

# How not to do a sensitivity analysis

Andrea Saltelli

Virtual talk in the ISoP MCS SIG Webinar series, Tuesday 8th of February 2022, 17.00 CET,

<https://sites.google.com/view/mcssig/mcs-sig>



# 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 square background.[HOME](#)[ABOUT ME](#)[PUBLICATIONS](#)[NEWS & VIDEOS](#)[RESOURCES](#)A large background image of terraced rice fields in a valley, with mountains in the background under a hazy sky. The text "CAETERIS ARE NEVER PARIBUS" is overlaid on the left side of the image.

CAETERIS ARE  
NEVER PARIBUS

Tweets by @AndreaSaltelli

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#statistiques #probabilités #modélisation  
#prédiction Isabelle Bruno du #CERAPS  
@univ\_lille @CNRS\_HdF @ScPoLille nous parle  
des dérives de la #quantophrénie dans un article à  
lire sur le media @FR\_Conversation  
[https://twitter.com/FR\\_Conversation/status/1302651033164881920](https://twitter.com/FR_Conversation/status/1302651033164881920)

♡ ↗

Sep 7, 2020

 **andrea saltelli**  
@AndreaSaltelli

Pour mes amis francophones. Honoured to be co-  
author of a statactivist like Isabelle Bruno du  
#CERAPS @univ\_lille @CNRS\_HdF @ScPoLille  
@OpenEvidence @UOCNews  
Statistiques et modèles mathématiques : doit-on

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- Don't use just any method
- Don't use One factor At a Time (OAT)
- Don't use method that are not model-independent
- Don't use either LHS or optimized LHS
- Don't run the model just once
- Don't use Morris' method
- Don't confuse the map with the territory
- Beware the dimension of your model
- Don't sample just parameters and boundary conditions
- Don't go public with your results without having seen your SA
- NEVER vary all factors of the same amount (5%, 10%, 20%)

“Which method is used and why?”

“Does the answer depends upon the model?”

# Don't use just any method

Use the method appropriate to context and purpose

# An introduction to variance based methods

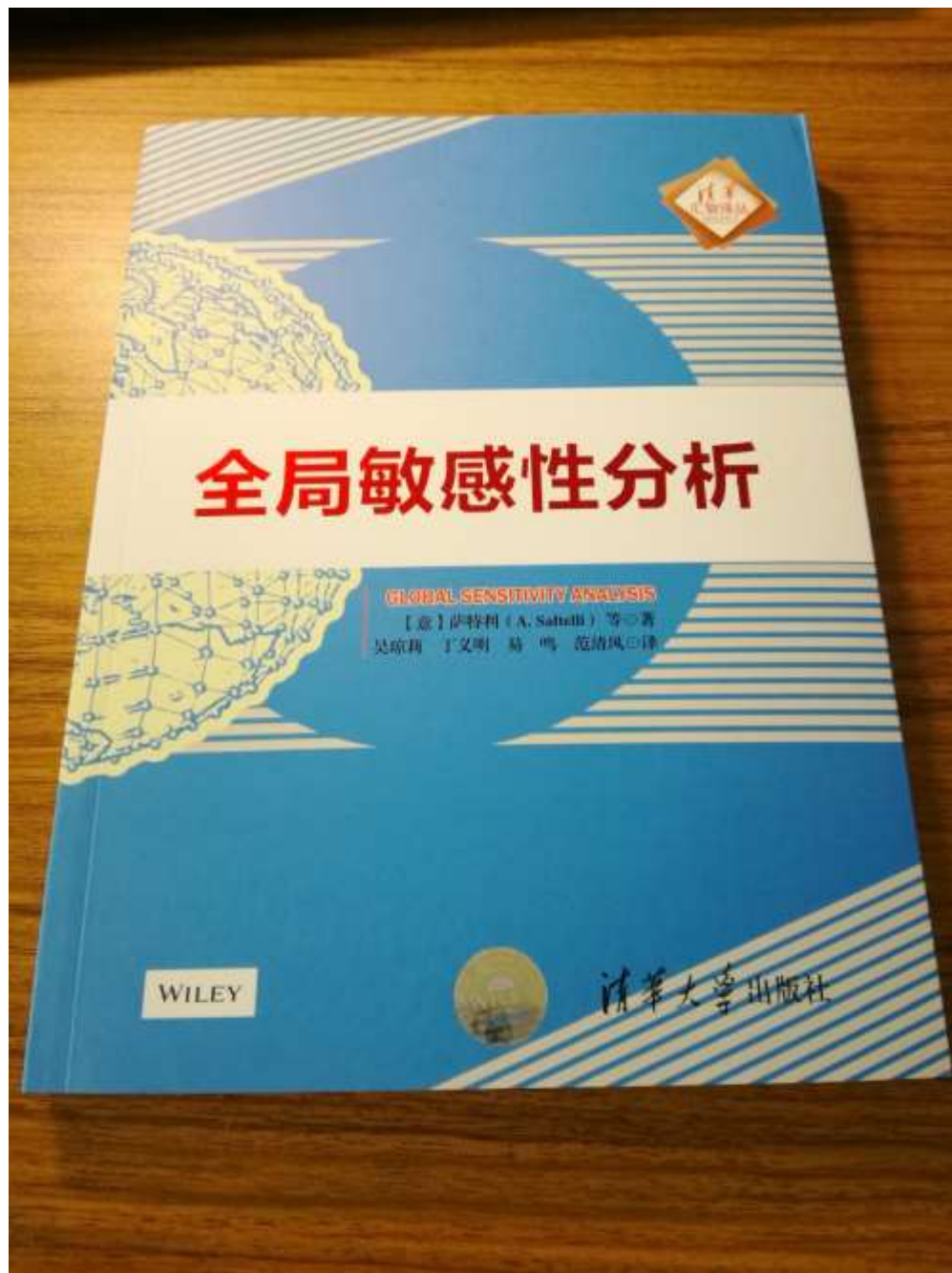


A. Saltelli, M. Ratto,  
T. Andres, F. Campolongo,  
J. Cariboni, D. Gatelli,  
M. Saisana, S. Tarantola

# 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

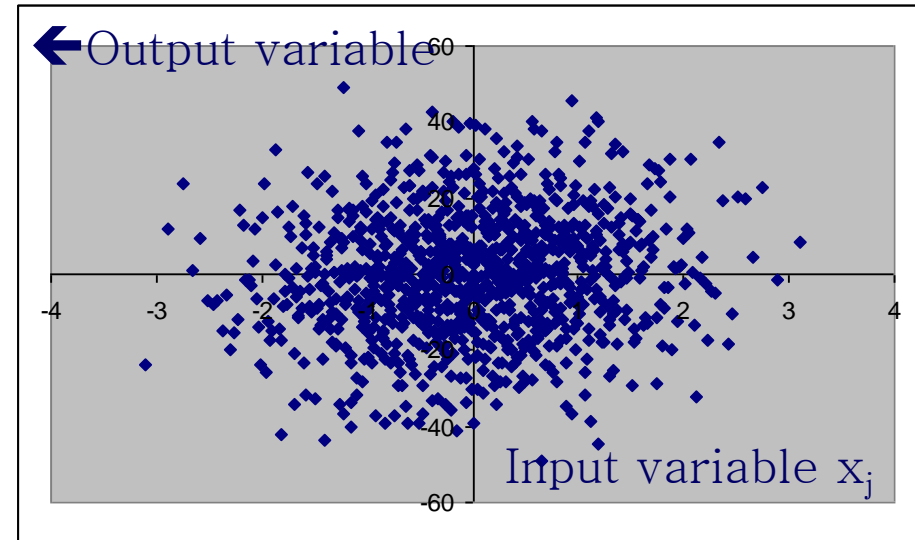
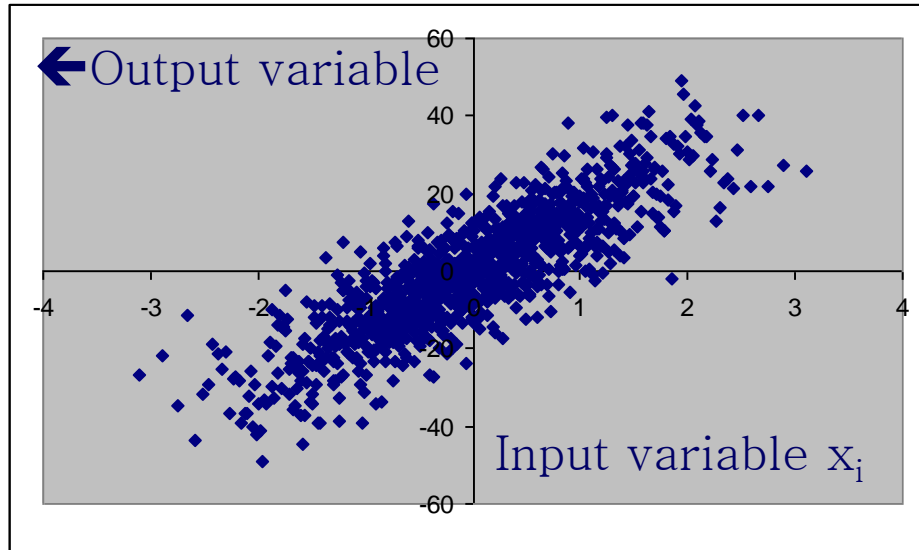
The Primer

 WILEY

Available for free at

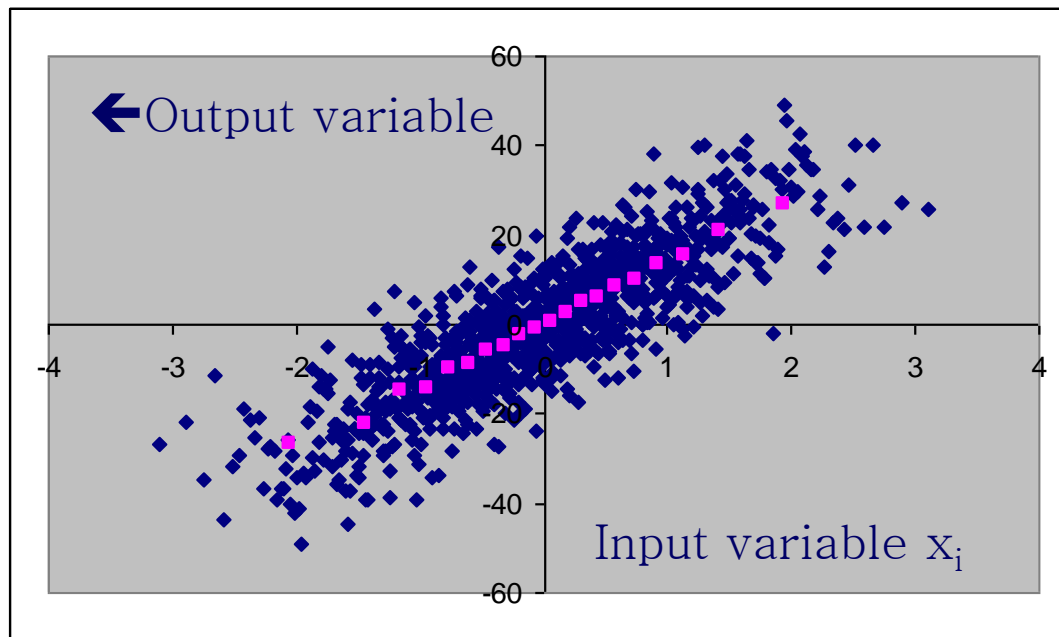
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Plotting the output as a function of two different input factors

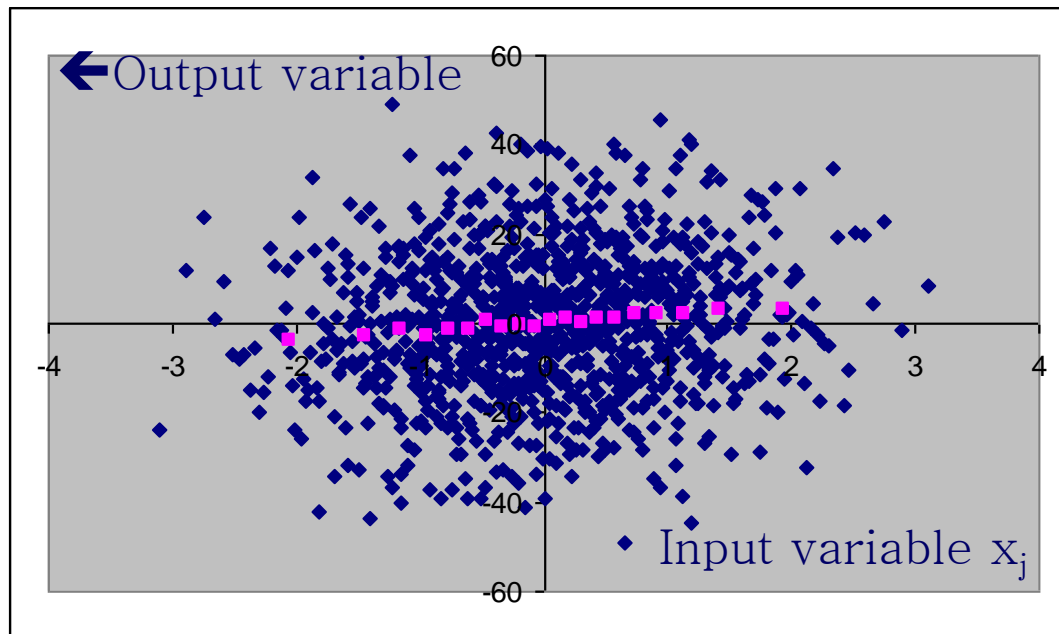
Which factor is more important?

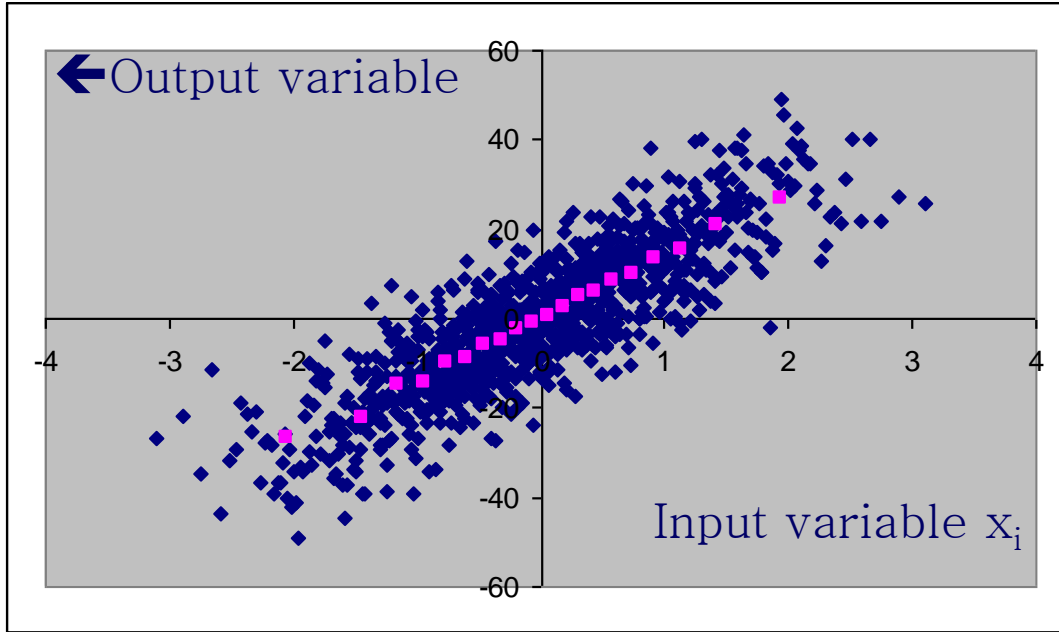


~1,000 blue points

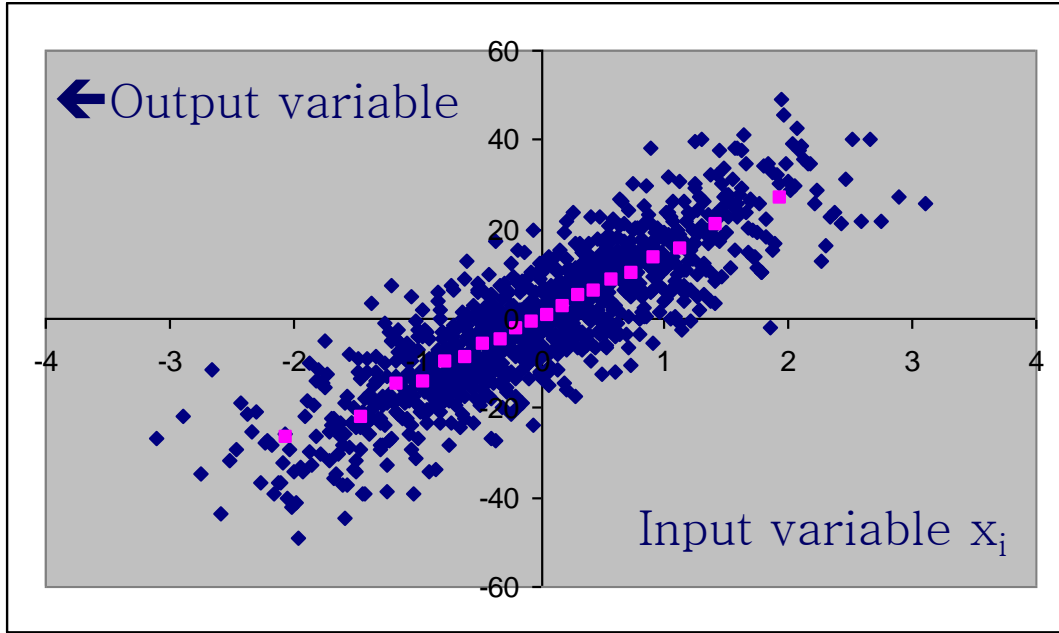
Divide them in 20 bins of ~ 50 points

Compute the bin's average (pink dots)



