

# Responsible modelling and forecasting

Andrea Saltelli

Course SDG207, University of Bergen,  
September 21, 2023



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



HOME ABOUT ME PUBLICATIONS NEWS & VIDEOS RESOURCES



## August 25 2023: The politics of modelling is out!



### Praise for the volume

*"A long awaited examination of the role —and obligation —of modeling."*

**Nassim Nicholas Taleb**, Distinguished Professor of Risk Engineering, NYU Tandon School of Engineering. Author, of the 5 -volume series *Incerto*.

\*\*\*

*"A breath of fresh air and a much needed cautionary view of the ever-widening dependence on mathematical modeling."*

**Orrin H. Pilkey**, Professor at Duke University's Nicholas School of the Environment, co-author with Linda Pilkey-Jarvis of *Useless Arithmetic: Why Environmental Scientists Can't Predict the Future*, Columbia University Press 2009.

\*\*\*

*"The methods by which power insinuates itself*

### Mastodon Toots by

@AndreaSaltelli



AndreaSaltelli

2023/8/28 11:24

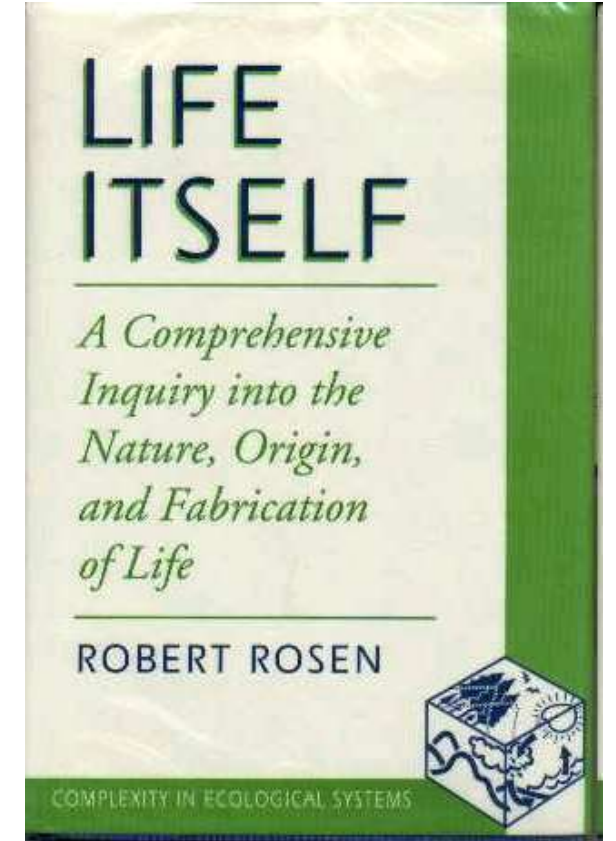
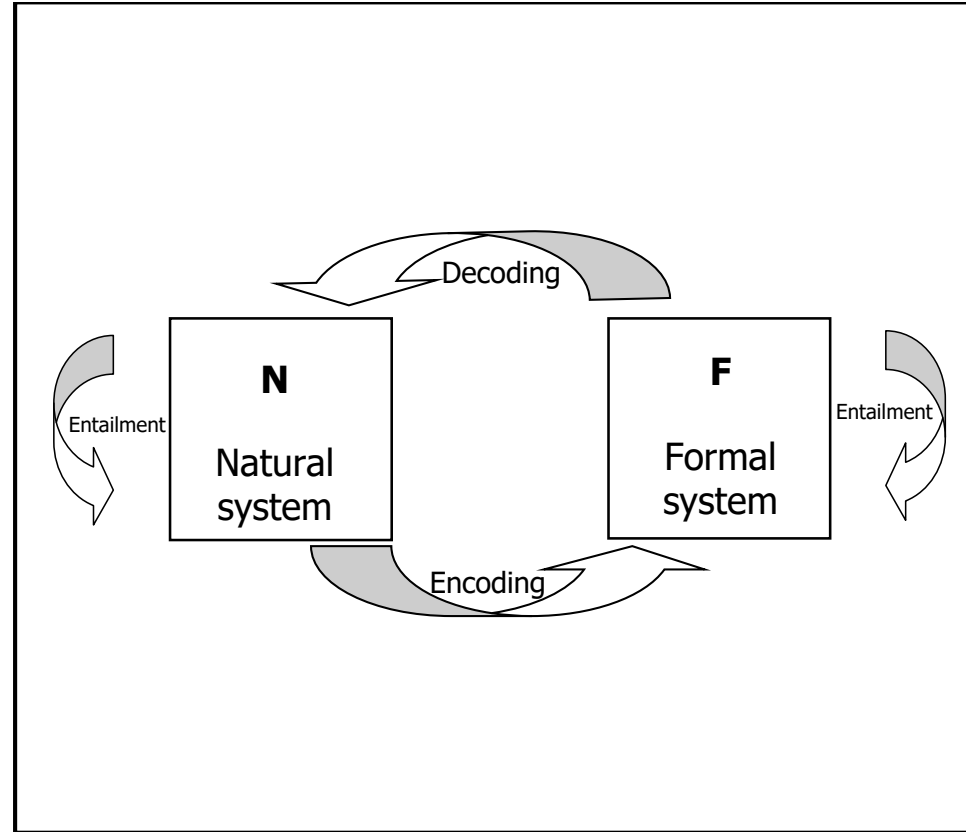
August 26 Podcast (16m) - interview for ABC NET RADIO, AUS: Assumptions and consequences: the politics of modelling, Guests: Ehsan Nabavi and Andrea Saltelli, Producer - Chris Bullock.

[abc.net.au/listen/programs/sun](http://abc.net.au/listen/programs/sun)

View on [mstdn.social](https://mstdn.social)

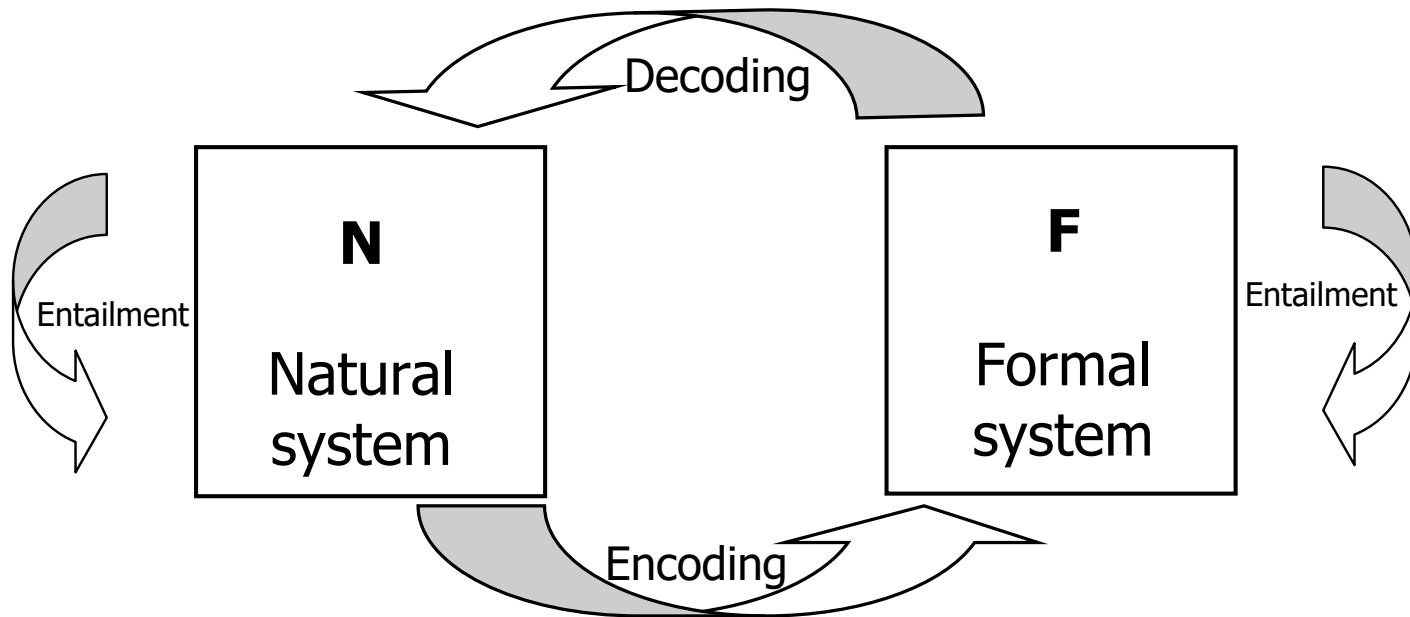
Modelling is a  
craft more than  
a science

# 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”

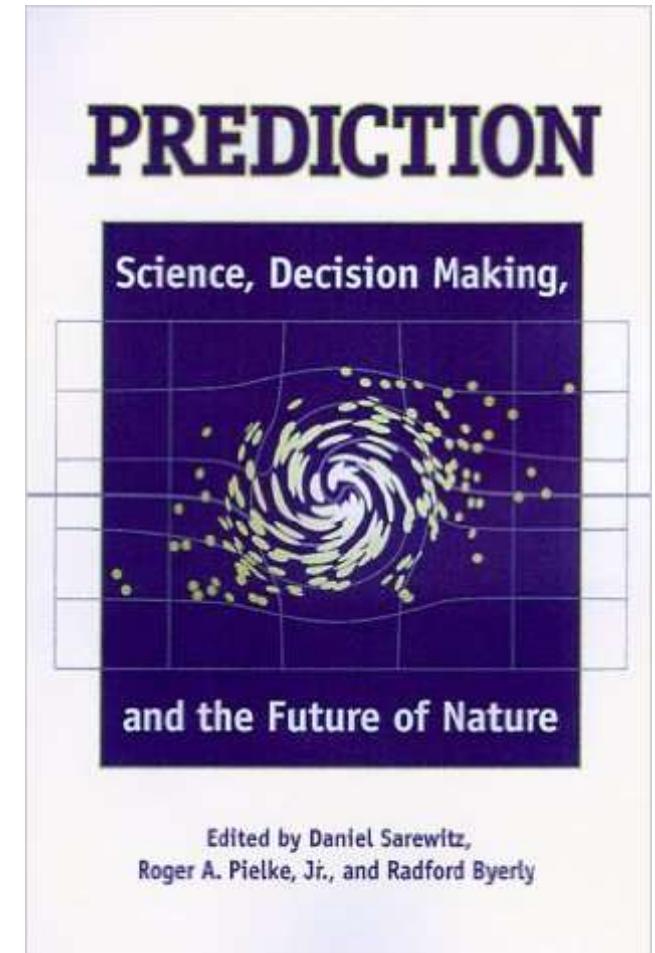


Naomi  
Oreskes

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

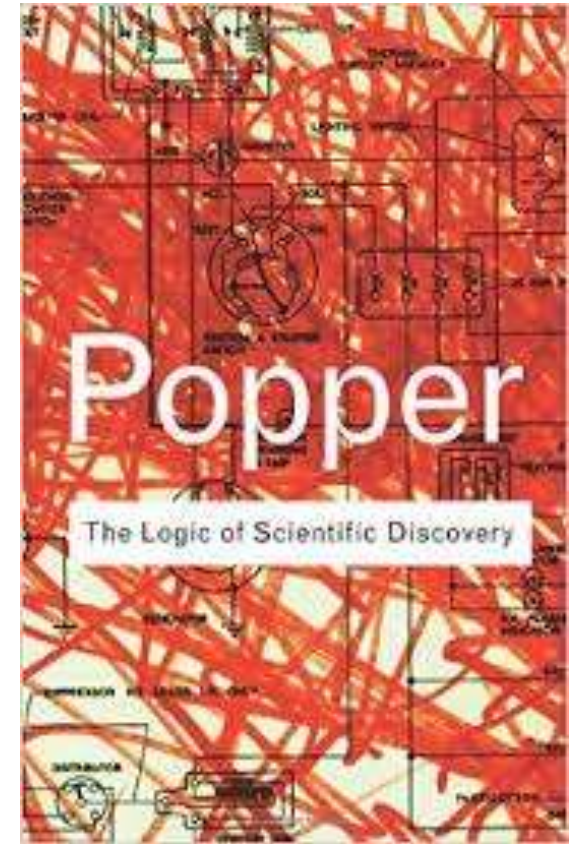


# Models are not physical laws



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.

