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Global Sensitivity Analysis or Multiverse Analysis?

Andrea Saltelli

Webinar of I4Driving, Friday 6th, 2026, h. 12.30

Andrea Saltelli

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Latest papers

Models and the common good

A short analysis of norms and counter-norms in modelling, discussing how models may misuse their epistemic authority for reasons of occasion, opportunity and interest.

Outline:
Narratives and counter-narratives,
State of exception,
Seeking Cinderella,
Reformation

Ranking the Rankers

Ranking the Rankers? We investigate using global sensitivity analysis the properties of the science-wide author databases' standardised citation indicators produced since 2015 by a team of researchers led by John P. A. Ioannidis.

Digital twins

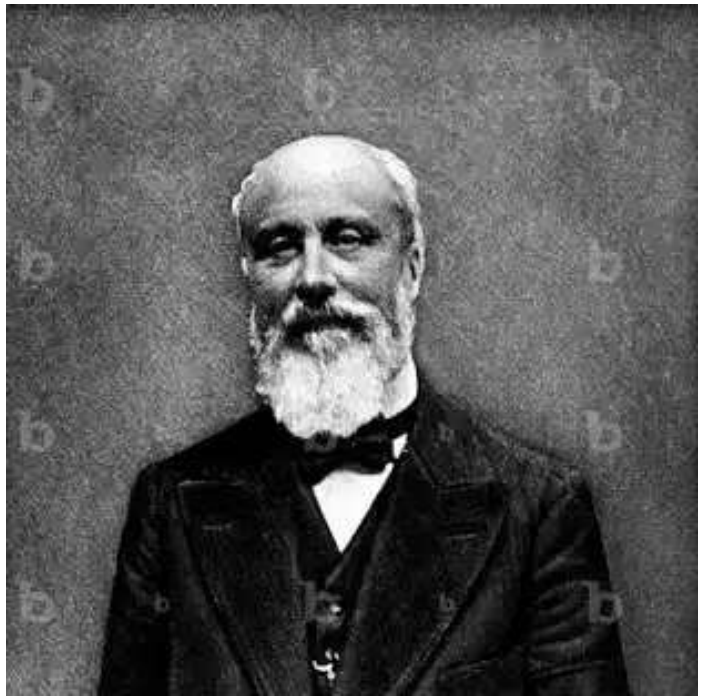
We reflect on the development of digital twins of

Where to find this talk:

www.andreasaltelli.eu

"… inferences from mathematical models of phenomena to real physical applications must also be demonstrated to be approximately correct when the assumptions of the model are only approximately true" [1]

Pierre Duhem (1861–1916) and his 'Principle of stability' ~1906

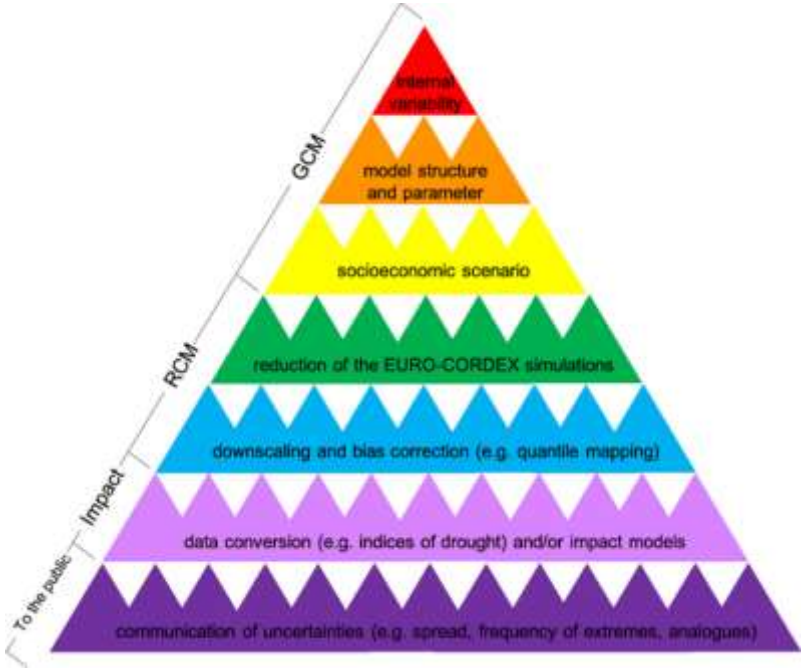


[1] See: S. C. Fletcher, 'The Principle of Stability', Philosopher's Imprint, vol. 20, no. 3, 2020, Accessed: Sep. 08, 2024. [Online].

Models are fragile

Duhem's principle of stability [1], links to the occurrence of either Butterfly [2] or Hawkmoth effects [3] … as well as to the accumulation of parametric error in a model, the so-called uncertainty cascade [4], that is the subject of global sensitivity analysis studies

[1] S. C. Fletcher, 'The Principle of Stability', Philosopher's Imprint, vol. 20, no. 3, 2020, Accessed: Sep. 08, 2024. [Online].
[2] H. G. Schuster, Deterministic Chaos: An Introduction, 2nd Rev edition. Weinheim: Vch Pub, 1998.
[3] E. Winsberg, 'Appendix: Structural Stability and the "Hawkmoth Effect"', in Philosophy and Climate Science, Cambridge: Cambridge University Press, 2018, pp. 232–246. doi: 10.1017/9781108164290.016.
[4] M. Christie, A. Cliffe, P. Dawid, and S. S. Senn, Simplicity, Complexity and Modelling. Wiley, 2011.



"I have proposed a form of organised sensitivity analysis that I call 'global sensitivity analysis' in which a neighborhood of alternative assumptions is selected and the corresponding interval of inferences is identified. Conclusions are judged to be sturdy only if the neighborhood of assumptions is wide enough to be credible and the corresponding interval of inferences is narrow enough to be useful."

Edward E. Leamer, 1990, Let's Take the Con Out of Econometrics, *American Economics Review*, 73 (March 1983), 31-43.

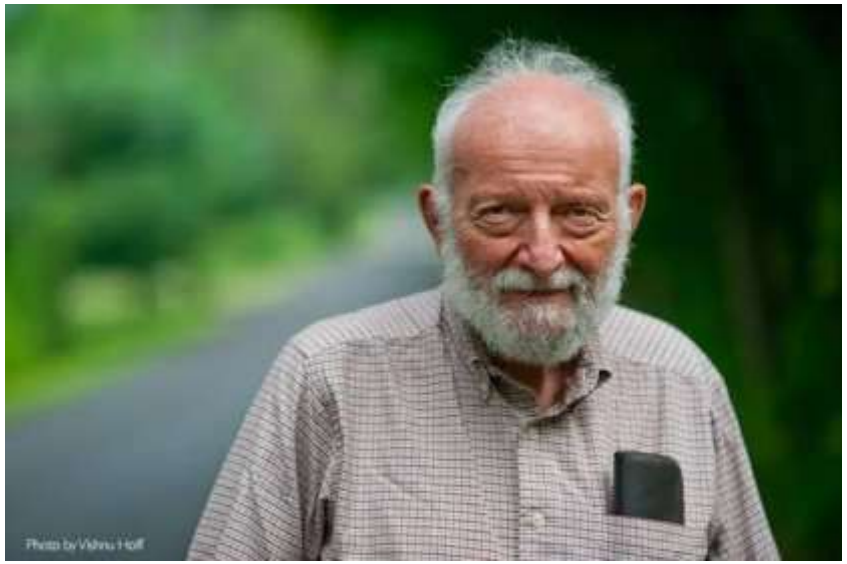
Edward E. Leamer

"One reason these methods are rarely used is their honesty seems destructive."

Tantalus on the Road to Asymptopia, Edward E. Leamer, 2010 *Journal of Economic Perspectives*, 24, (2), 31-46.

27 years

Edward E. Leamer, 1990, Let's Take the Con Out of Econometrics, *American Economics Review*, 73 (March 1983), 31-43.



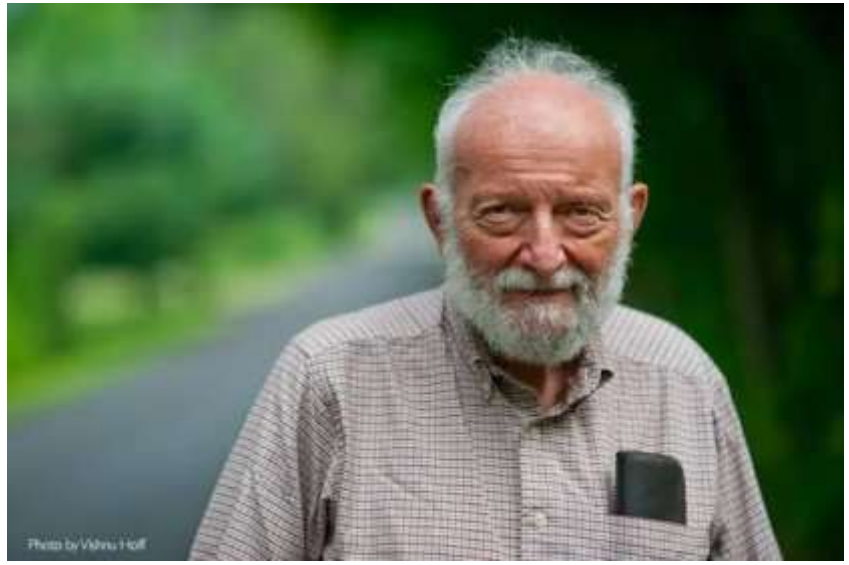
Richard Levins
1930-2016

Richard Levins' robustness analysis:

"Our truth is the intersection of independent lies"

➔ Construct multiple models with different assumptions and treat a result as credible only if it persists across those independent formulations

➔ Identify conclusions that are invariant to idealizations rather than artifacts of any single model.



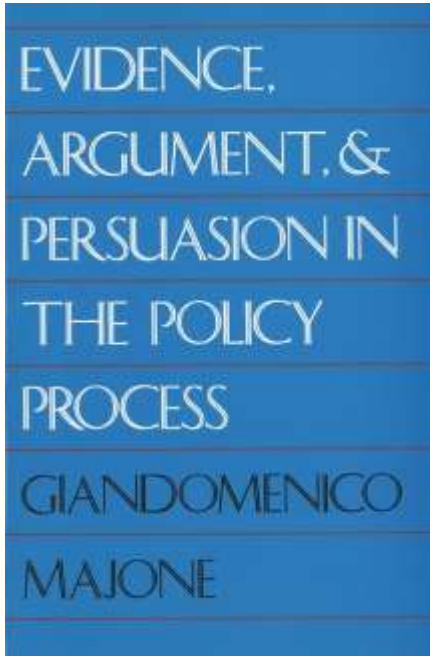
A fate similar to that of Leamer's global sensitivity analysis befell Richard Levins' robustness analysis

Richard Levins. The Strategy of Model Building in Population Biology. American Scientist, 54(4):421–431, 1966.