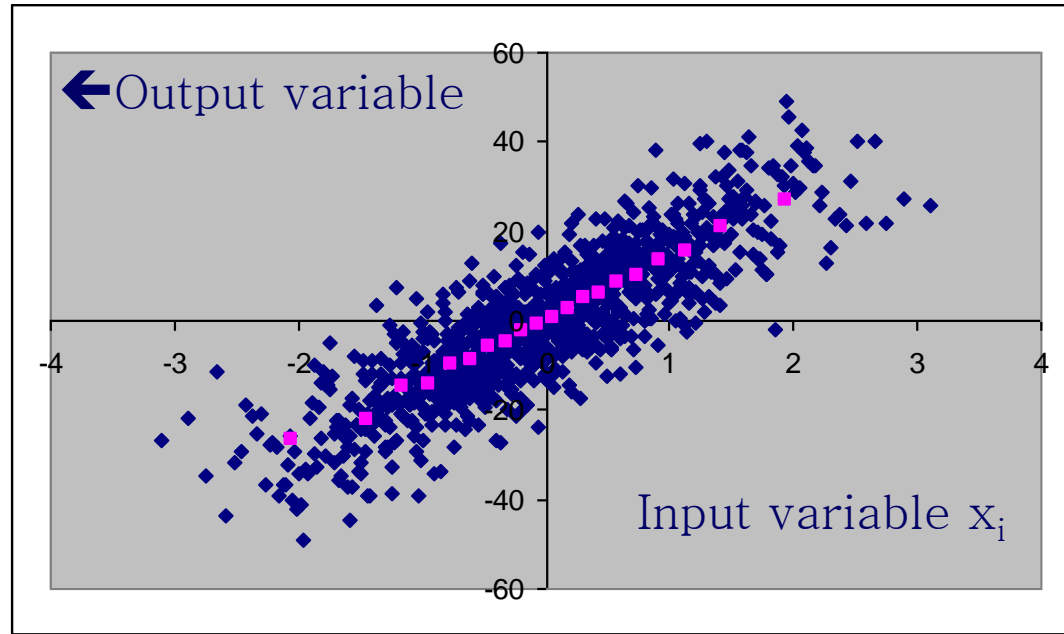


Each pink point is  $\sim E_{\mathbf{x}_{\sim i}}(Y|X_i)$

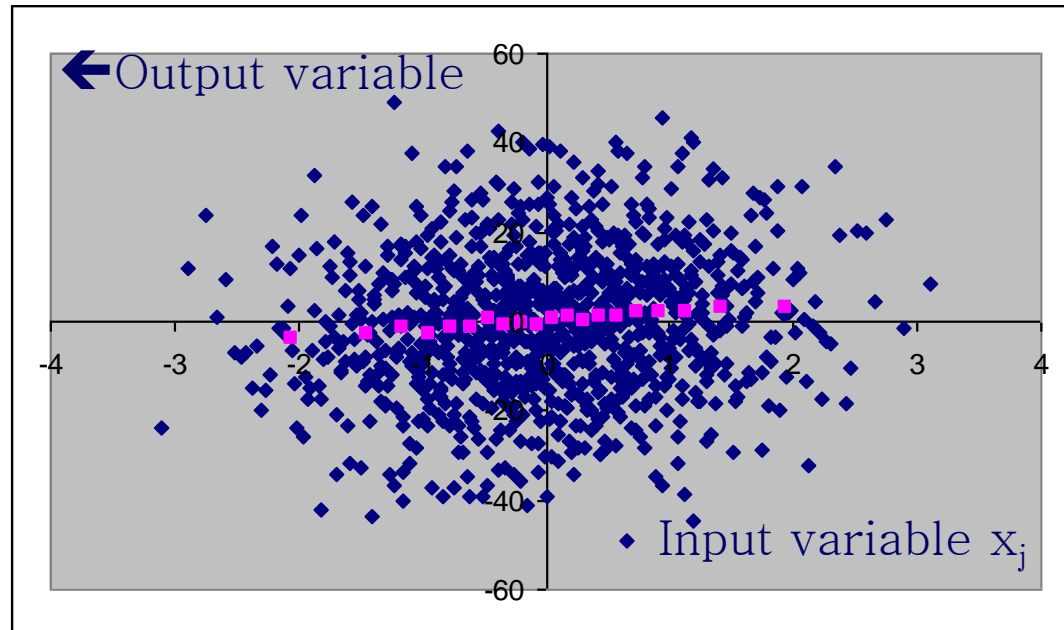


Take the variance of  
the pink points one  
obtains a sensitivity  
measure

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



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





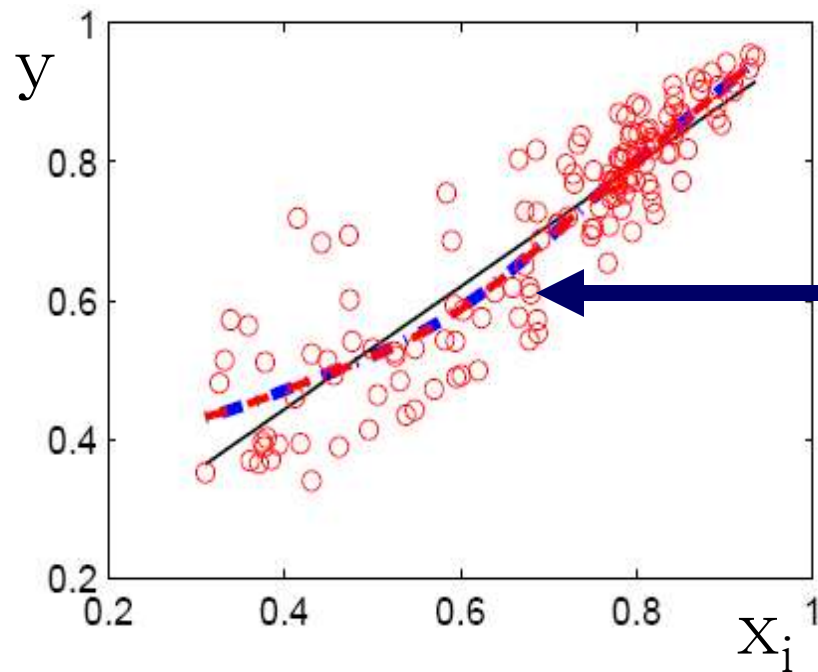
For additive models one can decompose the total variance as a sum of those partial variances

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

... 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

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

Verbose

$$S_i = \frac{V(E(Y | X_i))}{V(Y)}$$

Short

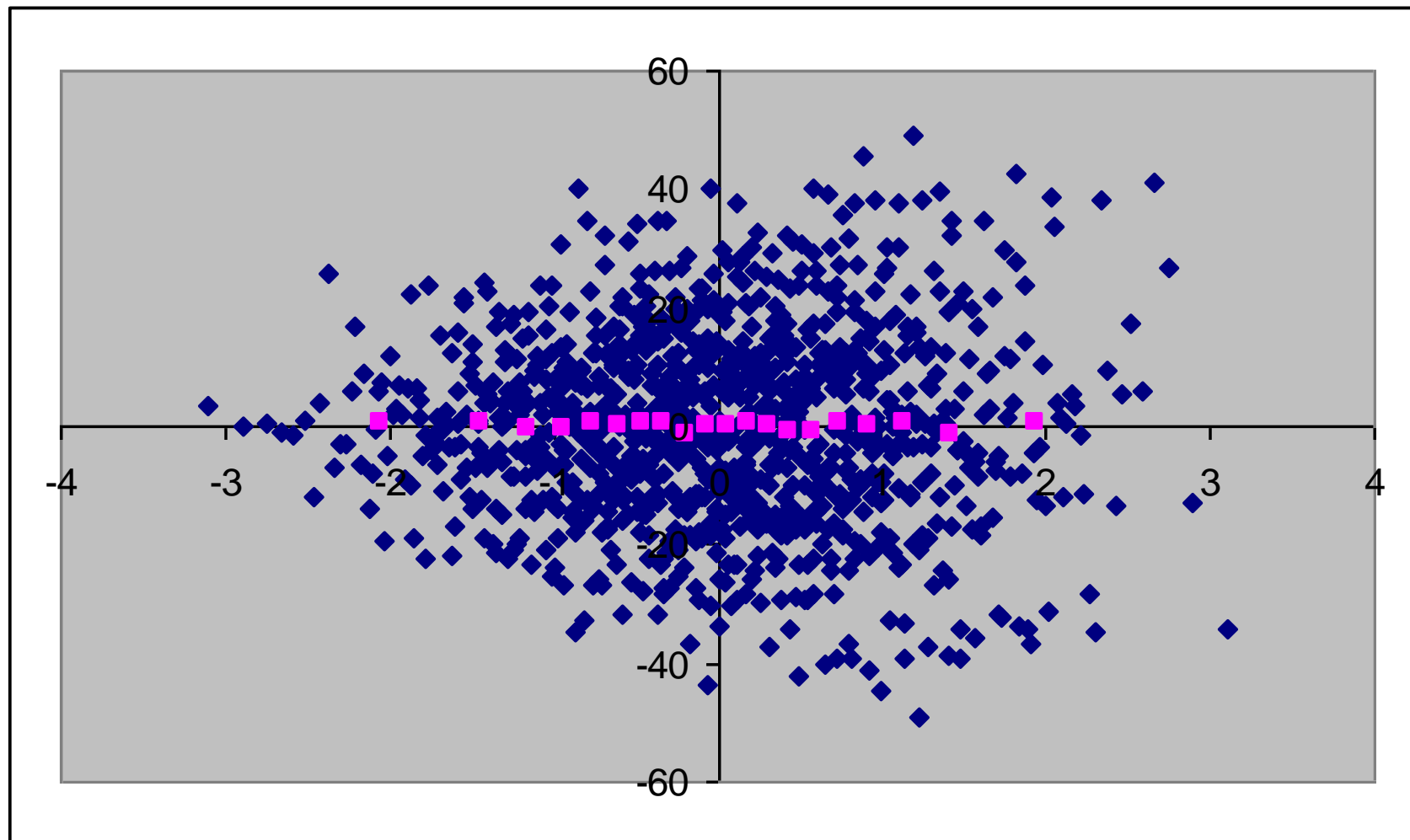


$$V_{X_i} \left( E_{\mathbf{X}_{\sim i}} (Y | X_i) \right)$$

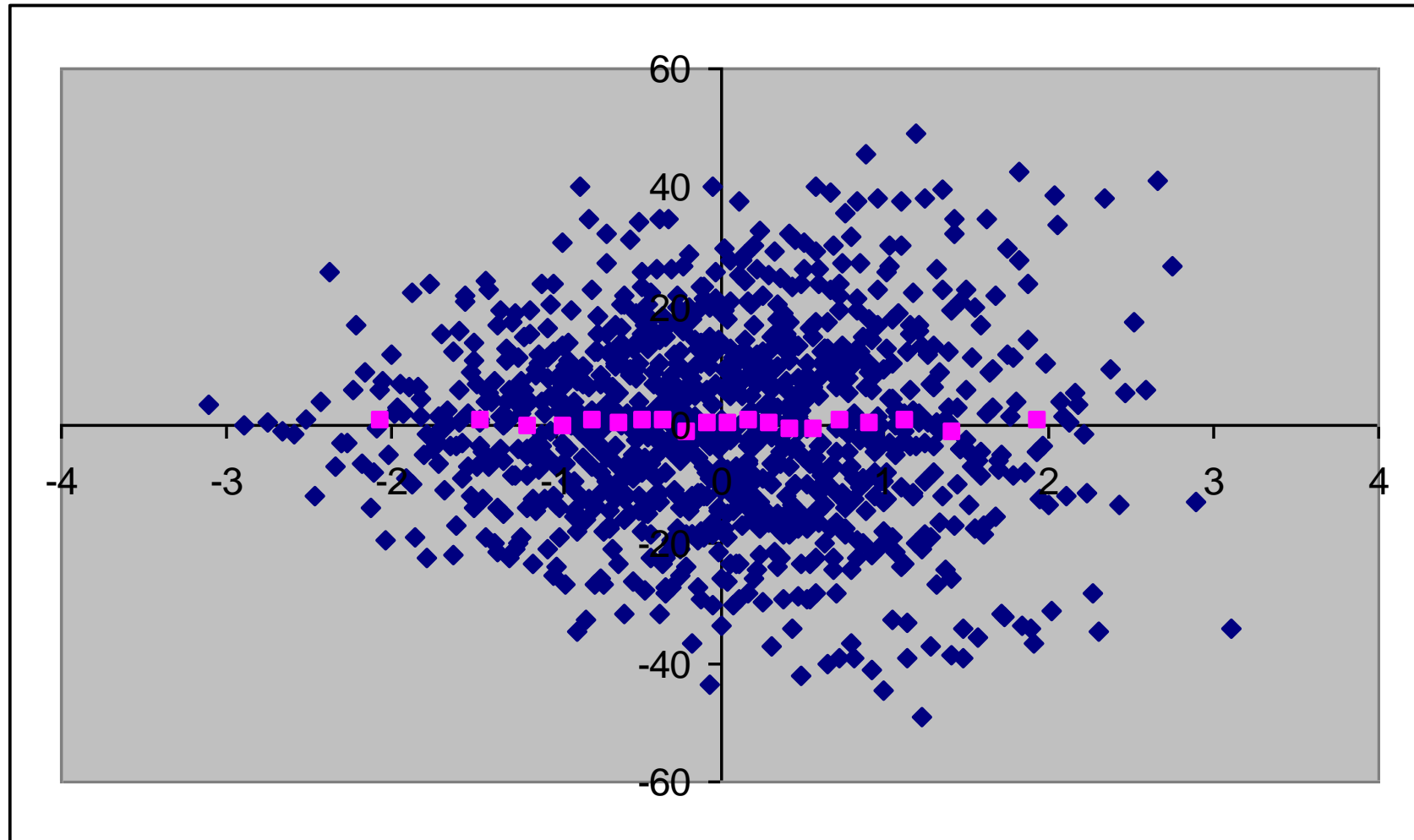
In plain English: the expected reduction in variance that would be achieved if factor  $X_i$  could be fixed.

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)

$$V(Y) =$$

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

Where does it come from?

$$f = f_0 + \sum_i f_i + \sum_i \sum_{j>i} f_{ij} + \dots + f_{12\dots k}$$



$$V(Y) = \sum_i V_i + \sum_i \sum_{j>i} V_{ij} + \dots + V_{12\dots k}$$

Dividing by the unconditional variance:

$$V(Y) = \sum_i V_i + \sum_i \sum_{j>i} V_{ij} + \dots + V_{12\dots k}$$



$$1 = \sum_i S_i + \sum_{j<i} S_{ij} + \dots + S_{12\dots k}$$

# 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 (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)



Wouldn't it be handy to have just a single 'importance' terms for all effects, inclusive of first order and interactions?

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

Thus given a model  $f(X_1, X_2, \dots, X_k)$

Where the variance decomposition would

read  $1 = S_1 + S_2 + S_3 + S_{12} + S_{13} + S_{23} + S_{123}$

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

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

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

I can as well divide the factors in  $f(X_1, X_2, \dots, X_k)$  in just two groups,  $u, v$  and the variance decomposition could be written as

$$1 = S_u + S_v + S_{uv}$$

instead of

$$1 = \sum_i S_i + \sum_{j < i} S_{ij} + \dots + S_{12\dots k}$$

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

In plain English:

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

is the expected variance that would be left if all factors but  $X_i$  could be fixed (self evident definition )

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

Verbose

$$T_i = \frac{E \left( V(Y | \mathbf{X}_{\sim i}) \right)}{V(Y)}$$

Short

# The measures expressed in plain English

First order effect =

=the expected reduction in variance that would be achieved if factor  $X_i$  could be fixed.

Also known as top marginal variance

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

Total order effect =

= the expected variance that would be left if all factors but  $X_i$  could be fixed

Also known as or bottom marginal variance

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

# The measures and their ‘settings’ = when to use them



**Journal of the American Statistical Association** >

Volume 97, 2002 - Issue 459

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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)

When the input factors are not independent:

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

Can still be used

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

Fails



# 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** ▼

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
- working with sets
- 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

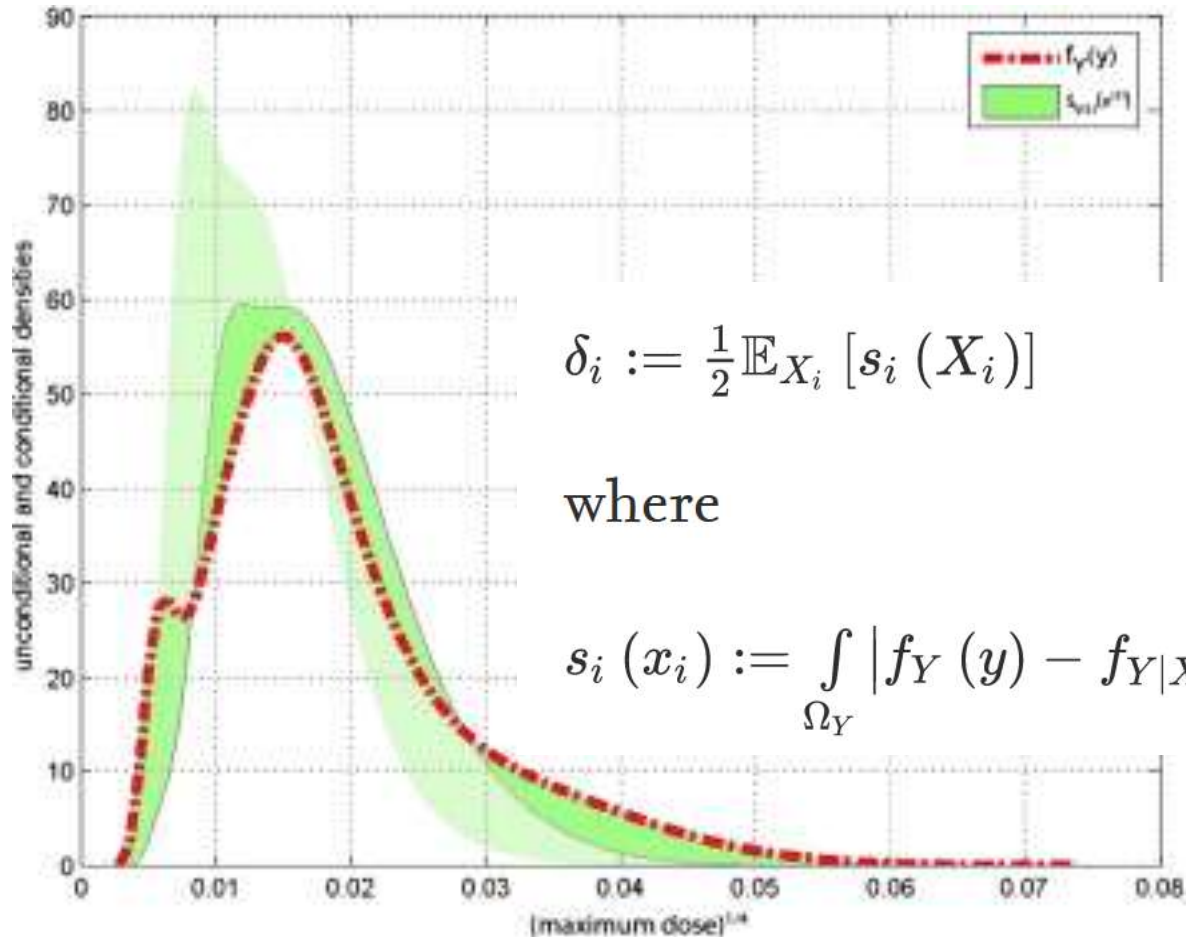


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# Is VARS more intuitive and efficient than Sobol' indices?

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



Contents lists available at ScienceDirect

## Environmental Modelling & Software

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

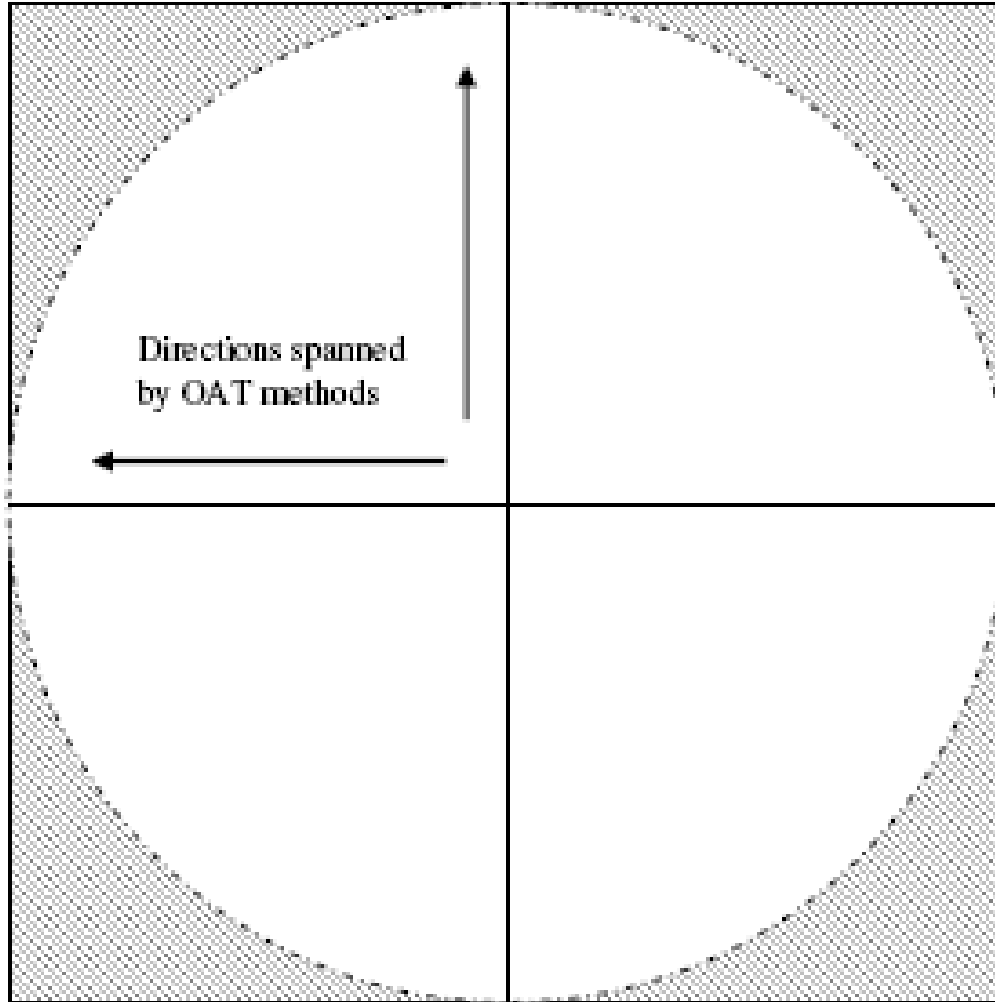


# How to avoid a **perfunctory** sensitivity analysis

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

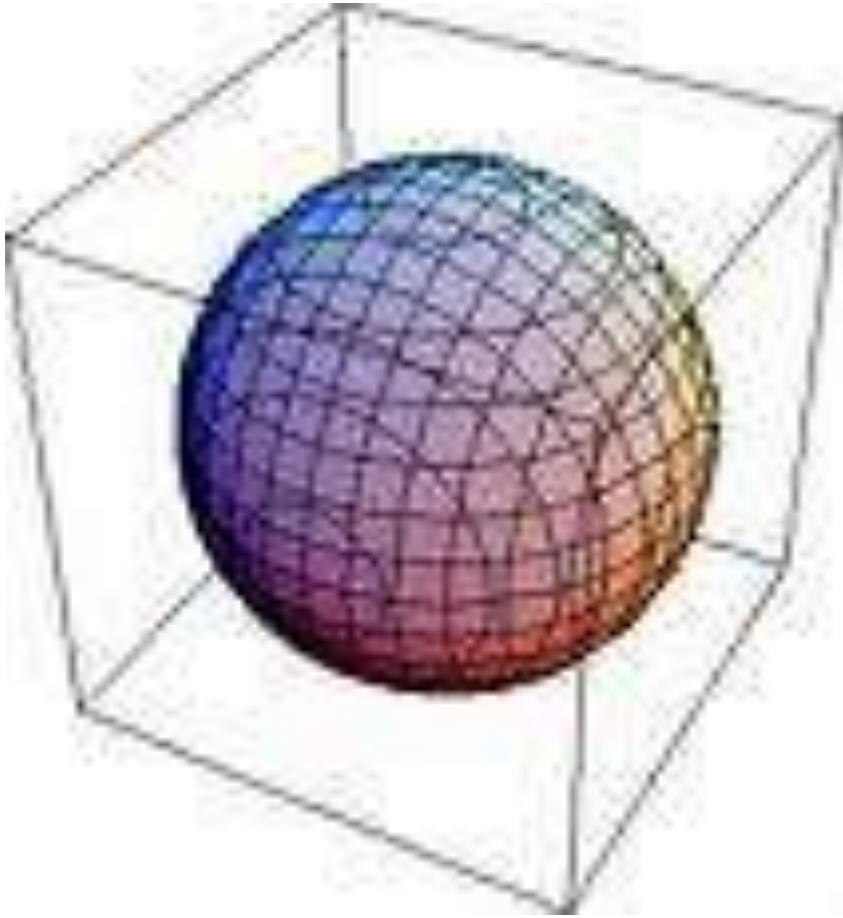


Area circle  
/ area  
square =?