# Dangers of mathematization of economics



Wolfgang Drechsler



Erik S. Reinert



Paul Romer



Philip Mirowski

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

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

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

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



UCL Institute for  
Innovation and  
Public Purpose



WORKING PAPER  
WP 2021/07

# Altered States: Cartesian and Ricardian dreams

**Erik S. Reinert**

Tallinn University of Technology

UCL Institute for Innovation and Public Purpose

**Monica di Fiore**

Institute for Cognitive Sciences and Technologies, Consiglio Nazionale delle Ricerche

**Andrea Saltelli**

Open Evidence Research, Universitat Oberta de Catalunya (UOC)

**Jerome R. Ravetz**

Institute for Science, Innovation and Society, University of Oxford

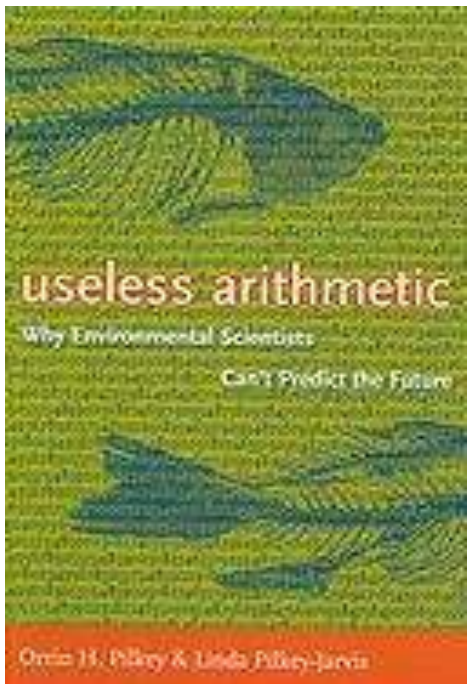
Don't confuse the map with  
the territory

If you do, sensitivity analysis will not save you

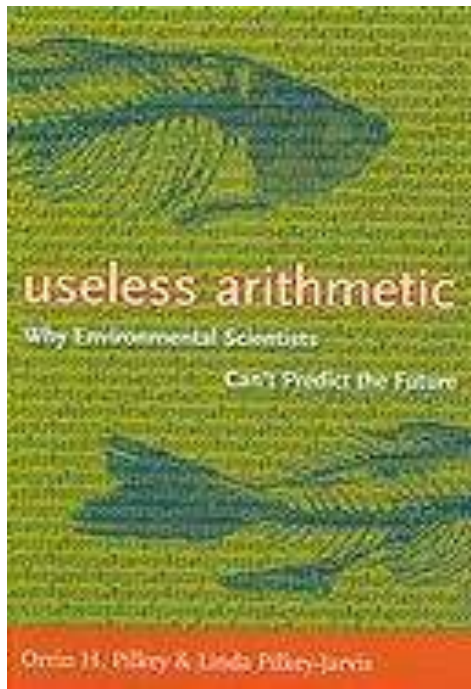


Orrin H.  
Pilkey

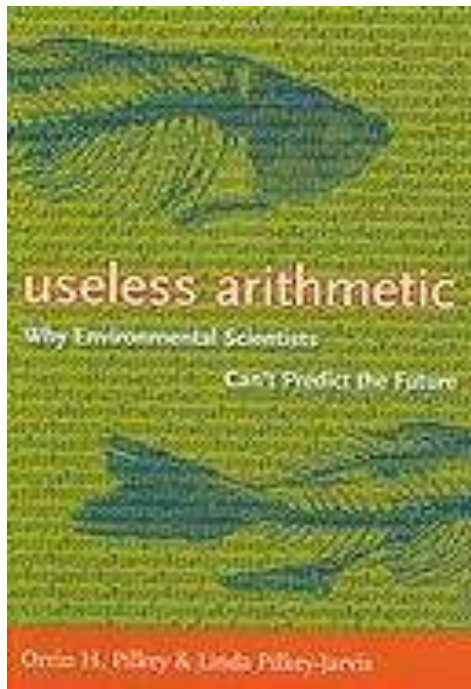
Useless Arithmetic: Why Environmental Scientists Can't Predict the Future  
by Orrin H. Pilkey and Linda Pilkey-Jarvis, Columbia University Press,  
2009.







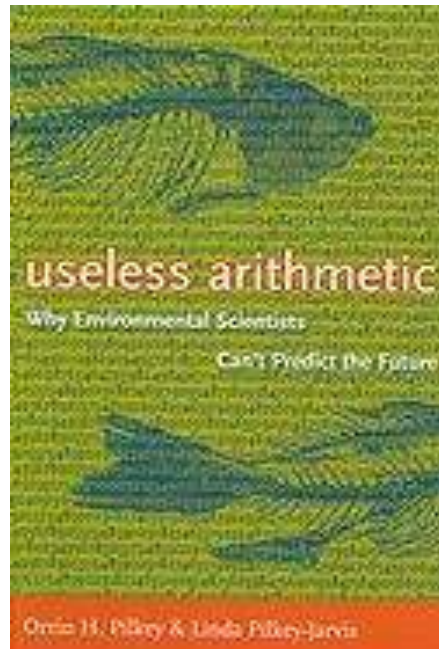
<<It is important, however, to recognize that the sensitivity of the parameter in the equation is what is being determined, not the sensitivity of the parameter in nature>>

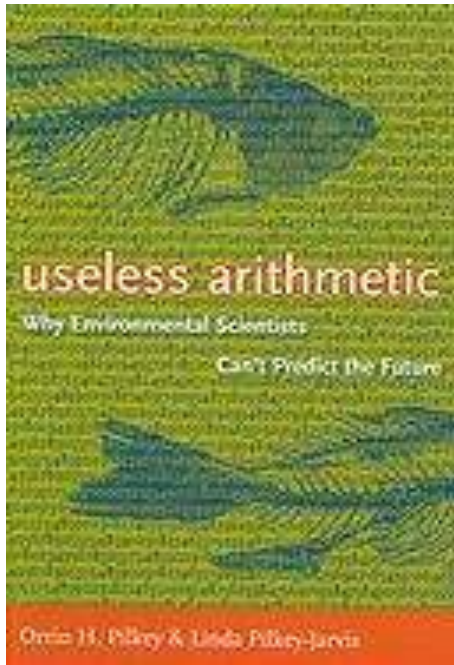


<<...If the model is wrong or if it is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit>>

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.

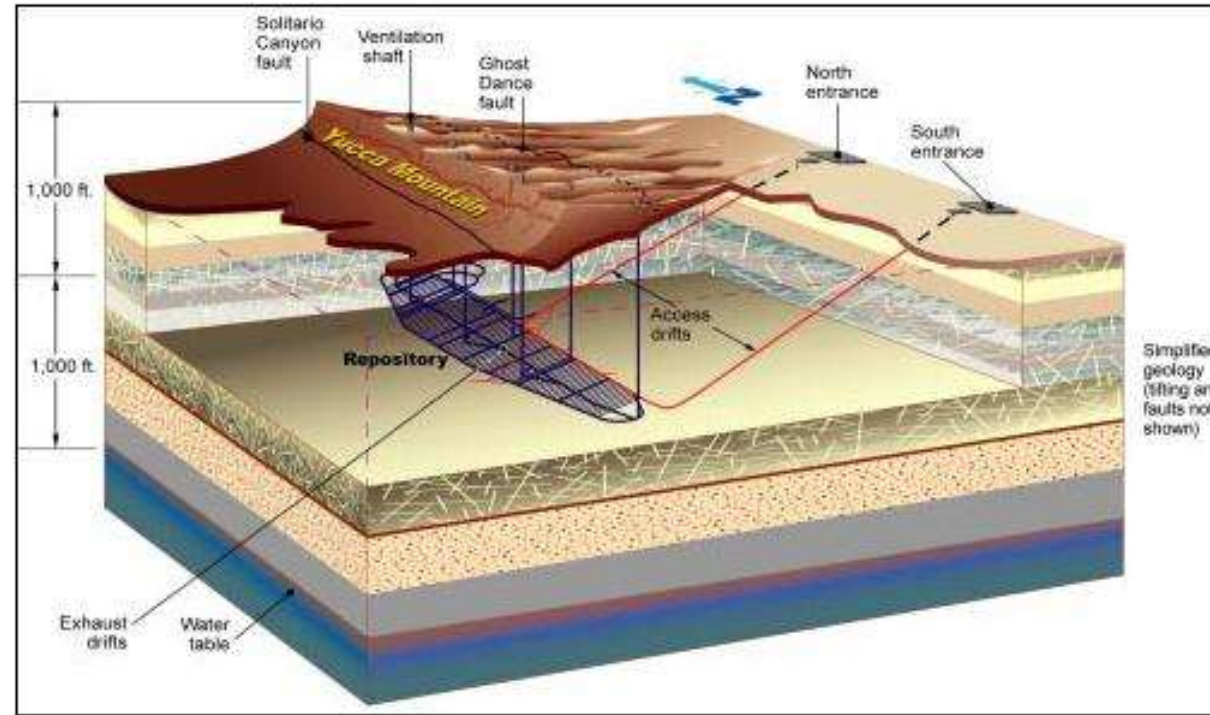
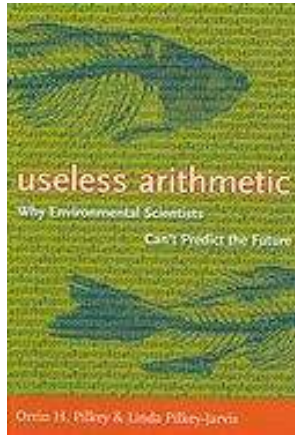




TSPA (like any other model) **relies on assumptions** → one is the low permeability of the geological formation → long time for the water to percolate from surface to disposal.







