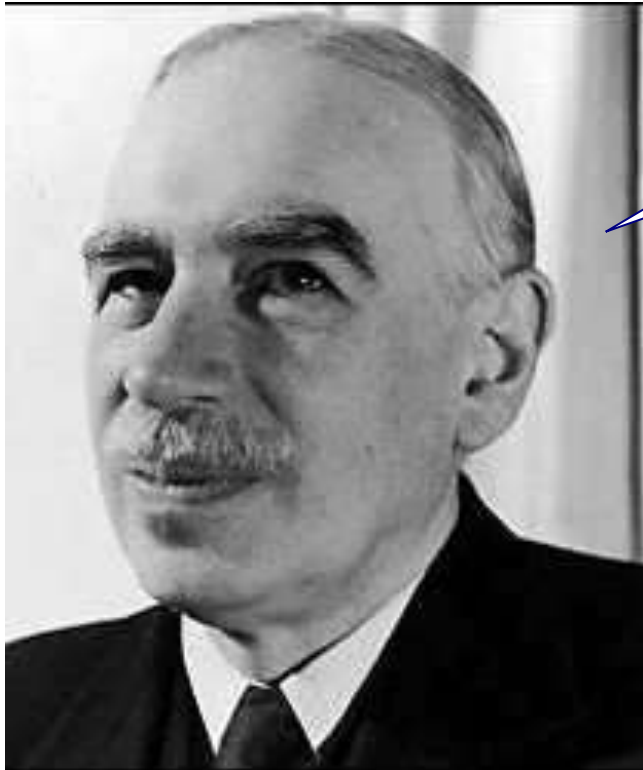
Conclusion:

Model prediction are too uncertain to adjudicate the dispute about the urgency of action on climate change;

Both assertion (Stern) and refutation (Nordhaus) are indefensible

Same criticism applies to Nordhaus – both authors frame the debate around numbers which are ...

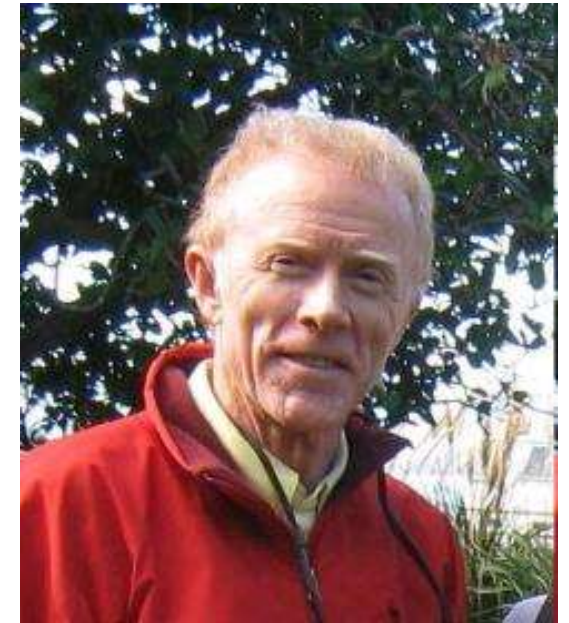
... precisely wrong



Peter Kennedy, A Guide to Econometrics.

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 “



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



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

... beside uncertainty can be used instrumentally



# Where to find this talk: [www.andreasaltelli.eu](http://www.andreasaltelli.eu)

Andrea  
Saltelli

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RESOURCES

CAETERIS ARE  
NEVER PARIBUS

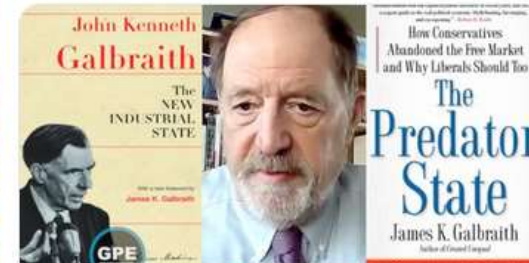
Tweets by @AndreaSaltelli



**andrea saltelli**  
@AndreaSaltelli

Worth listening all; pay heed to the bit at 31'.50".  
Why economics needs to pay heed to its  
biophysical bases @ICTA\_UAB @g\_kallis

Resource Limits to American Capitalism & the  
Predator State Today - % % [GPEnewsdocs.com](http://GPEnewsdocs.com)  
% [gpenewsdocs.com/resource-limit...](http://gpenewsdocs.com/resource-limit...)



**Resource Limits to American Capitalis...**

James K. Galbraith discusses the shift of ...  
[gpenewsdocs.com](http://gpenewsdocs.com)

Embed

[View on Twitter](#)



# Five ways to ensure that models serve society: a manifesto

Pandemic politics highlight how predictions need to be transparent and humble to invite insight, not blame.

>260 references  
SUPPLEMENTARY INFORMATION  
1. Additional information and references



Illustration by David Parkins



**nature**



**nature**

Andrea Saltelli , Gabriele Bammer, Isabelle Bruno, Erica Charters, Monica Di Fiore, Emmanuel Didier, Wendy Nelson Espeland, John Kay, Samuele Lo Piano, Deborah Mayo, Roger Pielke Jr, Tommaso Portaluri, Theodore M. Porter, Arnald Puy, Ismael Rafols, Jerome R. Ravetz, Erik Reinert, Daniel Sarewitz, Philip B. Stark, Andrew Stirling, Jeroen van der Sluijs & Paolo Vineis