40 years

Michael Weisberg. Robustness Analysis. Philosophy of Science, 73(5):730–742, 2006.

Giandomenico Majone



"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?"

p. 62, Giandomenico Majone. Evidence, argument, and persuasion in the policy process. Yale University Press, 1989.

Leo Breiman
1928-2005

Enters Leo Breiman's 'Two cultures' work

"The goal is not interpretability, but accurate information"

➔ Embrace model-agnostic algorithmic culture that prioritizes empirical predictive accuracy

Leo Breiman. Statistical Modeling: The Two Cultures
Statistical Science, 16(3):199–231, August 2001

Two cultures

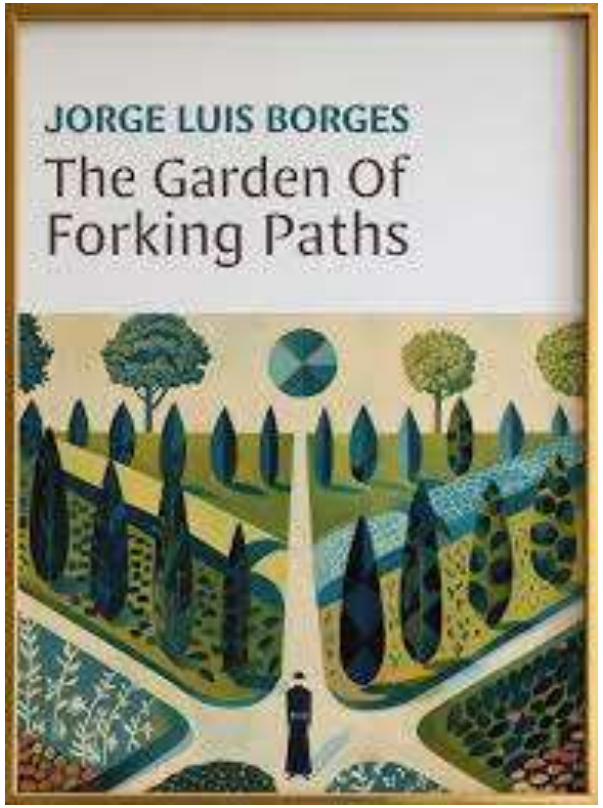
The Data Modelling Culture
Data are generated by a specific stochastic model; estimate its parameters.

The Algorithmic Modelling Culture
The data-generating mechanism is unknown; focus on predictive accuracy using algorithms.

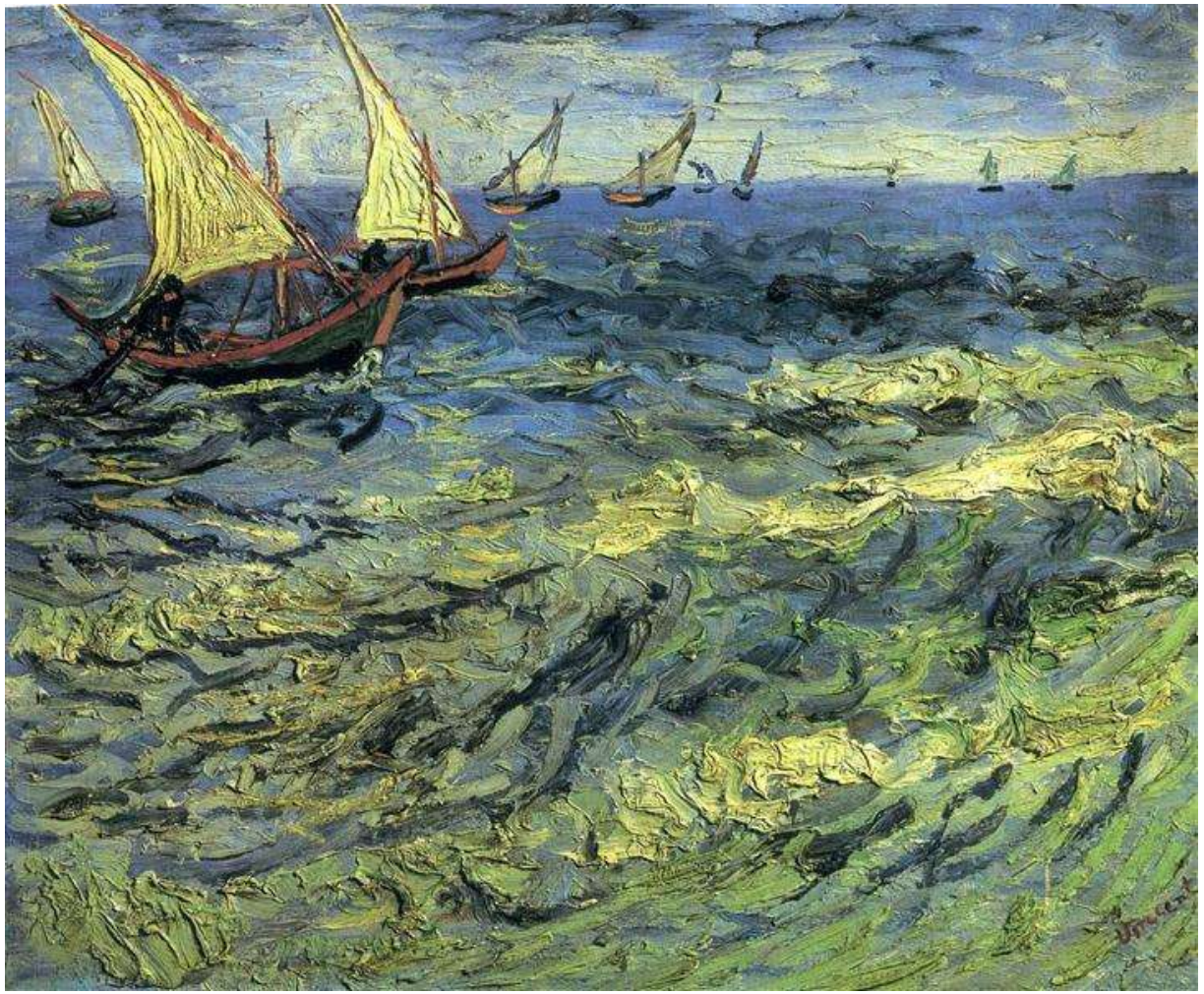
Leo Breiman. Statistical Modeling: The Two Cultures
Statistical Science, 16(3):199-231, August 2001

The Algorithmic Modelling Culture
Provided an epistemological justification for machine learning and, in time, AI

The Data Modelling Culture
Discovered the ‘Garden of Forking Paths; opened the season of multi-analyst experiments and multiverse analysis



Fishing expeditions? Forking paths?



Vincent van Gogh, Fishing Boats at Sea, source: https://www.wikiart.org/

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† and Eric Loken‡

14 Nov 2013

Many multi-analyst studies ongoing, e.g.:

"Are soccer players with dark skin tone more likely to receive red cards from referees?", Silberzahn et al. 2018

"Is there an impact of compulsory schooling on teenage pregnancy rates?", Huntington-Klein et al. (2021)

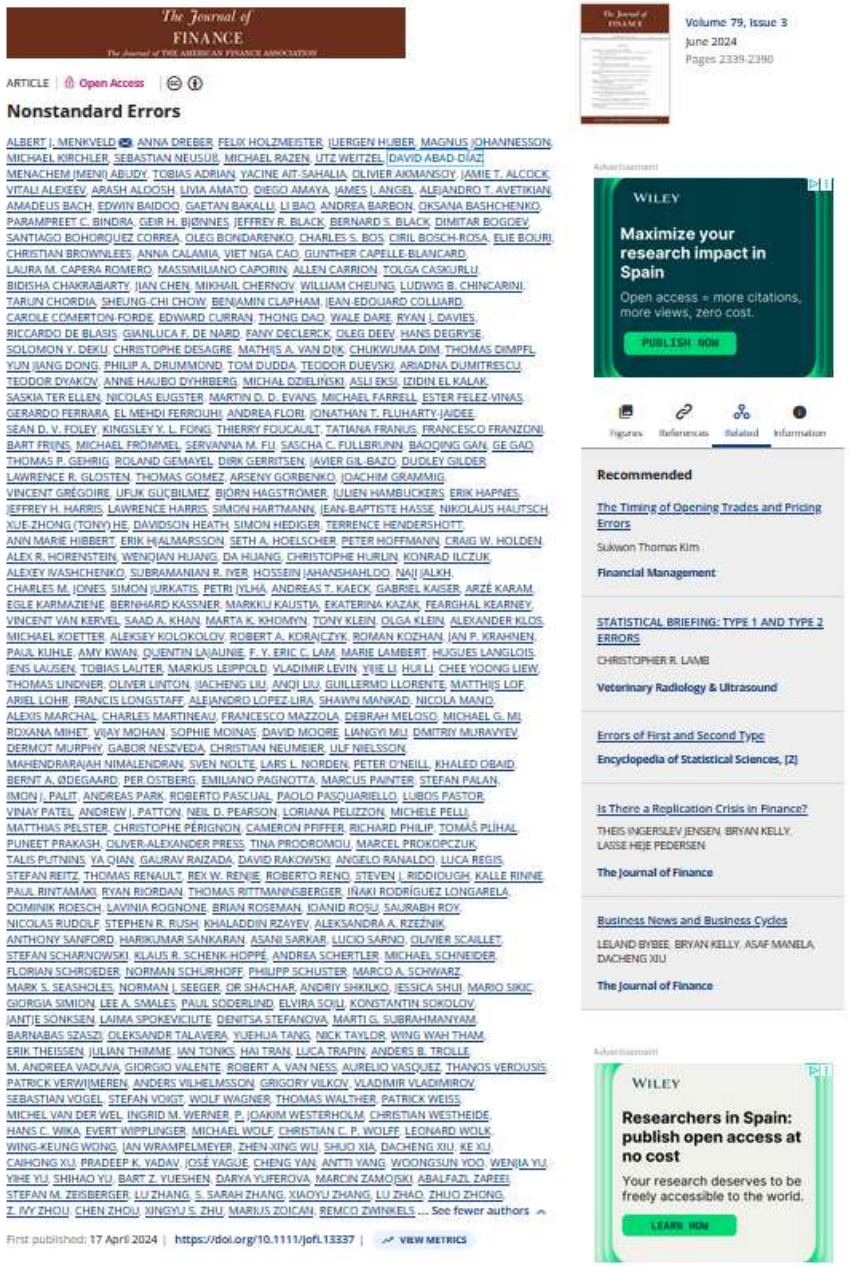
Source: BBC https://www.bbc.com/sport/football/68435064

HUNTINGTON-KLEIN, N., ARENAS, A., BEAM, E., BERTONI, M., BLOEM, J. R., BURLI, P., CHEN, N., GRIECO, P., EKPE, G., PUGATCH, T. et al. (2021). The influence of hidden researcher decisions in applied microeconomics. Economic Inquiry 59 944–960.
SILBERZAHN, R., UHLMANN, E. L., MARTIN, D. P., ANSELMI, P., AUST, F., AWTREY, E., BAHNÍK, Š., BAI, F., BANNARD, C., BONNIER, E. et al. (2018). Many analysts, one data set: Making transparent how variations in analytic choices affect results. Advances in Methods and Practices in Psychological Science 1, 337–356.