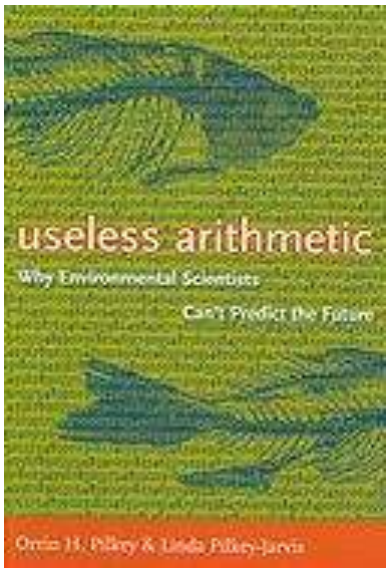
The confidence of the stakeholders in TSPA was not helped when evidence was produced which could lead to an upward revision of **4 orders of magnitude** of this parameter  
(the  $^{36}\text{Cl}$  story)



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

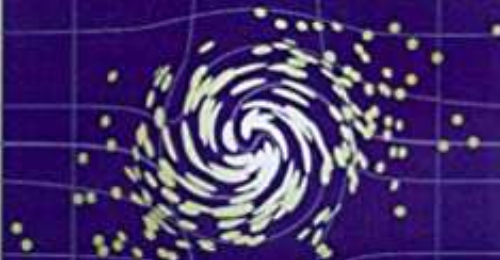
“Bay models are used to track nutrient loads to ensure the cap is not exceeded”

→ 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

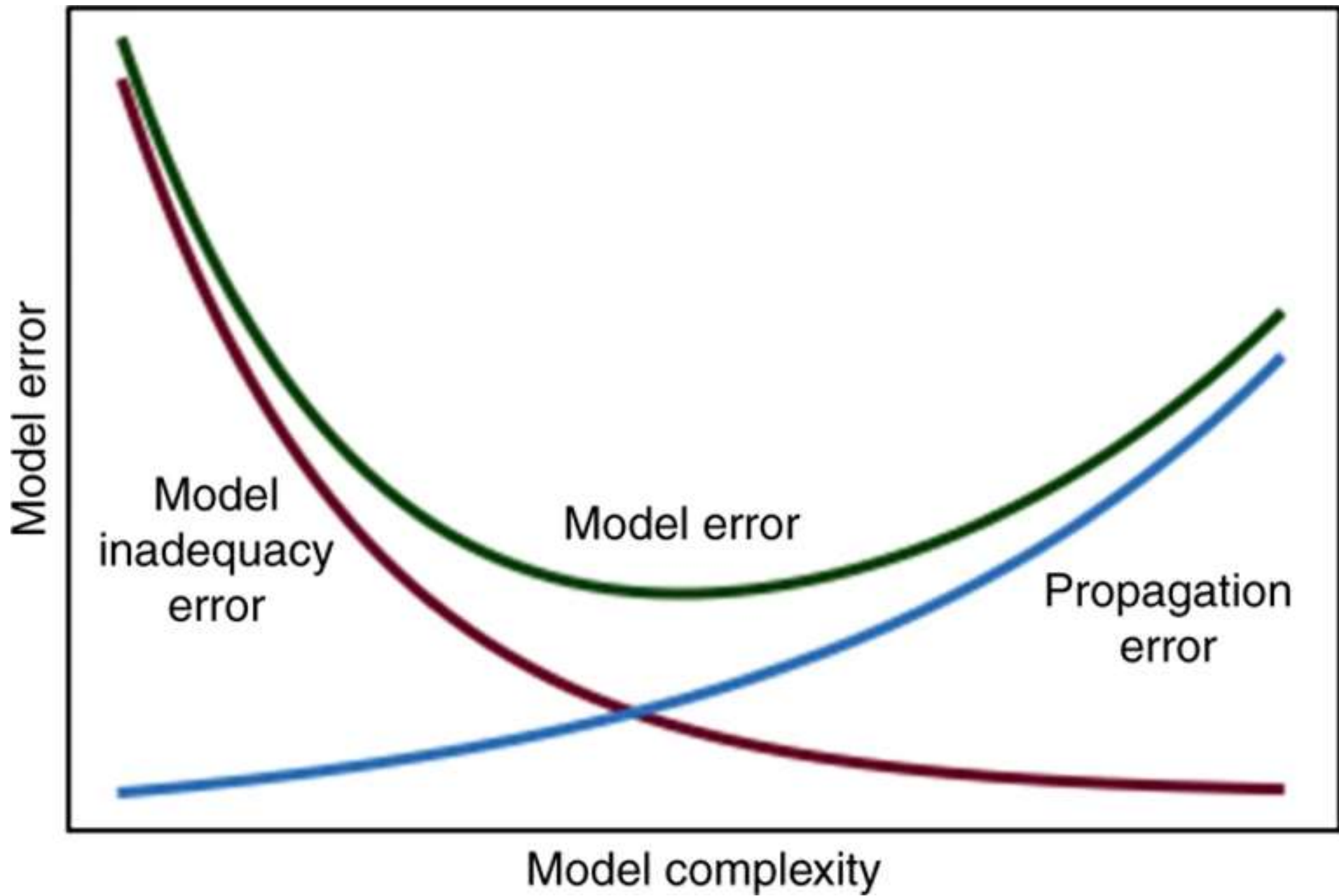
| [Open Access](#)

| Published: 27 August 2019

# A short comment on statistical versus mathematical modelling

Andrea Saltelli 

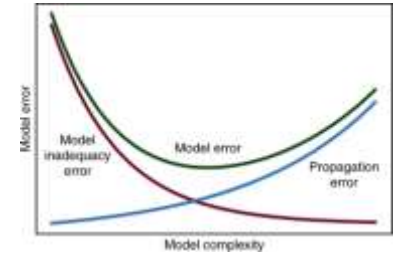
The author's name, Andrea Saltelli, followed by a blue square icon containing a white envelope symbol, indicating an email contact.



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.



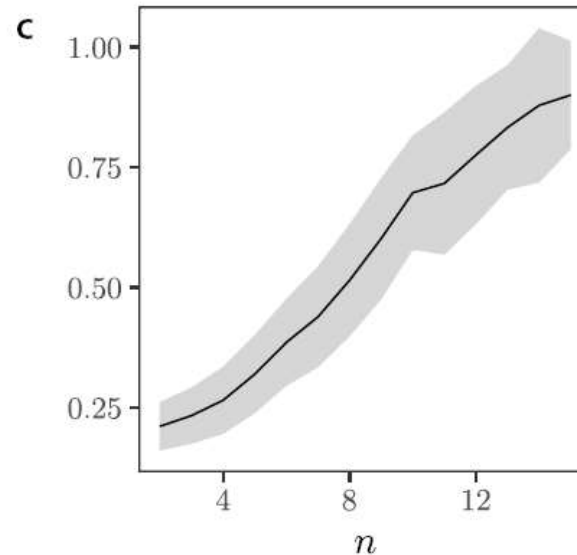
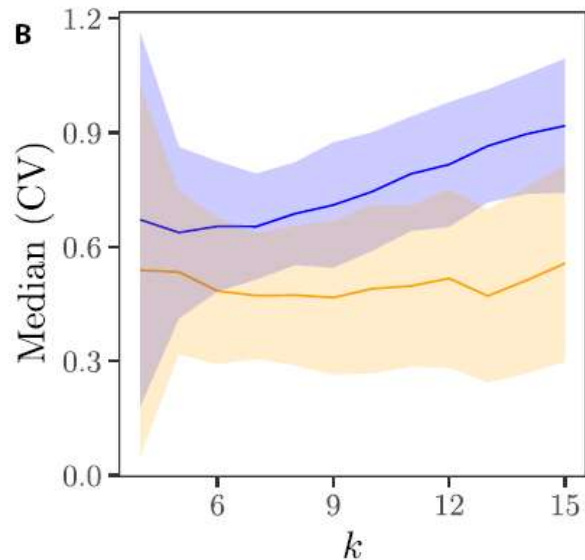
Empirical test using the SA-based concept of effective dimension

## Models with higher effective dimensions tend to produce more uncertain estimates

ARNALD PUY <sup>ID</sup>, PIERFRANCESCO BENEVENTANO, SIMON A. LEVIN <sup>ID</sup>, SAMUELE LO PIANO <sup>ID</sup>, TOMMASO PORTALURI, AND ANDREA SALTELLI <sup>ID</sup>

SCIENCE ADVANCES • 19 Oct 2022 • Vol 8, Issue 42 • DOI: 10.1126/sciadv.abn9450

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





# 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.

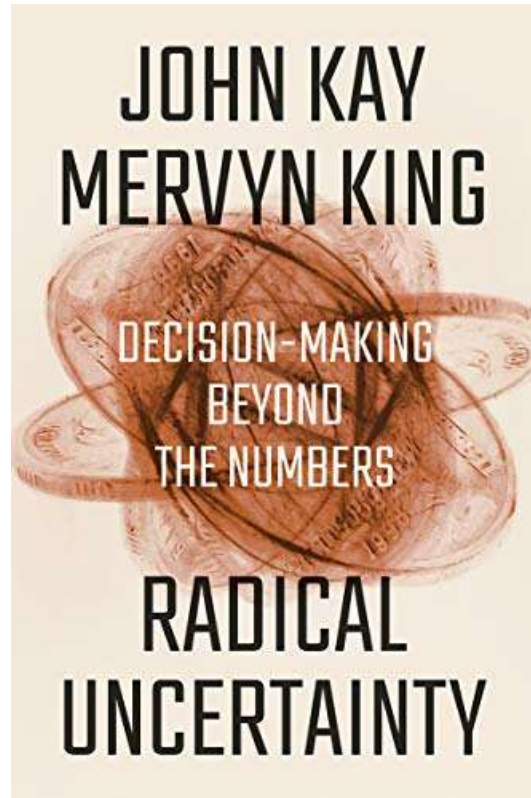
>260 references  
SUPPLEMENTARY INFORMATION  
1. Additional information and references



Illustration by David Parkins



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)

# Mind the assumptions

Assess uncertainty and sensitivity

## Mind the hubris

Complexity can be the enemy of relevance

## Mind the framing

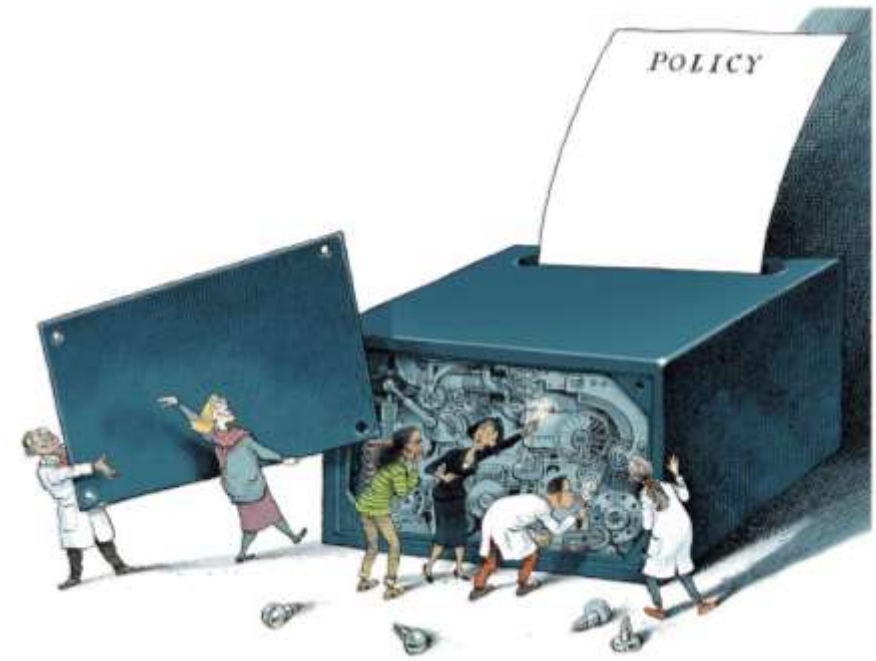
Match purpose and context

## Mind the consequences

Quantification can backfire.