**3 modellers** Lo Piano, Puy, Saltelli

**2 experts models and society** Pielke, van der Sluijs

**3 statisticians** Mayo, Stark, Portaluri

**2 statactivistes** Bruno, Didier

**2 economists** Kay, Raynert

**1 epidemiologist** Vineis

**2 sociologists of quantification**

Espeland, Porter

**3 STS scholars** Bammer, Sarewitz, Stirling

**1 philosopher** Ravetz

**1 historian** Charters

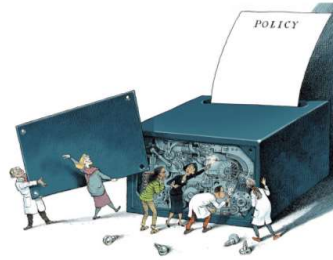
**1 political scientists** Di Fiore

**1 expert RRI - Open Science** Rafols





COVID-19 policies dictated by  
'science' with two digits precision  
in the presence of fundamental  
uncertainties



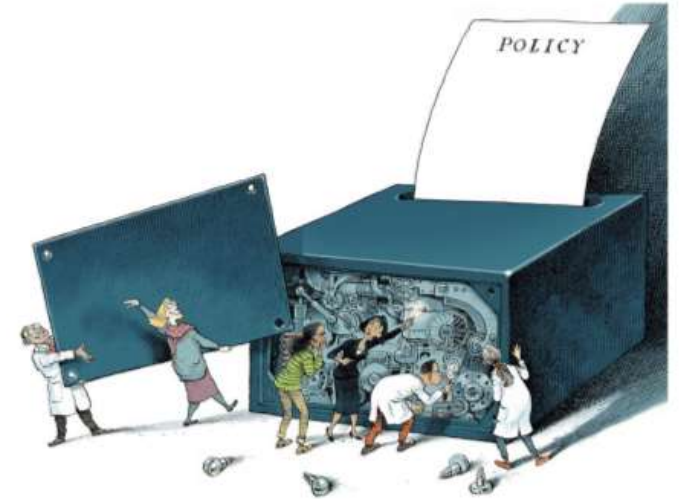
Undocumented research code used  
as a policy tool (chameleon models)



Pfleiderer, P. Chameleons: The Misuse of Theoretical Models in Finance and Economics. *Economica* 87, 81–107 (2020).

COVID has put mathematical models in the limelight

→ Power & controversy



# Power

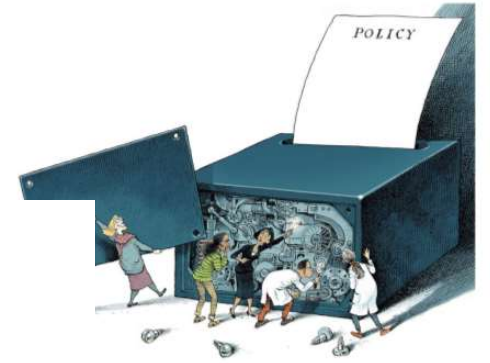
The New York Times

## *Behind the Virus Report That Jarred the U.S. and the U.K. to Action*

It wasn't so much the numbers themselves, frightening though they were, as who reported them: Imperial College London.

---

Landler, Mark, and Stephen Castle. 2020. Behind the Virus Report That Jarred the U.S. and the U.K. to Action – The New York Times.



# Conflicts, when questions of urgency, stakes, values and uncertainty collide

Rush Limbaugh

“Wild-Ass Covid numbers  
... The minute I hear  
anybody start talking about  
models and modeling, I  
blanch”



Rhodes, Tim, and Kari Lancaster. 2020. “Mathematical Models as Public Troubles in COVID-19 Infection Control: Following the Numbers”, *Health Sociology Review* 1–18. doi: 10.1080/14461242.2020.1764376





A 15 m tirade  
against Imperial  
College's model and  
its track record  
from foot and mouse  
disease to COVID-  
19

Bob Seely slams Imperial College and  
modelling

UK, conservative  
MEP.



<https://www.indigoumbrella.co.uk/bob-seely-slams-imperial-college-and-modelling/>

# **Mind the assumptions**

Assess uncertainty and sensitivity

## **Mind the hubris**

Complexity can be the enemy of relevance

## **Mind the framing**

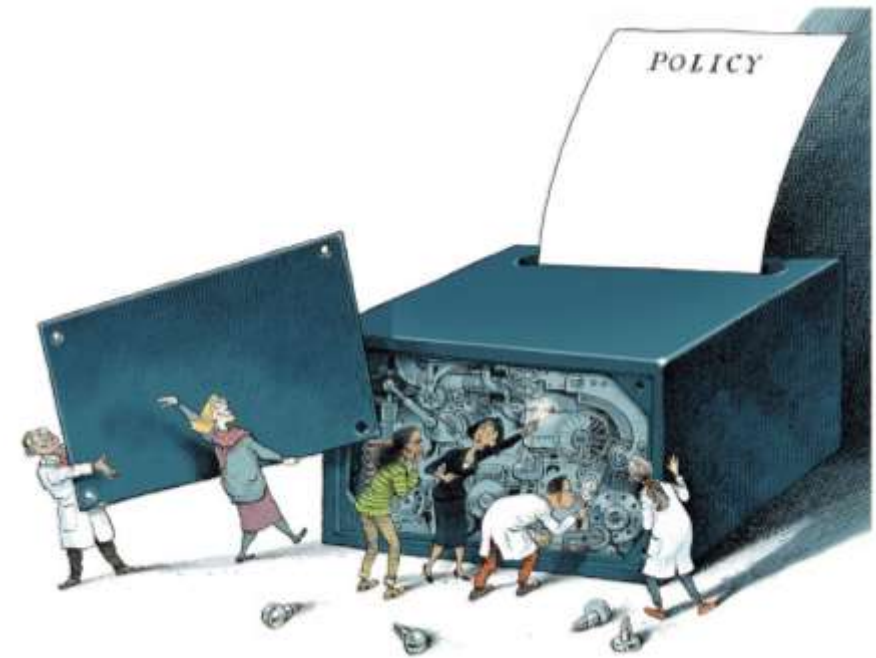
Match purpose and context

## **Mind the consequences**

Quantification can backfire.

