Global sensitivity analysis for policy impact assessment

Andrea Saltelli

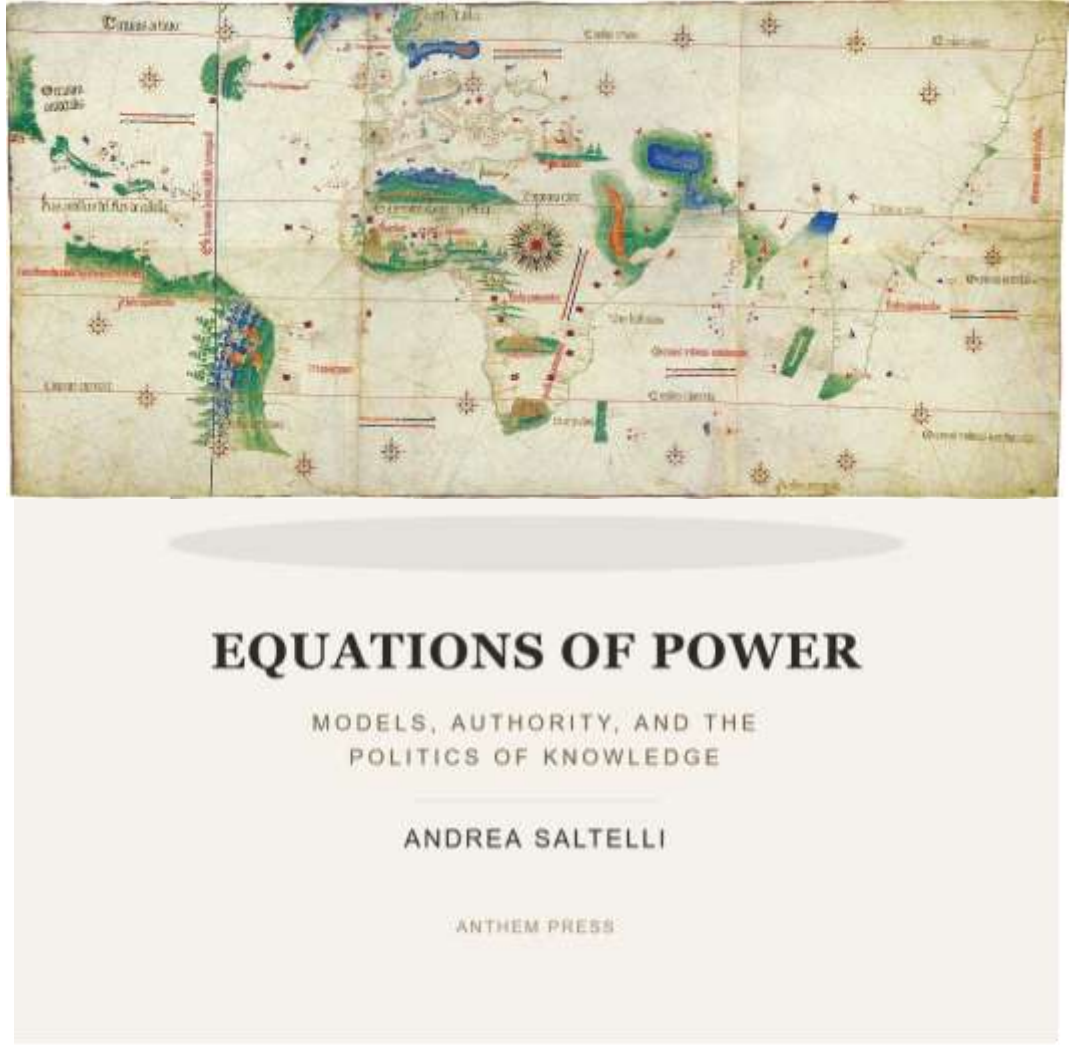
June 9, 2026, European University Institute, Fiesole

Scientific Organiser(s):

Gaby Umbach (European University Institute)

Mira Manini Tiwari (European University Institute)

2023



2026

Based on: Equations of Power: Models, Authority, and the Politics of Knowledge (Anthem Press, 2026)

…models should not be seen primarily as predictive tools, but as instruments for exploring how assumptions and uncertainties shape conclusions.

PART I — THE MISSING DIMENSION

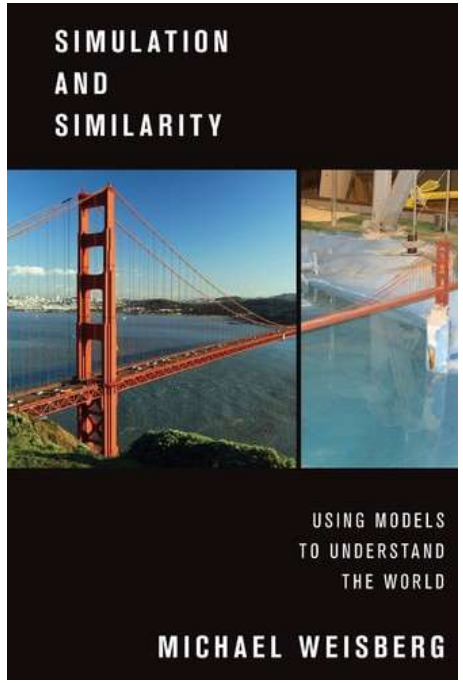
A philosopher's take

STRUCTURE
Three possibilities:
1. concrete,
2. mathematical,
3. computational

—MODEL DESCRIPTION —

THE WORLD
(target system)

CONSTRUAL
1. assignment,
2. scope,
3. dynamical fidelity,
4. representational fidelity

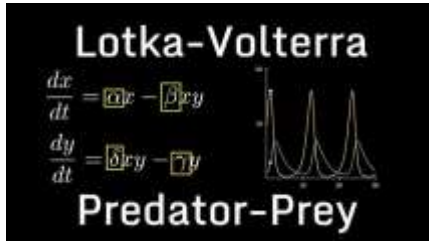


A philosopher's take

STRUCTURE
Three possibilities:

1. Concrete, physical scale model of San Francisco Bay

2. Mathematical, Lotka-Volterra

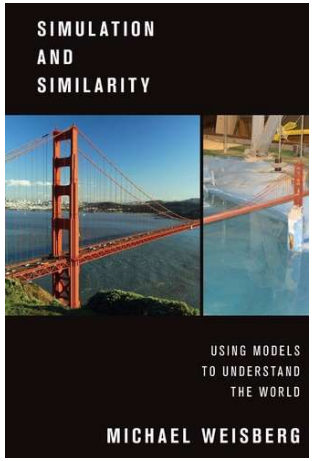


3. Computational, Schelling's segregation model

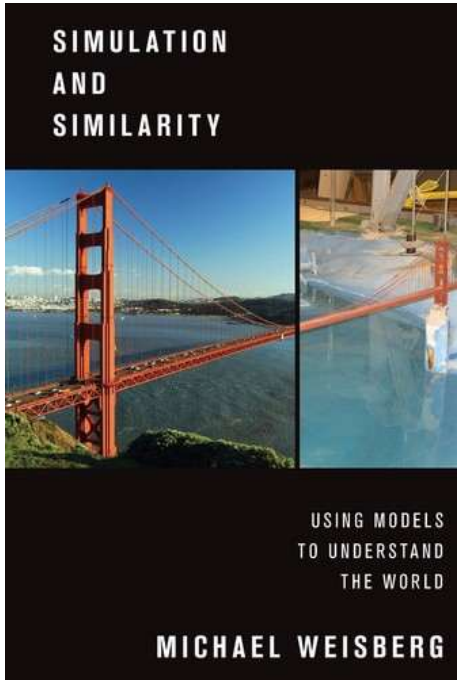
Dissatisfied because only 1/4 (25%) of neighbors are X