## Mind the unknowns

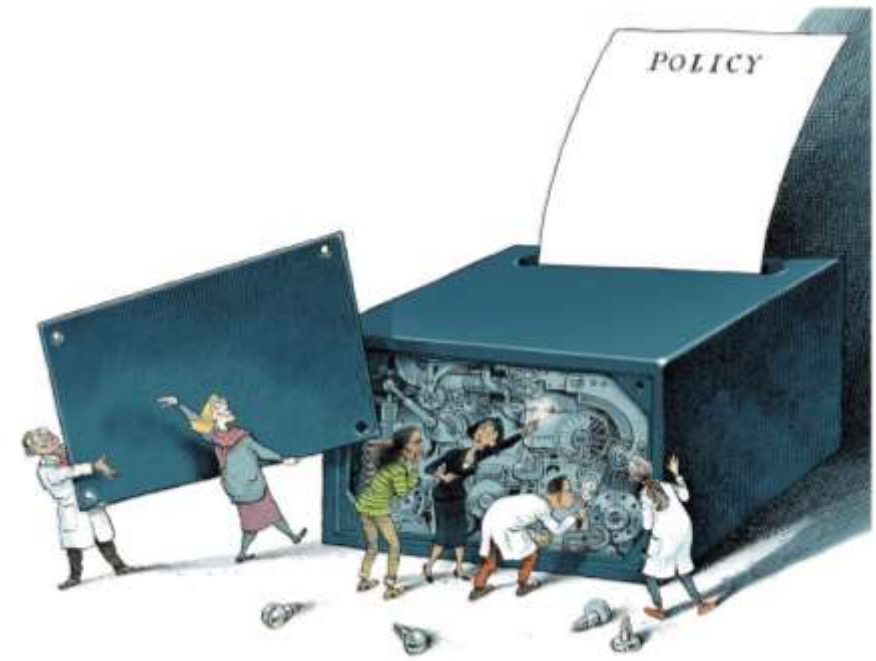
Acknowledge ignorance



# Mind the hubris

Complexity can be the enemy of relevance

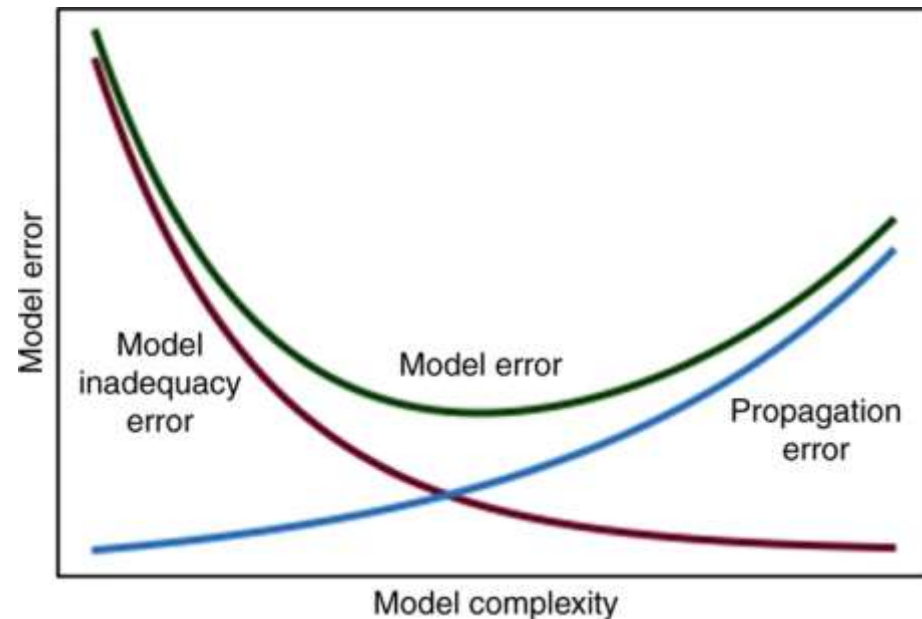
... many are seduced by the idea of adding complexity in an attempt to capture reality more accurately, but ...



## SUPPLEMENTARY INFORMATION

1. Additional information and references

>260 references



# Mind the assumptions

Assess uncertainty and sensitivity

# Mind the hubris

Complexity can be the enemy of relevance



# Mind the framing

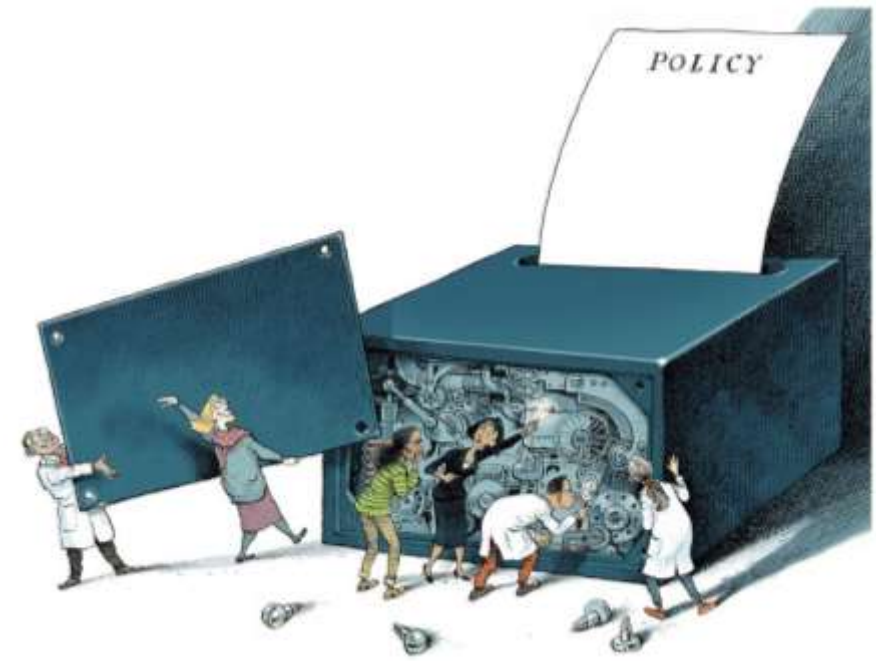
Match purpose and context

# Mind the consequences

Quantification can backfire.

# Mind the unknowns

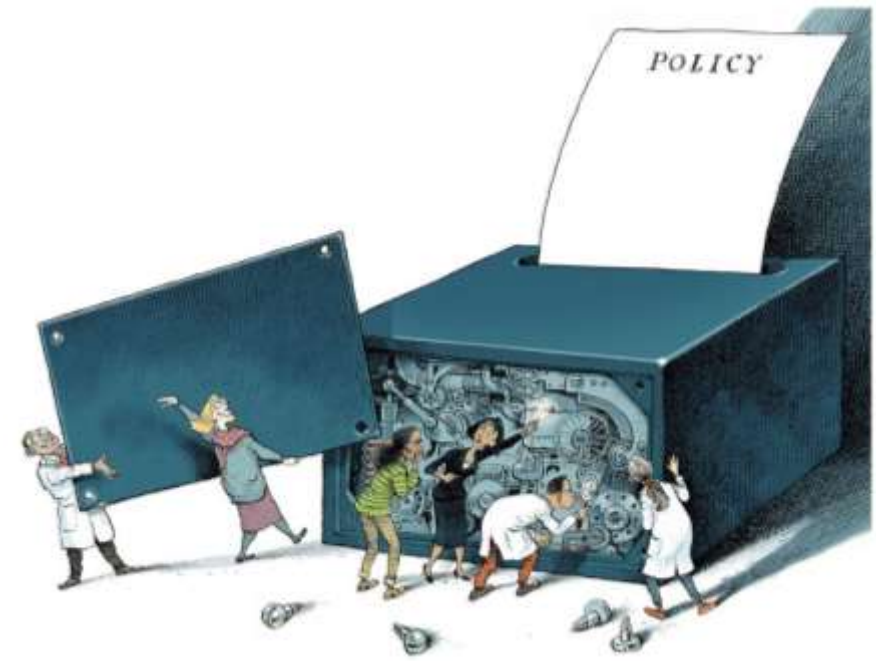
Acknowledge ignorance





# Mind the framing

Match purpose and context



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

## SUPPLEMENTARY INFORMATION

### 1. Additional information and references

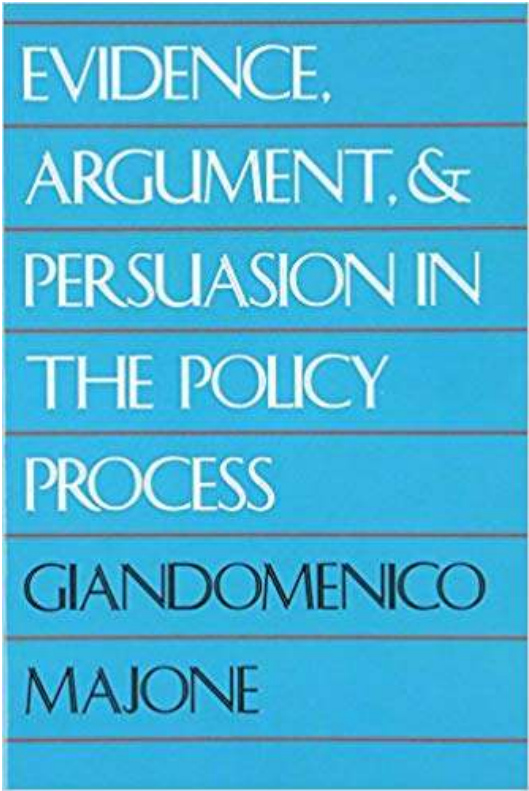
>260 references



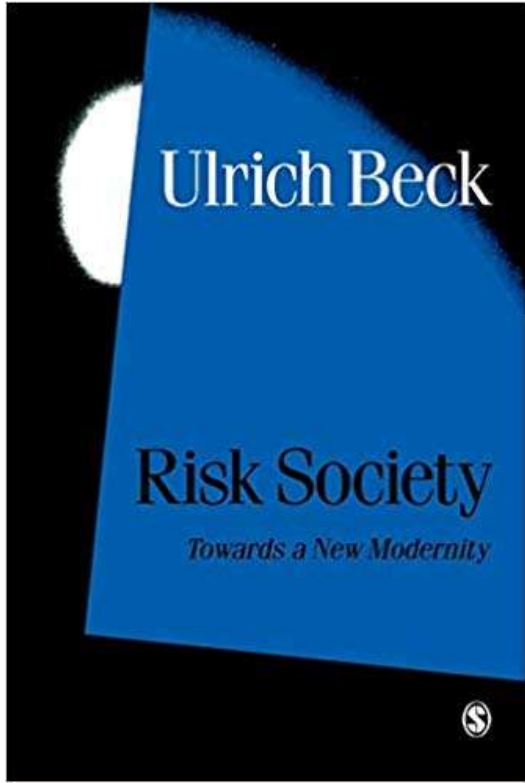
# From Ulrich Beck to Giandomenico Majone: the technique is never neutral



Ulrich Beck  
(1944 –2015)



1989



1992 (1986)