## **Mind the unknowns**

Acknowledge ignorance

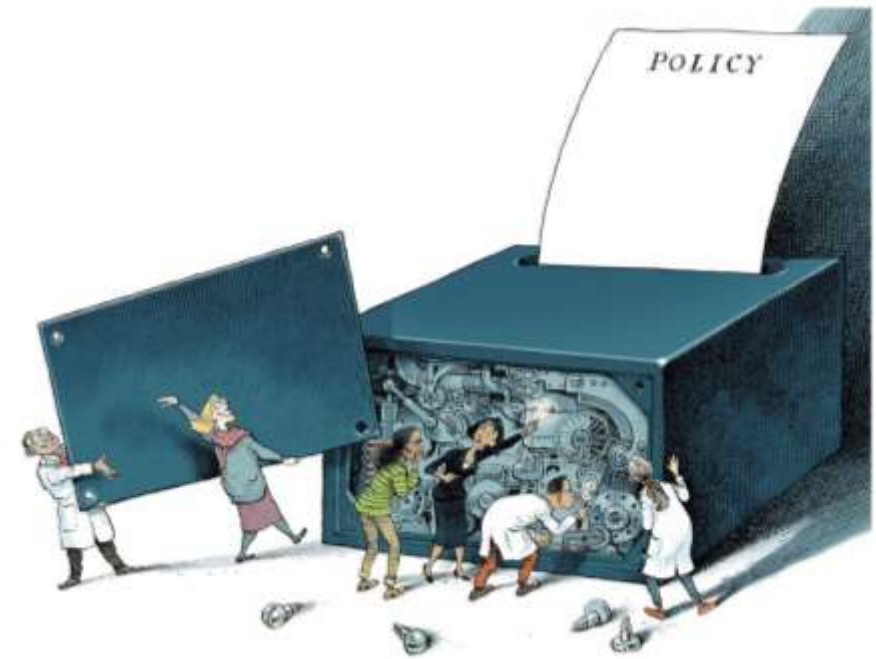


# Mind the assumptions

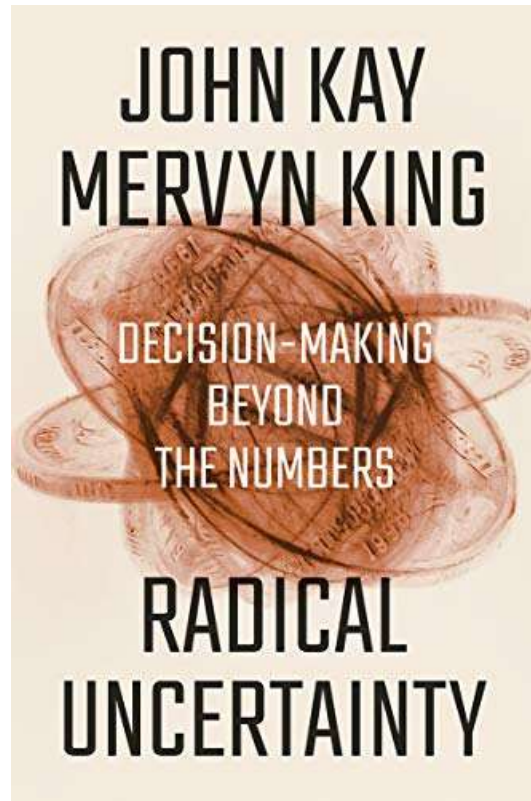
Assess uncertainty and sensitivity



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



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](https://www.ifs.org.uk/docs/john_kay_feb2012.pdf)