~ 3/4



# OAT in 3 dimensions



Volume sphere /  
volume cube =?

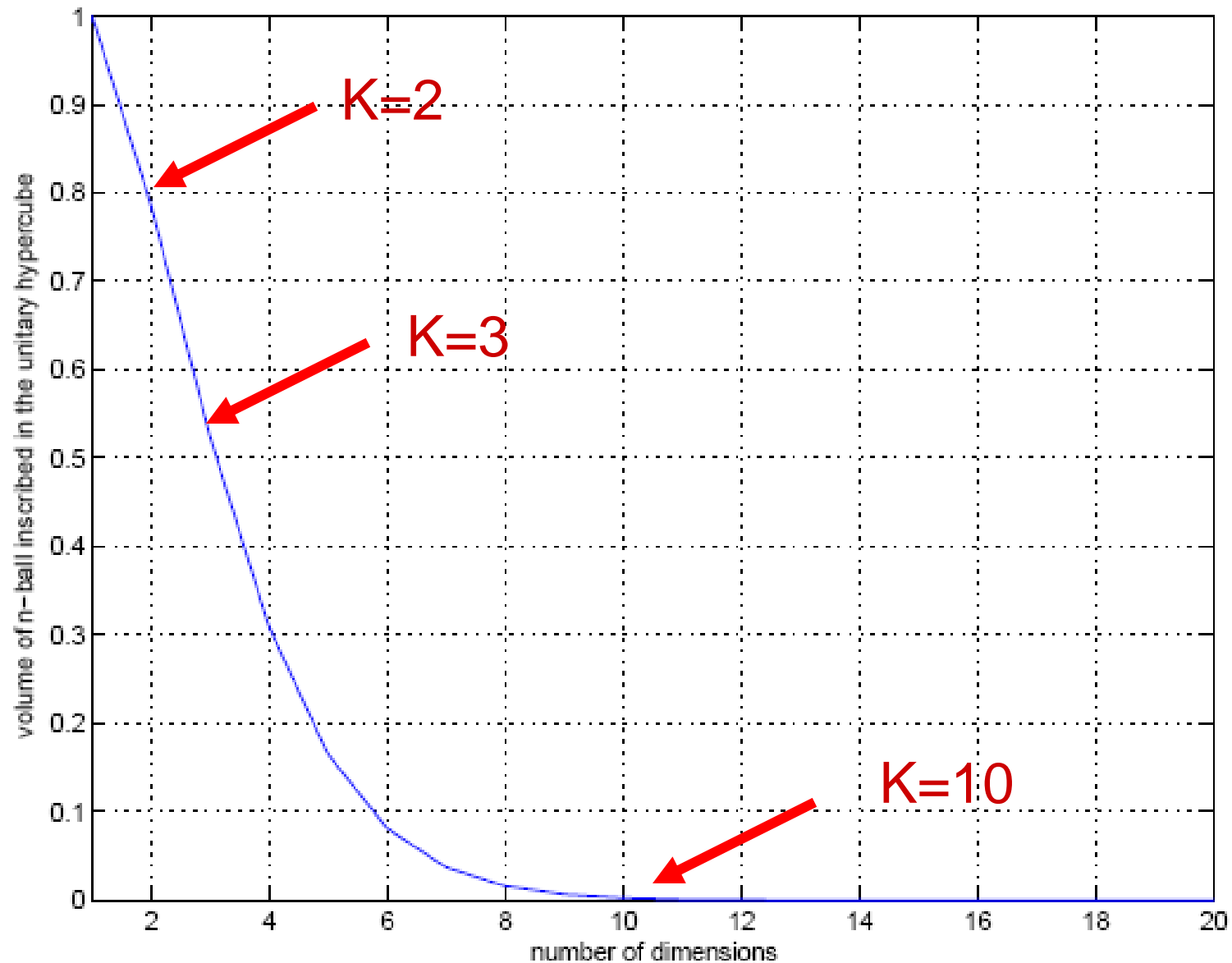
~ 1/2

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





# OAT in $k$ dimensions



OAT does not capture interactions

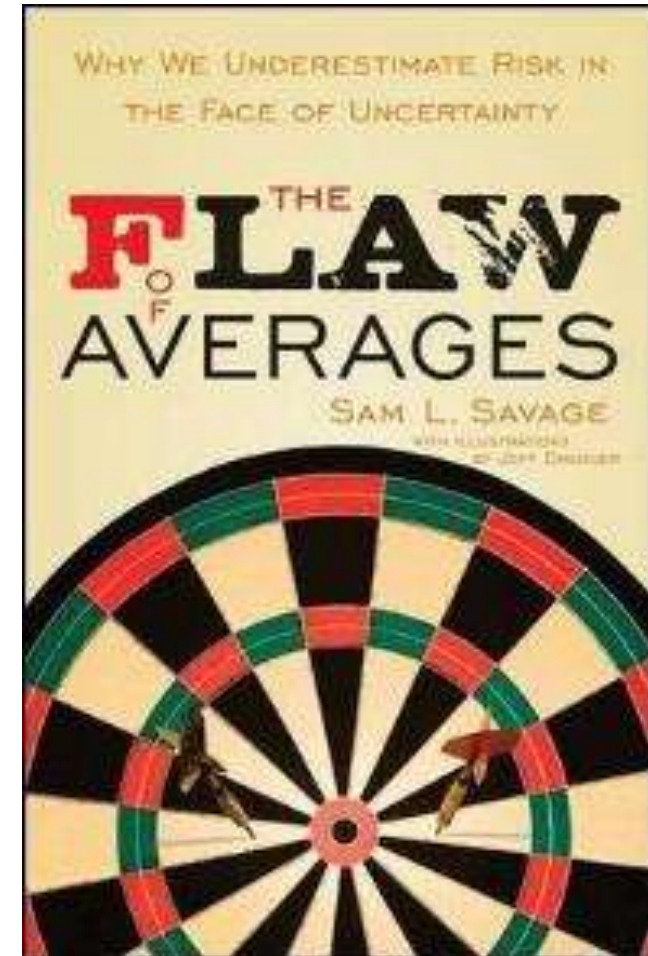
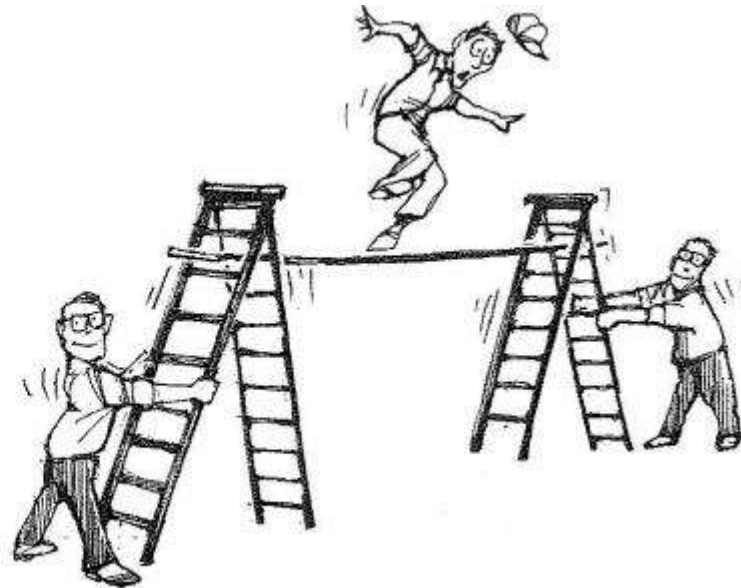
➔ The resulting analysis is non conservative

# 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



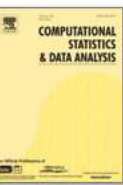
Non-parametric statistics in sensitivity analysis for model output: A comparison of selected techniques

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

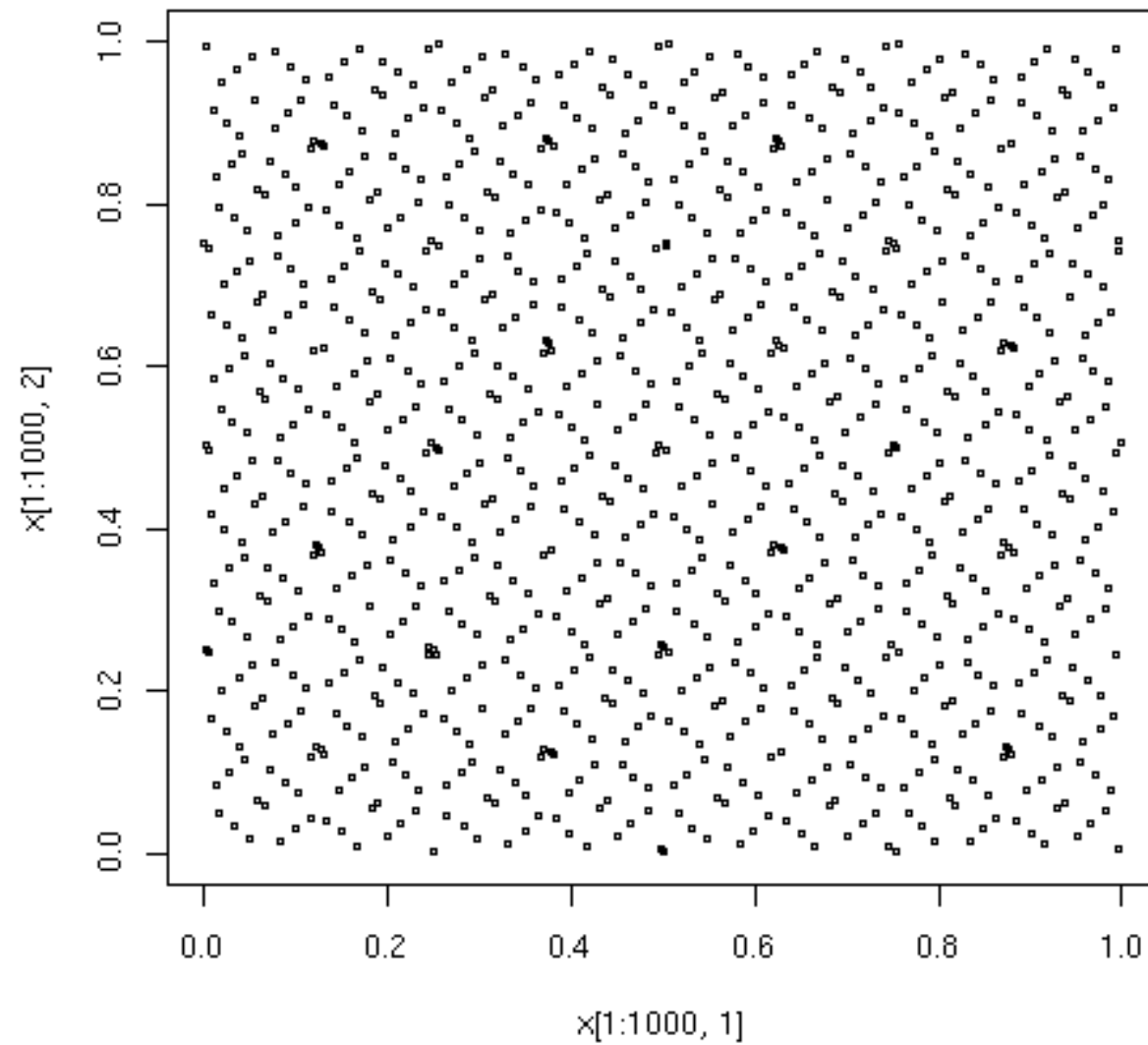
Quasi-random sequences are better



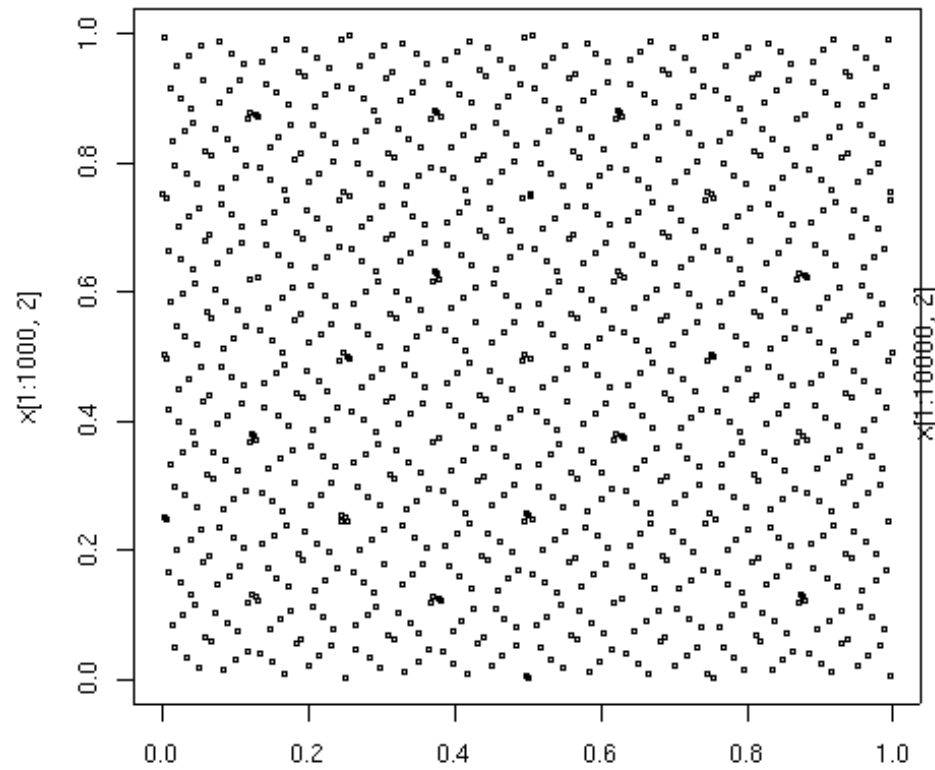
# Quasi random sequences

Ilya M. Sobol'