Environmental Science & Policy

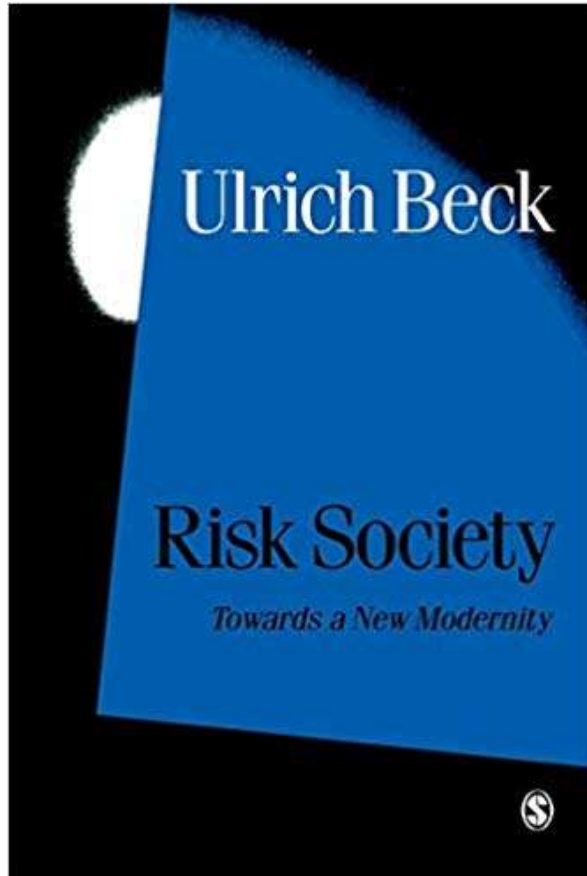
Volume 106, April 2020, Pages 87-98



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



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>

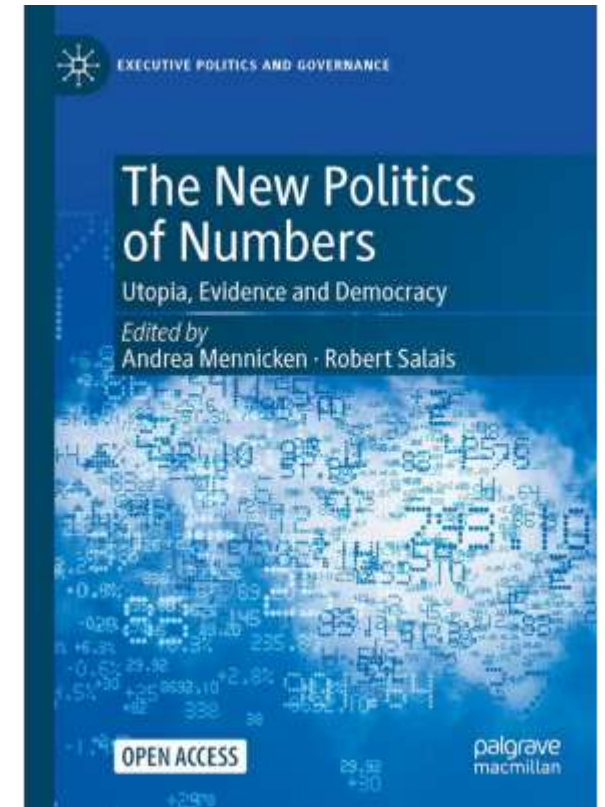
Combine more lenses, including Post-normal science (PNS), Bioeconomics, and Non-Ricardian economics

Since the technique is never neutral a technical proof of quality is illusory without a parallel investigation of normative quality

Technical Quality

Normative quality

How the numbers of neoliberalism (New Public Management) constitute a regime of a-democracy; the example of indicators of employment



Salais, R. (2022). “La donnée n’est pas un donné”: Statistics, Quantification and Democratic Choice. In *The New Politics of Numbers: Utopia, Evidence and Democracy*, Andrea Mennicken and Robert Salais, Palgrave Macmillan, pp. 379–415.





# Mind the assumptions

Assess uncertainty and sensitivity

# Mind the hubris

Complexity can be the enemy of relevance

# Mind the framing

Match purpose and context

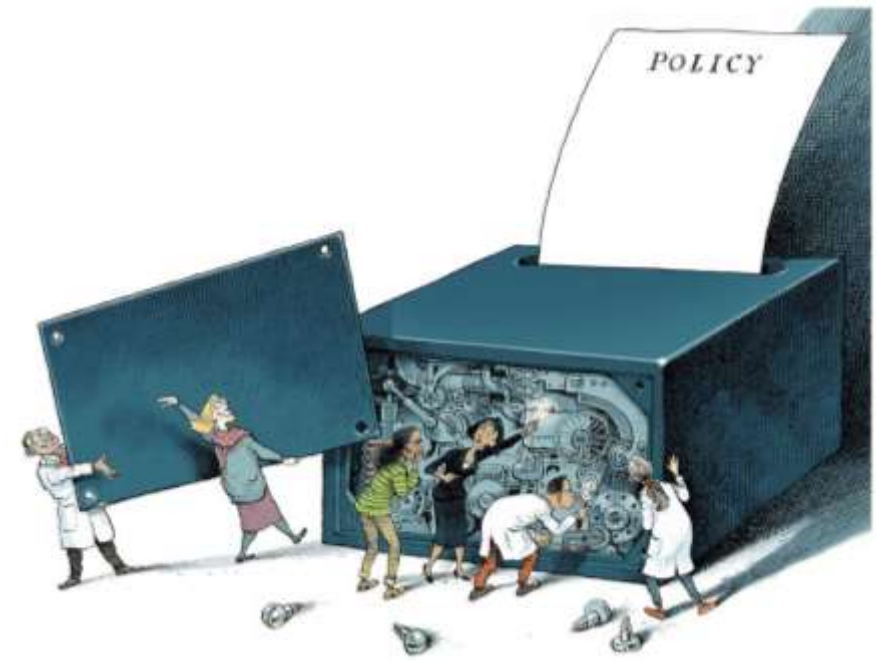


# Mind the consequences

Quantification can backfire.

# Mind the unknowns

Acknowledge ignorance



# Mind the consequences

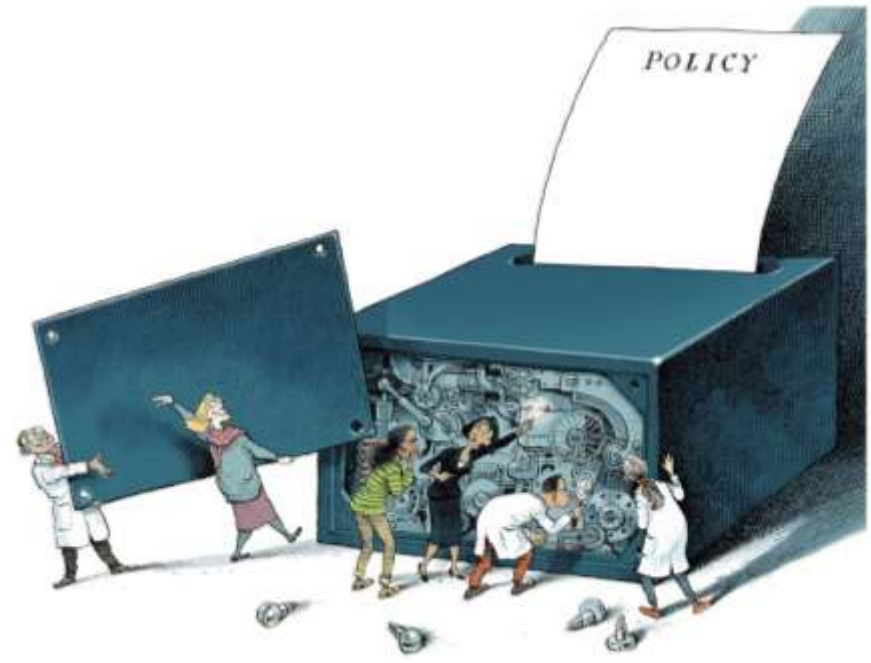
Quantification can backfire.

[← Back to Article](#)

WIRED MAGAZINE: 17.03

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

By Felix Salmon 02.23.09





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

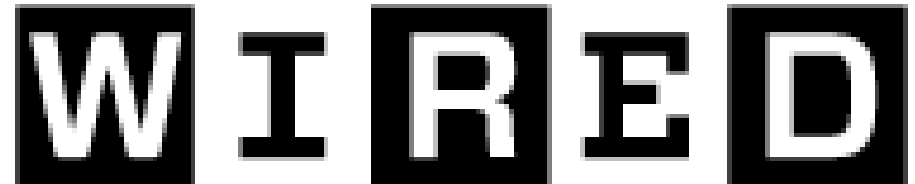
Here's what killed your 401(k) *David X. Li's Gaussian copula function as first published in 2000. Investors exploited it as a quick—and fatally flawed—way to assess risk. A shorter version appears on this month's cover of Wired.*

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/>

# Mind the assumptions

Assess uncertainty and sensitivity

# Mind the hubris

Complexity can be the enemy of relevance

# Mind the framing

Match purpose and context

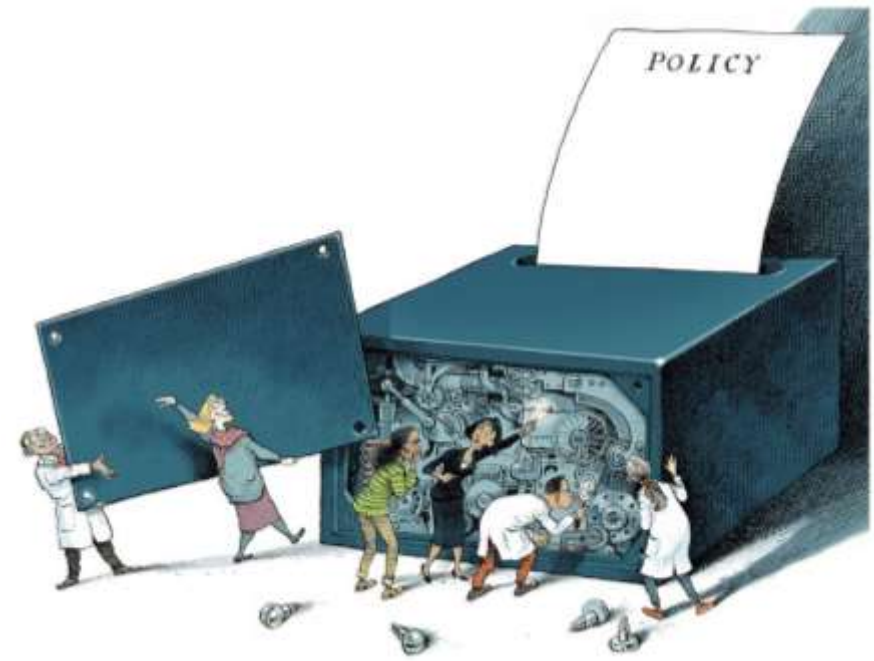
# Mind the consequences

Quantification can backfire.



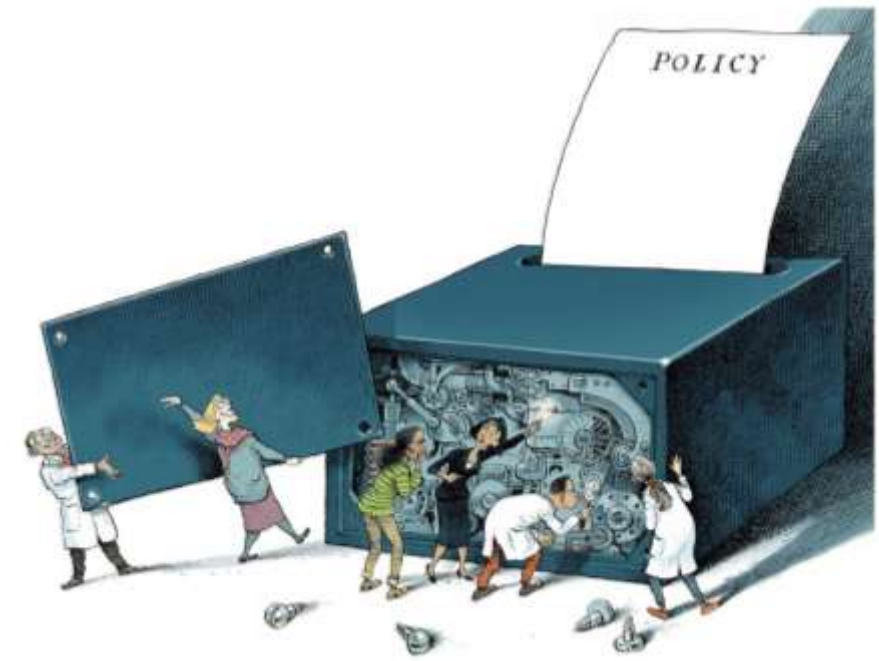
# Mind the unknowns

Acknowledge ignorance



# Mind the 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)

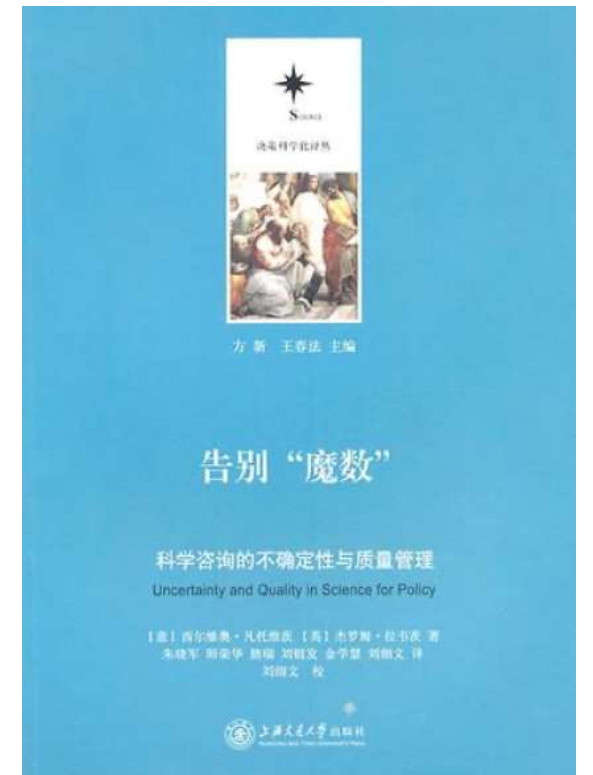
Technical Quality →

Sensitivity Analysis

Normative quality →

Sensitivity Auditing

This is not far from Funtowicz and Ravetz “uncertainty and quality”