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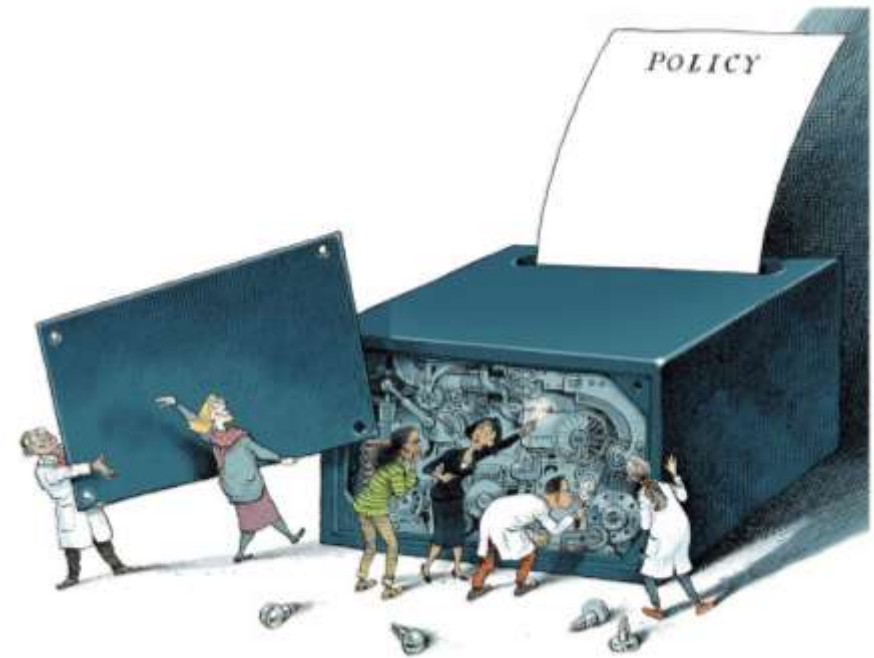
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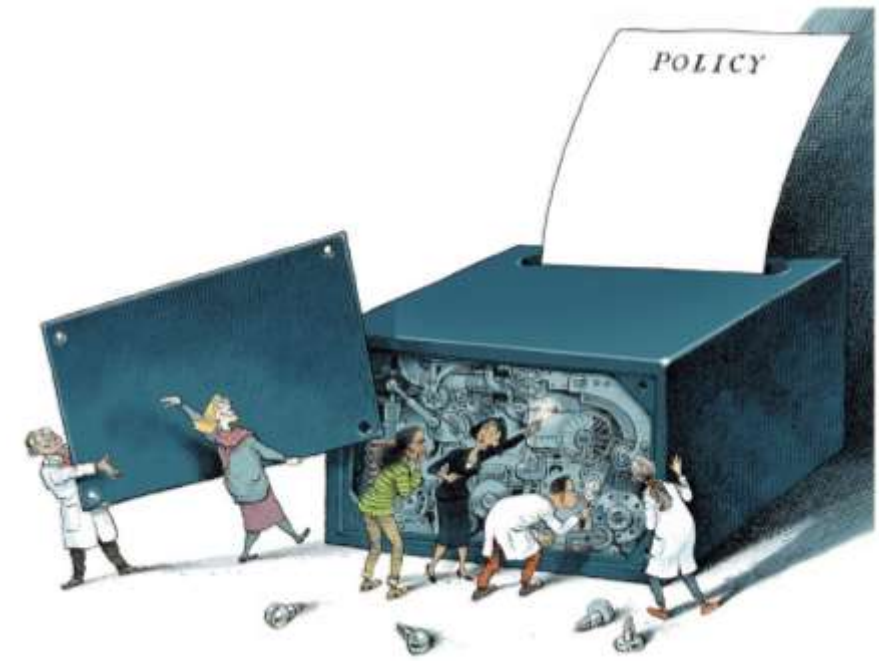
Acknowledge ignorance



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Complexity can be the enemy of relevance

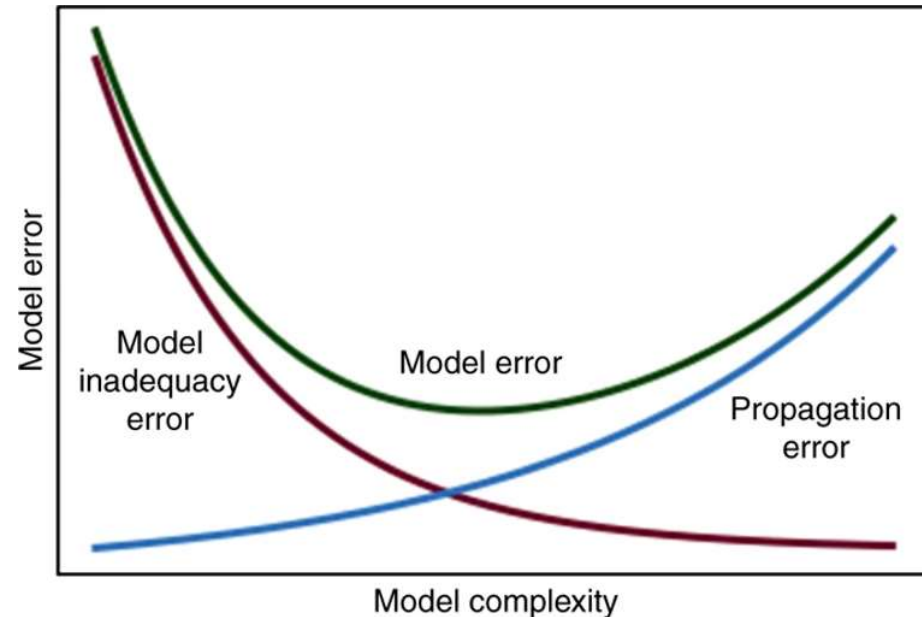
... many are seduced by the idea of adding complexity in an attempt to capture reality more accurately, but ...



## SUPPLEMENTARY INFORMATION

### 1. Additional information and references

>260 references





# Mind the assumptions

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Complexity can be the enemy of relevance