X	X	O	X	O
	O	O	O	O
X	X			
X	O	X	X	X
X	O	O		O

Source: http://nifty.stanford.edu/2014/mccown-schelling-model-segregation/



A philosopher's take



CONSTRUAL

x = Adriatic sardine population ← 1. assignment,

Small pelagic species under moderate exploitation regimes ← 2. scope,

Does it predict well? ← 3. dynamical fidelity,

Does it predict well for the right reasons? ← 4. representational fidelity

A philosopher's take

CONSTRUAL

x = Adriatic sardine population	← 1.	assignment,
Small pelagic species under moderate exploitation regimes	← 2.	scope,
Does it predict well?	← 3.	dynamical fidelity,
Does it predict well for the right reason?	← 4.	representational fidelity

What the construal does not include: a model's telos

A model commissioned by a large industrial conglomerate will differ from one produced by a local fisherman organisation

A philosopher's take

	CONSTRUAL
x = Adriatic sardine population	← 1. assignment,
Small pelagic species under moderate exploitation regimes	← 2. scope,
Does it predict well?	← 3. dynamical fidelity,
Does it predict well for the right reason?	← 4. representational fidelity

What the construal does not include: a model's telos

Dissatisfied because only 1/4 (25%) of neighbors are X

X	X	O	X	O
	O	O	O	O
X	X			
X	O	X	X	X
X	O	O		O

Source: http://nifty.stanford.edu/2014/mccown-schelling-model-segregation/

Schelling segregation: an agent moves if fewer than a third of its neighbours are of the same type. The construal is silent on redlining, restrictive covenants, racially selective mortgage lending …

CONSTRUAL

1. Assignment → Sign
2. Scope → Object
3. ? ← Interpretant

Construal versus Charles Sanders Peirce's triadic conception of the sign as structure connecting three elements

- the sign / *representamen*
- an object
- an "interpretant

Elements for a comprehensive assessment of public indicators

Paul-Marie Boulanger

2014

Editor: Andrea Saltelli

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC92162/lbna26921enn.pdf

Sign ⟷ Cry

The African vervet monkey (Cercopithecus aethiops) can distinguish with its cry the nature of the predator: aerial (eagle), terrestrial (leopard), ground (snake)

Object ⟷ Predator

Interpretant ⟷ Behaviour

↕

Telos

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC92162/lbna26921enn.pdf

Weisberg gives us the anatomy of a model. What it misses in its political physiology

PART II — MODELS IN POLICY

Models have migrated — from the margins of scientific practice to its epistemic and political core; the COVID and Climate cases

WIREs CLIMATE CHANGE

RMetS

Perspective | Open Access

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, Andy Stirling, Massimo Tavoni, Arnald Puy

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

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

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

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

LandlJarred the U.S. and the U.K. to Action - The New York Times. er, Mark, and Stephen Castle. 2020. Behind the Virus Report That

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Andrea Saltelli

Sections

Scientists have built a 'digital twin' of Earth to predict the future of climate change

The complex computer model takes into account weather and climate systems as well as our impact on the planet.

> DestinE is true game changer in our fight against climate change.
>
> *- Margrethe Vestager -*

Today, the future is literally at our fingertips

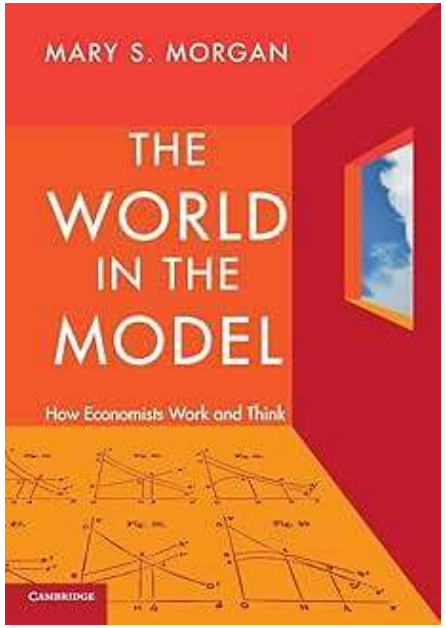
By Rosie Frost & Angela Symons

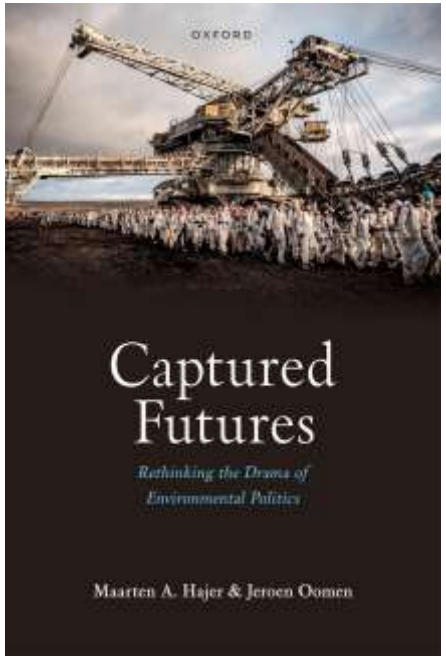
Published on 11/06/2024 - 16:00 GMT+2 • Updated 16:00

The political economy of models:

• their potentiality to colonise other worlds, starting from the world in the model (Morgan);

• their capacity of 'navigating the political', adapting their inference to an ongoing policy process, thus becoming agents in the process itself (Hajer and Oomen);





The political economy of models:

- their ability to act as chameleons, jumping from a context of investigation to one of prediction, and defending against criticism by reverting to 'this is just a study model' (Pfleiderer);

- their political influence being the higher, the more they can be presented as apolitical;

- their opportunity for bringing their topic to the forefront of attention via a process of problematisation (Callon), since they 'draw toward the centre' (Latour)

Source: National Geographic

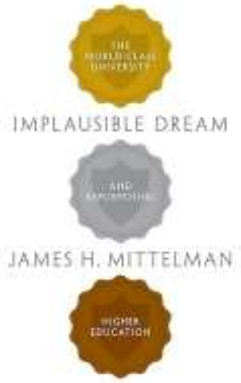
Pfleiderer, Paul. 2020. 'Chameleons: The Misuse of Theoretical Models in Finance and Economics'. Economica 87 (345): 81–107.

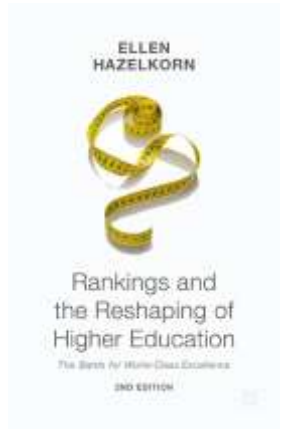
Michel Callon. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. The Sociological Review, 32(S1):196–233, 1984.

A model constitutes, not merely represents. It *does not describe X; it creates X as an object of political knowledge.*

Examples of X:

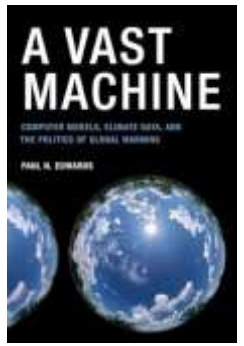
University rankings create higher education as a globalised enterprise

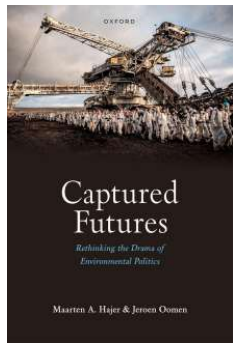


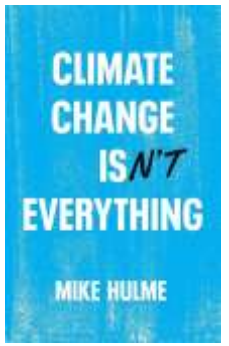


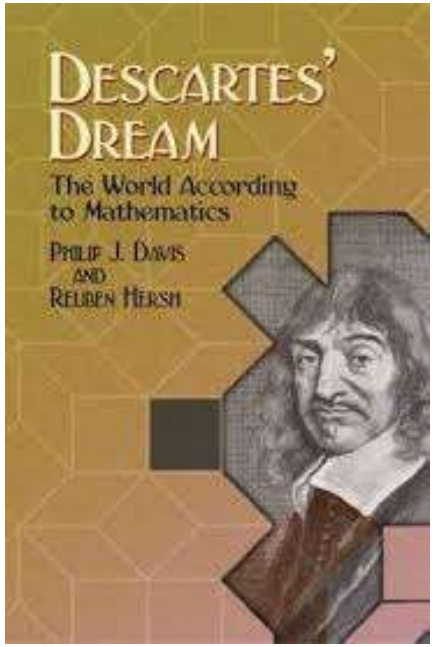
Pandemic models create the policies adopted to fight them