There are many (>20?) multi-analyst experiments brewing

Some are large! 343 authors of Menkveld et al. (2024)

MENKVELD, A. J., (2024). Nonstandard Errors. The Journal of Finance 79 2339–2390. https://doi.org/10.1111/jofi.13337.



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Nonstandard Errors

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GLOSTEN, THOMAS GOMEZ, ARSENY GORBENKO, JOACHIM GRAMMIG, VINCENT GRÉGOIRE, UFUK GÜÇBILMEZ, BJÖRN HAGSTRÖMER, JULIEN HAMBUCKERS, ERIK HAPNES, JEFFREY H. HARRIS, LAWRENCE HARRIS, SIMON HARTMANN, JEAN-BAPTISTE HASSE, NIKOLAUS HAUTSCH, XUE-ZHONG (TONY) HE, DAVIDSON HEATH, SIMON HEDIGER, TERRENCE HENDERSHOTT, ANN MARIE HIBBERT, ERIK HJALMARSSON, SETH A. HOELSCHER, PETER HOFFMANN, CRAIG W. HOLDEN, ALEX R. HORENSTEIN, WENQIAN HUANG, DA HUANG, CHRISTOPHE HURLIN, KONRAD ILCZUK, ALEXEY IVASHCHENKO, SUBRAMANIAN R. IYER, HOSSEIN JAHANSHAHLOO, NAJI JALKH, CHARLES M. JONES, SIMON JURKATIS, PETRI JYLHÄ, ANDREAS T. KAECK, GABRIEL KAISER, ARZÉ KARAM, EGLE KARMAZIENE, BERNHARD KASSNER, MARKKU KAUSTIA, EKATERINA KAZAK, FEARGHAL KEARNEY, VINCENT VAN KERVEL, SAAD A. KHAN, MARTA K. KHOMYN, TONY KLEIN, OLGA KLEIN, ALEXANDER KLOS, MICHAEL KOETTER, ALEKSEY KOLOKOLOV, ROBERT A. KORAJCZYK, ROMAN KOZHAN, JAN P. KRAHNEN, PAUL KUHLE, AMY KWAN, QUENTIN LAJAUNIE, F. Y. ERIC C. 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SARAH ZHANG, XIAOYU ZHANG, LU ZHAO, ZHUO ZHONG, Z. IVY ZHOU, CHEN ZHOU, XINGYU S. ZHU, MARIUS ZOICAN, REMCO ZWINKELS ... See fewer authors

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Multi-analyst studies ➔ multiverse analysis, though the two are different:

	Multi-Analyst Study	Multiverse Analysis
Unit of variation	Different analysts	Different analytic specifications
Source of variability	Human judgment	Enumerated decision space
Structure	Decentralized	Systematic grid
Scalability	Limited by analyst pool	Limited by comput. Complexity
Epistemic target	Researcher heterogeneity	Specification robustness

➔ **Multi-analyst studies** examine social epistemology — how scientific communities generate variability.

➔ **Multiverse analyses** examine statistical robustness — how conclusions depend on modelling choices.

Tools for multiverse analysis are being developed (2025)

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The Systematic Multiverse Analysis Registration Tool for defining multiverse analyses

Cassie Ann Short; Yusuf Coşku Inceler; Maximilian Frank; Andrea Hildebrandt

+ Author & article information

R Soc Open Sci. (2025) 12 (10): 250800 .

https://doi.org/10.1098/rsos.250800 **Article history**

Defining the multiverse (Simonsohn et al. 2020)

A systematic approach to handling:

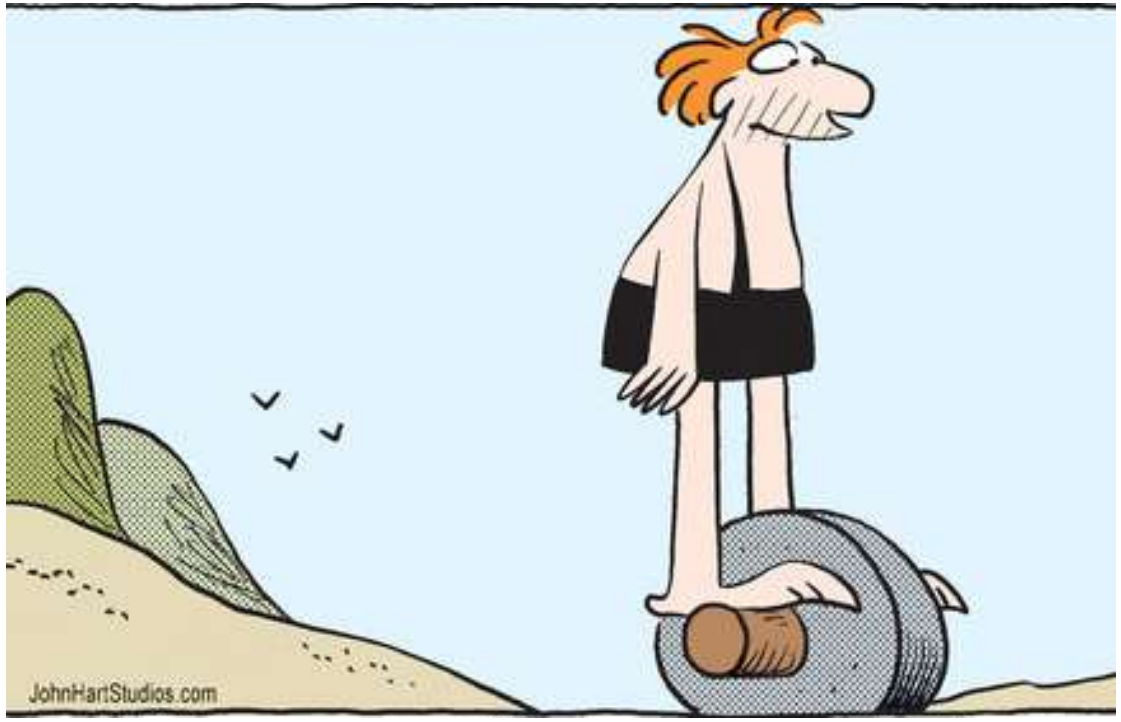
- Researchers' degrees of freedom
- Analytic flexibility
- Model specification choice

https://www.istockphoto.com/

Simonsohn, Uri, Joseph P. Simmons, and Leif D. Nelson. 2020. "Specification Curve Analysis." Nature Human Behaviour 4 (11): 1208–14.

Are different words being used for the same thing?

The Tower of Babel by Pieter Bruegel the Elder (1563). Source: Wikipedia Commons



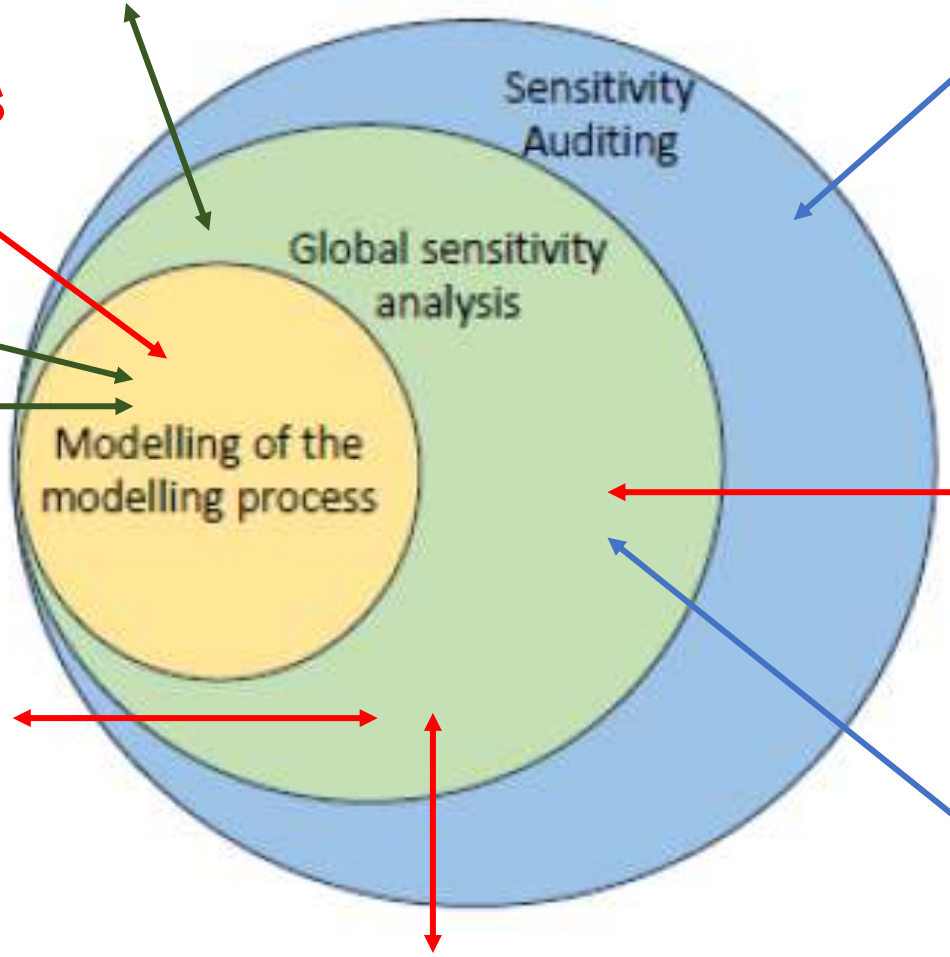
BC, comic strip by cartoonist Johnny Hart

Or is a wheel rediscovered

Leamer's 'Con' and Tantalus papers (1983–2010)

Normative quality

Multiverse analysis



Rodrik's 'Economic Rules' book (2016)

Breiman's 'Two cultures' paper (2001)