# Sensitivity analysis

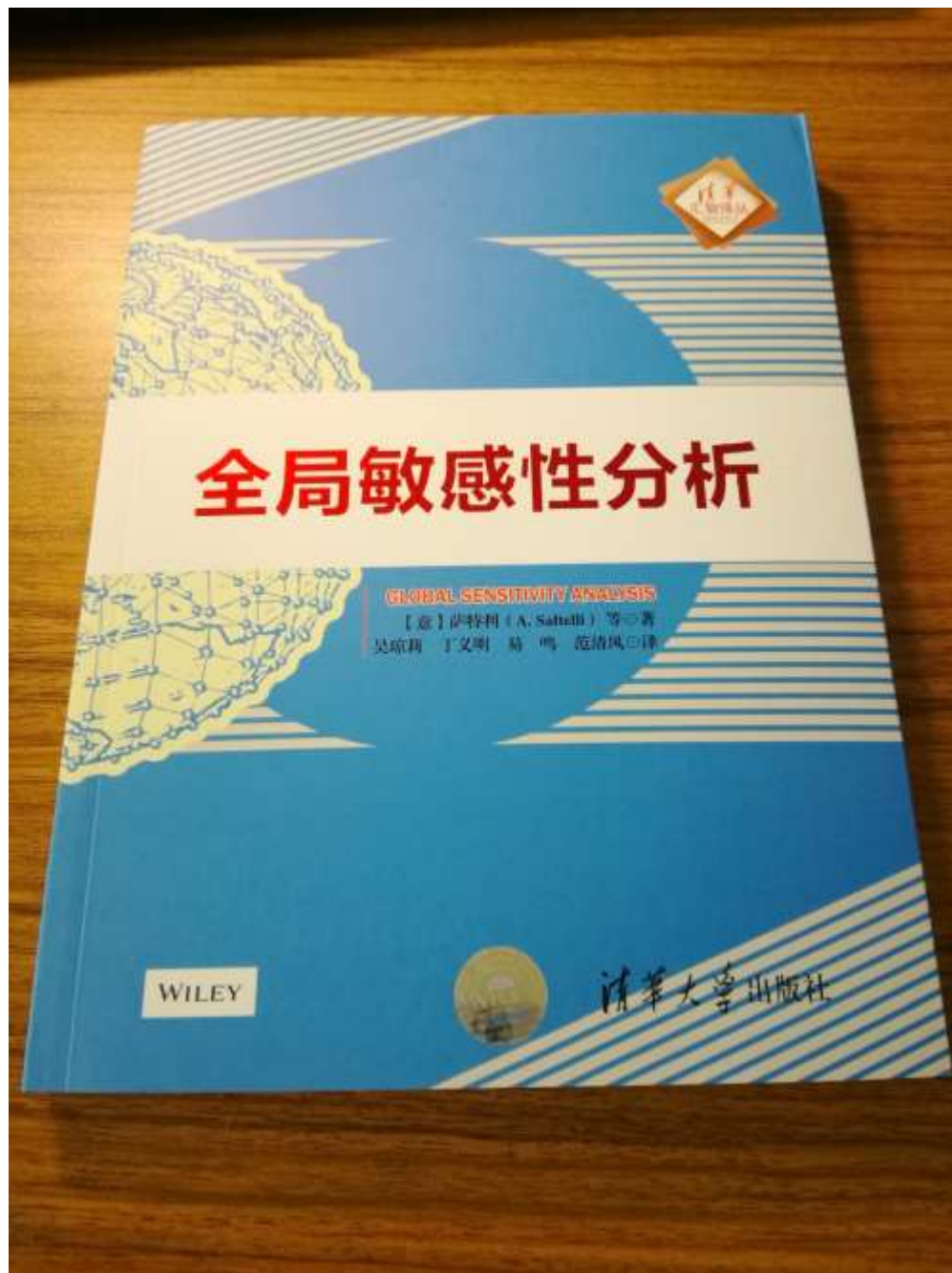


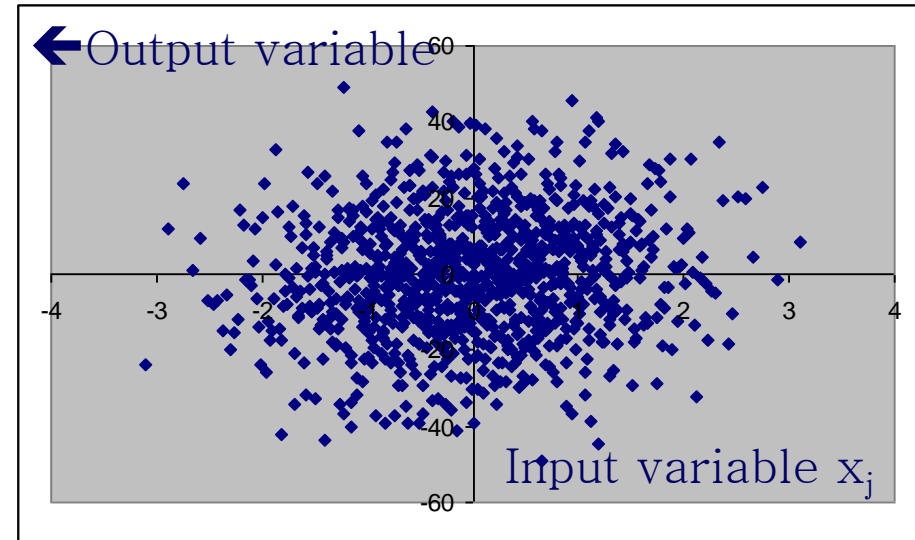
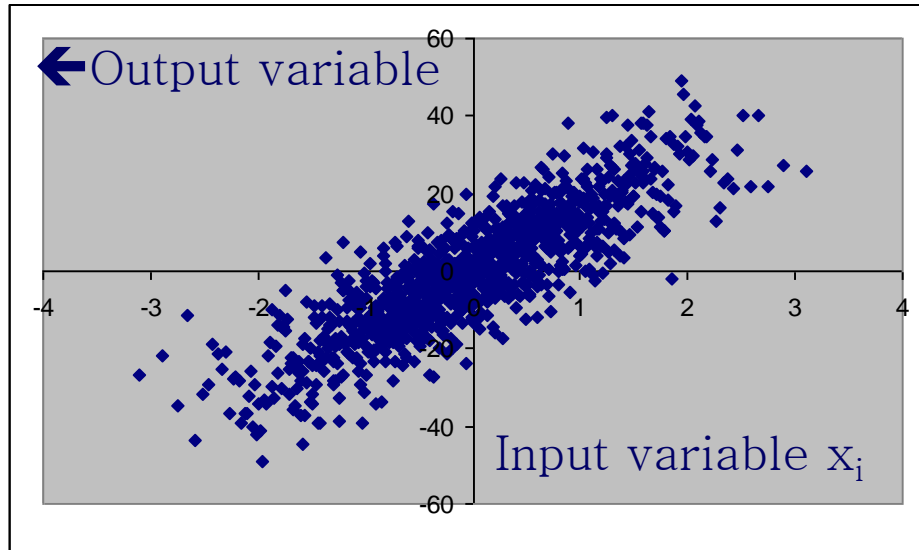
A. Saltelli, M. Ratto,  
T. Andres, F. Campolongo,  
J. Cariboni, D. Gatelli,  
M. Saisana, S. Tarantola