IAM creates global climate as we know it









Models derive epistemic authority from mathematics

Are less explored (by sociologists of quantification) than algorithms, AI or indicators

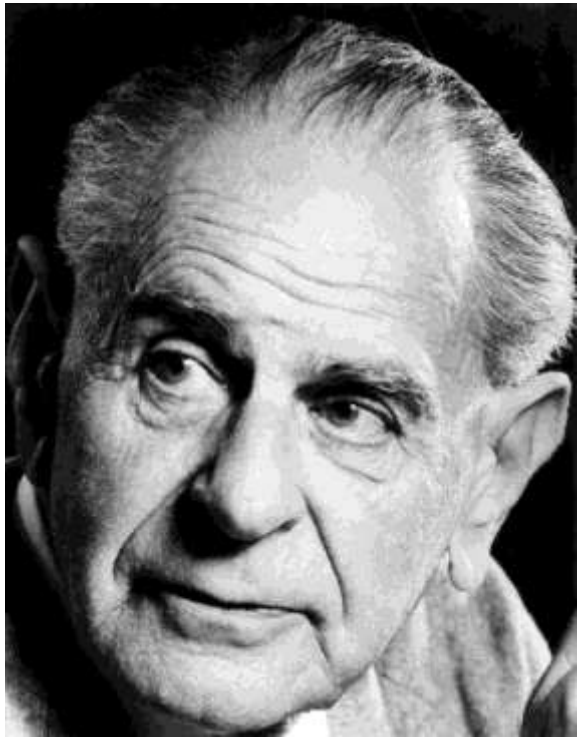
Resist falsification …

Models that take no risks

The empirical content of a theory is measured by the risks it takes — the observations that could prove it wrong (severe tests)

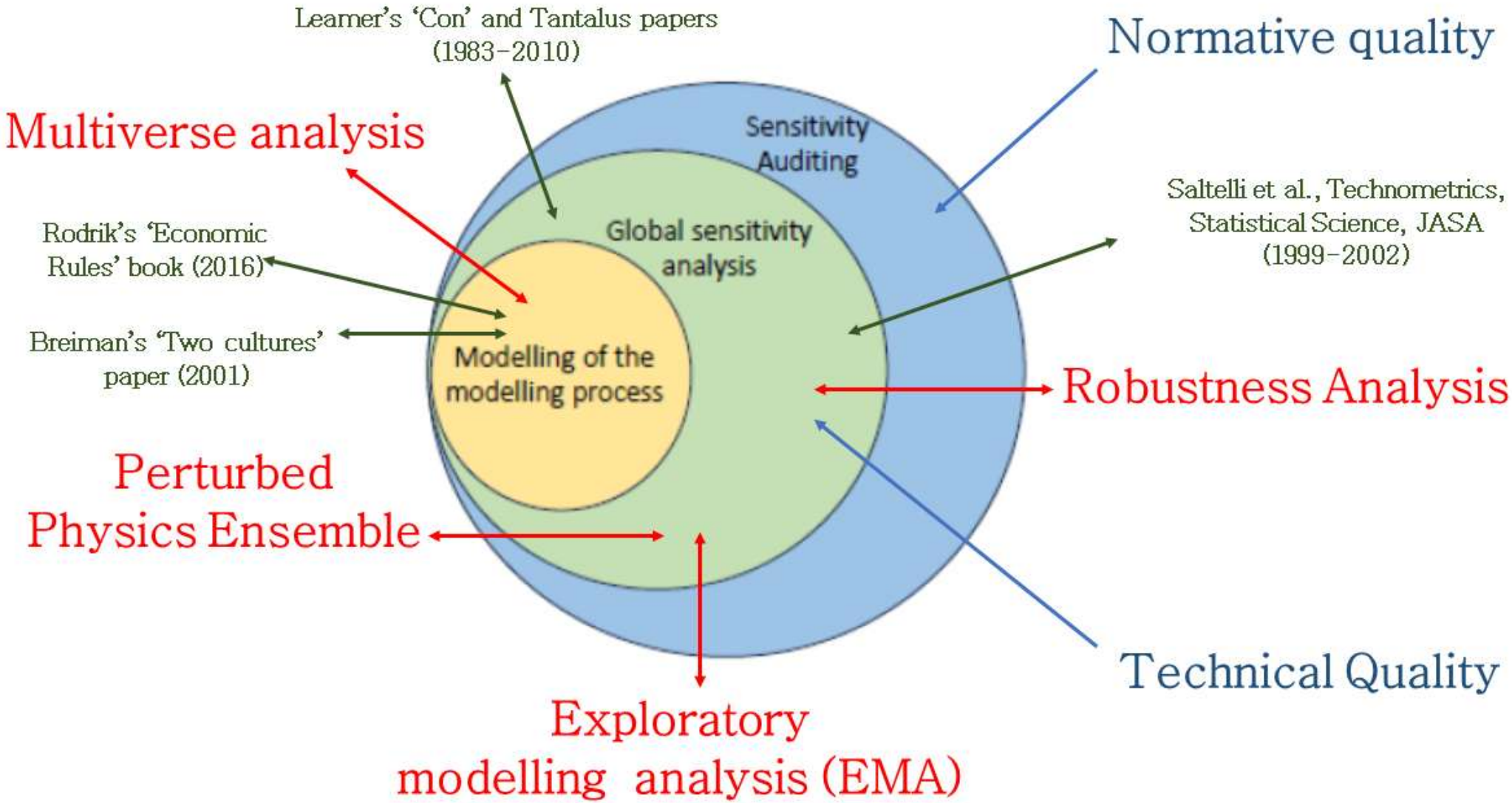
Climate models projecting the cost of CO2 to 2300.
Nuclear waste safety models covering a million years.
Digital twins simulating ecosystem dynamics with 50-year horizons

These models take no risks. No severe tests here



Karl Popper
(1902-1994)

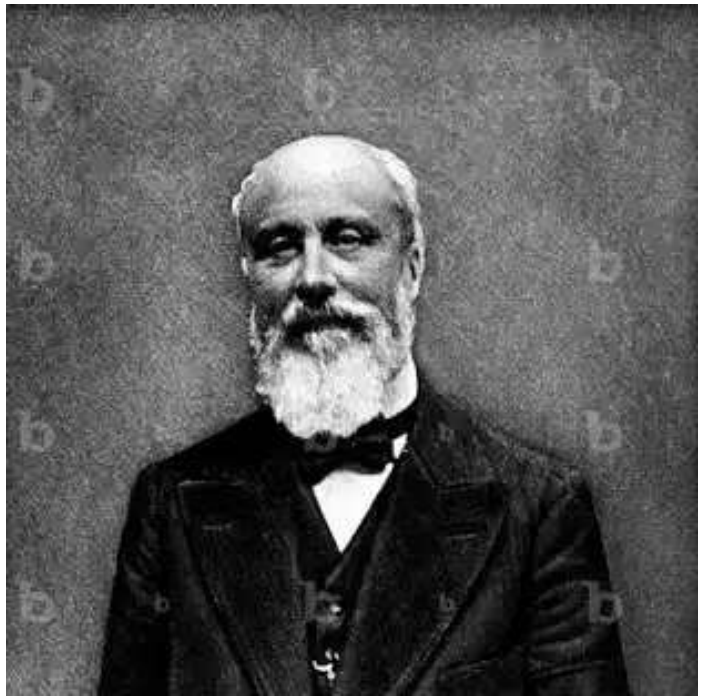
PART III — GLOBAL SENSITIVITY ANALYSIS


Learner's 'Con' and Tantalus papers (1983-2010)
Normative quality
Multiverse analysis
Sensitivity Auditing
Saltelli et al., Technometrics, Statistical Science, JASA (1999-2002)
Rodrik's 'Economic Rules' book (2016)
Global sensitivity analysis
Breiman's 'Two cultures' paper (2001)
Modelling of the modelling process
Robustness Analysis
Perturbed Physics Ensemble
Technical Quality
Exploratory modelling analysis (EMA)

Is GSA important? According to whom?