Robustness Analysis

Levins' robustness paper 1966

Perturbed Physics Ensemble

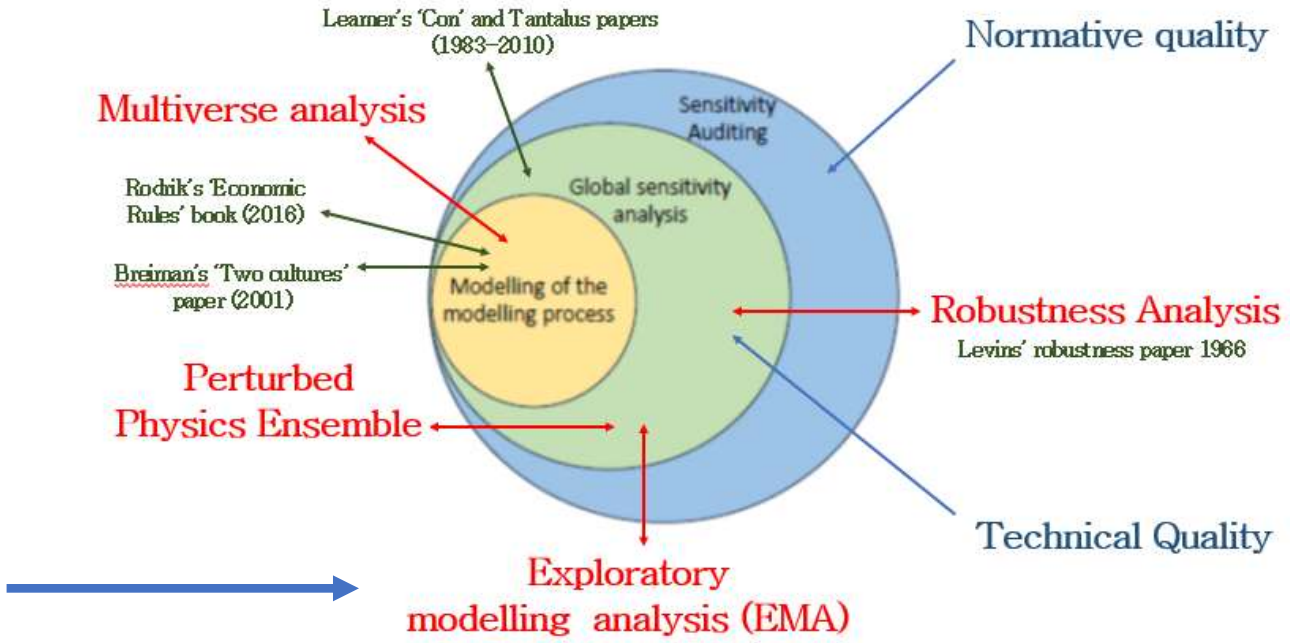
Technical Quality

Exploratory modelling analysis (EMA)

Exploratory modelling analysis (RAND corporation)

Explore scenarios[*] and simulate

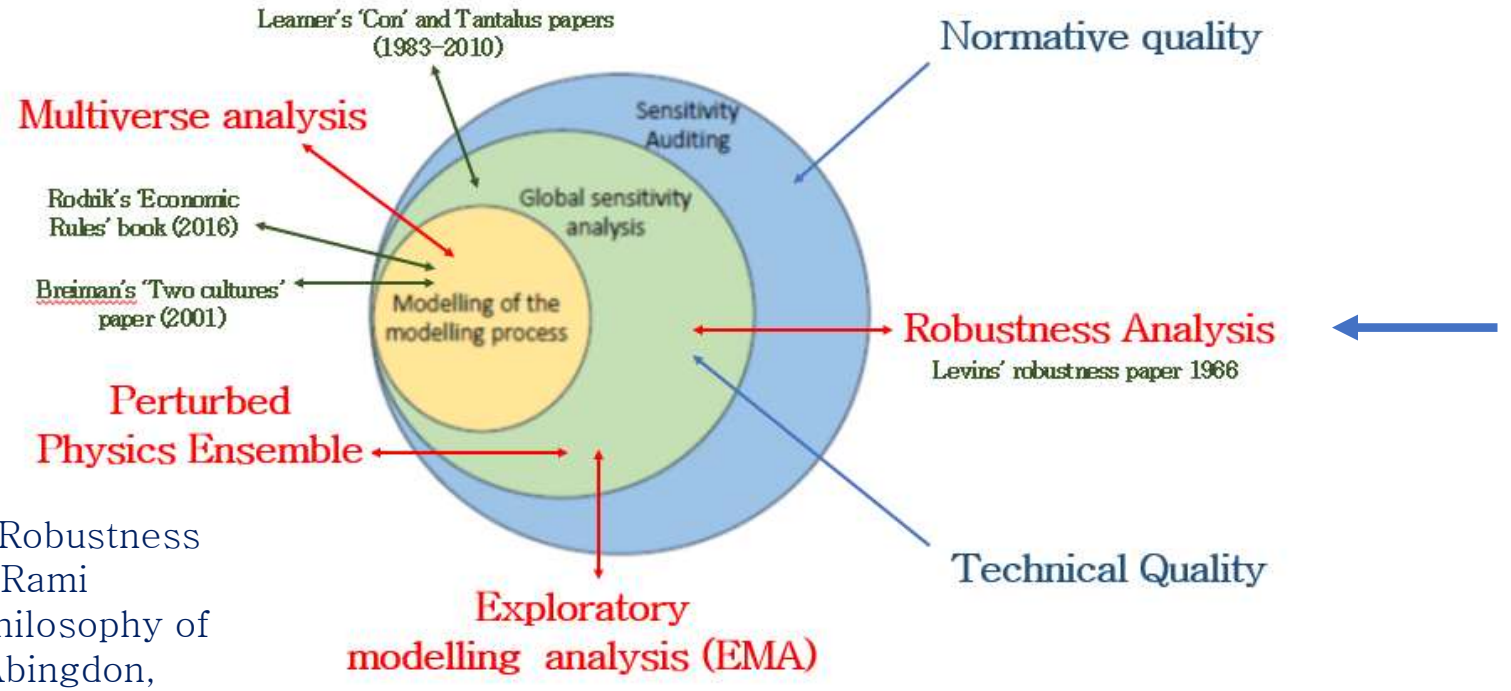
[*] (Too) liberally



Jan H. Kwakkel and Erik Pruyt. Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. Technological Forecasting and Social Change, 80(3):419–431, March 2013.

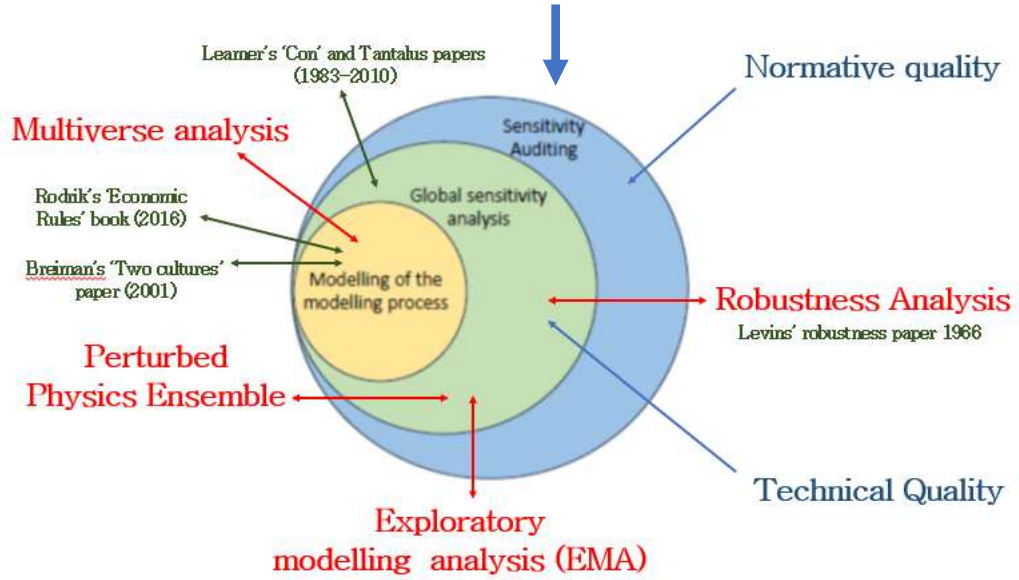
Robustness analysis (Houkes et al., 2024)

parameter RA ➔ dependence on model parameters
structural RA ➔ dependence on structural assumption
representational RA ➔ model philosophy, e.g., moving from a math / differential equations to agent-based modelling



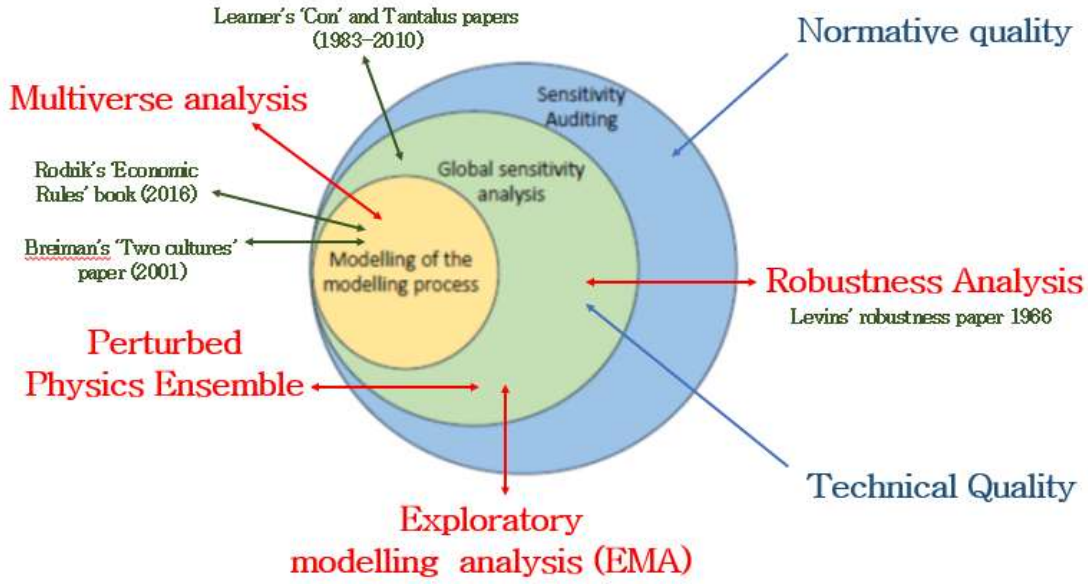
Wybo Houkes, Dunja Šešelja, and Krist Vaesen. Robustness Analysis. In Tarja Knuuttila, Natalia Carrillo, and Rami Koskinen, editors, The Routledge Handbook of Philosophy of Scientific Modeling, pages 195–207. Routledge, Abingdon, Oxon ; New York, NY, 2024.