# GLOBAL SENSITIVITY ANALYSIS

The Primer

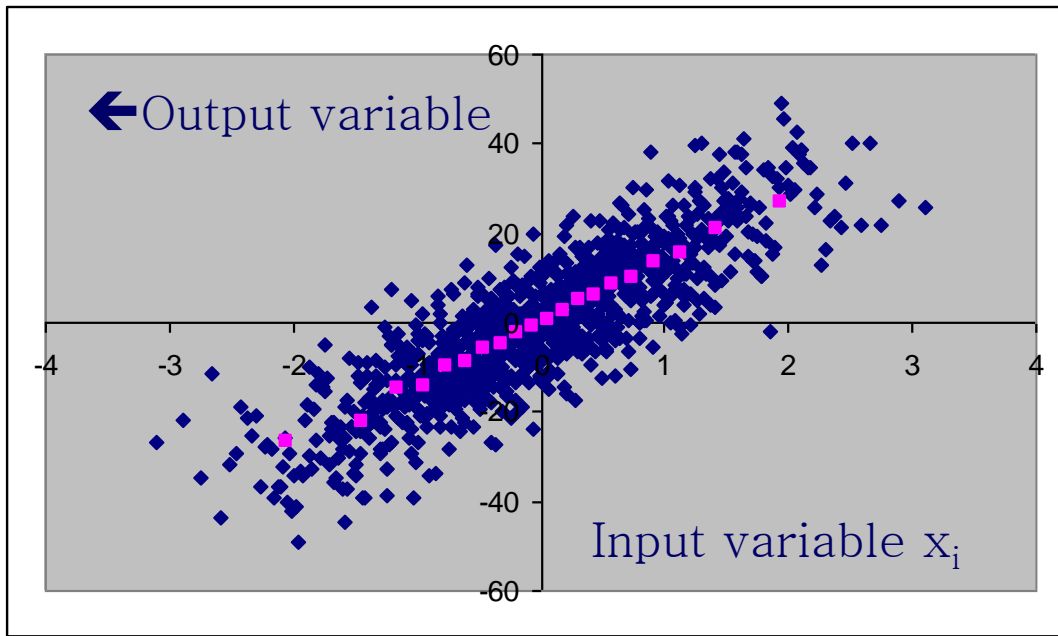
 WILEY





Plotting the output as a function of two different input factors

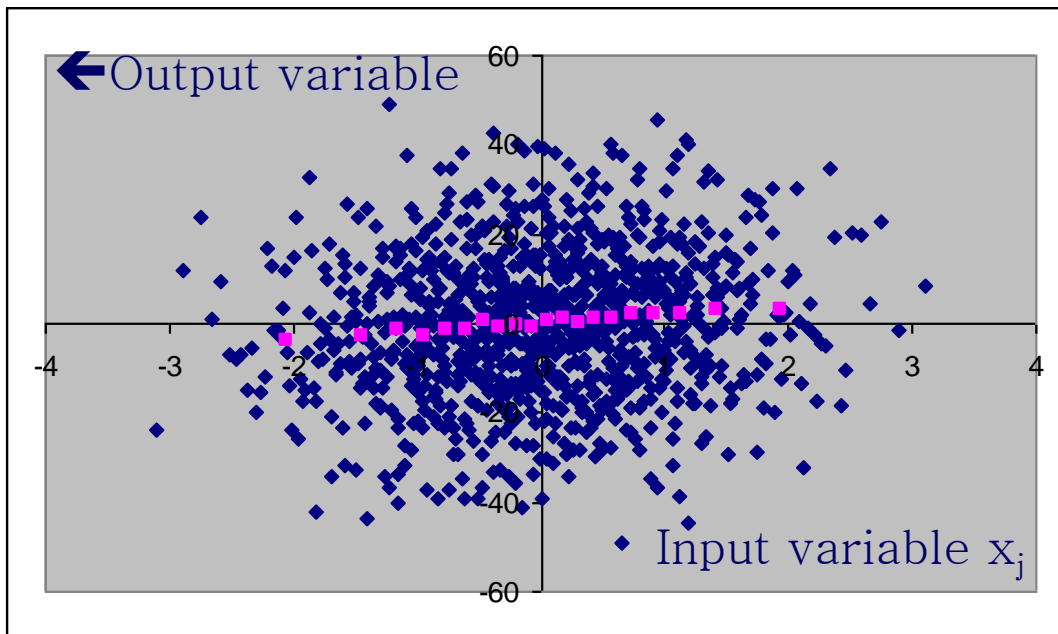
Which factor is more important?

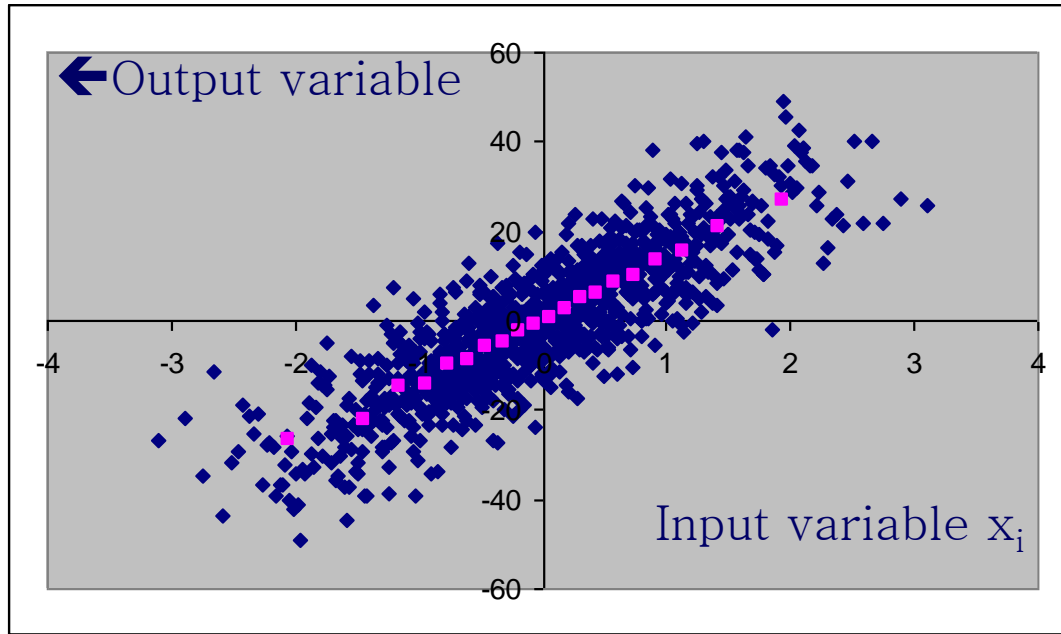


~1,000 blue points

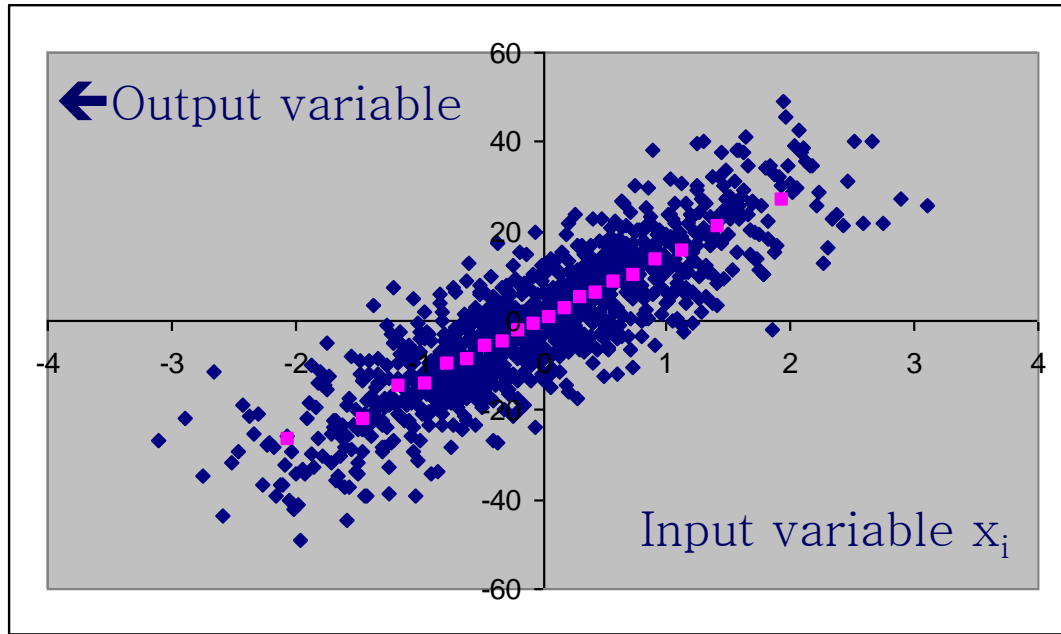
Divide them in 20 bins of ~ 50 points

Compute the bin's average (pink dots)



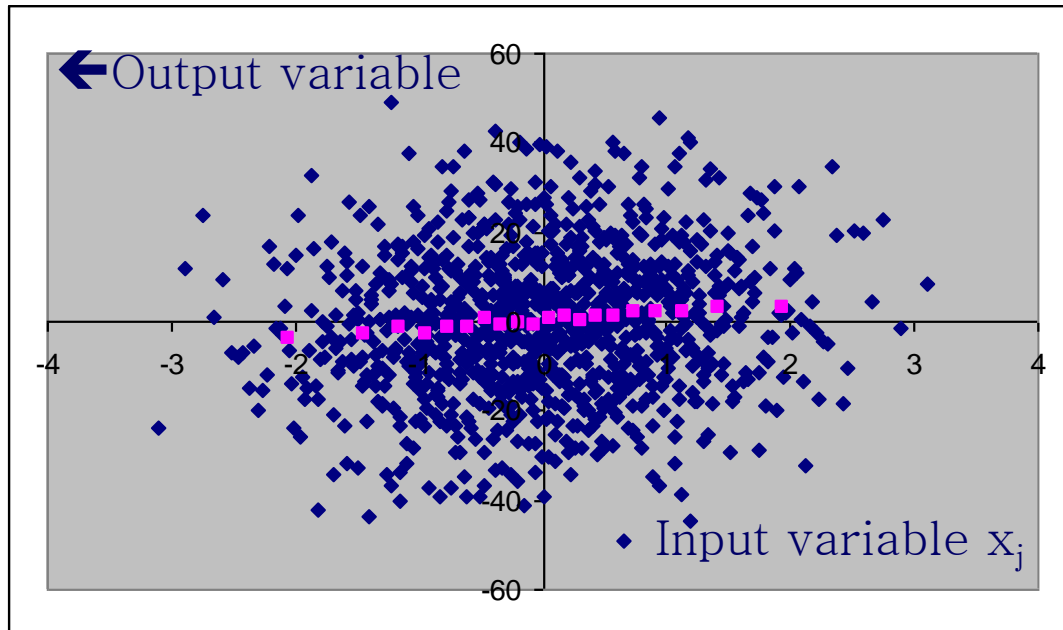
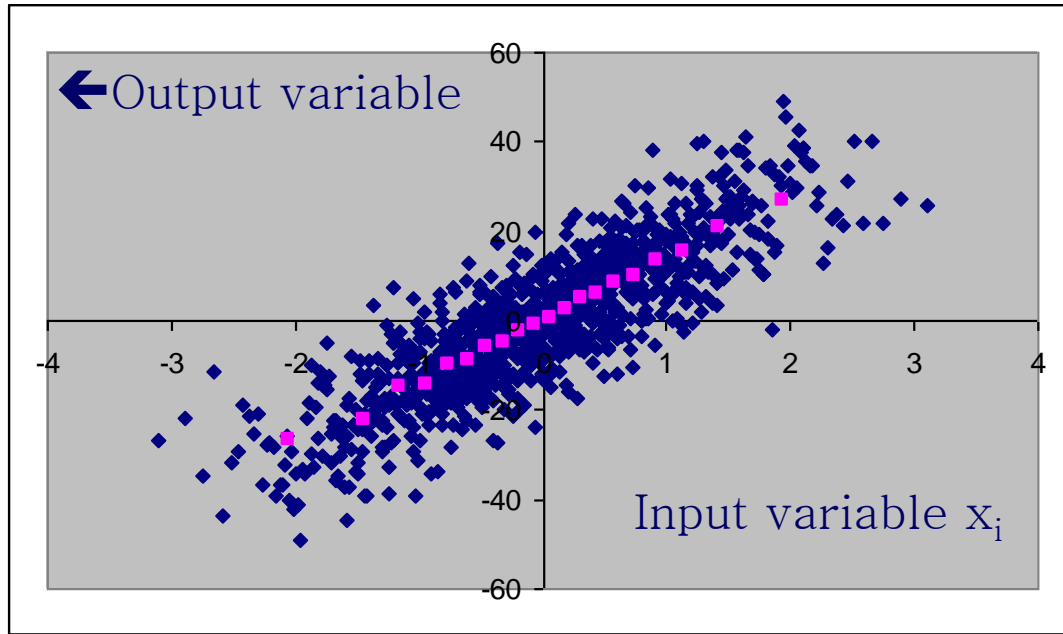