"… 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

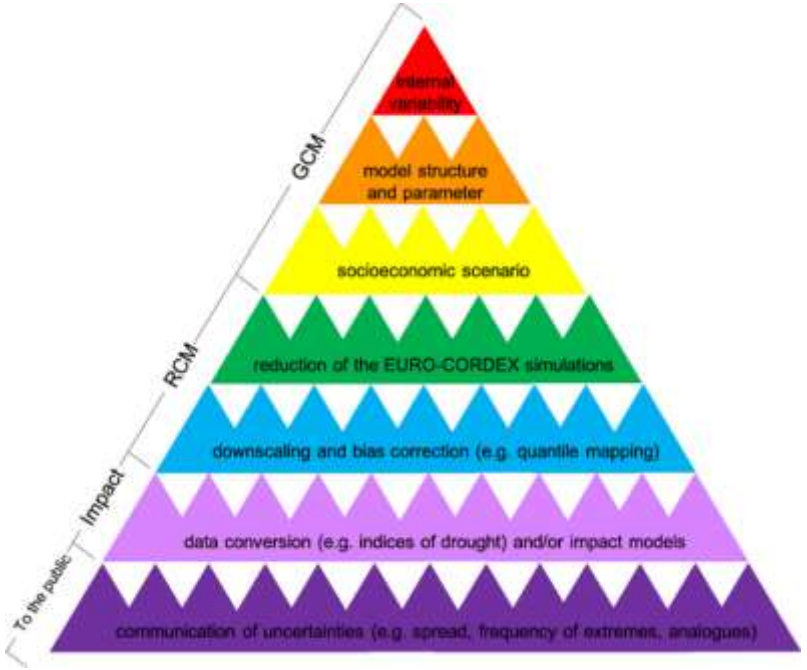


[1] See: S. C. Fletcher, 'The Principle of Stability', Philosopher's Imprint, vol. 20, no. 3, 2020, Accessed: Sep. 08, 2024. [Online].

Models are fragile

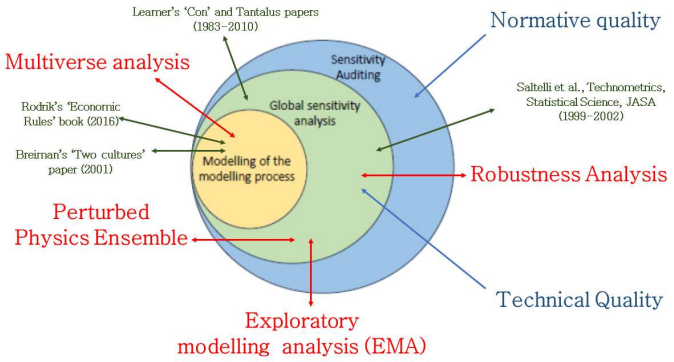
Duhem's principle of stability [1], links to the occurrence of either Butterfly [2] or Hawkmoth effects [3] … as well as to the accumulation of parametric error in a model, the so-called uncertainty cascade [4], that is the subject of global sensitivity analysis studies

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



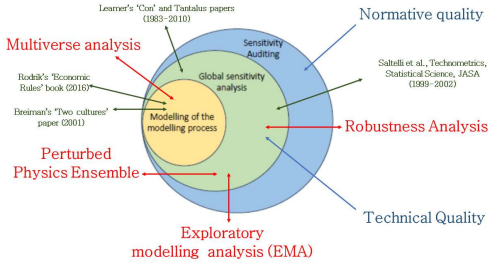
Edward E. Leamer

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

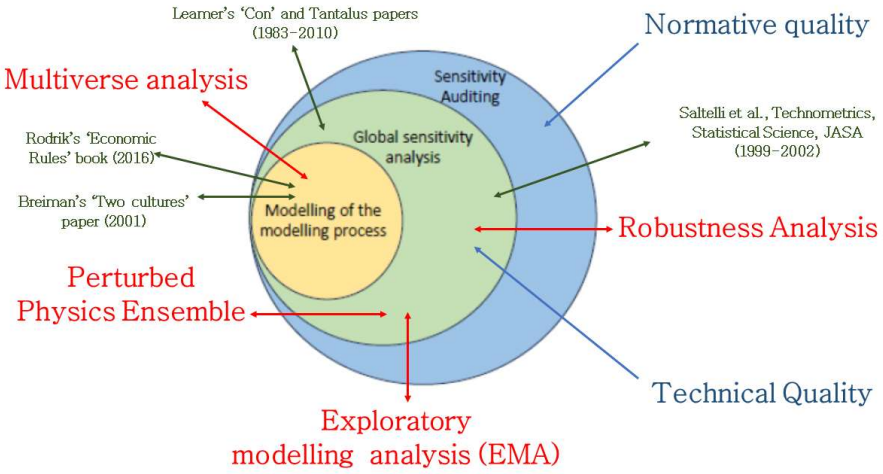
Tantalus on the Road to Asymptopia, Edward E. Leamer, **2010** *Journal of Economic Perspectives*, **24**, (2), 31–46.

27 years

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



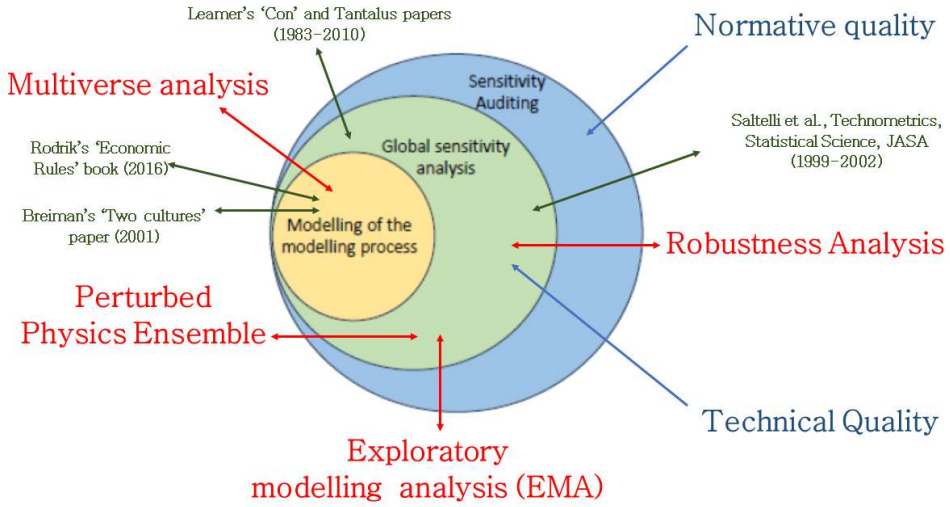
Perturbed parameter (or physics) ensemble: same as uncertainty quantification and sensitivity analysis when done by physicists in climate modelling