## Mind the framing

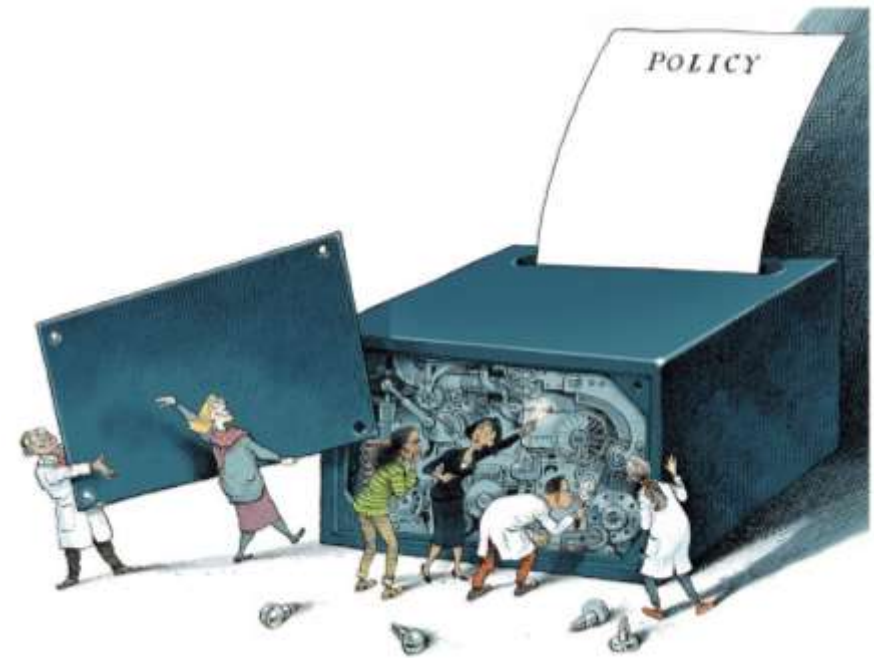
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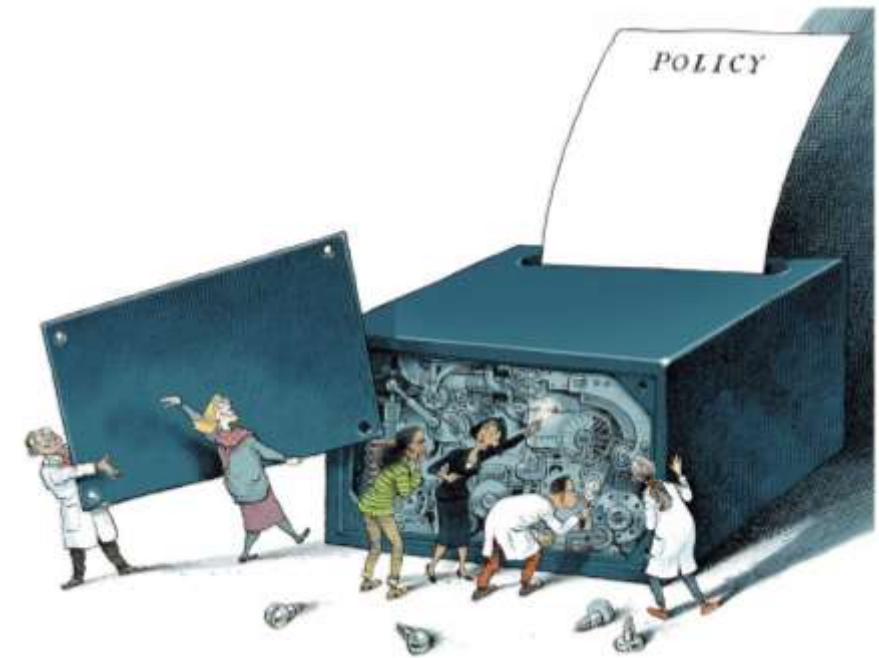
## Mind the unknowns

Acknowledge ignorance



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Match purpose and context



… models will reflect the interests, disciplinary orientations and biases of the developers…

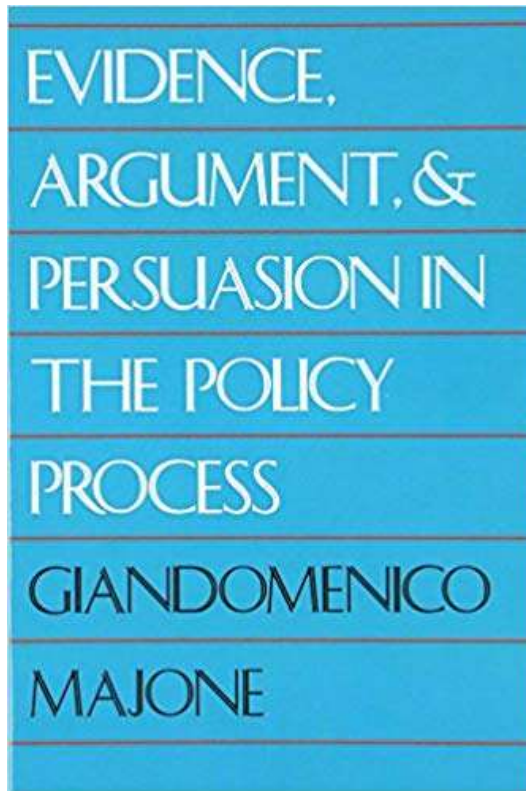
## SUPPLEMENTARY INFORMATION

1. Additional information and references >260 references

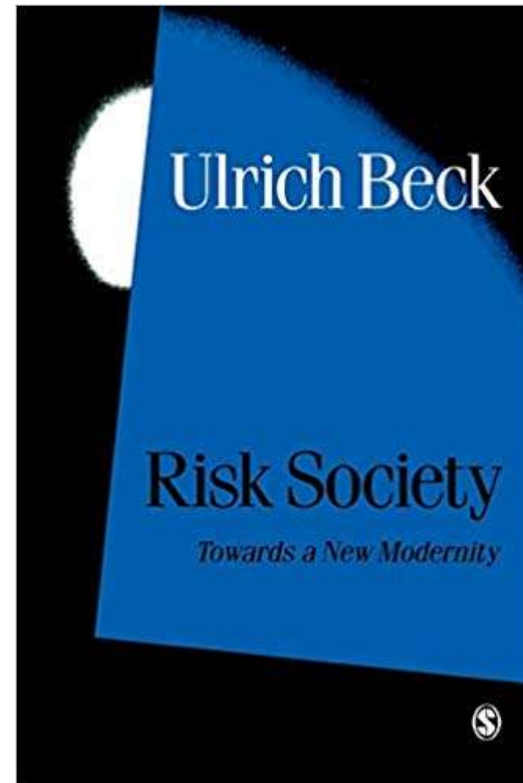
# From Ulrich Beck to Giandomenico Majone: the technique is never neutral