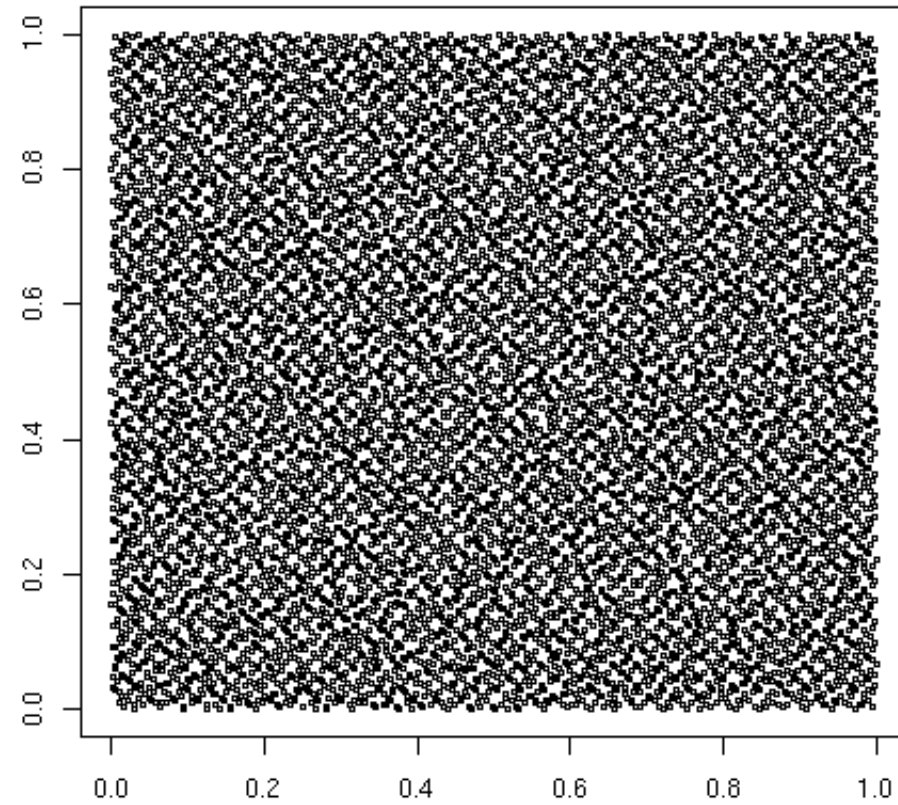




An  $LP_\tau$  sequence

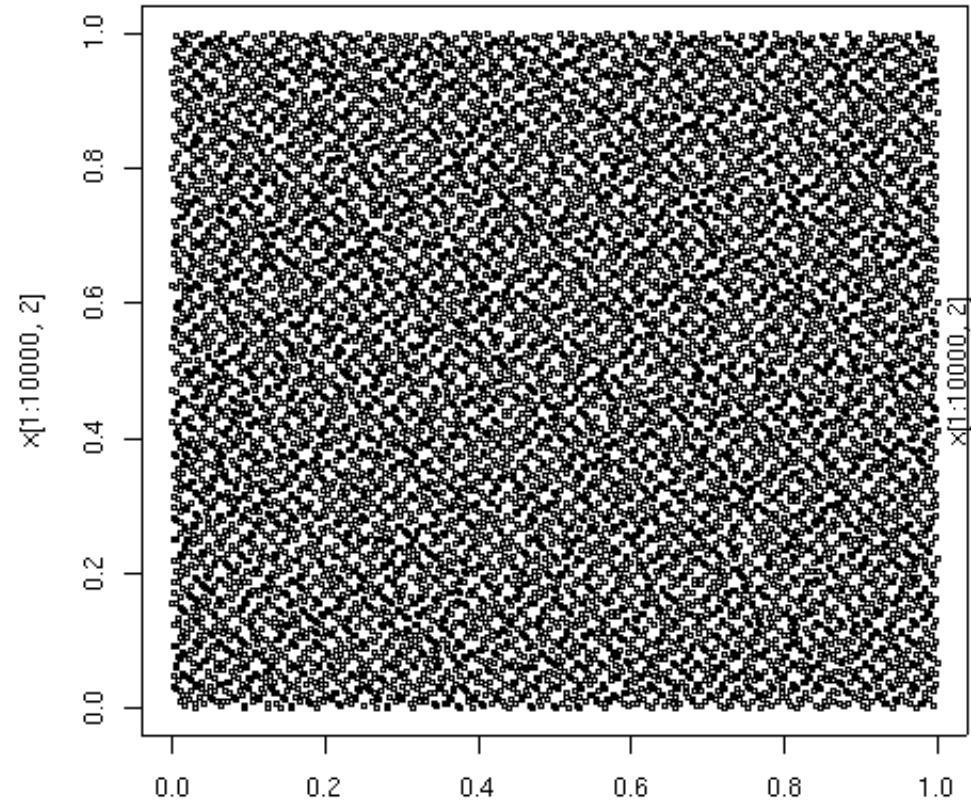


$X_1, X_2$  plane, 1000 Sobol' points

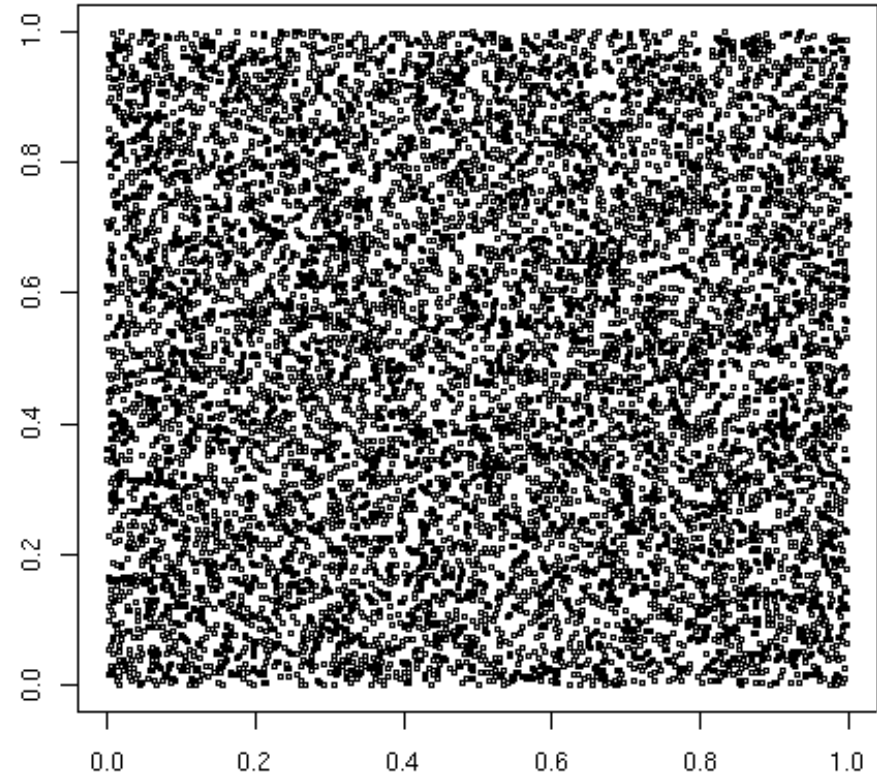


$X_1, X_2$  plane, 10000 Sobol' points

Sobol' sequences of quasi-random points



X1,X2 plane, 10000 Sobol' points

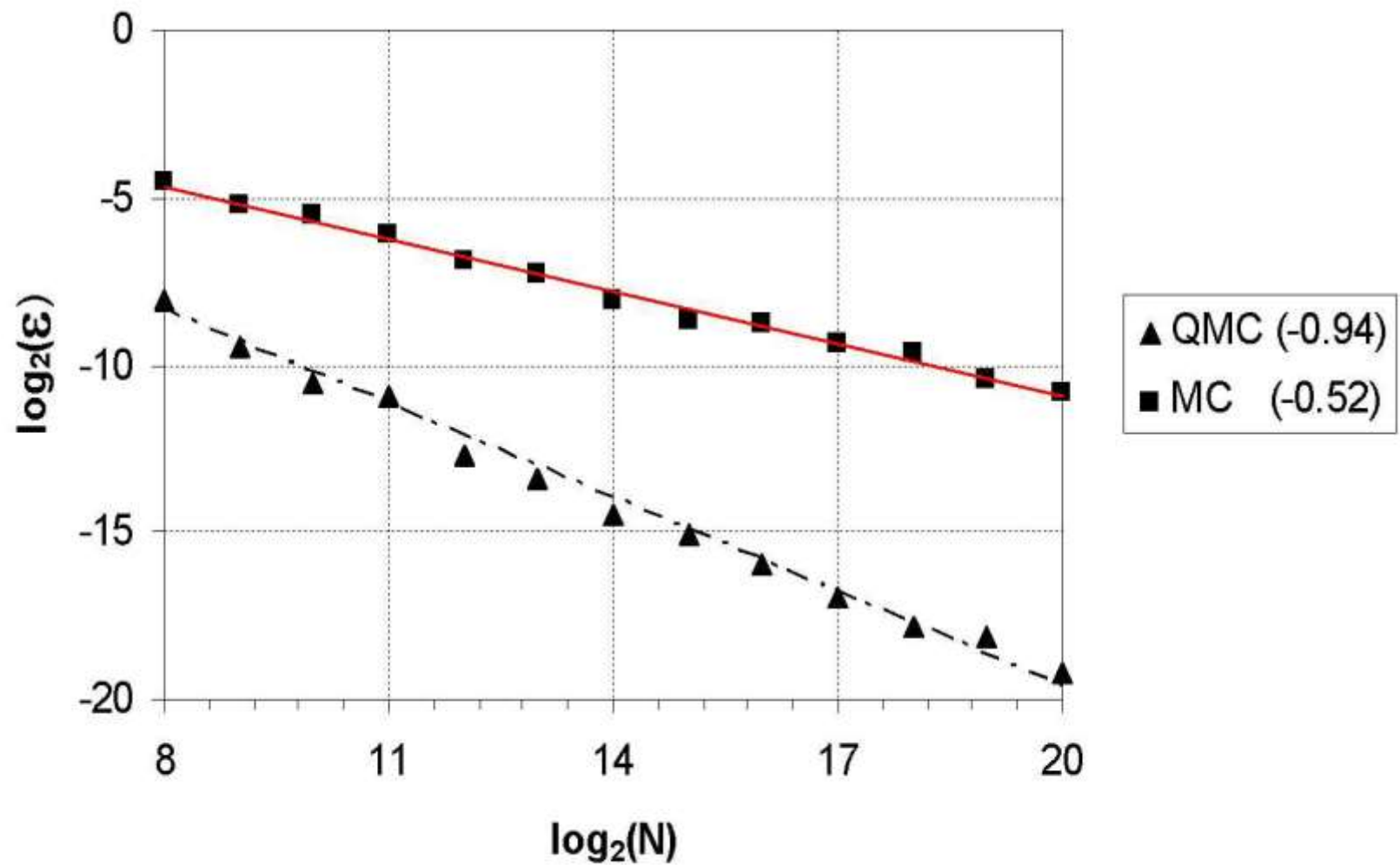


X1,X2 plane, 10000 random points

Sobol' sequences of quasi-random points  
against random points

# Why quasi-random: they have faster convergence

Kucherenko S., Feil B., Shah N., Mauntz W. The identification of model effective dimensions using global sensitivity analysis Reliability Engineering and System Safety 96 (2011) 440–449.



$$\varepsilon = \left( \frac{1}{K} \sum_{k=1}^K (I[f] - I_k[f])^2 \right)^{1/2}$$

$$\sum_{i=1}^n (-1)^i \prod_{j=1}^i x_j$$

Error=numeric-  
versus-analytic  
value the integral  
of the function (for  
n=360) over its  
dominion.

Root mean square error over K=50 different trials.



**Statistics > Applications**

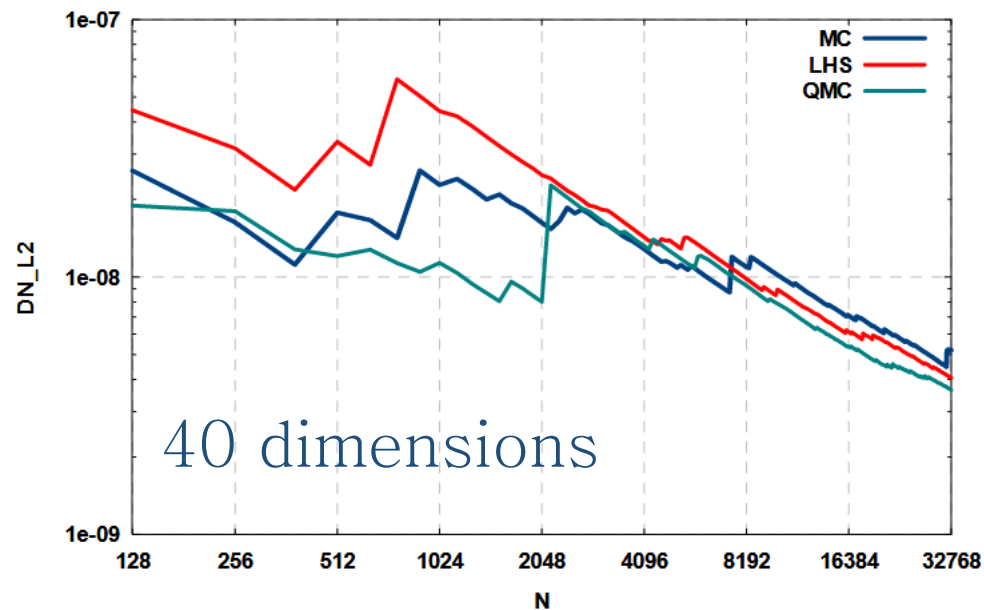
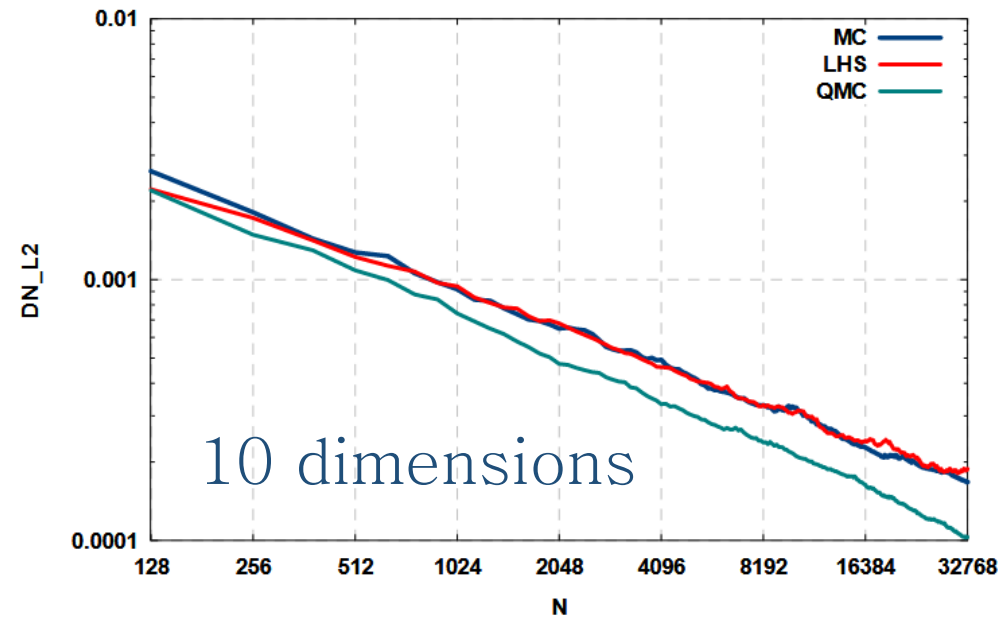
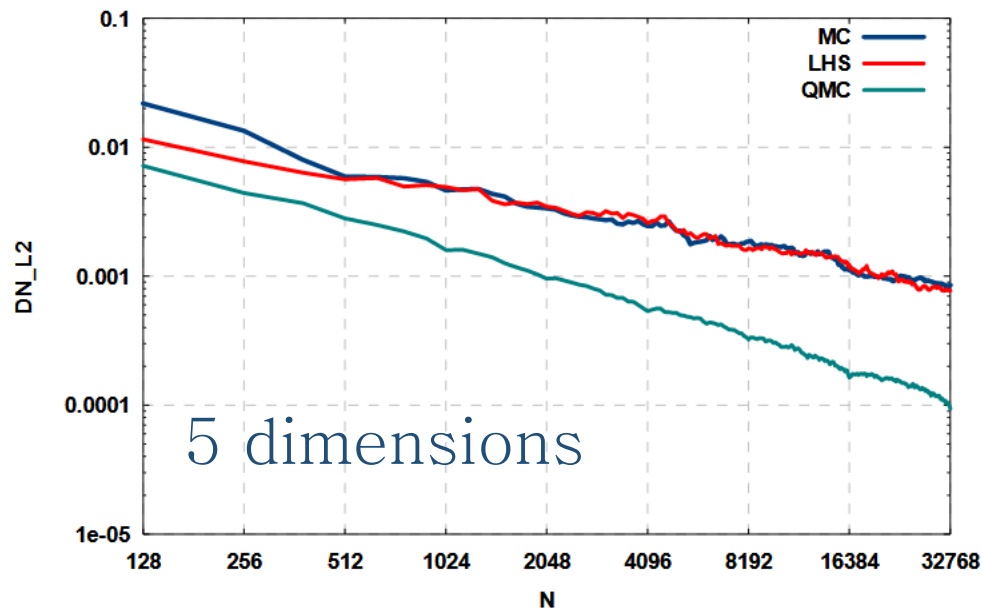
*[Submitted on 10 May 2015]*

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

Sergei Kucherenko, Daniel Albrecht, Andrea Saltelli

Comparing three different sampling methods  
over an array of functions of different  
dimensionality and difficulty

The concept of effective dimension



Discrepancy in 5, 10, 40  
dimensions (model  
independent), op. cit.  
arXiv:1505.02350

Don't use plain LHS and think twice about optimized LHS

If in doubt try it for yourself with a set of test functions of varying dimensionality



# 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

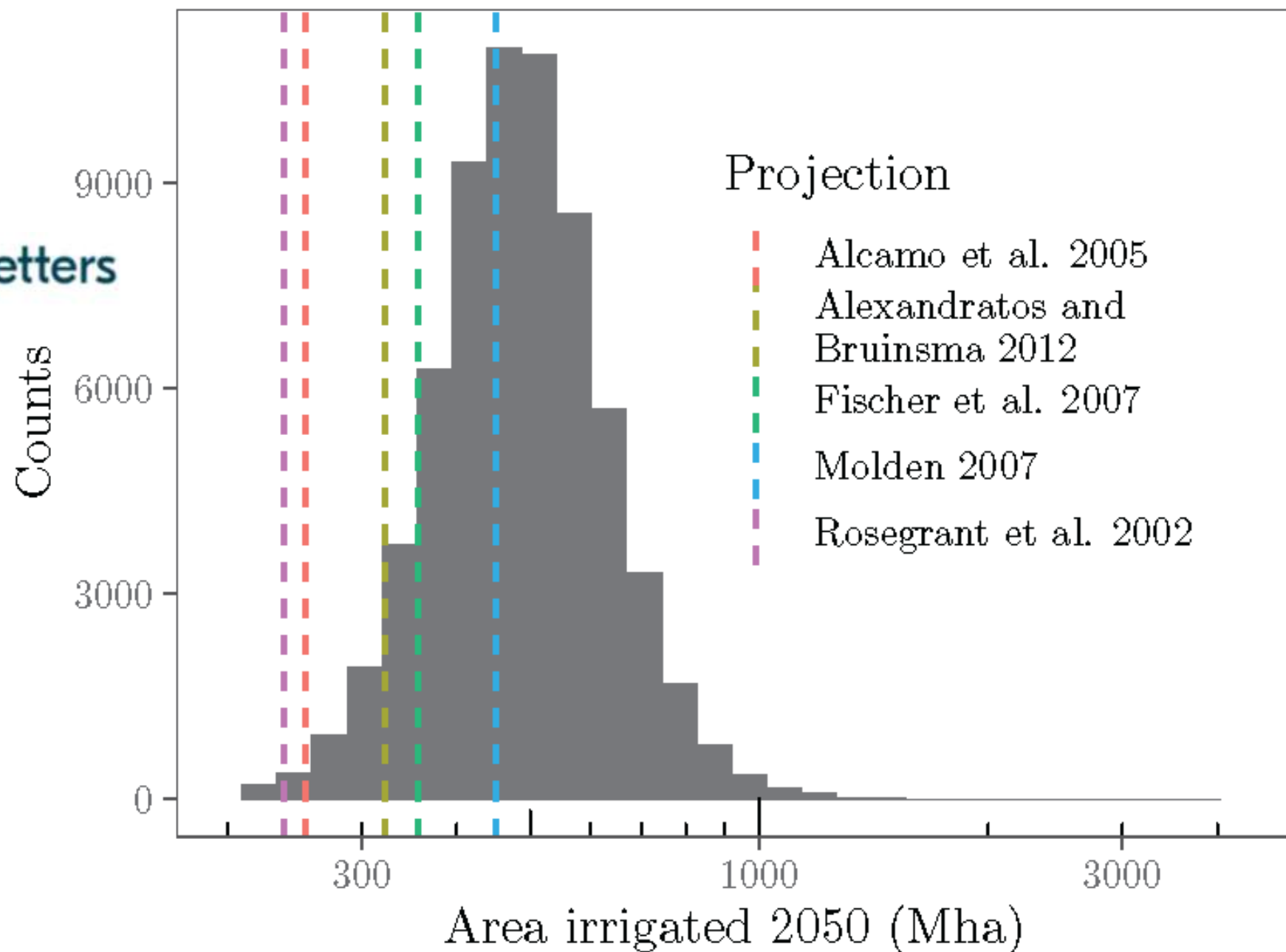
# Current Models Underestimate Future Irrigated Areas

## 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>



# Don't use Morris' method

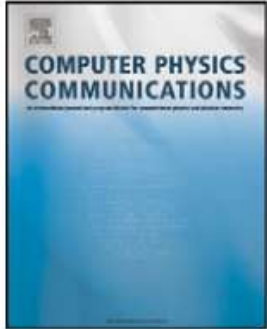
More cumbersome and fragile than the total sensitivity index that is its close equivalent



Contents lists available at ScienceDirect

## Computer Physics Communications

[www.elsevier.com/locate/cpc](http://www.elsevier.com/locate/cpc)



### From screening to quantitative sensitivity analysis. A unified approach

Francesca Campolongo<sup>\*</sup>, Andrea Saltelli, Jessica Cariboni

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

Morris

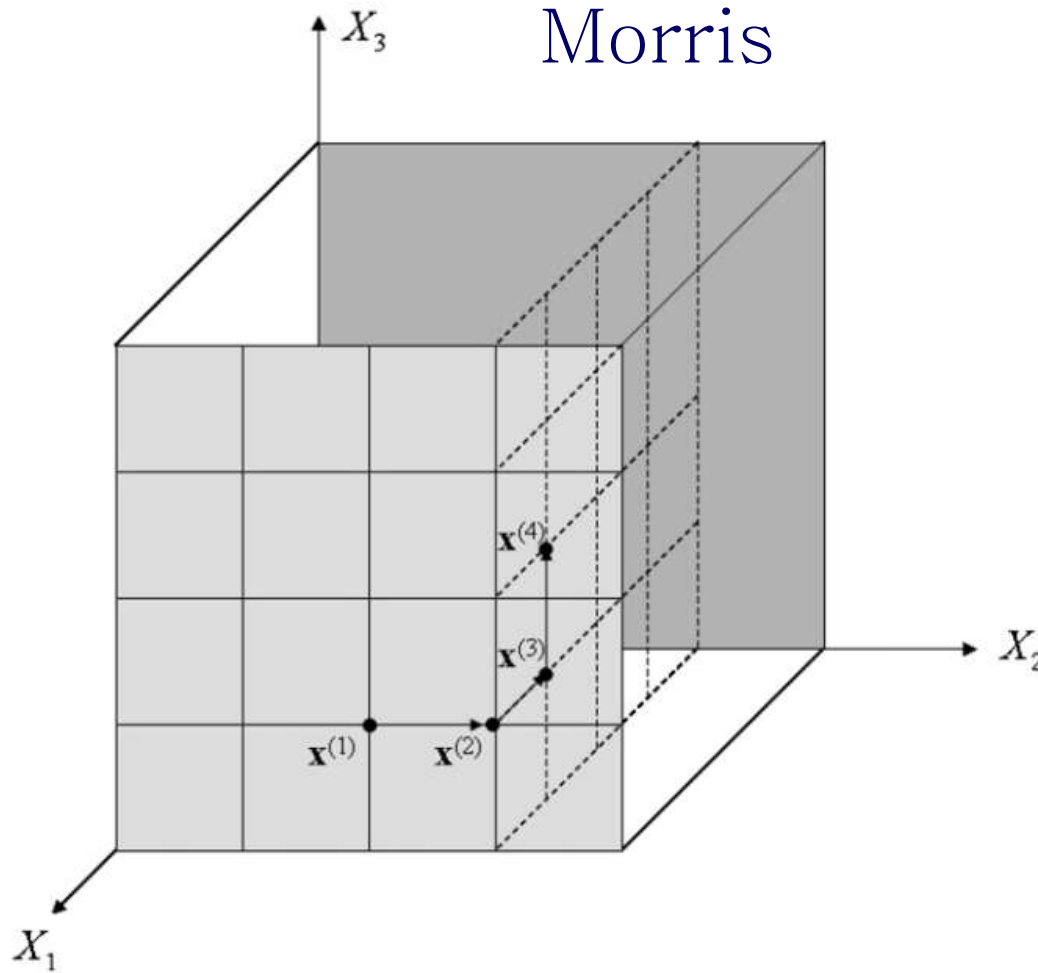


Fig. 1. Example of trajectory in 3 dimensions for the original EE method.