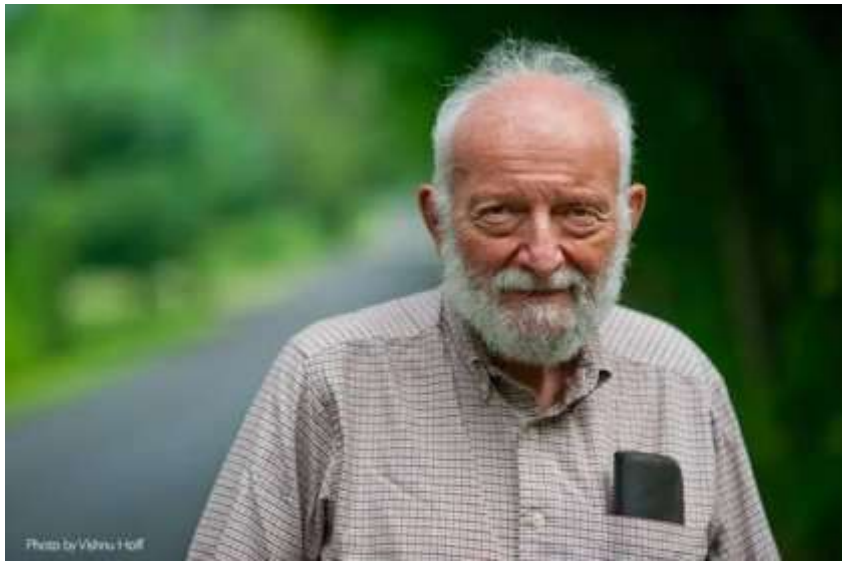
John W. Rostron, David M. H. Sexton, Carol F. McSweeney, Kuniko Yamazaki, Timothy Andrews, Kalli Furtado, Mark A. Ringer, and Yoko Tsushima. The impact of performance filtering on climate feedbacks in a perturbed parameter ensemble. Climate Dynamics, 55(3):521–551, August 2020. doi:10.1007/s00382-020-05281-8

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.



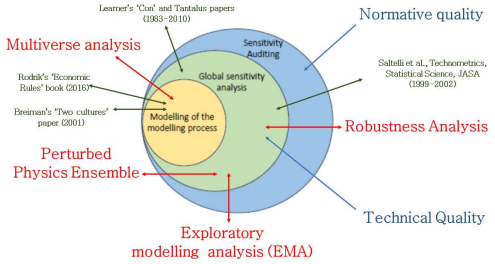
Richard Levins
1930-2016

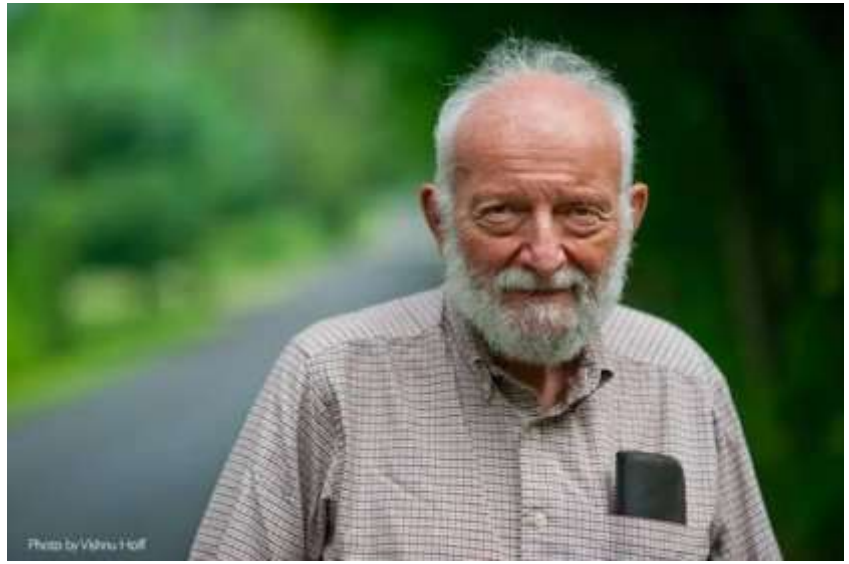
Richard Levins' robustness analysis:

"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.



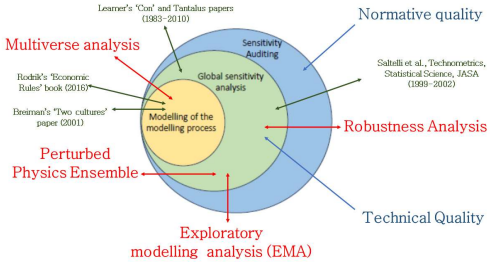


A fate similar to that of Leamer's global sensitivity analysis befell Richard Levins' robustness analysis

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

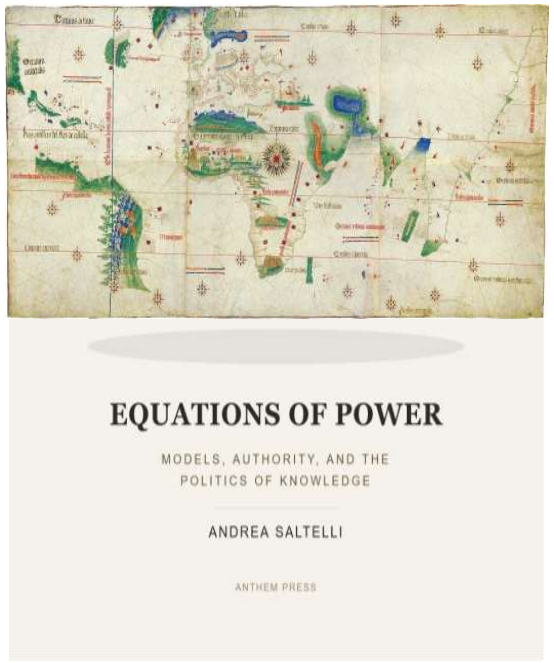
40 years

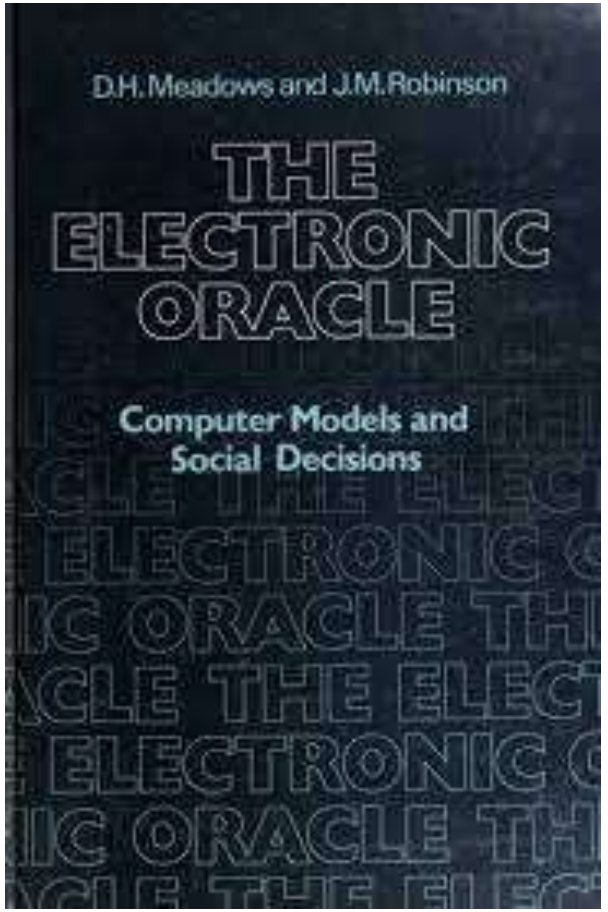
Michael Weisberg. Robustness Analysis. Philosophy of Science, 73(5):730–742, 2006.



Validation methods have historically lacked traction, and Dana Meadows lamented this going on ‘for decades’ in 1985 … Why?