Ulrich Beck  
(1944 –2015)



1989



1992 (1986)



Environmental Science & Policy

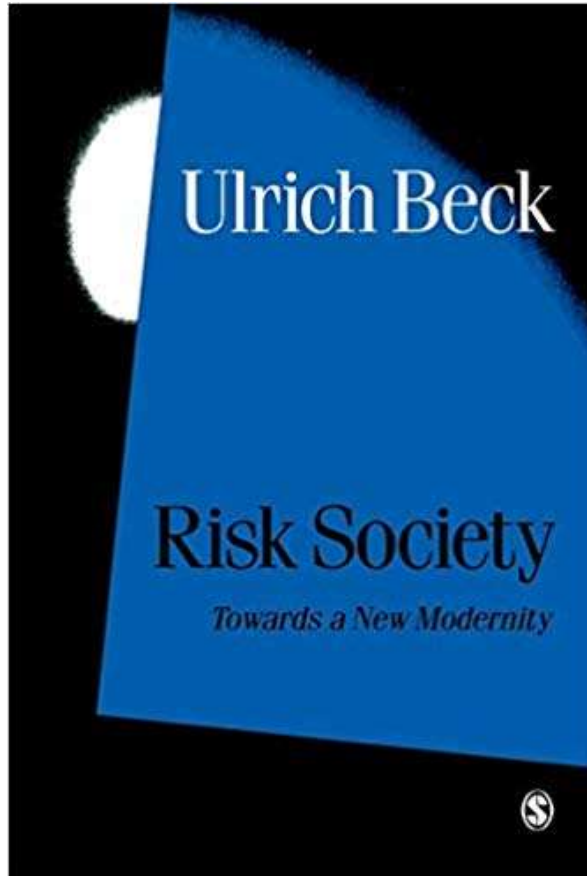
Volume 106, April 2020, Pages 87-98



The technique is never neutral. How  
methodological choices condition the  
generation of narratives for sustainability

Andrea Saltelli <sup>a, b</sup> ✉, Lorenzo Benini <sup>c</sup>, Silvio Funtowicz <sup>a</sup>, Mario Giampietro <sup>d, e</sup>, Matthias Kaiser <sup>a</sup>,  
Erik Reinert <sup>a, f</sup>, Jeroen P. van der Sluijs <sup>a, g, h</sup>

“It is not uncommon for political programs to be decided in advance simply by the choice of what expert representatives are included in the circle of advisers.”



1992 (1986)



Ulrich Beck  
(1944 –2015)

# The technique is never neutral. How methodological choices condition the generation of narratives for sustainability



Environmental Science & Policy  
Volume 106, April 2020, Pages 87–98



Andrea Saltelli <sup>a, b</sup>  , Lorenzo Benini <sup>c</sup>, Silvio Funtowicz <sup>a</sup>, Mario Giampietro <sup>d, e</sup>, Matthias Kaiser <sup>a</sup>, Erik Reinert <sup>a, f</sup>, Jeroen P. van der Sluijs <sup>a, g, h</sup>

Combine more lenses, including Post-normal science (PNS), Bioeconomics, and Non-Ricardian economics



# Mind the assumptions

Assess uncertainty and sensitivity

## Mind the hubris

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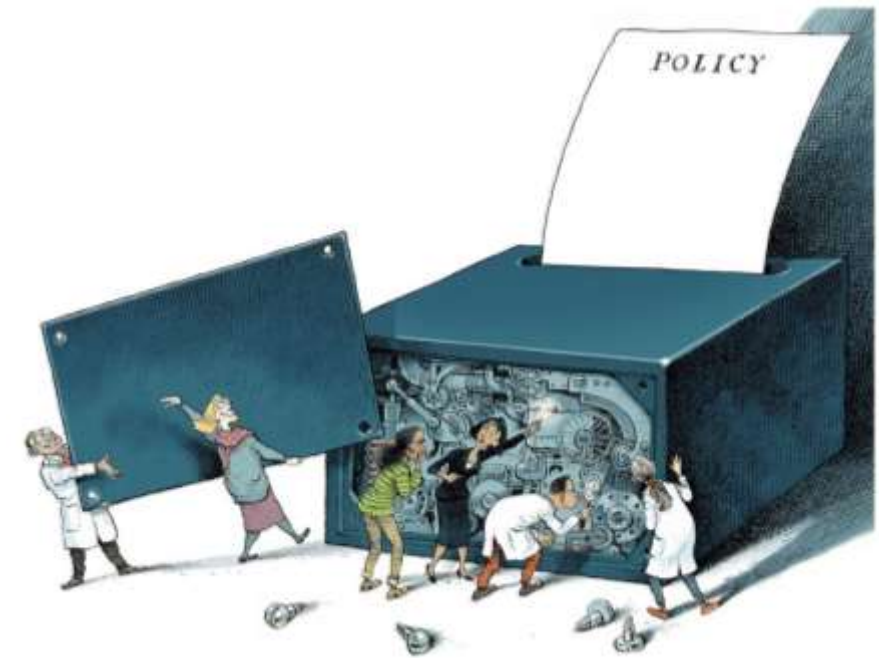


## Mind the consequences

Quantification can backfire.