Sensitivity auditing: "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" (European Commission, 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

Perturbed parameter (or physics) ensemble: same as uncertainty quantification and sensitivity analysis when done by physicists in climate modelling

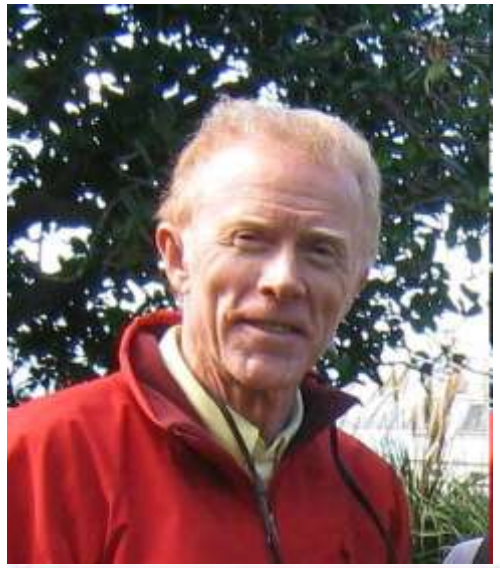


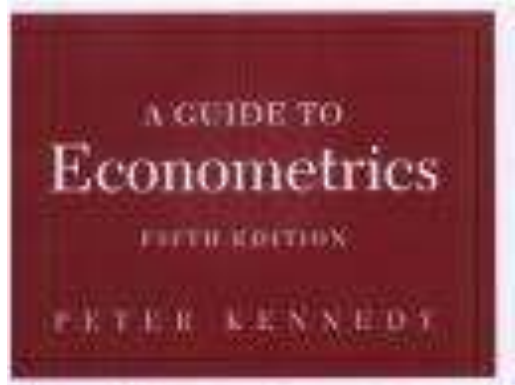
John W. Rostron, David M. H. Sexton, Carol F. McSweeney, Kuniko Yamazaki, Timothy Andrews, Kalli Furtado, Mark A. Ringer, and Yoko Tsushima. The impact of performance filtering on climate feedbacks in a perturbed parameter ensemble. Climate Dynamics, 55(3):521–551, August 2020. doi:10.1007/s00382-020-05281-8

What is global sensitivity analysis

Peter Kennedy, A Guide to Econometrics. Anticipating criticism by applying sensitivity analysis. This is 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 >>





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

Charles A.S. Hall

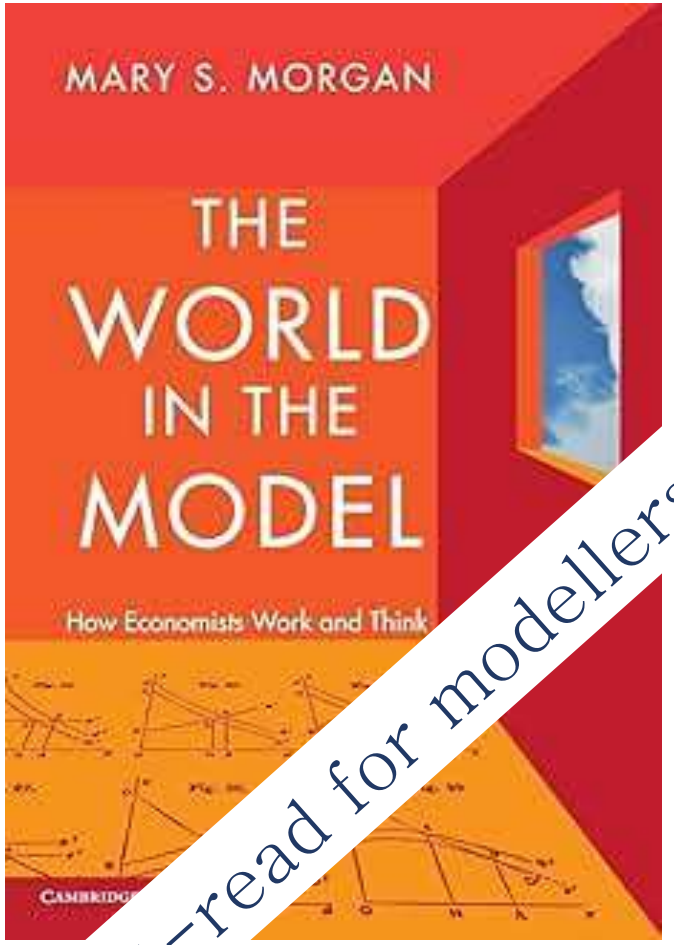
Hall, C. A. S. (2020). Systems Ecology and Limits to Growth: History, Models, and Present Status. In G. S. Metcalf, K. Kijima, & H. Deguchi, eds., *Handbook of Systems Sciences*, Singapore: Springer, , pp. 1–38.

Mary S. Morgan

Hall's words resonate with Mary Morgan's 'the world in the model'

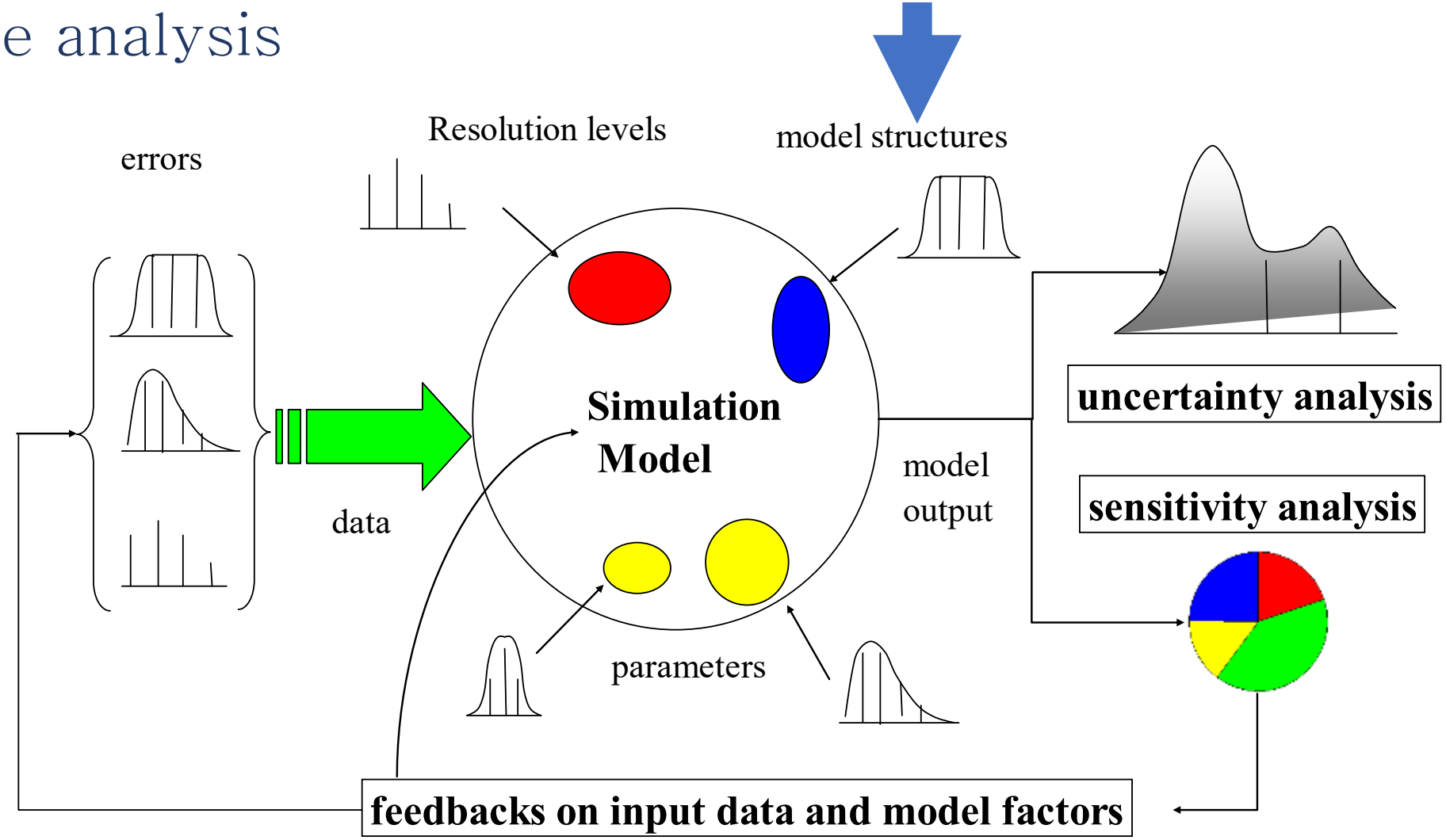
Playing with a model's moving parts to see what this gives, before seeing if it chimes with 'the model in the world'

Nothing to do with SA, at least explicitly!



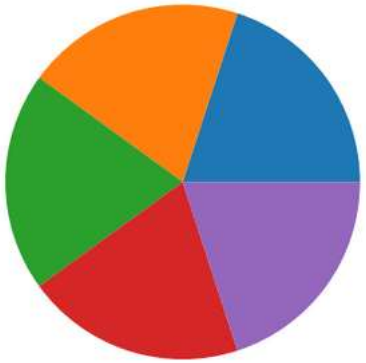
A must-read for modellers

When sampling modelling choices via 'triggers', global sensitivity analysis becomes a modelling of the modelling process = multiverse analysis



Example of using triggers: an integer in [1-5] is used to select one out of 5 possible evapotranspiration formulae at each model run

Trigger=an integer variable, whose value is determined via 'Russian roulette' in Monte Carlo jargon



nature communications

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The delusive accuracy of global irrigation water withdrawal estimates