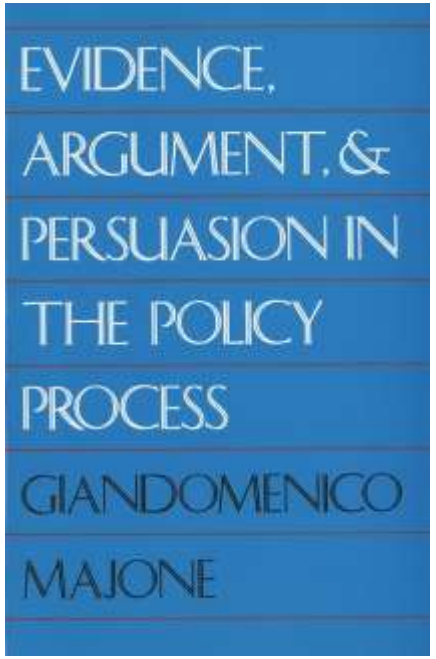
- Supply-side incentives (models produced for career, not policy needs)
- Conspicuous cognition (allegiance to complexity as cultural marker)
- Institutional lock-in (modelling infrastructures create constituencies)
- Absence of institutional demand (politicians like models’ neutrality)





Published in 1985

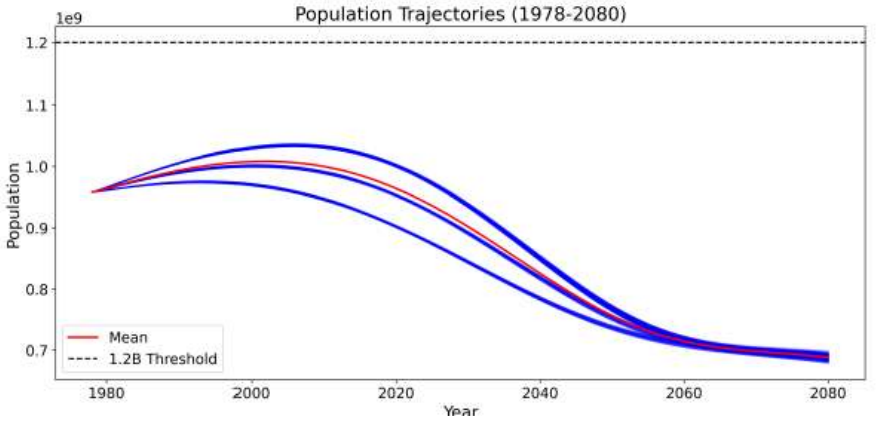
Giandomenico Majone



"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.

The Song Jian / one-child policy 1980's model. We find near-insensitivity to inputs …



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SSRN

What Demographic Prediction Can and Cannot Achieve

14 Pages • Posted: 19 May 2026

Samuele Lo Piano
Gdańsk University of Technology - Faculty of Management and Economics

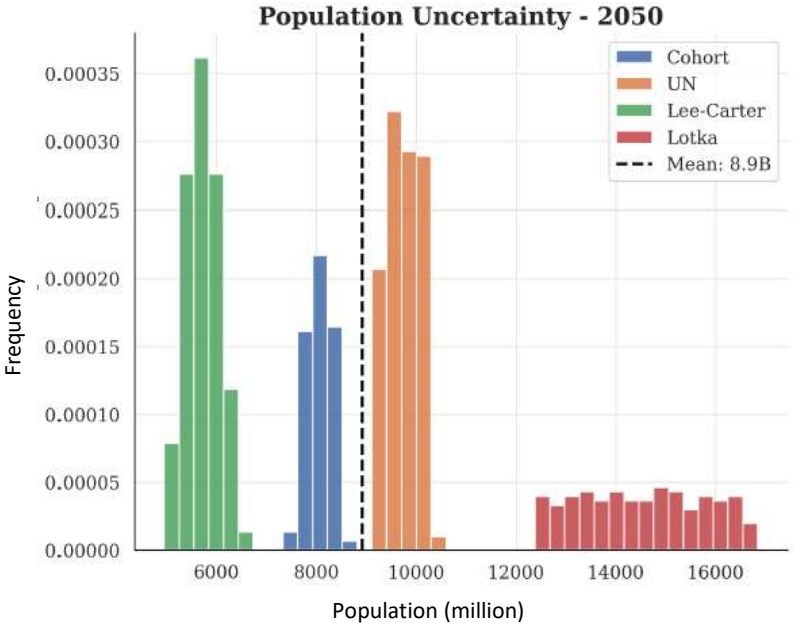
Marta Kuc Czarnecka
Gdańsk University of Technology

Roger Pielke
University of Colorado at Boulder

Andrea Saltelli
UPF Barcelona School of Management

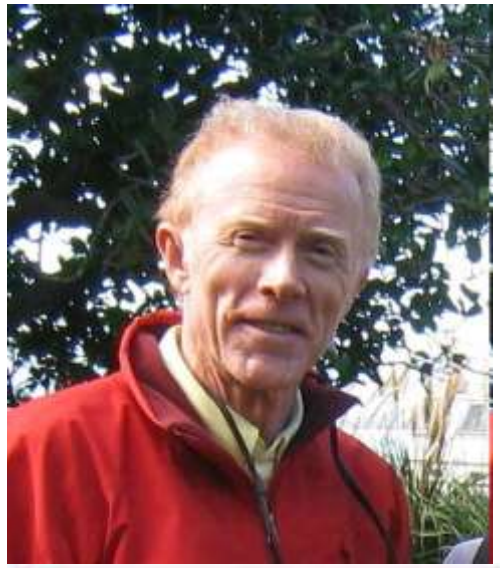
Date Written: May 15, 2026

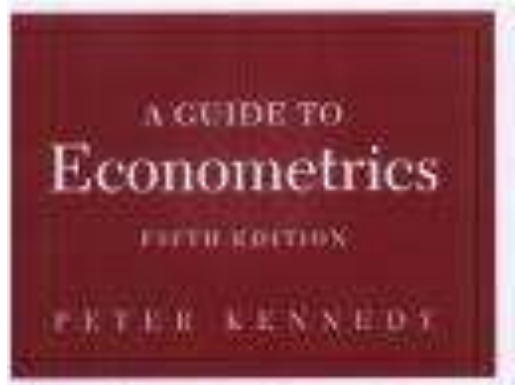
… and projections **today in use** are dramatically model-dependent



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)

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

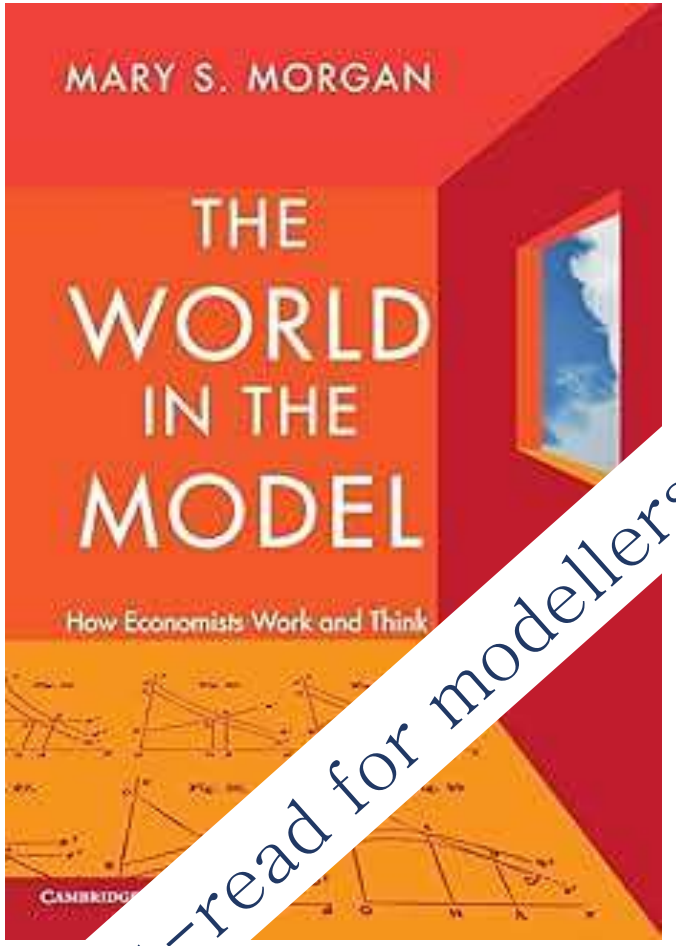
Charles A.S. Hall

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'



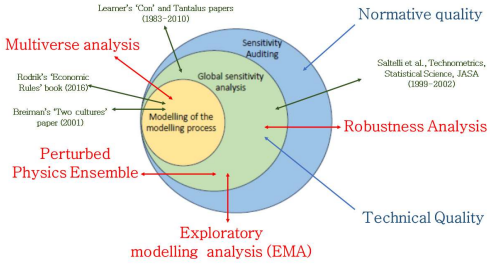
A must-read for modellers

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

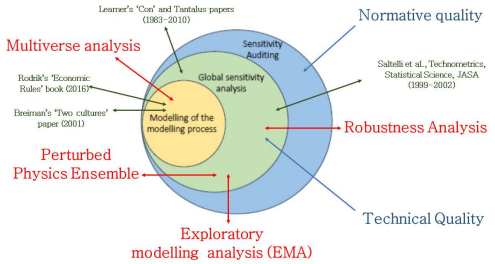


Leo Breiman. Statistical Modeling: The Two Cultures
Statistical Science, 16(3):199–231, August 2001

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.