## Mind the unknowns

Acknowledge ignorance





# Mind the consequences

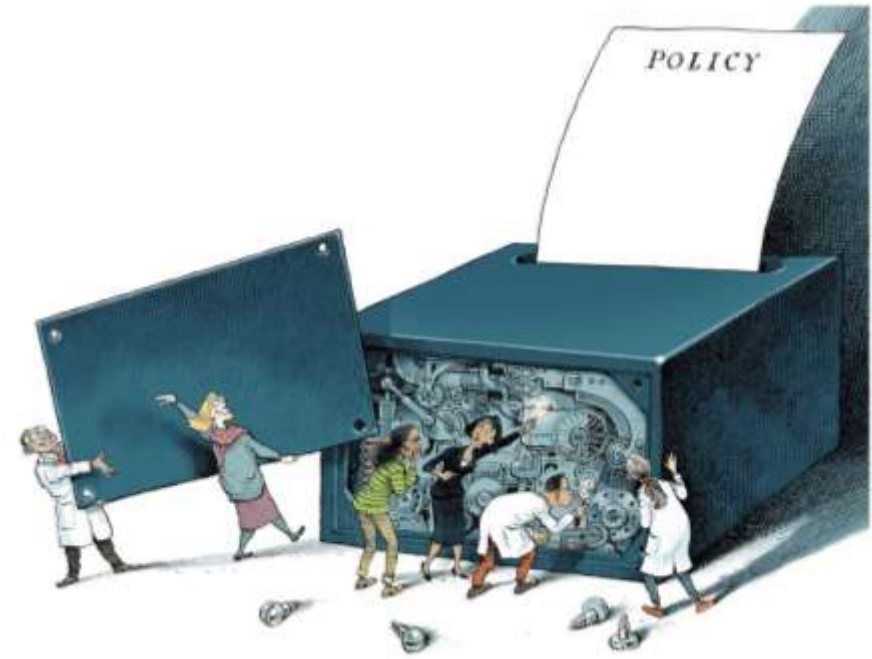
## Quantification can backfire.

[« Back to Article](#)

WIRED MAGAZINE: 17.03

### Recipe for Disaster: The Formula That Killed Wall Street

By Felix Salmon 02.23.09



$$\Pr[T_A < 1, T_B < 1] = \Phi_2(\Phi^{-1}(F_A(1)), \Phi^{-1}(F_B(1)), \gamma)$$

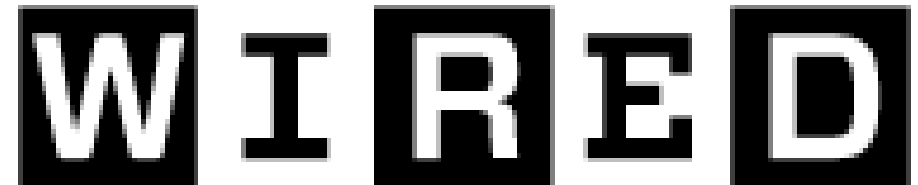
Here's what killed your 401(k) *David X. Li's Gaussian copula function as first published in 2000. Investors exploited it as a quick—and fatally flawed—way to assess risk. A shorter version appears on this month's cover of Wired.*

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



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

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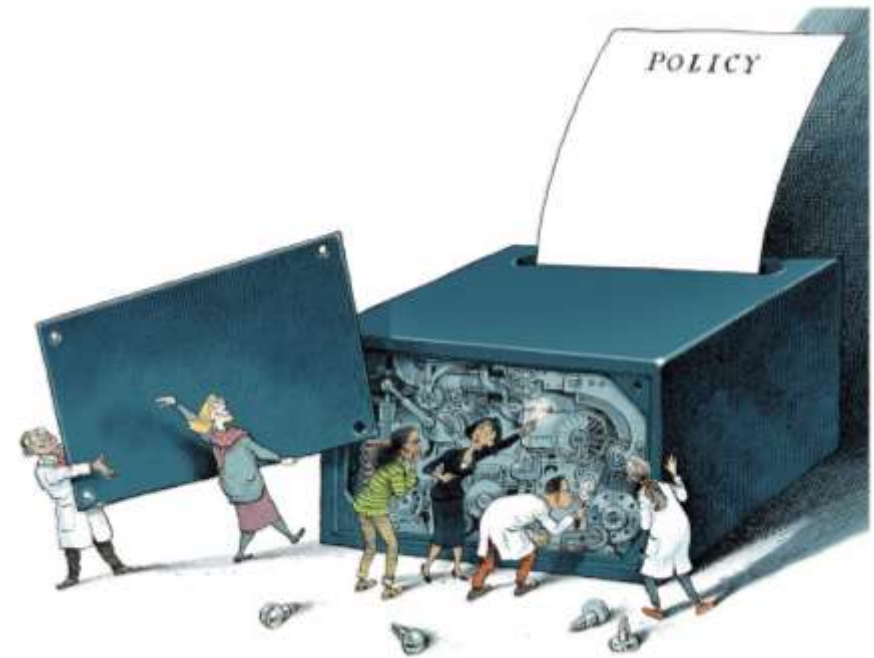
## Mind the consequences

Quantification can backfire.