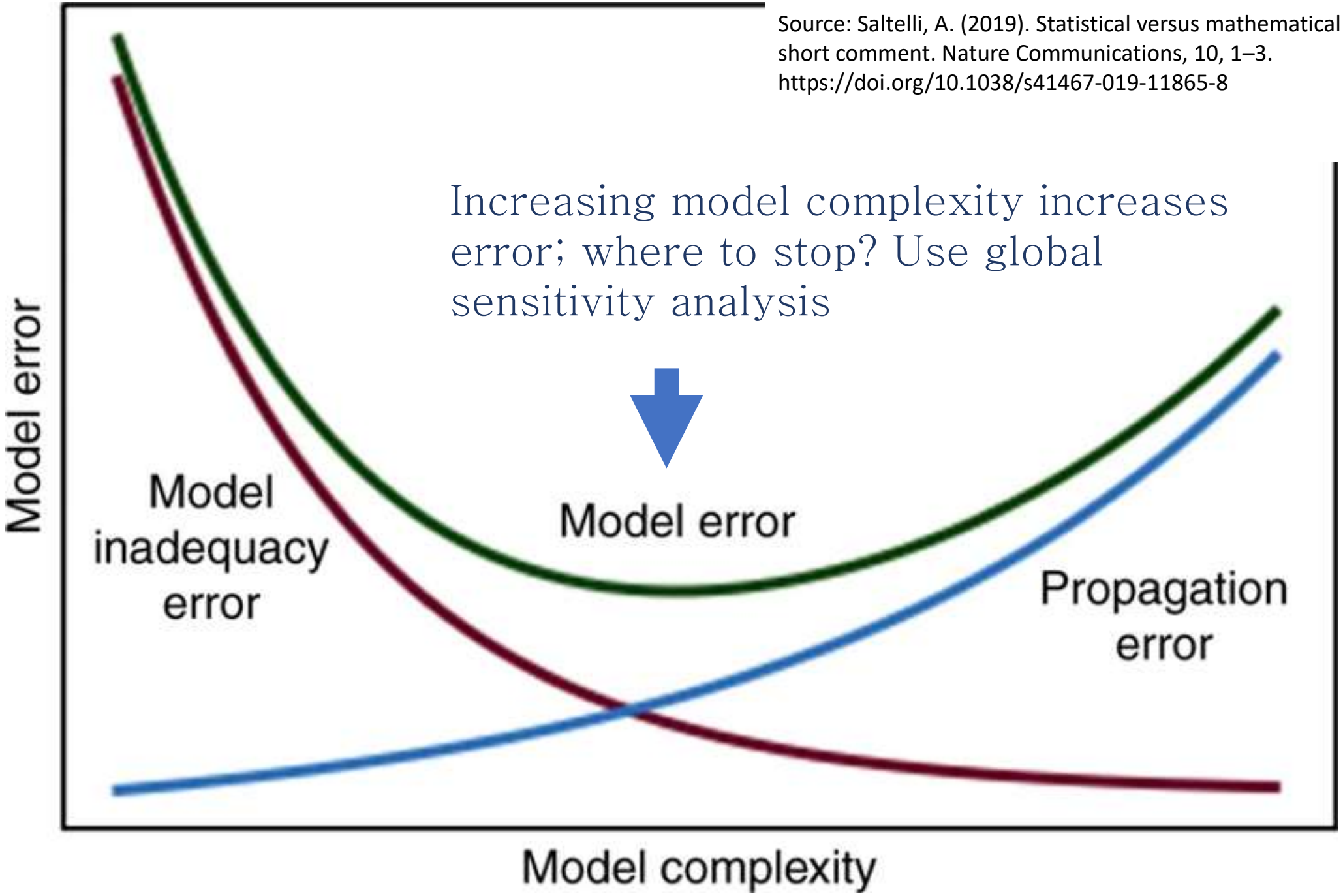
Arnald Puy ✉, Razi Sheikholeslami, Hoshin V. Gupta, Jim W. Hall, Bruce Lankford, Samuele Lo Piano, Jonas Meier, Florian Pappenberger, Amilcare Porporato, Giulia Vico & Andrea Saltelli

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

10k Accesses | **79** Citations | **93** Altmetric | Metrics

Russian roulette as depicted in the 1925 film The Night Club. Source: Wikipedia Commons

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



Back to the garden, multi-analyst studies and multiverse

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*

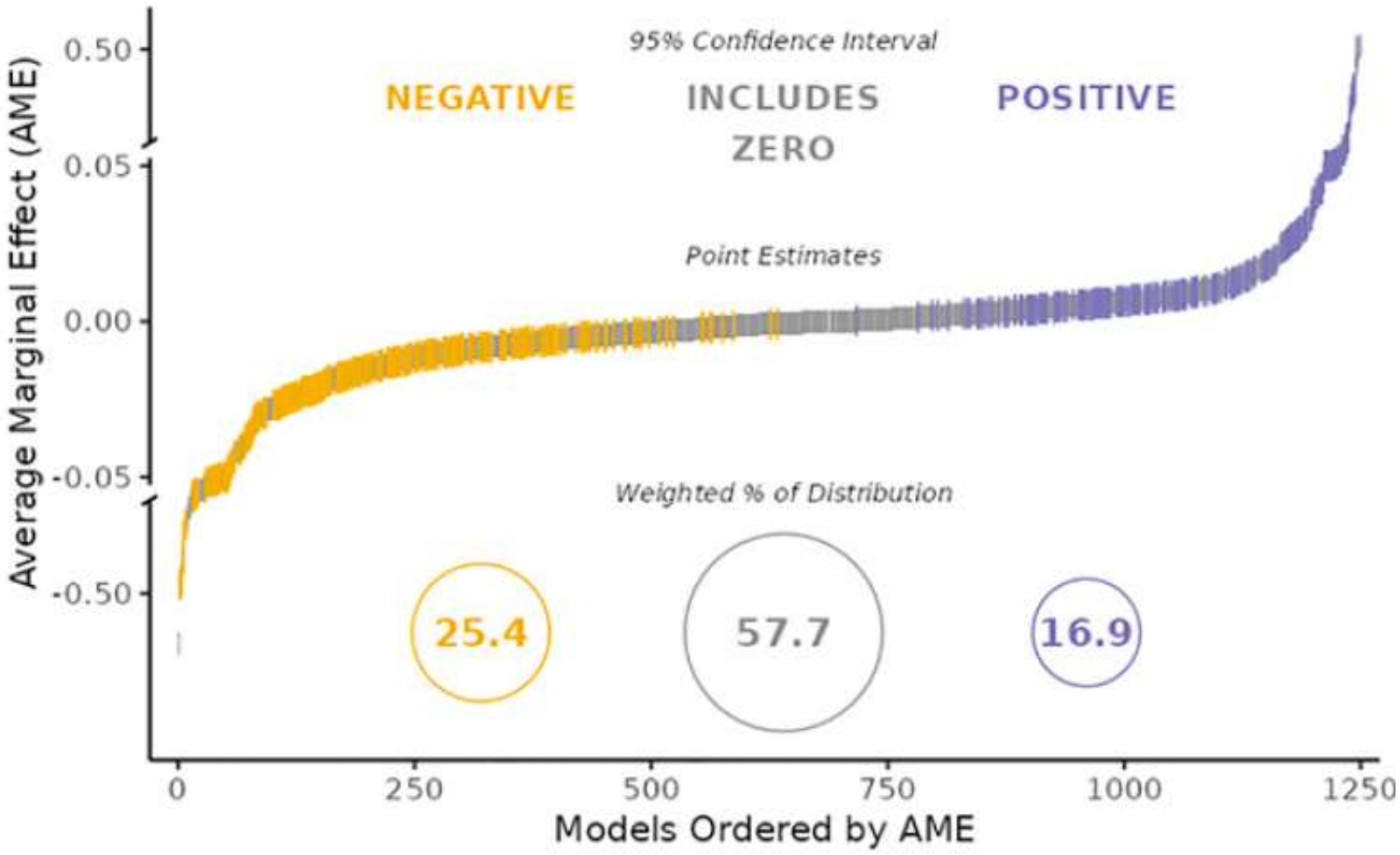
Andrew Gelman† and Eric Loken‡

14 Nov 2013

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 analysing the same data?

…teams' results varied greatly, ranging from large negative to large positive effects"

PNAS RESEARCH ARTICLE | SOCIAL SCIENCES OPEN

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

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

In the PNAS multi-analyst study the normative (political) orientation of the analysts was found **not** to explain much of the variance

The modelling variables themselves were found to explain at most a few percent of the variance of the results … **where does the variance come from?**

https://www.istockphoto.com/

A new analysis from the GSA and multiverse communities

Leamer Reloaded: A Long-Neglected Suggestion Is Rediscovered To Apply Global Sensitivity Analysis To A Quantification Before Publishing It

Andrea Saltelli[*1,2], Alessio Lachi[3,4], Arnald Puy[5], and Nate Breznau[6]

https://osf.io/preprints/metaarxiv/sq34n_v1

[1]University Pompeu Fabra - Barcelona School of Management (UPF-BSM), Barcelona, Carrer de Balmes 132-134, Barcelona, 08008, Spain
[2]Centre for the Study of the Sciences and the Humanities, University of Bergen, Parkveien 9, PB 7805, Bergen, 5020, Norway
[3]Saint Camillus International University of Health and Medical Sciences (UniCamillus), Via Sant'Alessandro 8, Rome, 00131, Italy
[4]Department of Statistics, Computer Science, Applications "Giuseppe Parenti" (DiSIA), University of Florence, Viale Giovanni Battista Morgagni 59, Florence, 50134, Italy
[5]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, United Kingdom
[6]German Institute for Adult Education/Leibniz Center for Lifelong Learning, Heinemannstraße 12-14, 53175 Bonn, Germany

k_i	Variable	Description
1	*age*	Inclusion or non-inclusion of the covariates age and square age of participants
2	*all − ethnic*	Inclusion or non-inclusion of a covariate that takes into account all ethnic categories
3	*bootstrap*	Inclusion or non-inclusion of the bootstrap procedure
4	*cont − europe*	Inclusion or non-inclusion of continental Europe countries in the analysis
9	*income*	Inclusion or non-inclusion of the covariate related to the income
10	*pop − wb*	Inclusion or non-inclusion of the covariate related to the information about country-specific numerosity of population
11	*rich − dems*	Inclusion or non-inclusion of rich democracies in the analysis
12	*SE*	Inclusion or non-inclusion of clustered standard error
13	*socx − oecd*	Inclusion or non-inclusion of the covariate related to social expenditure
14	*X*1	Inclusion or non-inclusion of the covariates related to the migration indexes
15	*Y*	Choice of policy dependent variable

3 *bootstrap* Inclusion or non-inclusion of the bootstrap procedure
4 *cont − europe* Inclusion or non-inclusion of continental Europe countries in the analysis

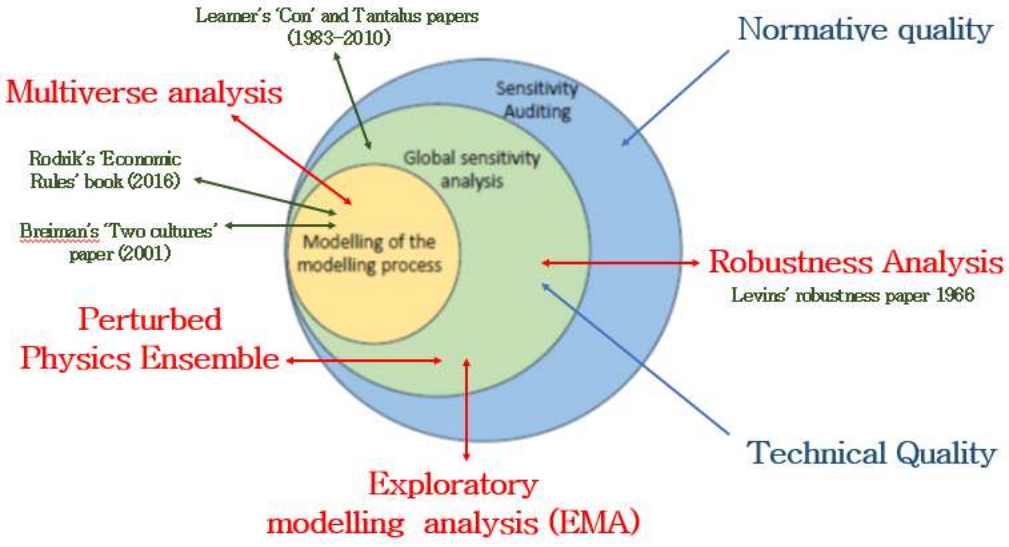
Table 1. Descriptions of variables included in the analysis.