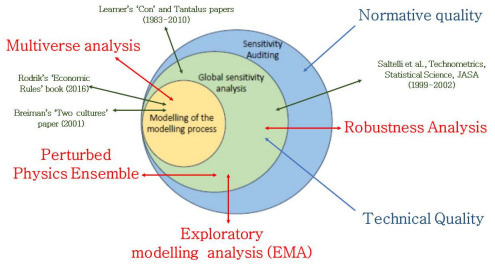
Leo Breiman. Statistical Modeling: The Two Cultures
Statistical Science, 16(3):199–231, August 2001

Leo Breiman, Rashomon effect, Rashomon sets

Many models fit the same data, and variable importance varies across models (Breiman)
→ a sensitivity analysis that keeps the model fixed is incomplete

Rashomon

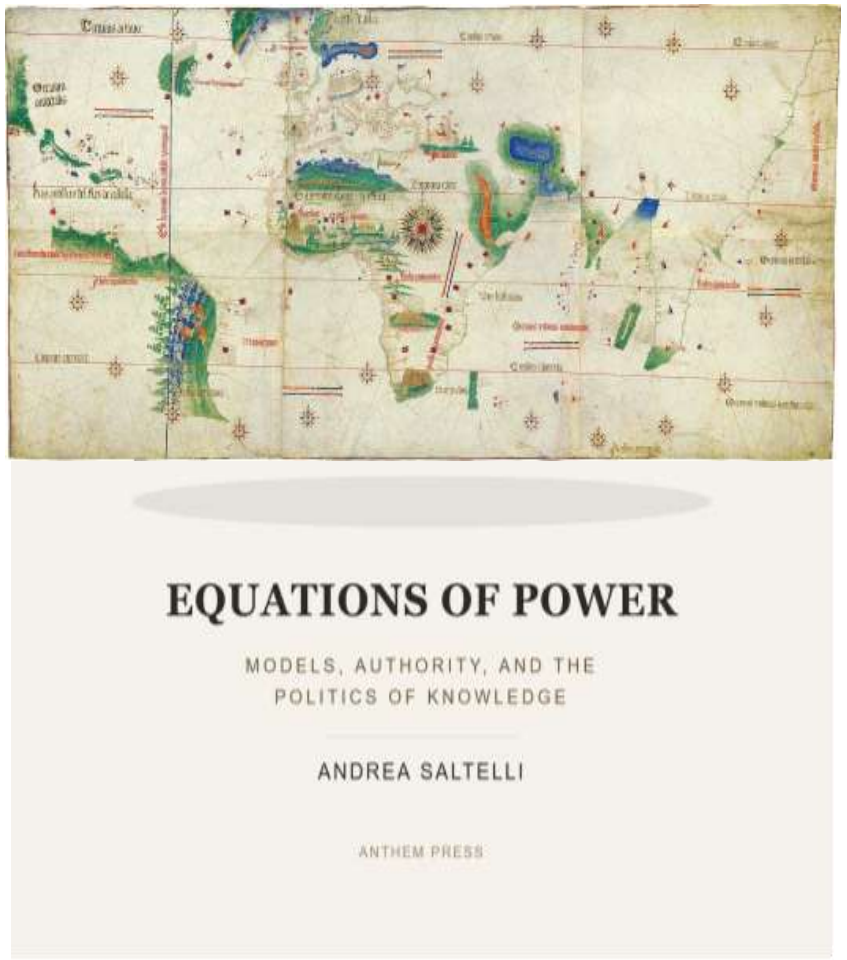
Poster of Rashomon, Kurosawa's movie, source: Wikipedia Commons

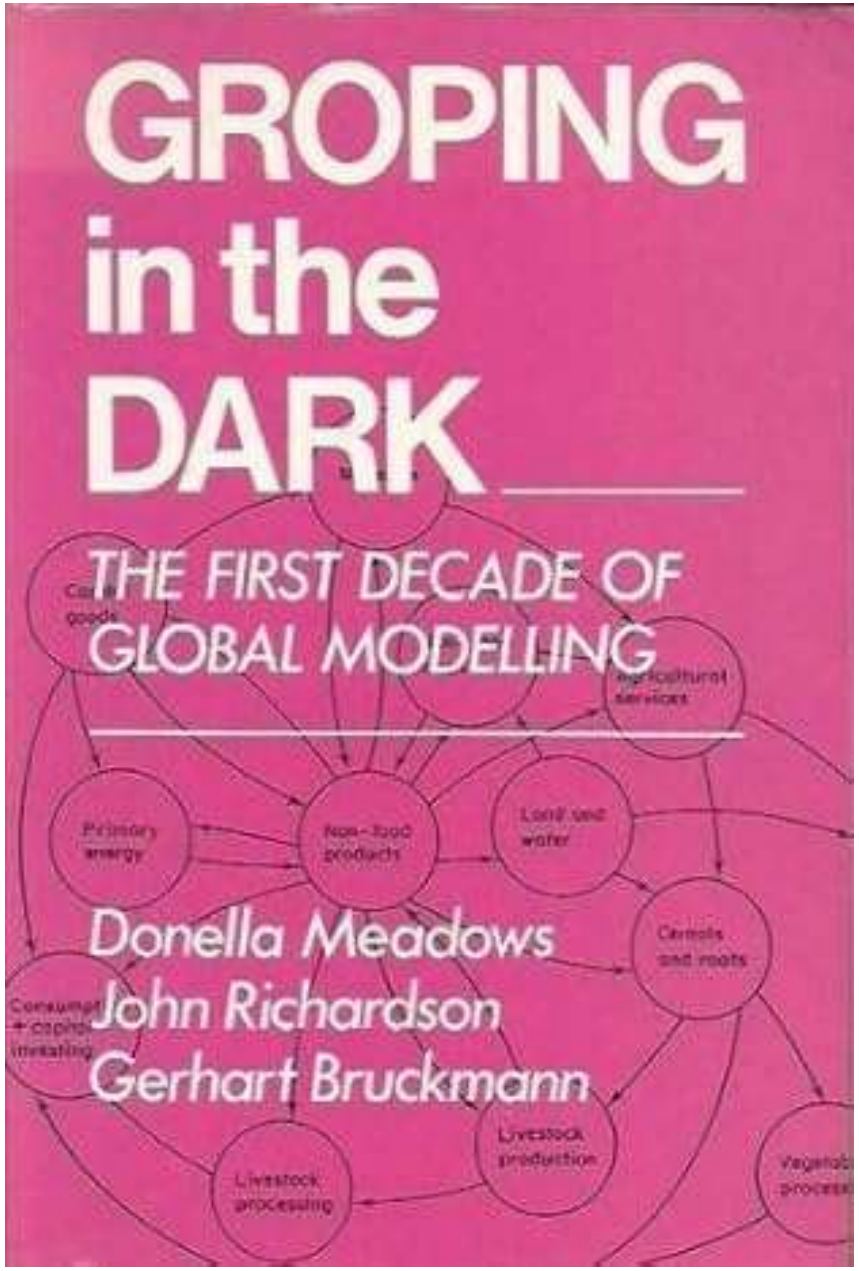


Aristotle's four causes applied to models

- material (data)
- formal (model)
- efficient (analyst)
- final (objective)

→ Results should be sensitive to material and final; insensitive to formal and efficient.