Total sensitivity index  $T_i$

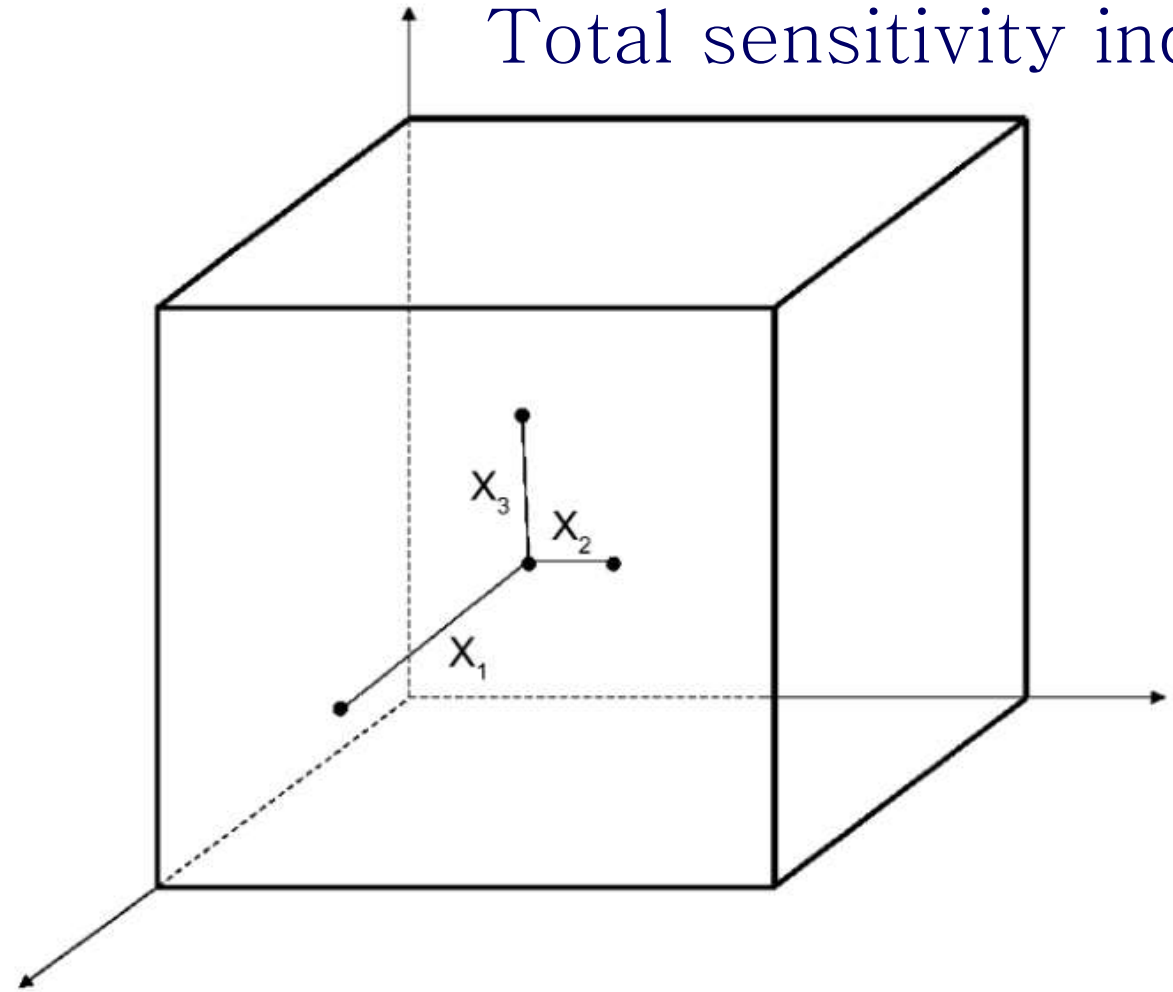
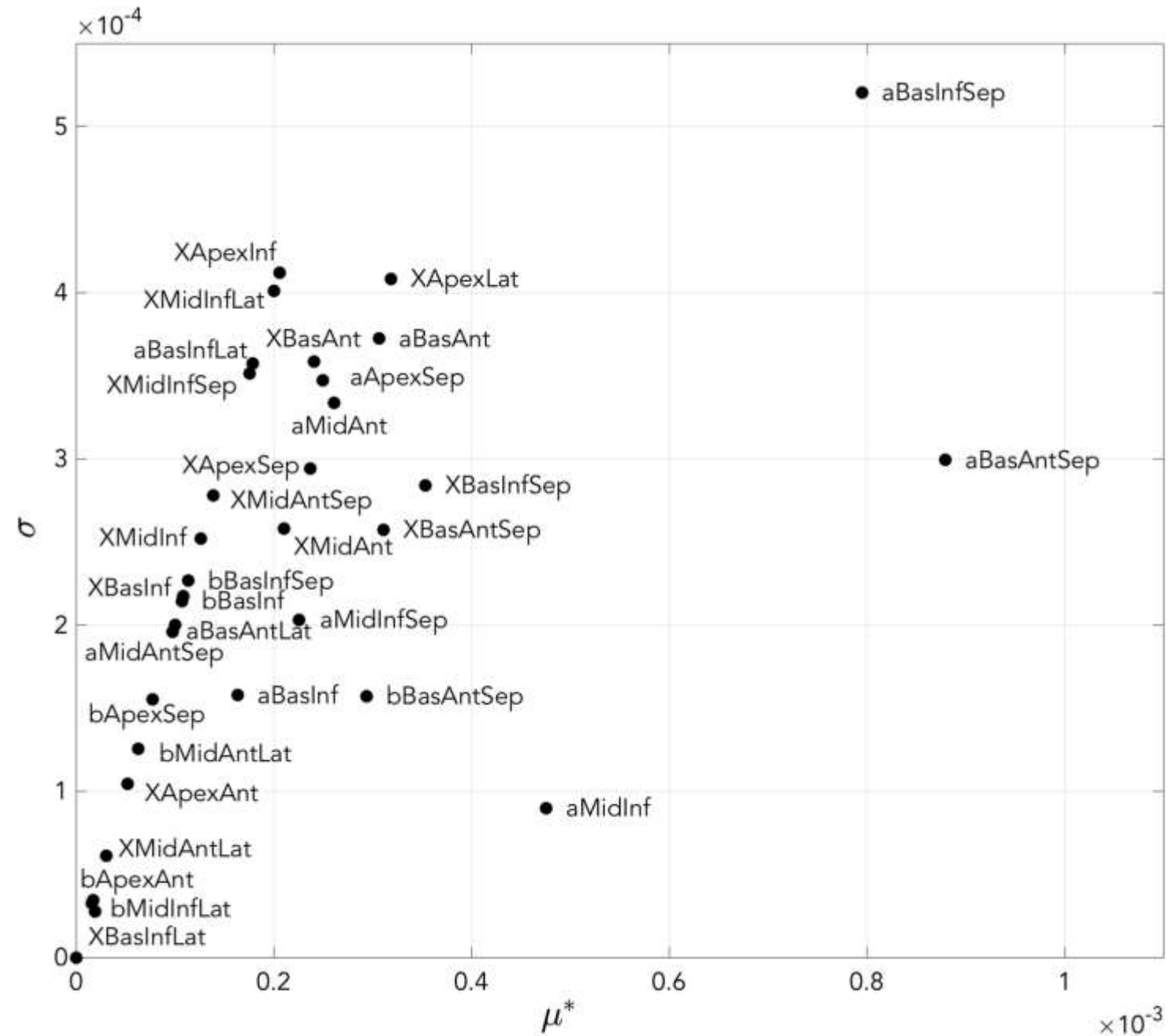


Fig. 3. Example of a radial sample in three dimensions.

Morris needs one more design parameter than  $T_i$ :  
the space step for the grid



Morris is more cumbersome to interpret (two outputs:  $\mu$  and  $\sigma$ )



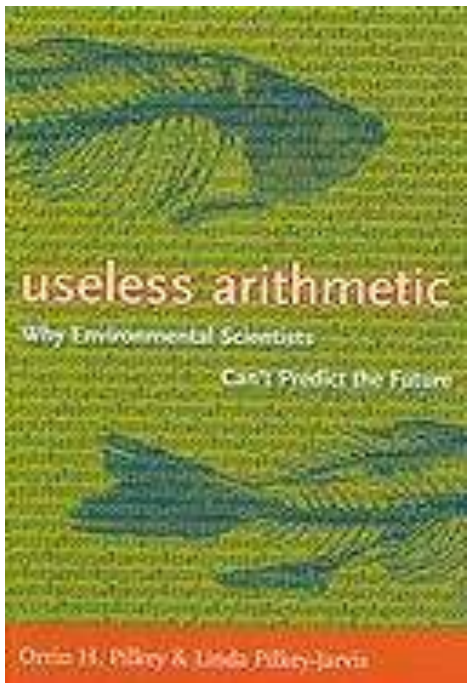


Don't confuse the map with  
the territory

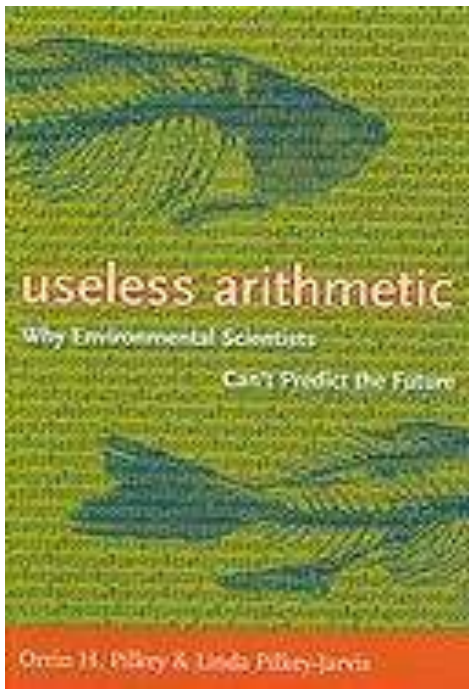
If you do, sensitivity analysis will not save you



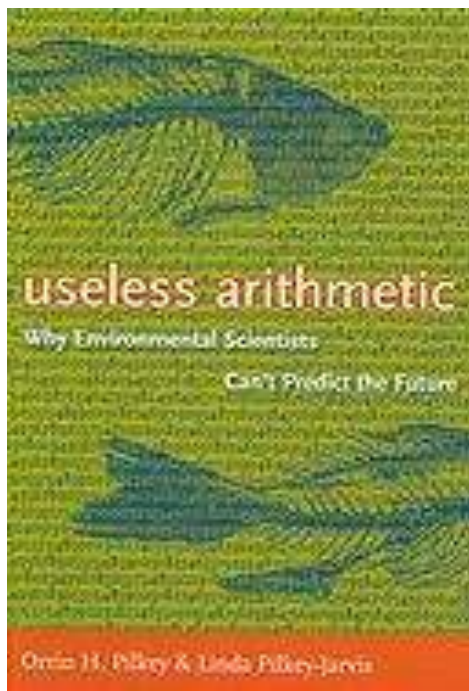
Orrin H.  
Pilkey



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



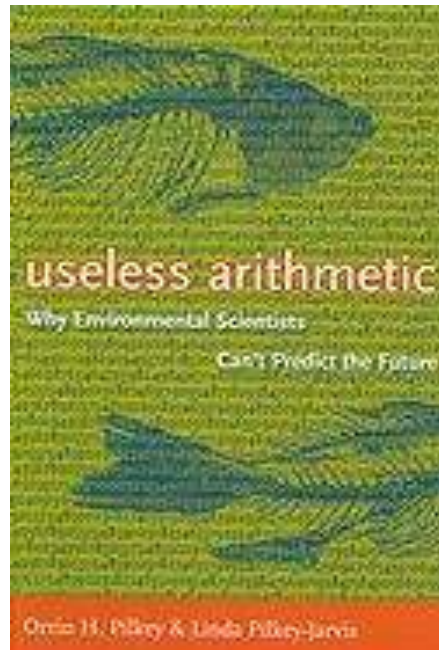
<<It is important, however, to recognize that the sensitivity of the parameter in the equation is what is being determined, not the sensitivity of the parameter in nature>>



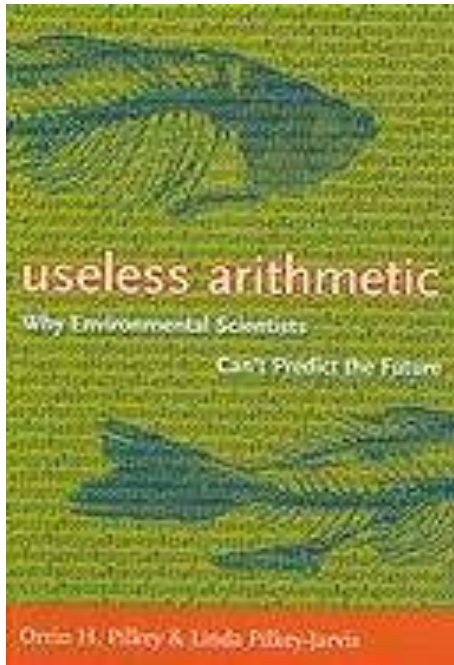
<<...If the model is wrong or if it is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit>>

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.

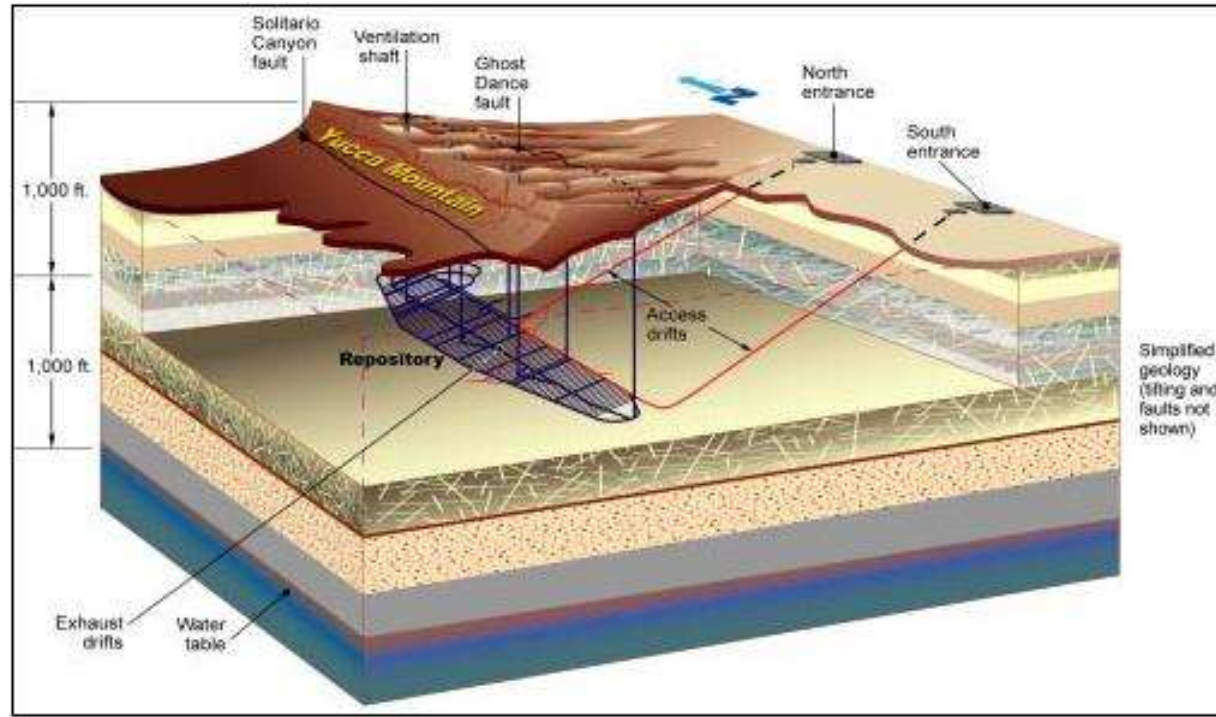
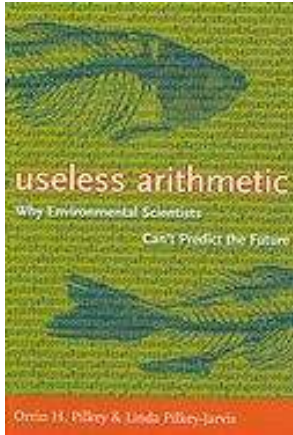






TSPA (like any other model) **relies on assumptions** → one is the low permeability of the geological formation → long time for the water to percolate from surface to disposal.





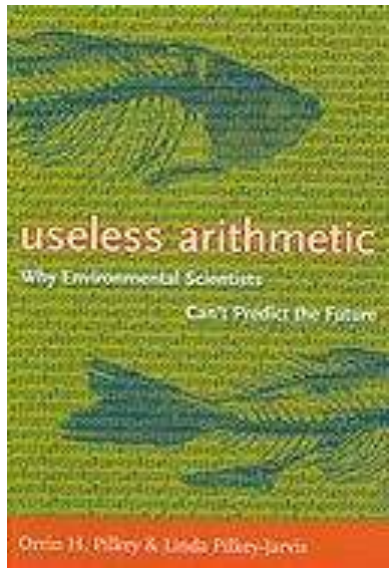
The confidence of the stakeholders in TSPA was not helped when evidence was produced which could lead to an upward revision of 4 orders of magnitude of this parameter  
(the  $^{36}\text{Cl}$  story)