We simulate different paths using triggers, then we do a global sensitivity analysis

https://www.istockphoto.com/

We simulate different paths using triggers, then we do a global sensitivity analysis

In other words: a multiverse analysis



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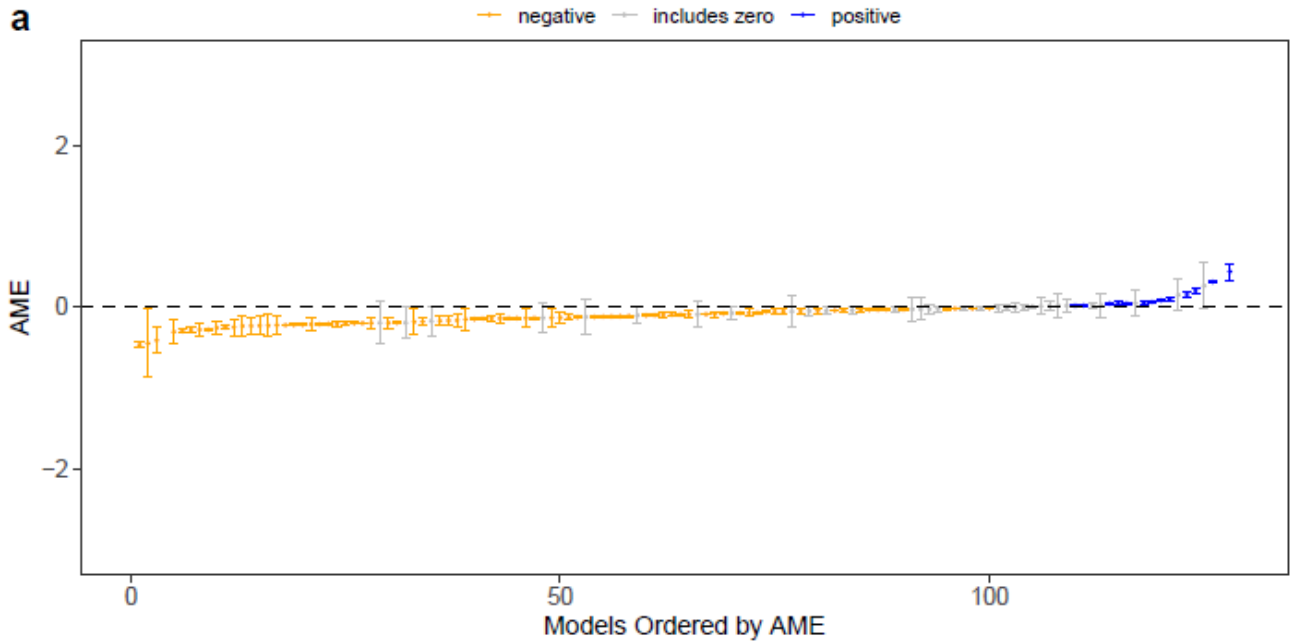
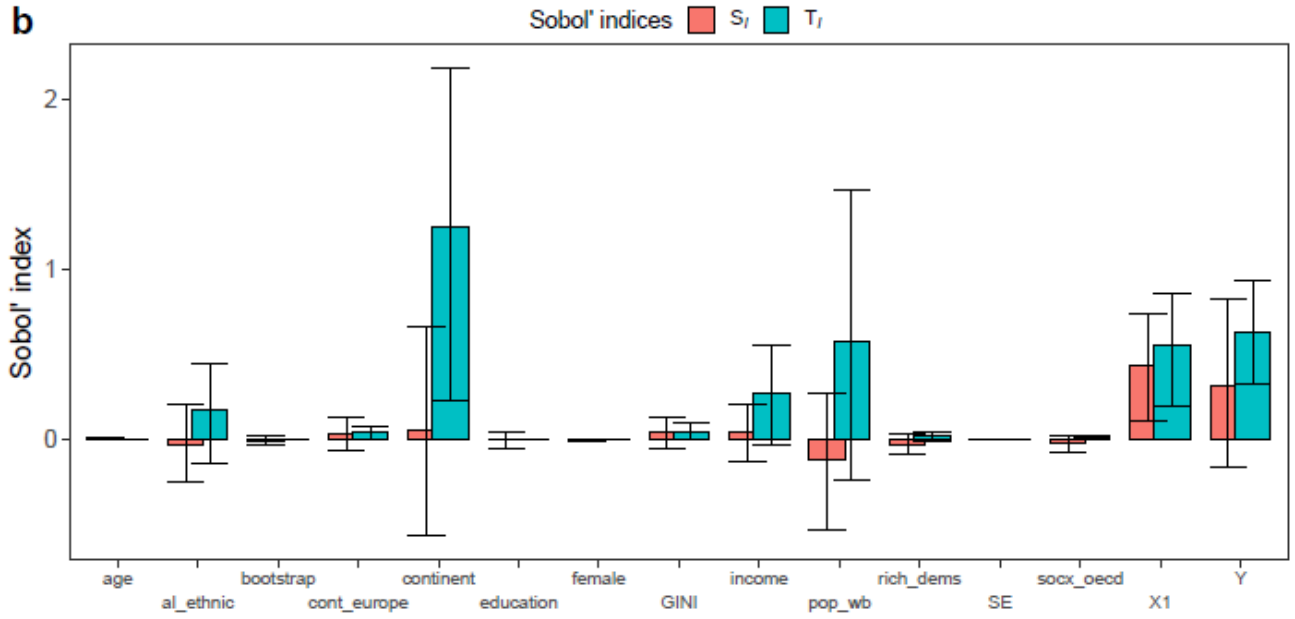
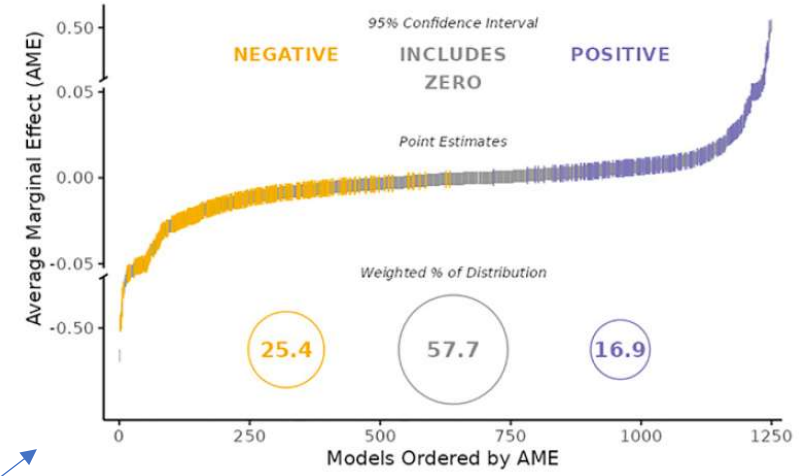