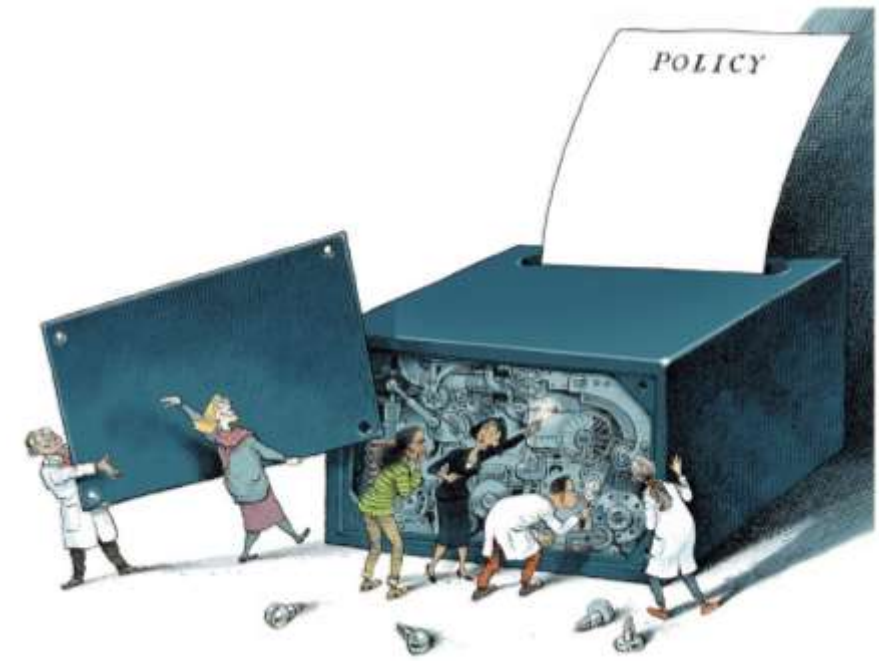
## Mind the unknowns

Acknowledge ignorance



# Mind the unknowns

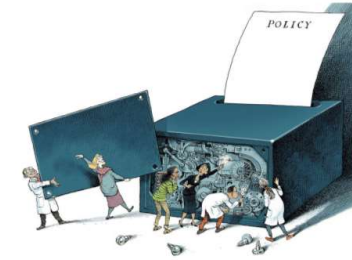
## Acknowledge ignorance



From Socrates's “knowing of not knowing” to Nicolaus Cusanus’ *Docta Ignorantia* was a virtue until Descartes



“There is no number-answer to your question”



Anthony Fauci

March 12, 2020, Anthony Fauci before the House Oversight and Reform Committee  
[https://archive.org/details/CSPAN\\_20200314\\_141500\\_Dr.\\_Redfield\\_Dr.\\_Fauci\\_\\_Others\\_Testify\\_on\\_Coronavirus\\_Response\\_Part\\_1](https://archive.org/details/CSPAN_20200314_141500_Dr._Redfield_Dr._Fauci__Others_Testify_on_Coronavirus_Response_Part_1)

Reproducibility

is a necessary  
condition for

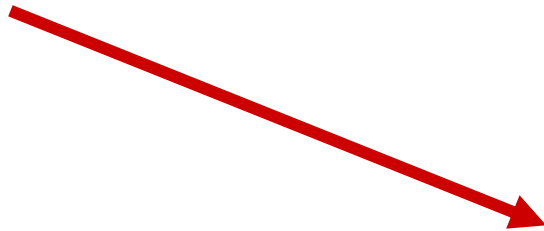
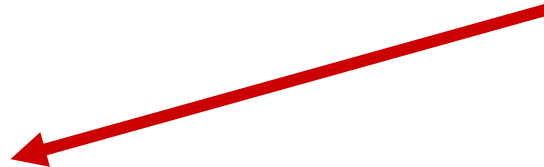
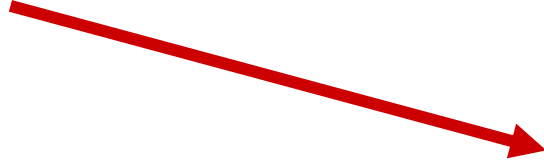
Transparency

is a necessary  
condition for

Legitimacy

is a necessary  
condition for

Epistemic authority





Sensitivity auditing

# EC impact assessment guidelines: sensitivity analysis & auditing



*Better Regulation*  
**TOOLBOX**

November 2021

European Commission. November 2021. “Better Regulation: Guidelines and Toolbox.”

[https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox\\_en](https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox_en)

# Sensitivity auditing in the EC Guidelines (p. 563)

“Sensitivity auditing is a wider consideration of the effect of all types of uncertainty, including structural assumptions embedded in the model, and subjective decisions taken in the framing of the problem.”



*Better Regulation*  
**TOOLBOX**

November 2021

## Sensitivity auditing in the EC Guidelines (p. 563)

“In general, sensitivity auditing stresses the idea of clearly communicating the extent to which particular models can be used to support policy decisions and their results can be trusted, taking into account as much as possible all forms of potential uncertainty, ...”



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**TOOLBOX**

November 2021

# Sensitivity auditing in the EC Guidelines (p. 563)

“... and to anticipate criticism by third parties. In particular, one should avoid giving the impression of false confidence by ‘quantification at all costs’.”



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**TOOLBOX**

November 2021

# Sensitivity auditing in the EC Guidelines (p. 563)

“In some cases there is simply not enough data, or the process is too complex, to give a meaningful quantitative prediction.”



*Better Regulation*  
**TOOLBOX**

November 2021



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## **What do I make of your latinorum? Sensitivity auditing of mathematical modelling**

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Saltelli, A., Guimarães Pereira, Â.,  
Van der Sluijs, J.P. and Funtowicz, S.

# The rules of sensitivity auditing

(similar to the Manifesto)

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.

# The End

@andreasaltelli



## Question 1



The influence of the key variables should be investigated by a sensitivity analysis.

- Is something wrong about the statement above (p. 384 of EC guidelines)

## Question 2



“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?” (Majone 1989)

Please comment



## Question 3



What uses can you imagine for sensitivity analysis?