## 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.

Beware the dimension of  
your model

Mind the conjecture of O'Neil



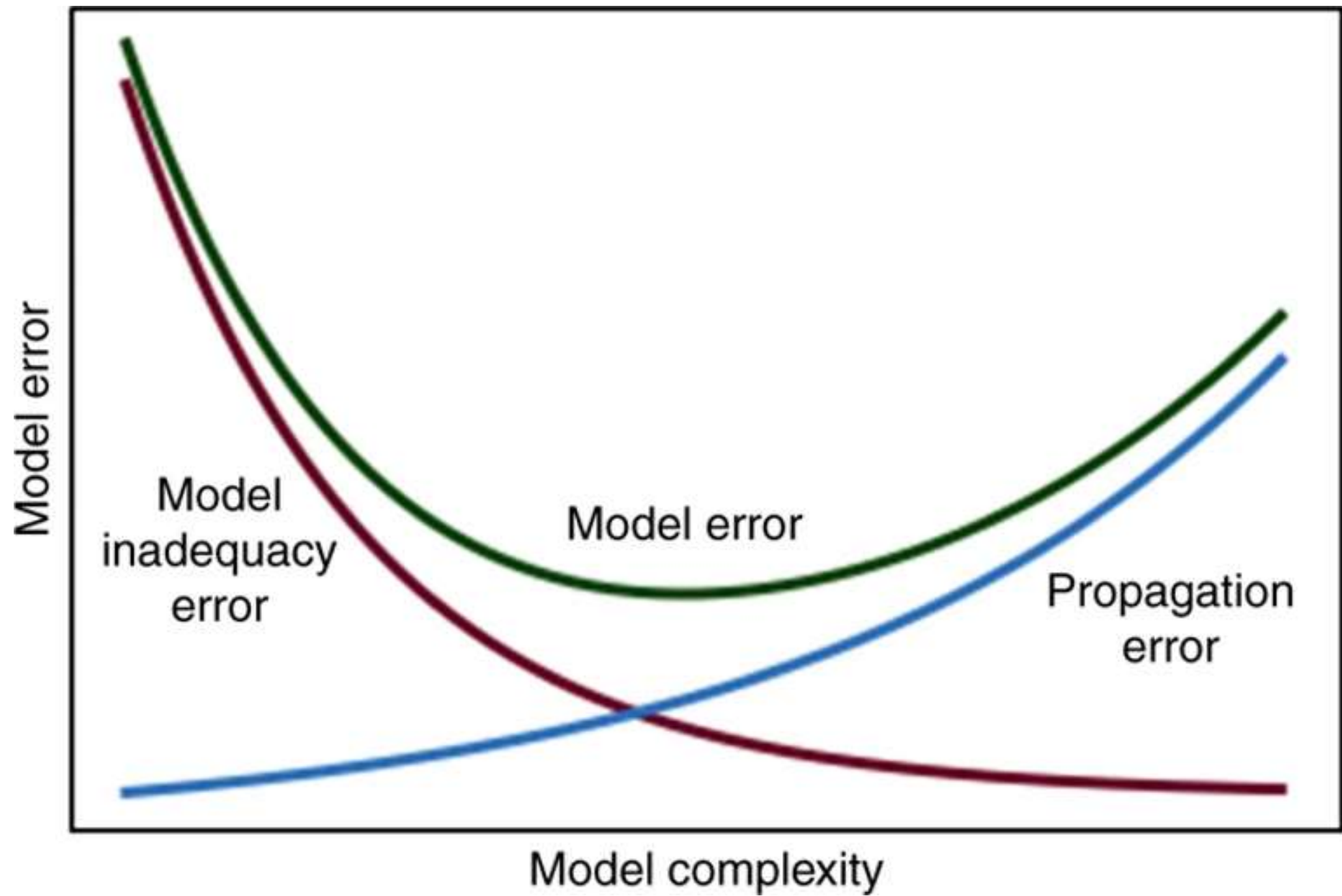
Comment

Open Access

Published: 27 August 2019

# A short comment on statistical versus mathematical modelling

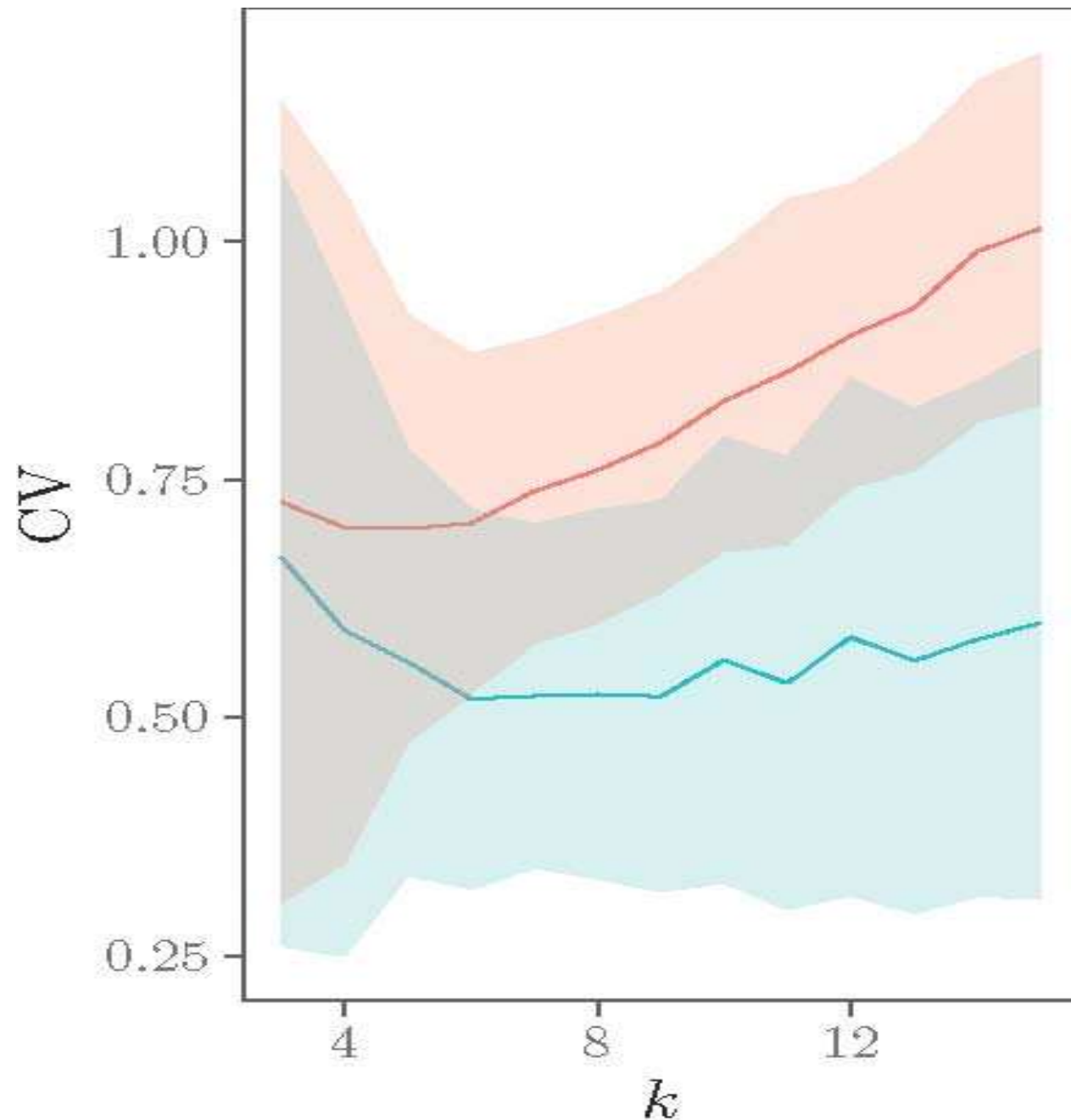
Andrea Saltelli 



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.



O'Neil conjecture and effective dimension; CV=coefficient of variation = STD/mean;  
 $k$  model dimensionality

### Interactions

- Up to the  $k$ -th order
- Up to the  $n$ -th order  
with  $n \leq k$

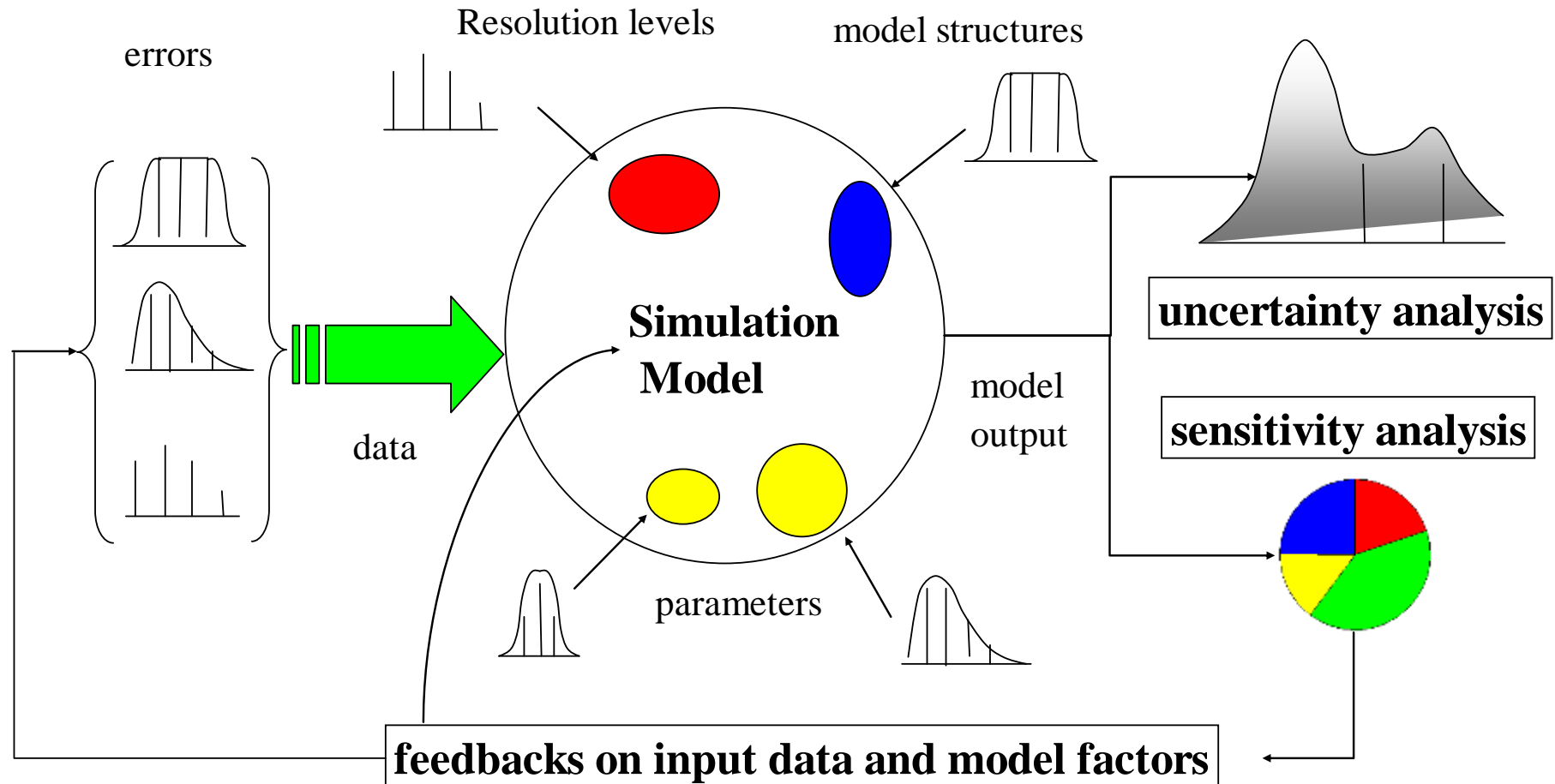
From A. Puy et al, "Effective dimension and model uncertainty", **submitted**



Don't sample just  
parameters and boundary  
conditions

Explore thoroughly the space of the  
assumptions

# An engineer's vision of UA, SA

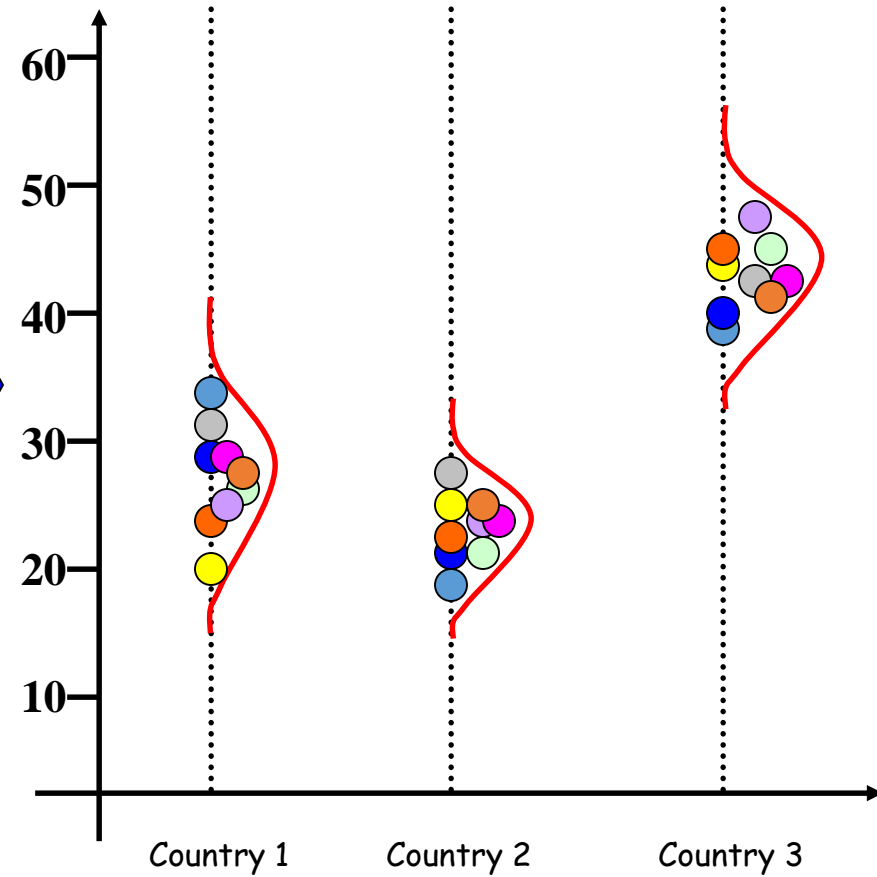
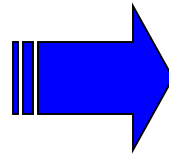
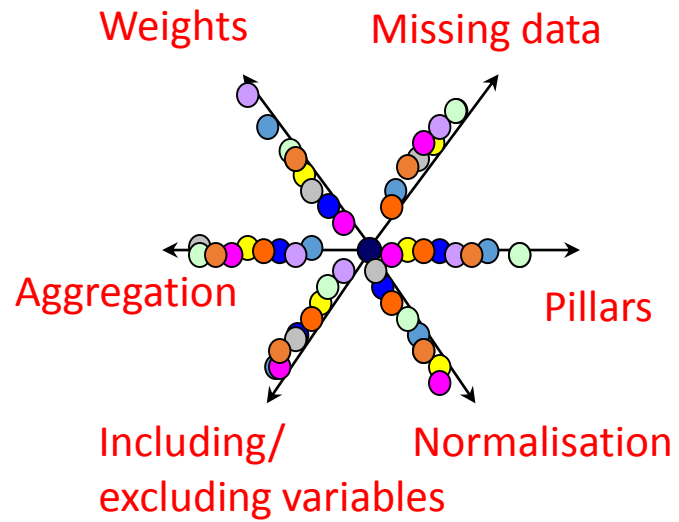


One can sample more than just factors:

- 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

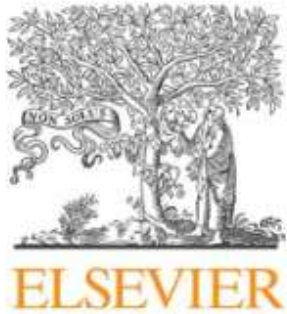
## Space of alternatives



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

Find SA before SA finds you

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

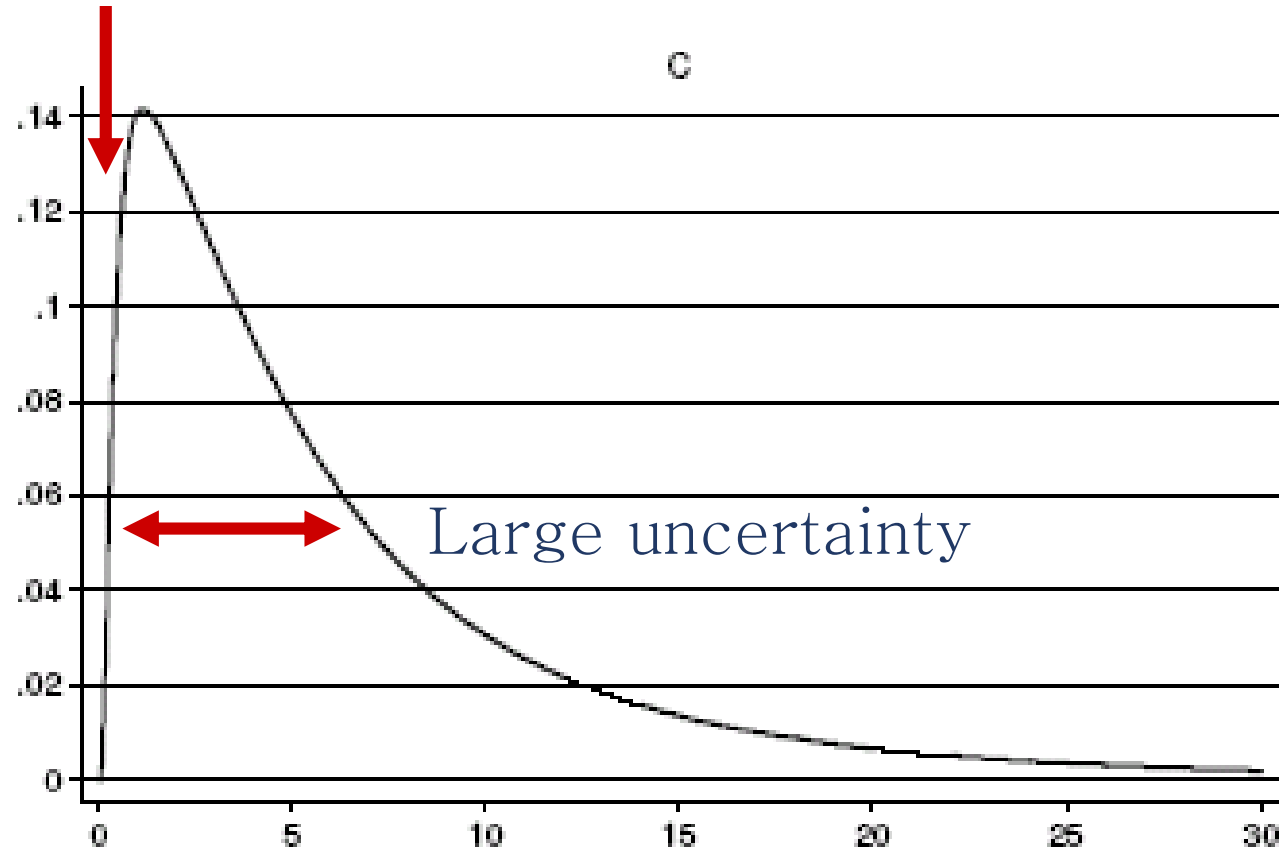
Stern, N., Stern Review on the Economics of Climate Change. UK Government Economic Service, London, [www.sternreview.org.uk](http://www.sternreview.org.uk).

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



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

Missing points



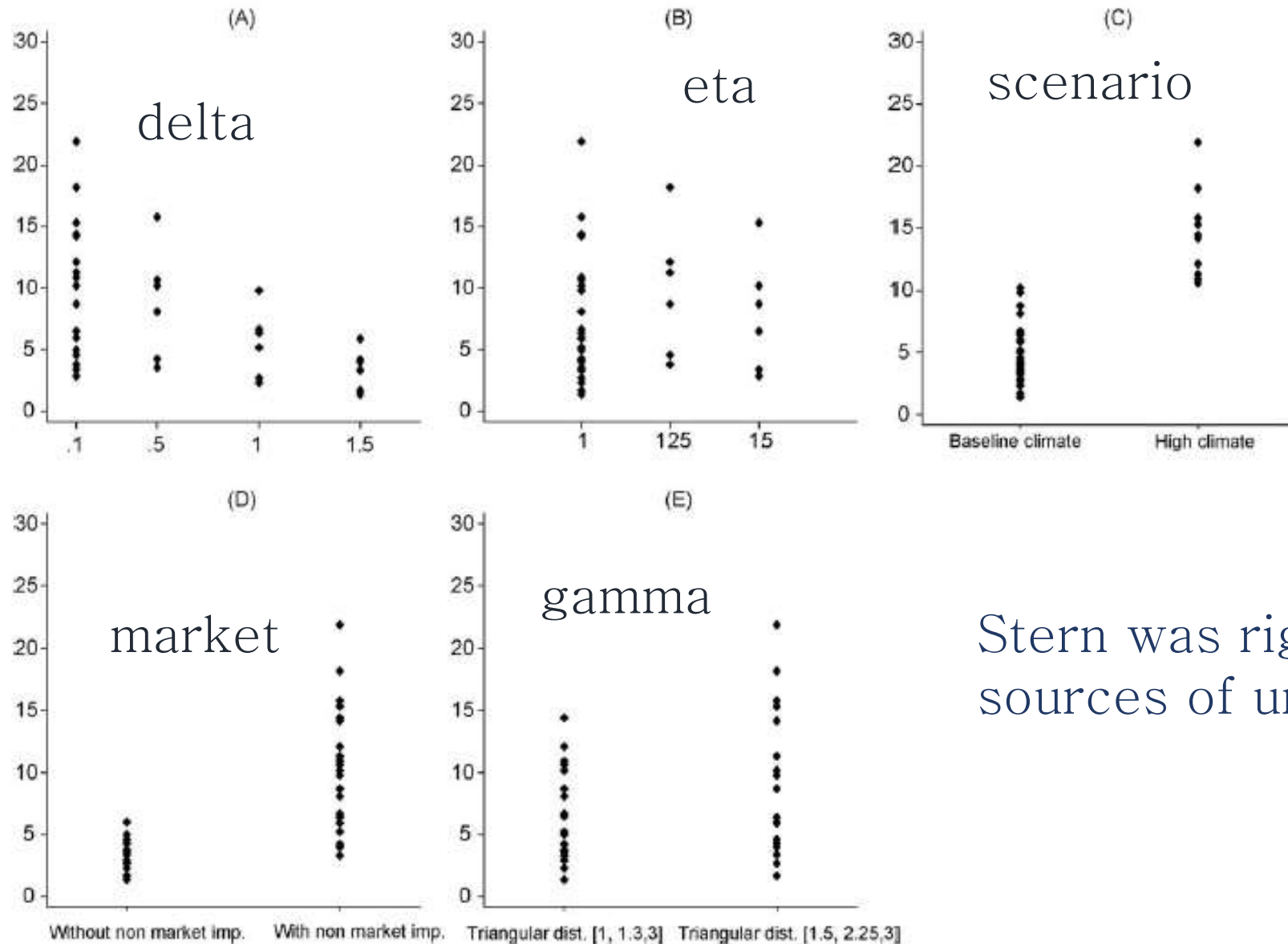
% loss in GDP per capita

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

# Sensitivity analysis here (by reverse engineering)

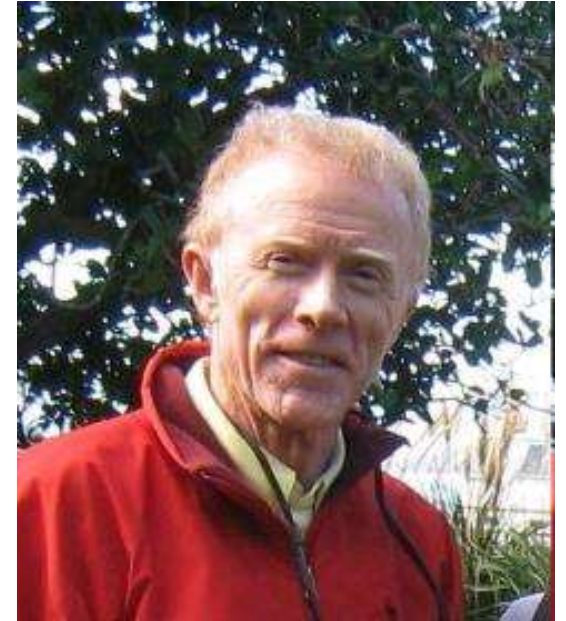


Stern was right about the sources of uncertainty

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%



“... a modern pseudo-science where the uncertainty of its inputs must be suppressed, lest they render its outputs totally indeterminate...”