Each pink point is  $\sim E_{\mathbf{X}_{\sim i}}(Y|X_i)$



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



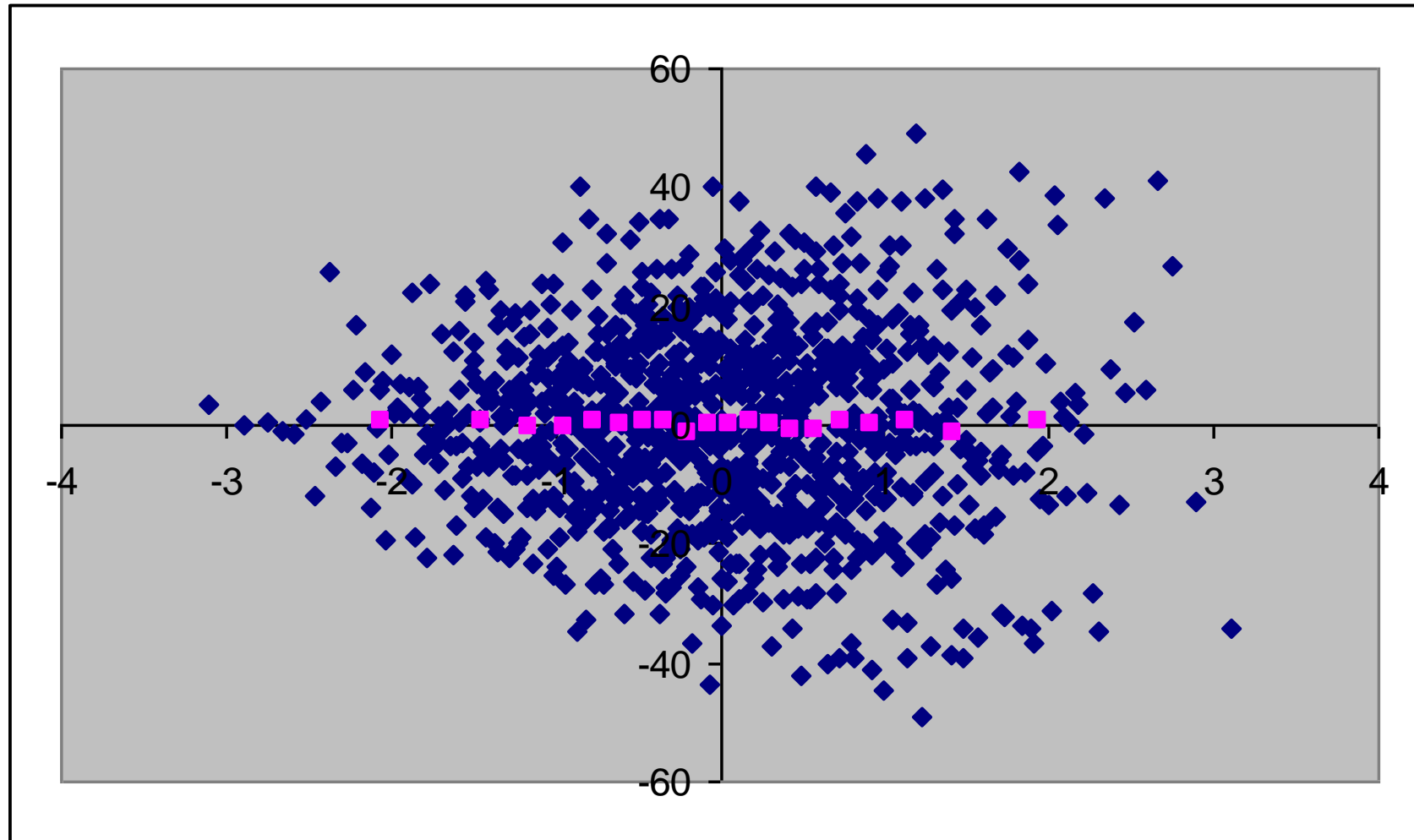
Pearson's correlation  
ratio

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

First order sensitivity index

Unconditional  
variance

Is  $S_i = 0$ ?



# 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.”





# The rules of sensitivity auditing

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

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

Fishing  
expeditions,  
forking paths ...



Jorge Luis Borges  
(1899–1986)



Taking different  
narratives within the  
same novel like Ts'ui Pên

The garden of forking paths: Why multiple comparisons can be a problem, even when there is no “fishing expedition” or “p-hacking” and the research hypothesis was posited ahead of time\*

Andrew Gelman<sup>†</sup> and Eric Loken<sup>‡</sup>

14 Nov 2013

The garden of forking paths: Why multiple comparisons can be a problem, even when there is no “fishing expedition” or “p-hacking” and the research hypothesis was posited ahead of time\*

Andrew Gelman<sup>†</sup> and Eric Loken<sup>‡</sup>

14 Nov 2013

Why this matters?



**PNAS**

RESEARCH ARTICLE

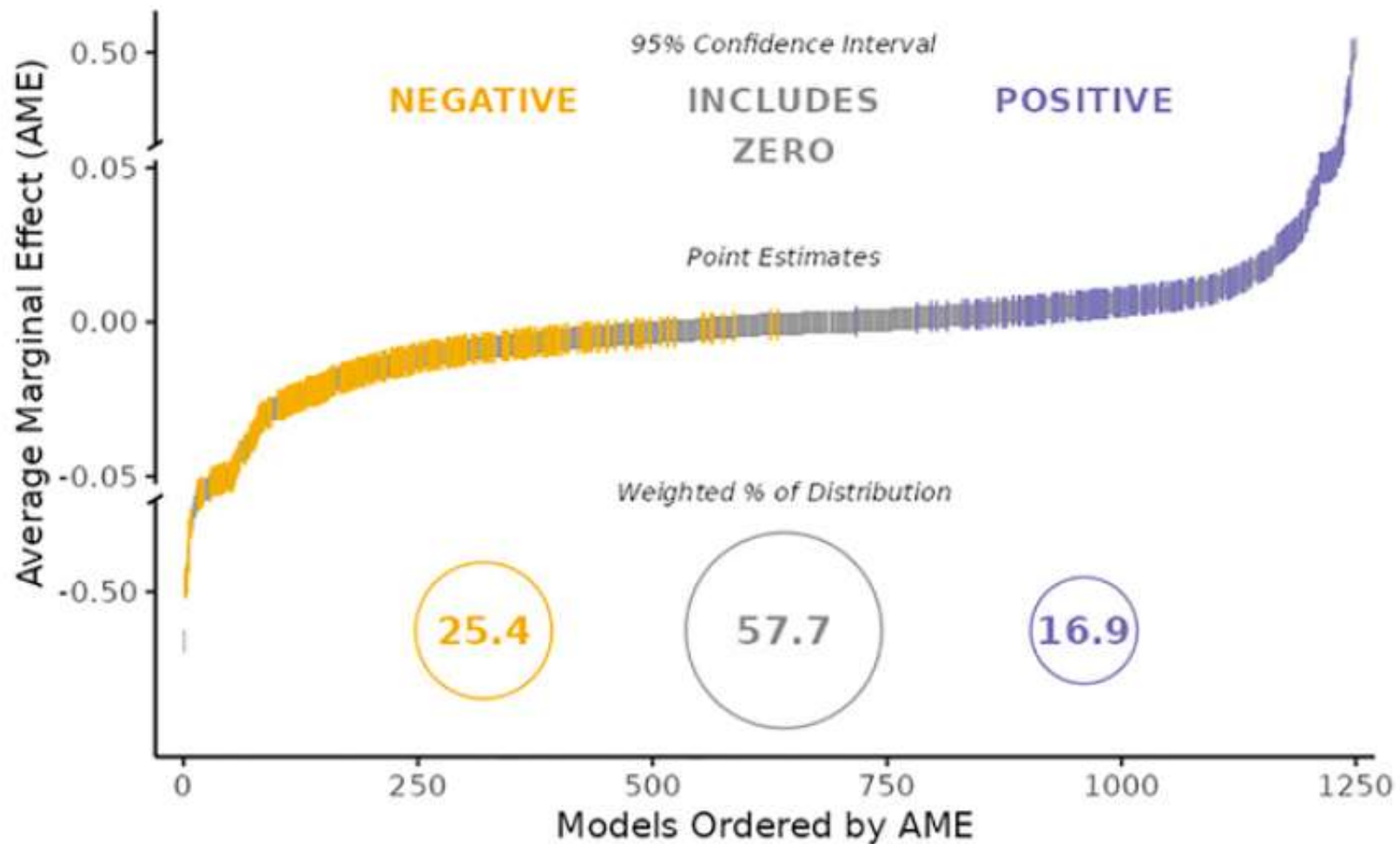
SOCIAL SCIENCES

 OPEN

**Observing many researchers using the same data and hypothesis reveals a hidden universe of uncertainty**

Edited by Douglas Massey, Princeton University, Princeton, NJ; received March 6, 2022; accepted August 22, 2022





“Will different researchers [73 teams] converge on similar findings when analyzing the same data?”

...

...teams’ results varied greatly, ranging from large negative to large positive effects”

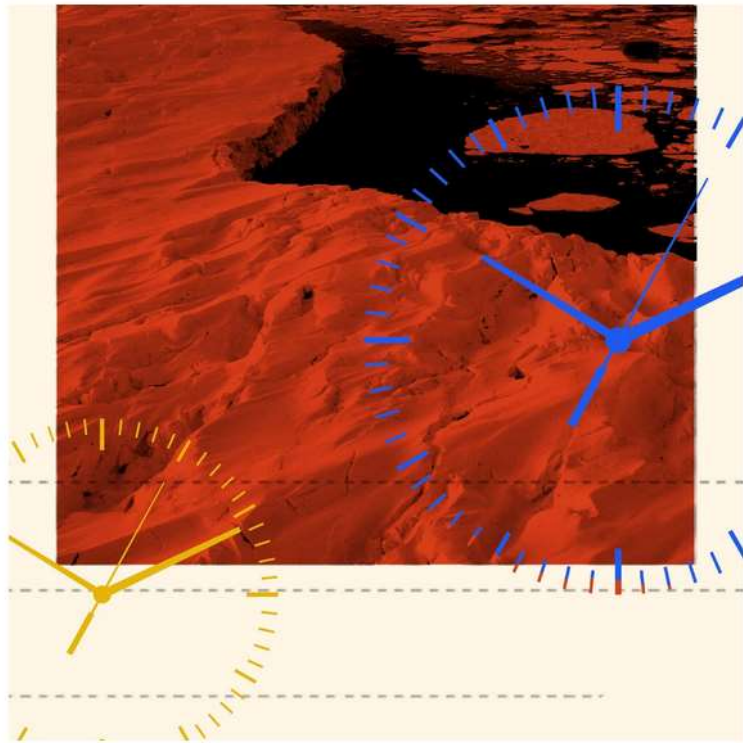
(Massey et al. 2022)

Do we live immersed in  
fantastic numbers?

OPINION  
PETER COY

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

Sept. 17, 2021



“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

We have perhaps reached a complex epistemic state, where on the one hand ‘everybody knows’ that some numbers are pseudo-precise and that numbers can be gamed, while the game works only because most people don’t know about it



Jerome R. Ravetz





# The politics of modelling. Numbers between science and policy

Andrea Saltelli and Monica Di Fiore Eds.



From  
Epilogue: these special  
models, by the editors



OXFORD  
UNIVERSITY PRESS

## Are models 'special'?

Unlimited repertoire of methods

Not a discipline

Escape sociology of quantification

Epistemic authority from mathematics



# Consequences?



**OXFORD**  
UNIVERSITY PRESS

A pretence of neutrality (Luhmann's deparadoxification)

No antibodies to fight degeneration (Ravetz)

A ground for trans-science (Weinberg)

Ritual use (Gigerenzer)



# Solutions to resolve the state of exception

- Thinking about reproducibility of models (Ioannidis)
- Complexity of interpretation rather than complexity of construction
- Follow the example of statistics' stactivism
- Reciprocal domestication between models and society / Breach the solitude of modellers
- Defog the mathematics of uncertainty (Funtowicz & Ravetz, 1990)
- Practice assumption hunting / modelling of the modelling process / sensitivity analysis and auditing



Reproducibility

is a necessary  
condition for



Transparency

is a necessary  
condition for



Legitimacy

is a necessary  
condition for



Epistemic authority



Large model

Important institution

&



Gianus Bifrons, Vatican Museum.  
Source: Wikipedia Common

Different political economies of modelling



The End



Plan of the talk:

"Responsible modelling"

The talk will illustrate elements of sensitivity analysis, sensitivity auditing, sociology and ethics of quantification in relation to the use of mathematical models.