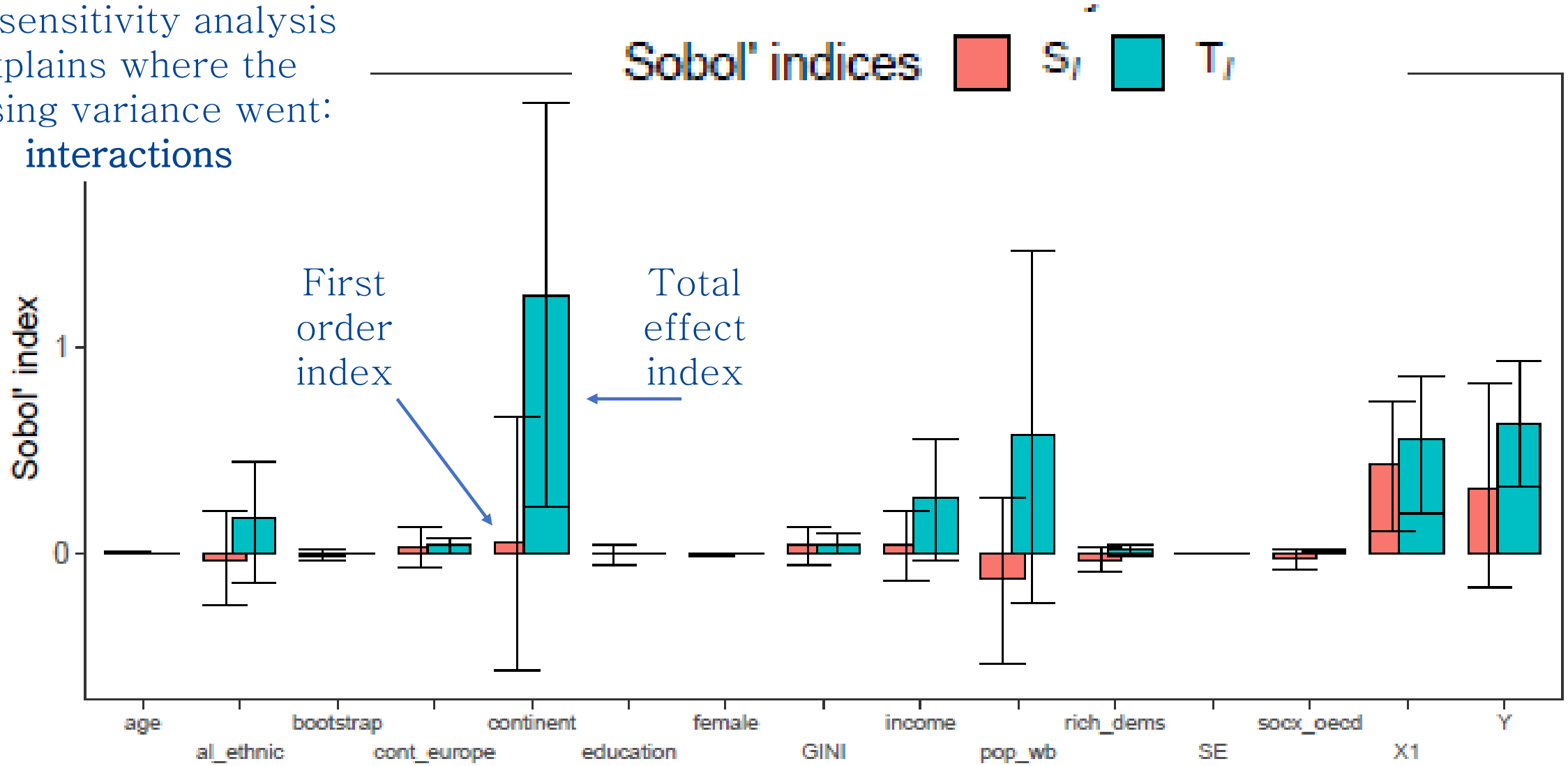


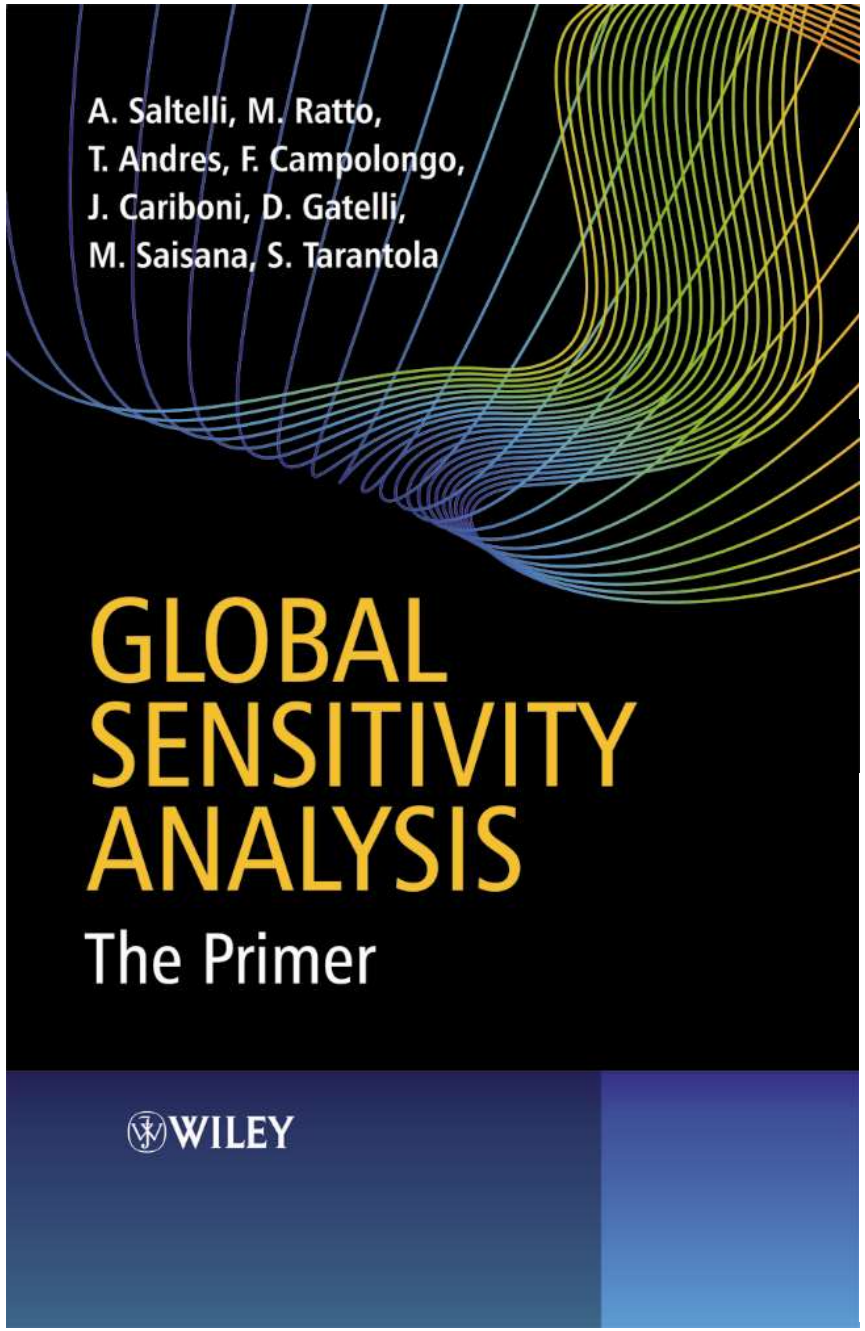


Uncertainty analysis broadly reproduces the results of the multi-analyst experiment

Our sensitivity analysis explains where the missing variance went: **interactions**

Our sensitivity analysis explains where the missing variance went: **interactions**





All about variance-based sensitivity analysis and Sobol indices

(available online)

1.6 EXERCISES

1. Prove that

$$V(Y) = E(Y^2) - E^2(Y).$$

2. Prove that for an additive model of two independent variables X_1 and X_2, fixing one variable can only decrease the variance of the model.

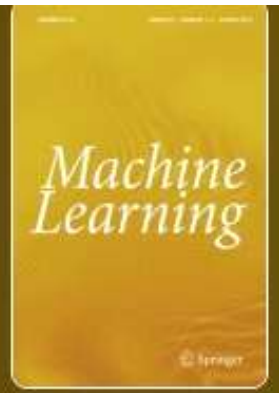
For users of machine leaning: SA to ascertain that an algorithm does not make implicit use of protected attributes

Home > Machine Learning > Article

Fairness seen as global sensitivity analysis

Published: 24 June 2022

Volume 113, pages 3205–3232, (2024) Cite this article



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Clément Bénesse, Fabrice Gamboa, Jean-Michel Loubes & Thibaut Boissin

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Bénesse, C., Gamboa, F., Loubes, J.-M., & Boissin, T. (2022). Fairness seen as Global Sensitivity Analysis. *Machine Learning*. https://doi.org/10.1007/s10994-022-06202-y

The End

Andrea Saltelli

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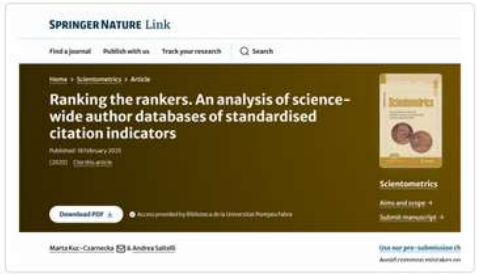


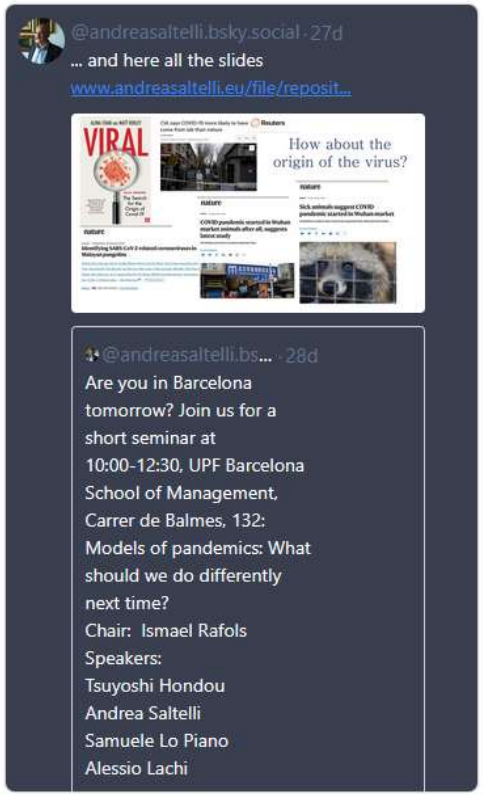
Models and the common good

A short analysis of norms and counter-norms in modelling, discussing how models may misuse their epistemic authority for reasons of occasion, opportunity and interest.

Outline:
Narratives and counter-narratives,
State of exception,
Seeking Cinderella,
Reformation

Ranking the Rankers

Ranking the Rankers? We investigate using global sensitivity analysis the properties of the science-wide author databases' standardised citation indicators produced since 2015 by a team of researchers led by John P. A. Ioannidis.

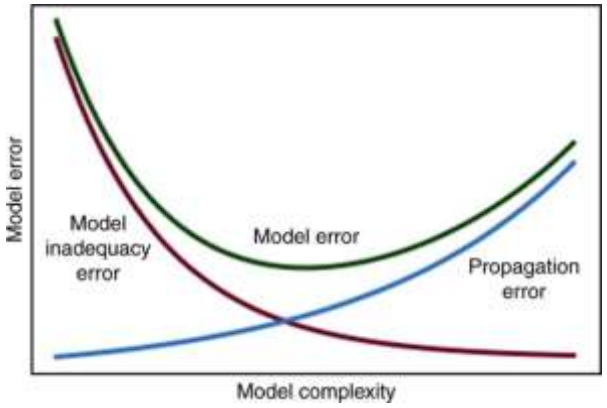


www.andreasaltelli.eu

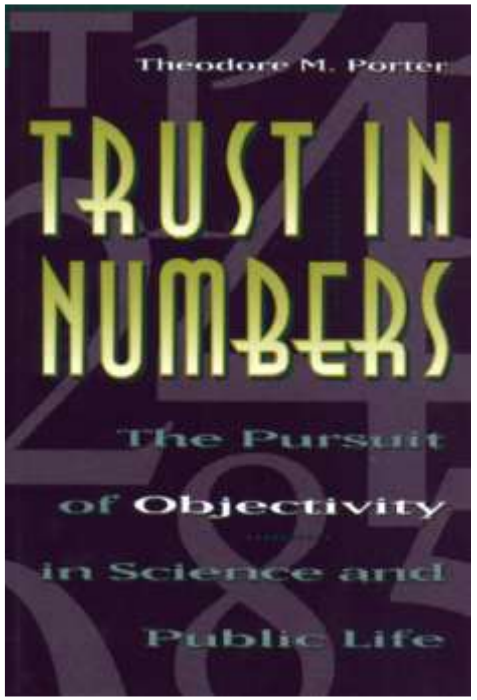
Sensitivity analysis and auditing can assist sociology of quantification in activities of de- and re-construction (e.g. for statactivists)

Modelling of the modelling process, to

➔ retrace what was assumed
➔ check the level of complexity
…



Some model generated number are ‘funny’



Porter, Theodore M.: ‘Funny Numbers’, *Culture Unbound*, Volume 4, 2012: 585-598. Hosted by Linköping University Electronic Press: http://www.cultureunbound.ep.liu.se

WIREs CLIMATE CHANGE

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Bring digital twins back to Earth

Andrea Saltelli, Gerd Gigerenzer, Mike Hulme, Konstantinos V. Katsikopoulos, Lieke A. Melsen, Glen P. Peters, Roger Pielke Jr, Simon Robertson ... See all authors

First published: 26 August 2024 | https://doi.org/10.1002/wcc.915

Edited by Matthias Heymann, Domain Editor and Maria Carmen Lemos, Editor-in-Chief