GIGO-Science=Garbage In, Garbage Out

THEORY AND DECISION LIBRARY

SERIES A: PHILOSOPHY AND METHODOLOGY  
OF THE SOCIAL SCIENCES

SILVIO O. FUNTOWICZ AND JEROME R. RAVETZ

UNCERTAINTY AND QUALITY  
IN  
SCIENCE FOR POLICY

KLUWER ACADEMIC PUBLISHERS

“How much of our present social, economic, military and technological policies make essential use of GIGO-Sciences is one of the more important questions of our age”

(1990)

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SERIES A: PHILOSOPHY AND METHODOLOGY  
OF THE SOCIAL SCIENCES

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UNCERTAINTY AND QUALITY  
IN  
SCIENCE FOR POLICY

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# ‘The Most Important Number You’ve Never Heard Of’

Sept. 17, 2021

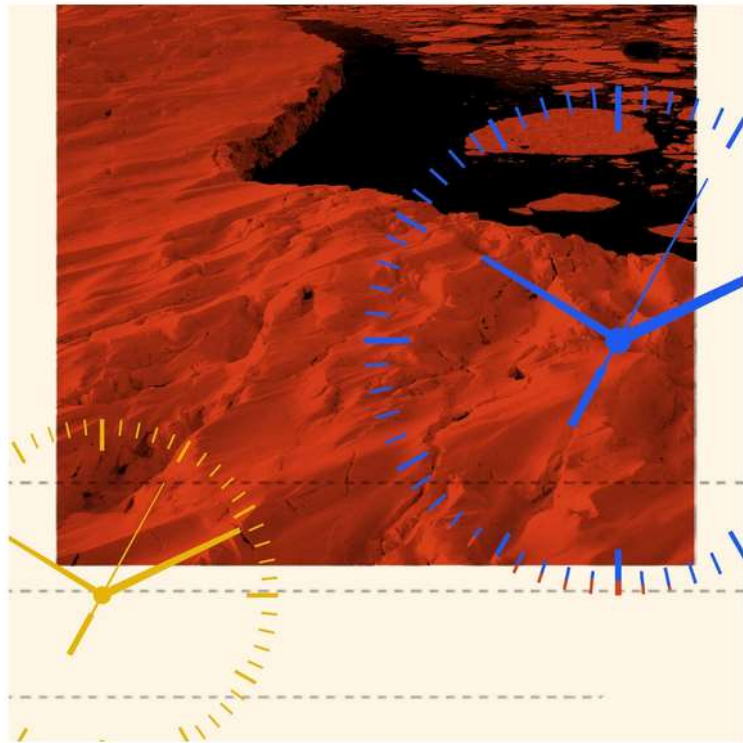


Illustration by Arsh Raziuddin, The New York Times

“social cost of carbon:

= \$56 a ton on average at a 3 percent discount rate

= \$171 a ton on average at a 2 percent discount rate”

**The New York Times**





# **The Social Cost of Carbon: Advances in Long-Term Probabilistic Projections of Population, GDP, Emissions, and Discount Rates**

Kevin Rennert, Brian C. Prest, William A. Pizer, Richard G. Newell, David Anthoff,  
Cora Kingdon, Lisa Rennels, Roger Cooke, Adrian E. Raftery, Hana Ševčíková,  
and Frank Errickson

Working Paper 21-28  
October 2021

Averaged till year 2300

Feeds into policy design

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 most expensive to get

Take home points

**Don't use just any method**

- ➔ Use the method appropriate to context and purpose; the example of variance based / moment independent / VARS methods

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

- ➔ Geometric proof paper plus 'why false SA' paper

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

- ➔ Early SA papers CSDA RESS

**Don't use either LHS or optimized LHS**

- ➔ Quasi random numbers and relative papers; mind the constructive dimension (Owen, Kucherenko)

**Don't run the model just once**

- ➔ Lubarsky's cybernetic enthomology

**Don't use Morris' method**

- ➔ Dependence upon one extra design parameter plus ambiguity in interpretation ( $\mu$  and  $\sigma$ ); Paper 2011 showing superiority  $T_j$  over Morris

**Don't confuse the map with the territory**

- ➔ J.L. Borges; Yucca Mountain example; Rayner's displacement

**Beware the dimension of your model**

- ➔ The conjecture of O'Neil

**Don't sample just parameters and boundary conditions**

- ➔ Use e.g. triggers to explore the effect of other assumptions

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

The case of the Stern-Nordhaus controversy

**NEVER vary all factors of the same amount** (5%, 10%, 20%)

- ➔ Avoiding GIGO

# TWO And Now for Something Completely Different

Home



Last on

BBC  
TWO

Sun 7 Jan 2018

23:30

BBC TWO NORTHERN IRELAND



# 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.

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





# **Mind the assumptions**

Assess uncertainty and sensitivity

## **Mind the hubris**

Complexity can be the enemy of relevance

## **Mind the framing**

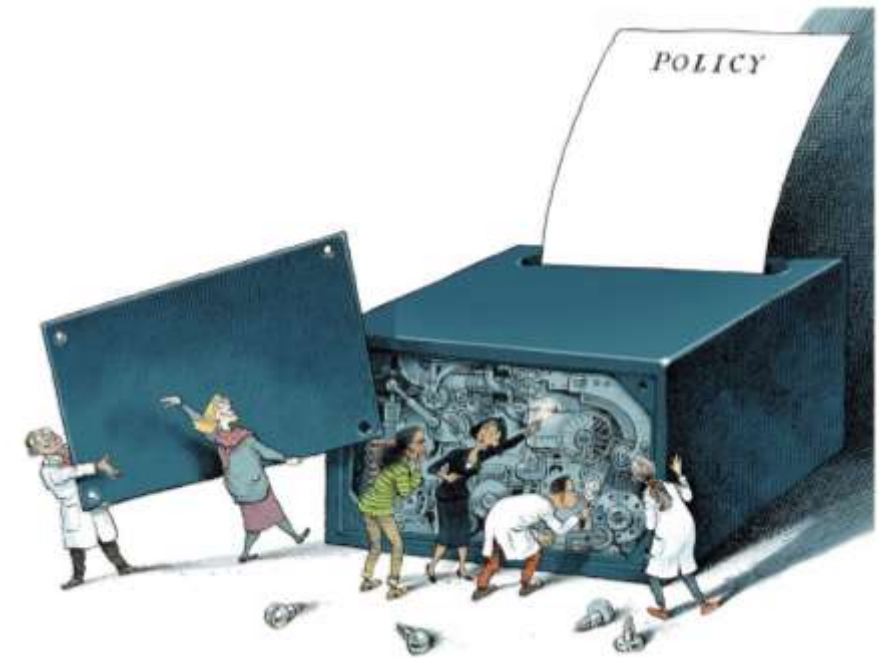
Match purpose and context

## **Mind the consequences**

Quantification can backfire.

## **Mind the unknowns**

Acknowledge ignorance

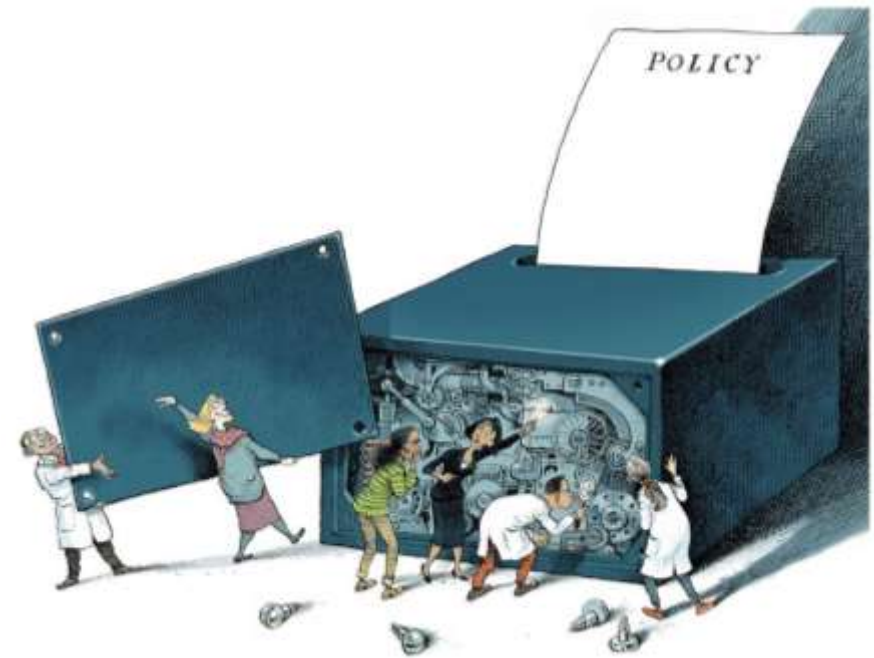


# Mind the assumptions

Assess uncertainty and sensitivity



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





# Mind the assumptions

Assess uncertainty and sensitivity

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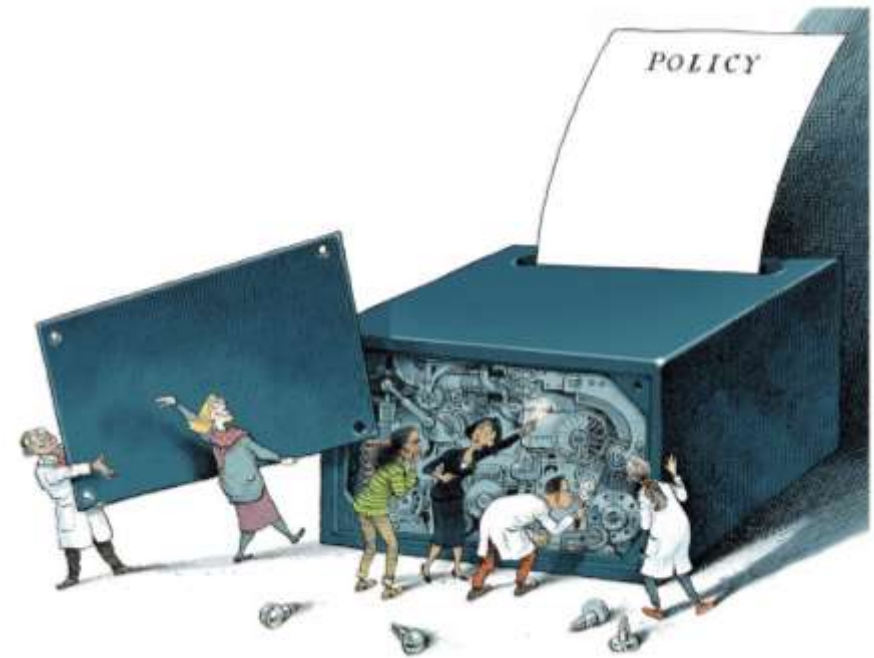
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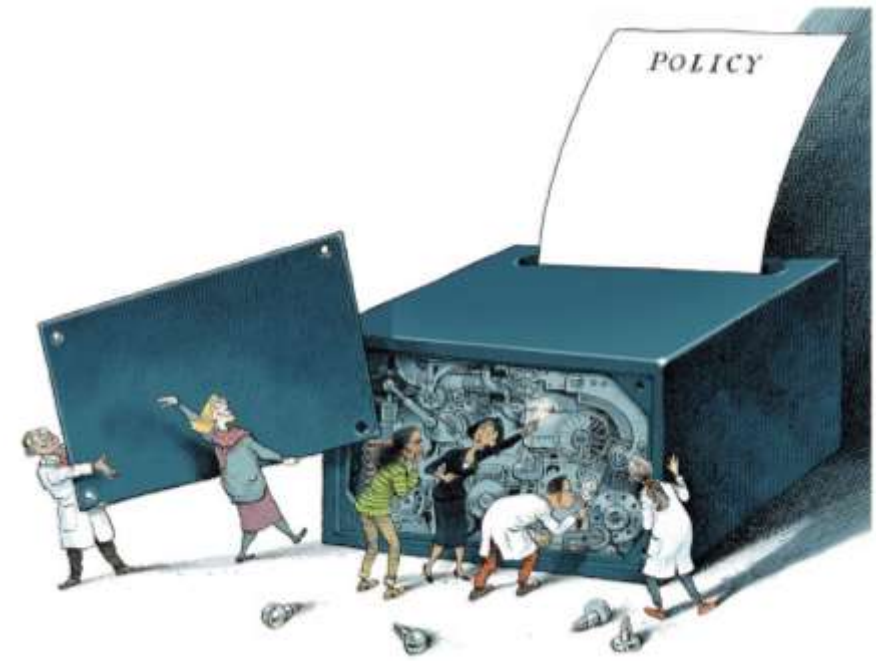
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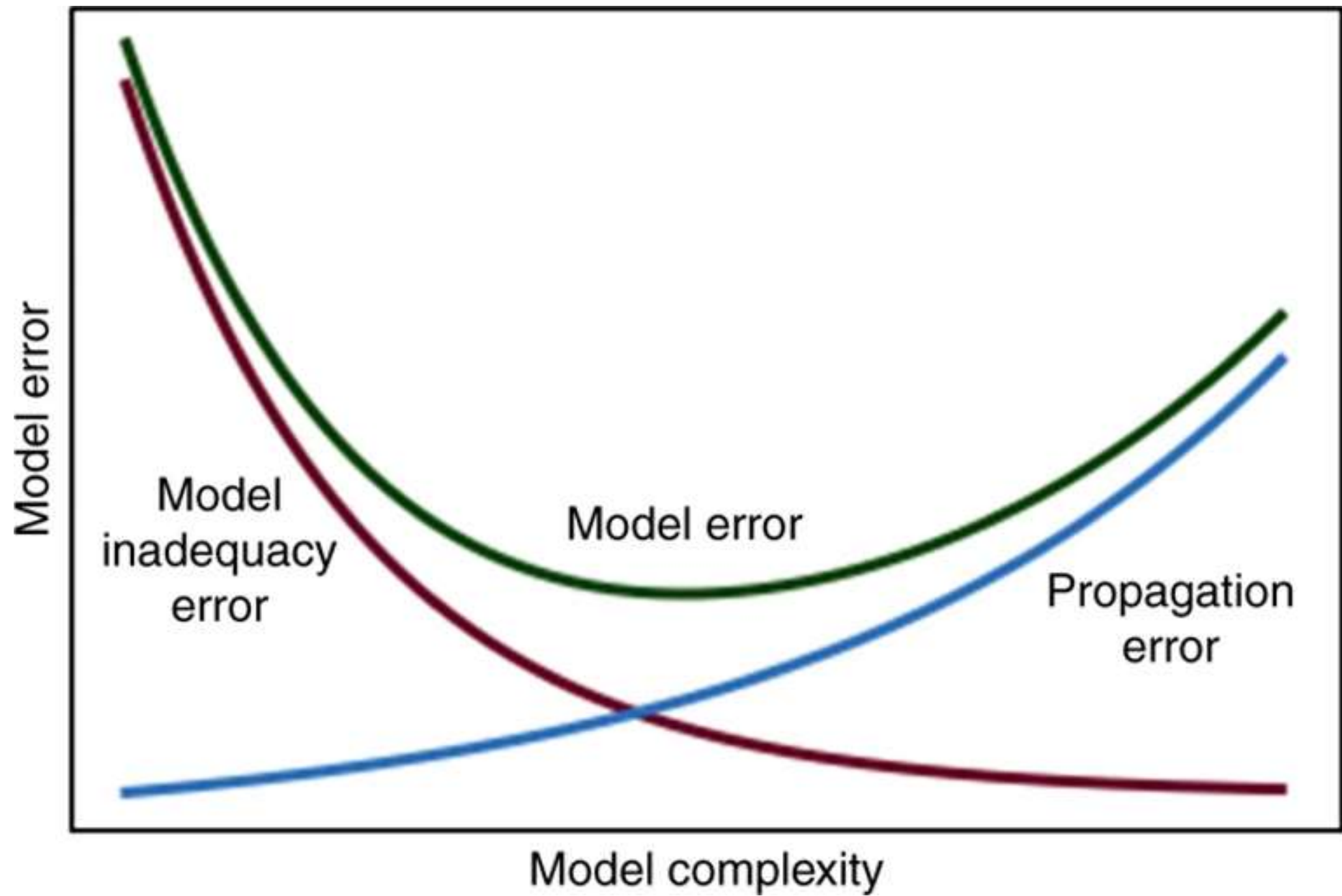
Complexity can be the enemy of relevance



... 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

Assess uncertainty and sensitivity

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Complexity can be the enemy of relevance



## Mind the framing

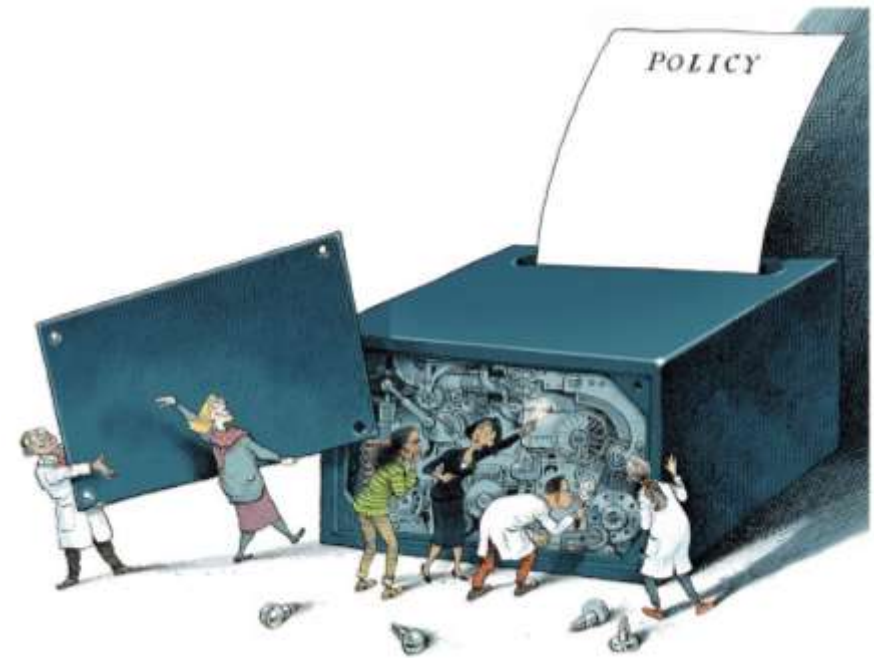
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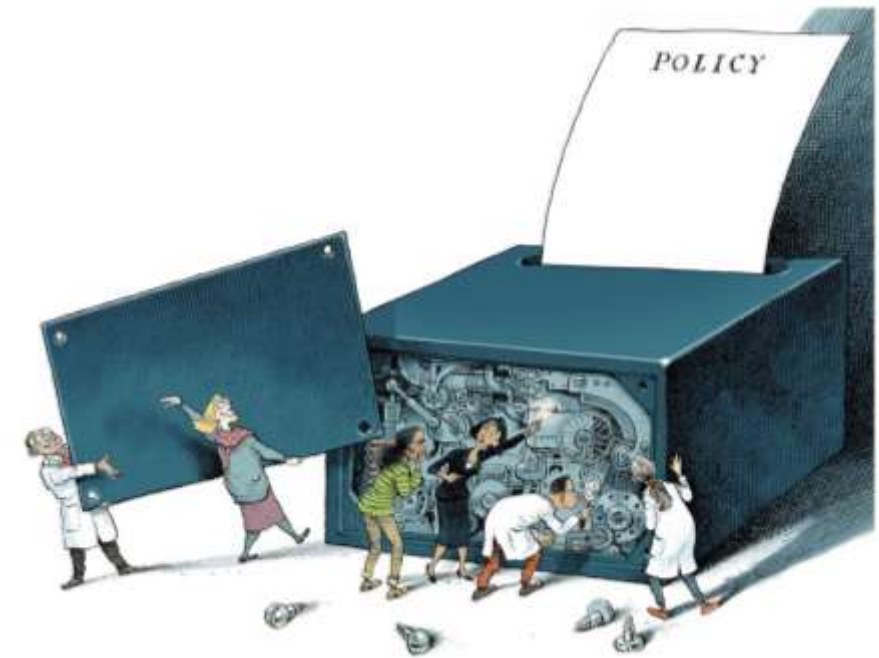
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# Mind the framing

Match purpose and context



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

## SUPPLEMENTARY INFORMATION

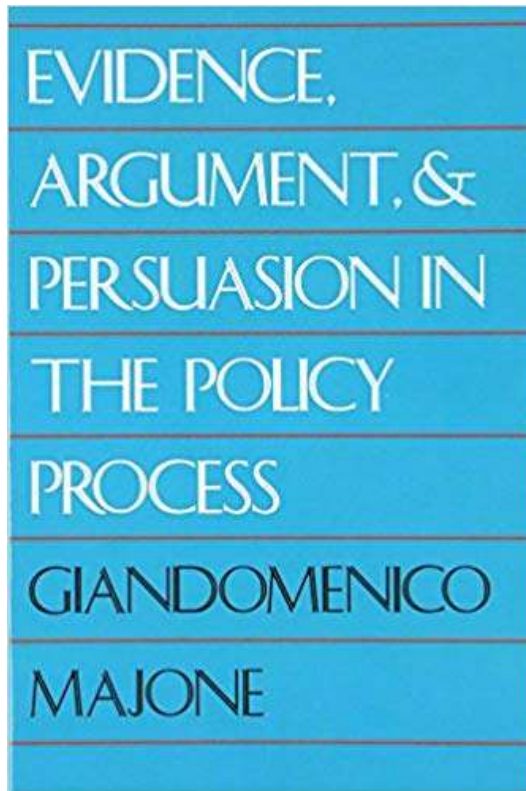
1. Additional information and references >260 references



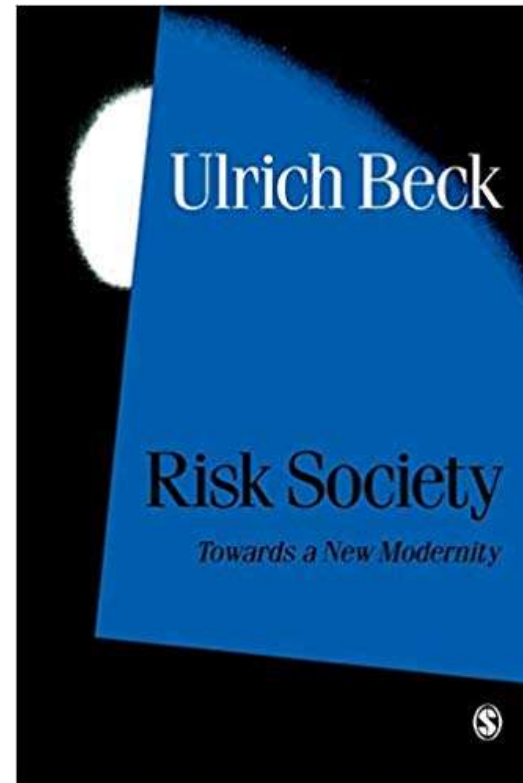
# From Ulrich Beck to Giandomenico Majone: the technique is never neutral



Ulrich Beck  
(1944 –2015)



1989



1992 (1986)



Environmental Science & Policy

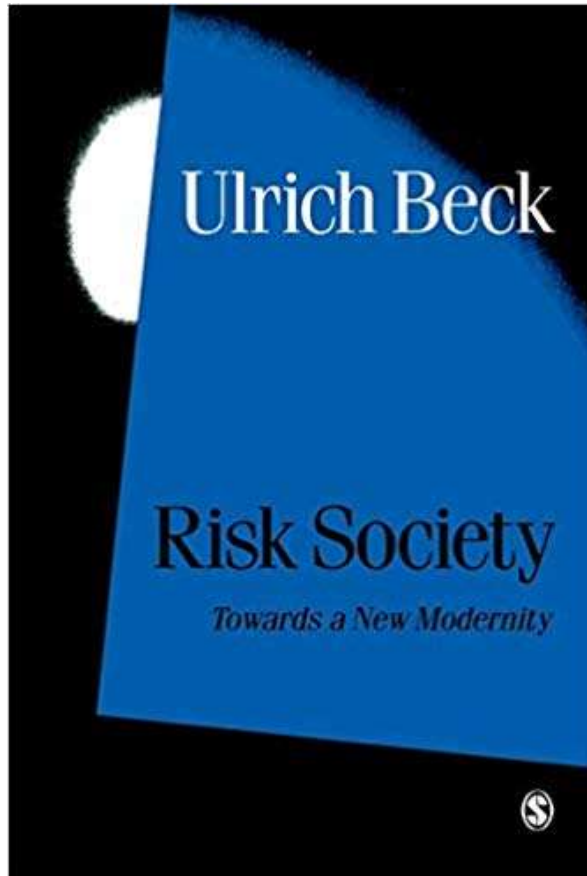
Volume 106, April 2020, Pages 87-98



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

Complexity can be the enemy of relevance

## Mind the framing

Match purpose and context

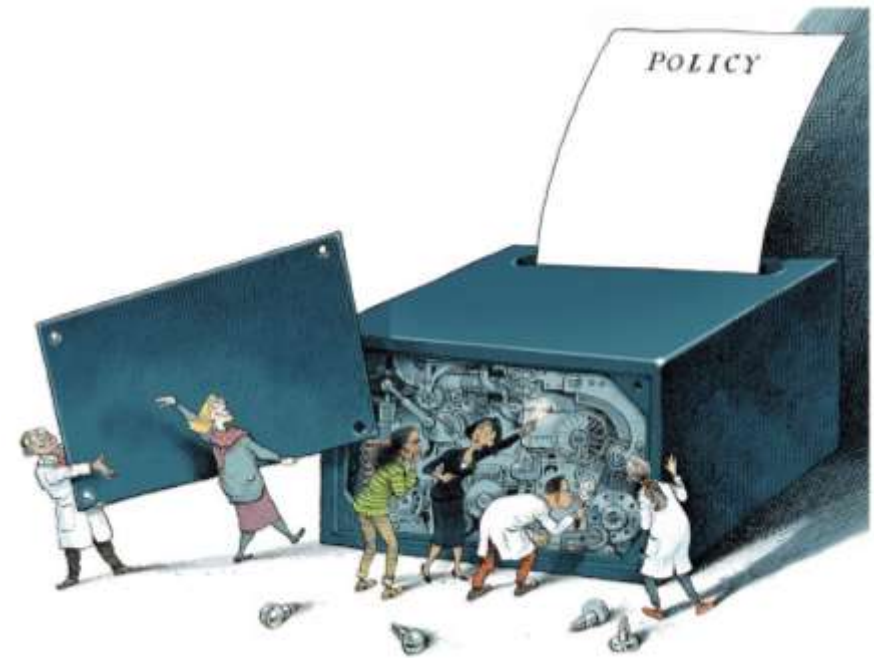


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Quantification can backfire.

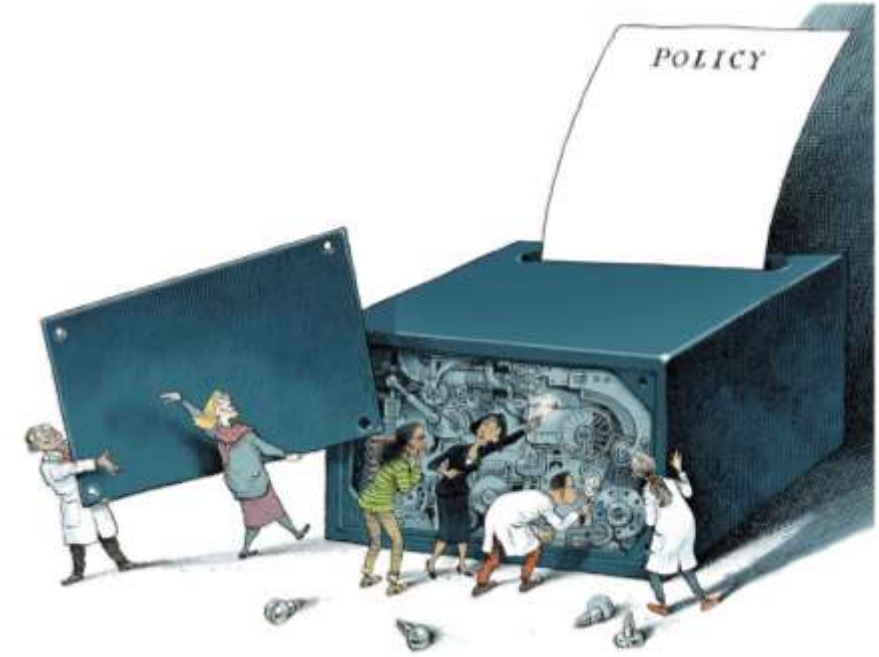
## Mind the unknowns

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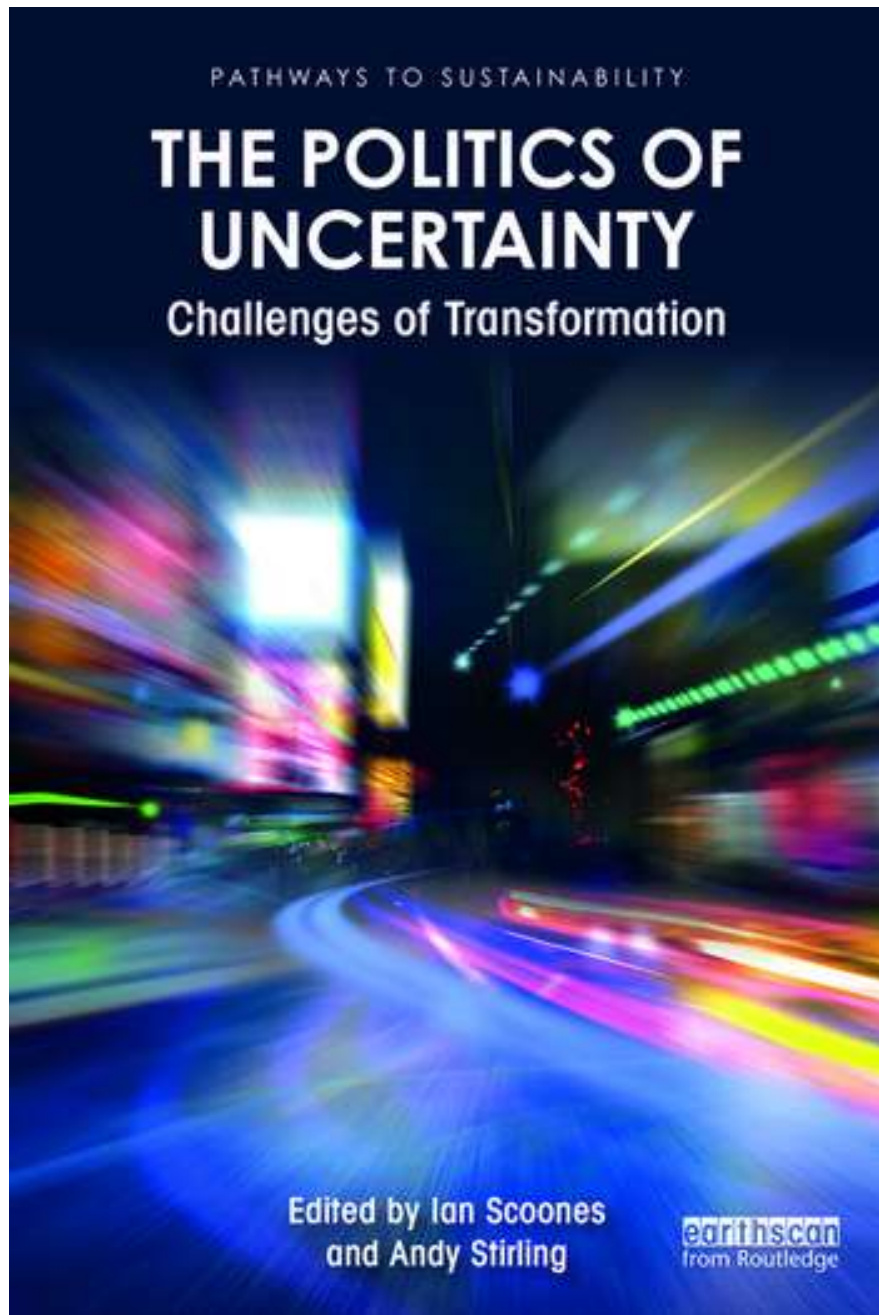
Quantification can backfire



From the risk of financial products to the management of coastal zones to the models for disaster insurance bad modelling may lead to wrong decisions

## SUPPLEMENTARY INFORMATION

1. Additional information and references >260 references



# 3

## SHARING RISKS OR PROLIFERATING UNCERTAINTIES?

Insurance, disaster and development

*Leigh Johnson*

Model-based parametric insurance led to dramatic consequences for developing countries experiencing draughts

Open access: <https://www.taylorfrancis.com/books/politics-uncertainty-ian-scoones-andy-stirling/e/10.4324/9781003023845>

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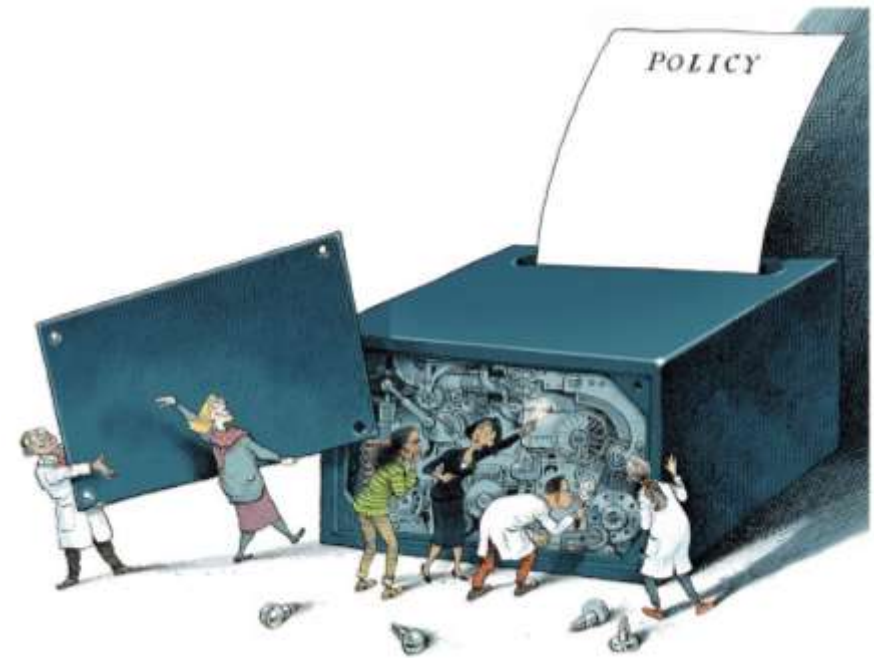
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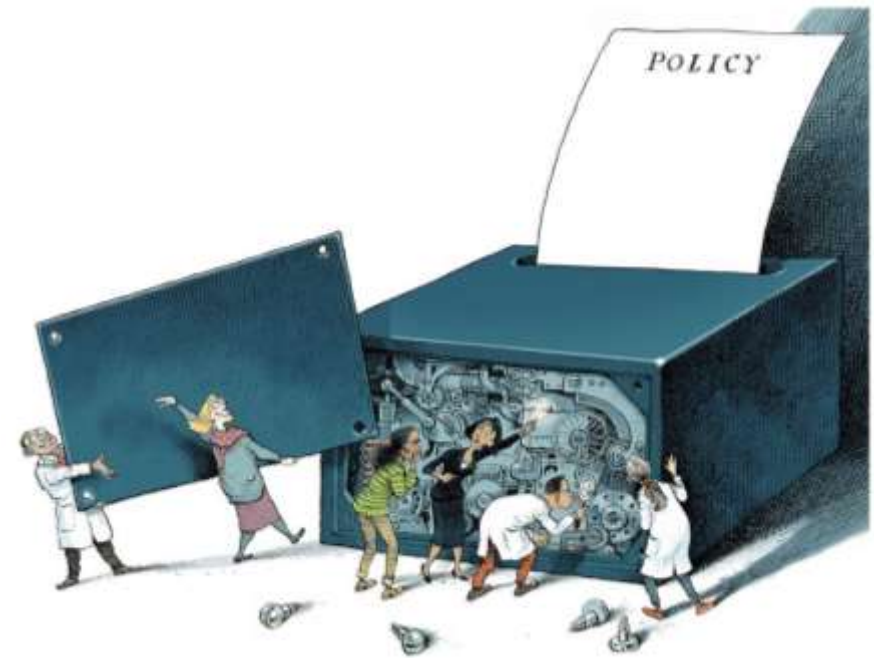




# Mind the unknowns

## Acknowledge ignorance

“there is no  
number-answer to  
your question”



### SUPPLEMENTARY INFORMATION

#### 1. Additional information and references

>260 references

Anthony Fauci

# The End

@andreasaltelli



# Why ethics of quantification is needed now

---

**Andrea Saltelli**

Open Evidence Research, Universitat Oberta de Catalunya, Barcelona, Spain

---

**Antonio Andreoni**

UCL Institute for Innovation and Public Purpose;  
South African Research Chair in Industrial Development, University of Johannesburg, South Africa

---

**Wolfgang Drechsler**

Tallinn University of Technology, Estonia;  
UCL Institute for Innovation and Public Purpose;  
Davis Center at Harvard University, United States

---

**Jayati Ghosh**

University of Massachusetts Amherst, United States;  
UCL Institute for Innovation and Public Purpose

---

---

**Rainer Kattel**

UCL Institute for Innovation and Public Purpose

---

**Ingrid H. Kvangraven**

Department of Politics, University of York

---

**Ismael Rafols**

Centre for Science and Technology Studies, Leiden University, the Netherlands

---

**Erik S. Reinert**

Tallinn University of Technology, Estonia;  
UCL Institute for Innovation and Public Purpose

---

**Andy Stirling**

Science Policy Research Unit, University of Sussex

---

**Ting Xu**

School of Law at the University of Essex

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**UCL Institute for  
Innovation and  
Public Purpose**

WORKING PAPER  
WP 2021/05



... our world is structured by numbers, visible and invisible, where truth is conveyed and reality constructed

Numbers are seductive, performative, confer to their masters' epistemic power and legitimacy

Governing the modern state, or even contesting it, without numbers is impossible

Numbers are the prevalent means to express value in our societies  
... Access & production of numbers reflect and reinforce power imbalances



**UCL Institute for  
Innovation and  
Public Purpose**

WORKING PAPER  
WP 2021/05



Numbers capture our attention; they illuminate the part of reality which is being numerified, and fatally push those parts into the background which come without the clothing of ...

... numbers are so deeply entrenched in our existence that we barely reflect on them critically them anymore — too close to us, they have become part of the very lens through which we attend to and comprehend the world.

Scope for harm from ‘wrong numbers’ e.g. in :

- Medical research
- Higher education
- Governance of science
- Finance
- Numbers from international organizations
  - Food and Agriculture Organization
  - The World Bank
  - OECD
  - ...
- ...

‘Trendy’ methods may also harm

- Randomized control trials) may be misused to suggest more general conclusions that may not be valid
- Sophisticated statistical/econometric techniques that can be designed in ways that promote particular policy conclusions reflecting researchers’ biases

Ethics of quantification, Video curated by the Open University of Catalonia, September 2011.



Universitat Oberta  
de Catalunya

## Ethics of quantification

### Ethics of quantification

Andrea  
Saltelli



[http://materials.cv.uoc.edu/cdocent/PID\\_00284929/](http://materials.cv.uoc.edu/cdocent/PID_00284929/)