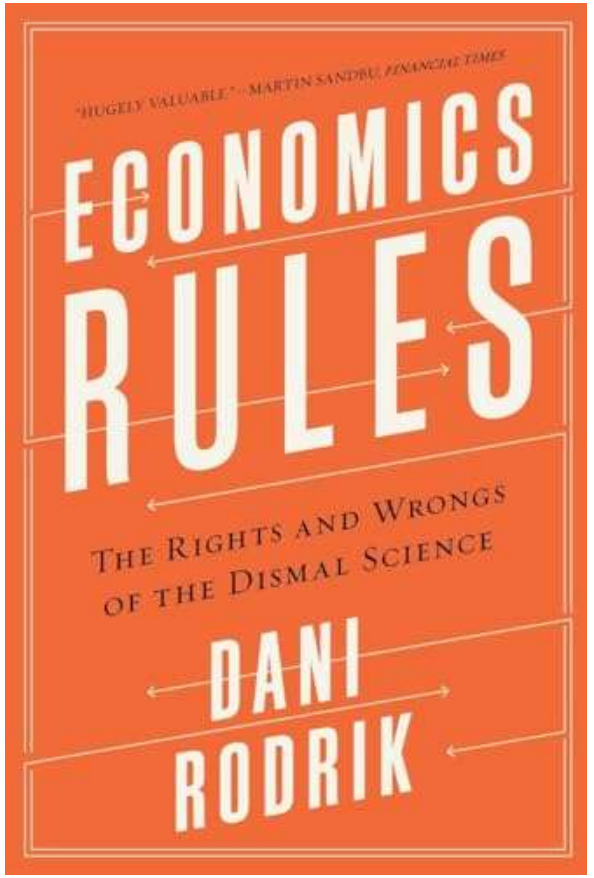
1982

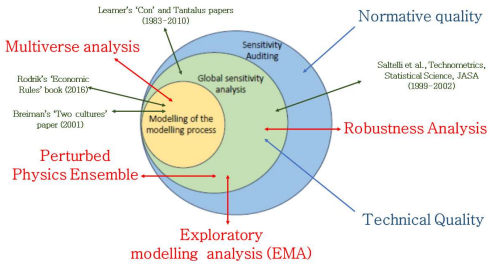
"We define 'sensitive' in a way that does not appear to be widely shared in the modelling community. We call a parameter sensitive **not when a change in it changes the value of an output number but when it changes the policy conclusions** we would draw from the model" (p. 132)

Memento interpretant

Rodrik's rules about models (and GSA)

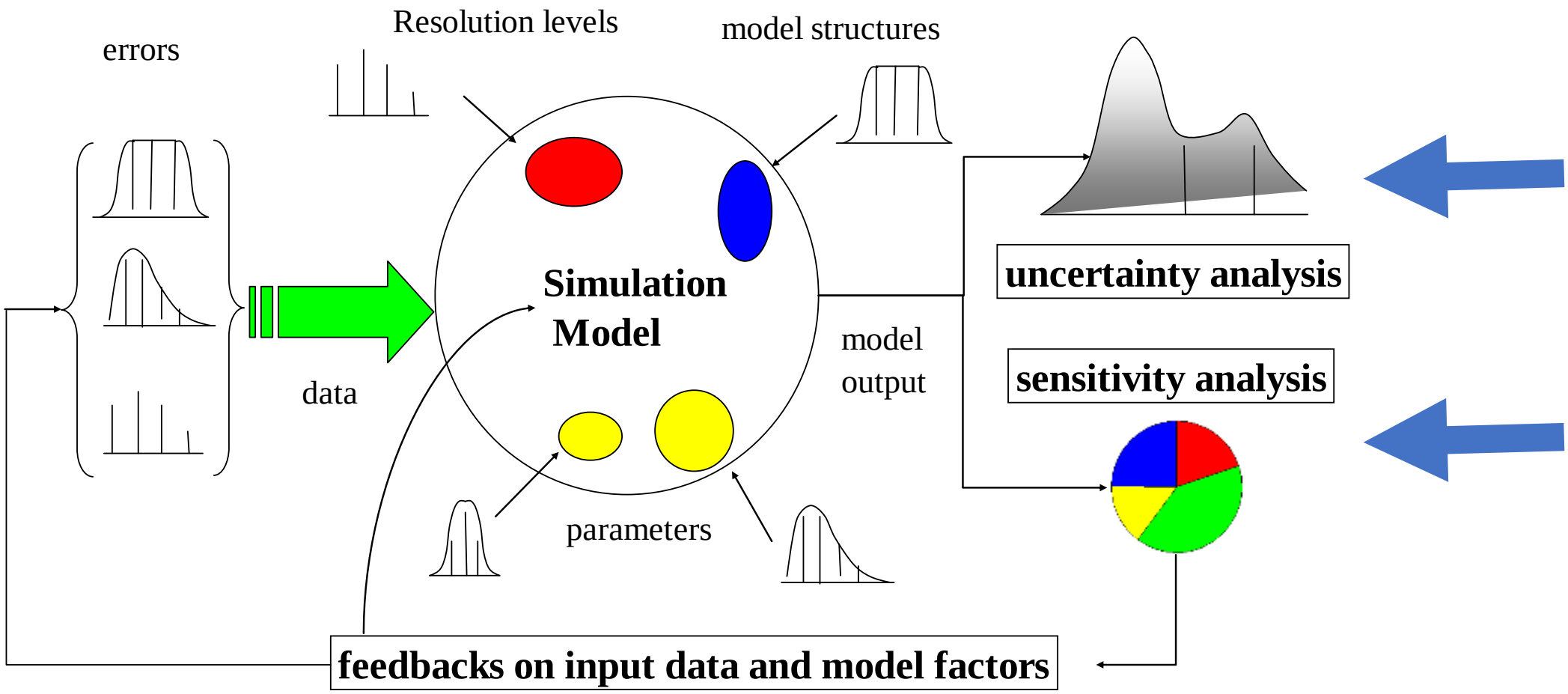
- Economics is a collection of models; cherish their diversity.
- It's a model, not the model.
- Make your model simple enough to isolate specific causes and how they work, but not so simple that it leaves out key interactions among causes.
- Unrealistic assumptions are OK; unrealistic critical assumptions are not OK





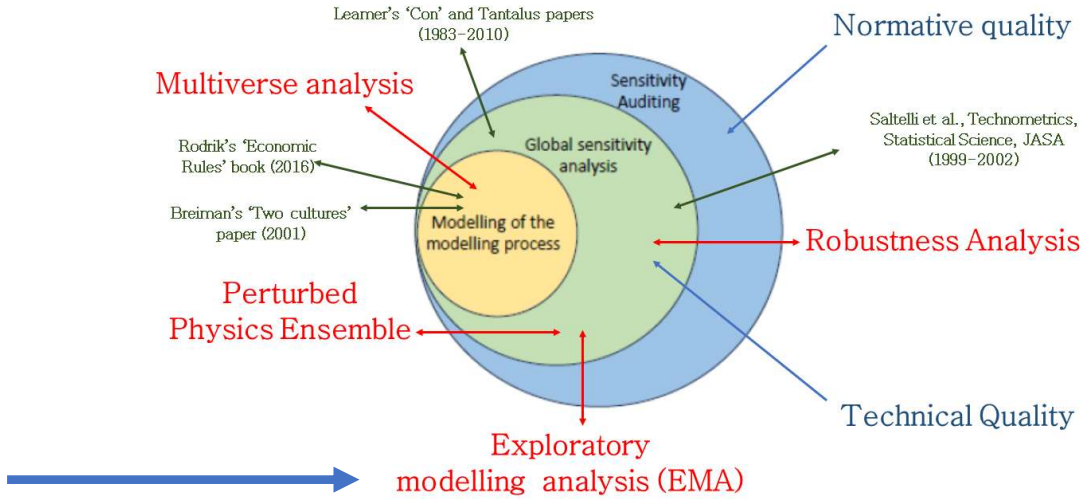
→ When modelling, move horizontally rather than vertically

Stefano Tarantola, circa 2008

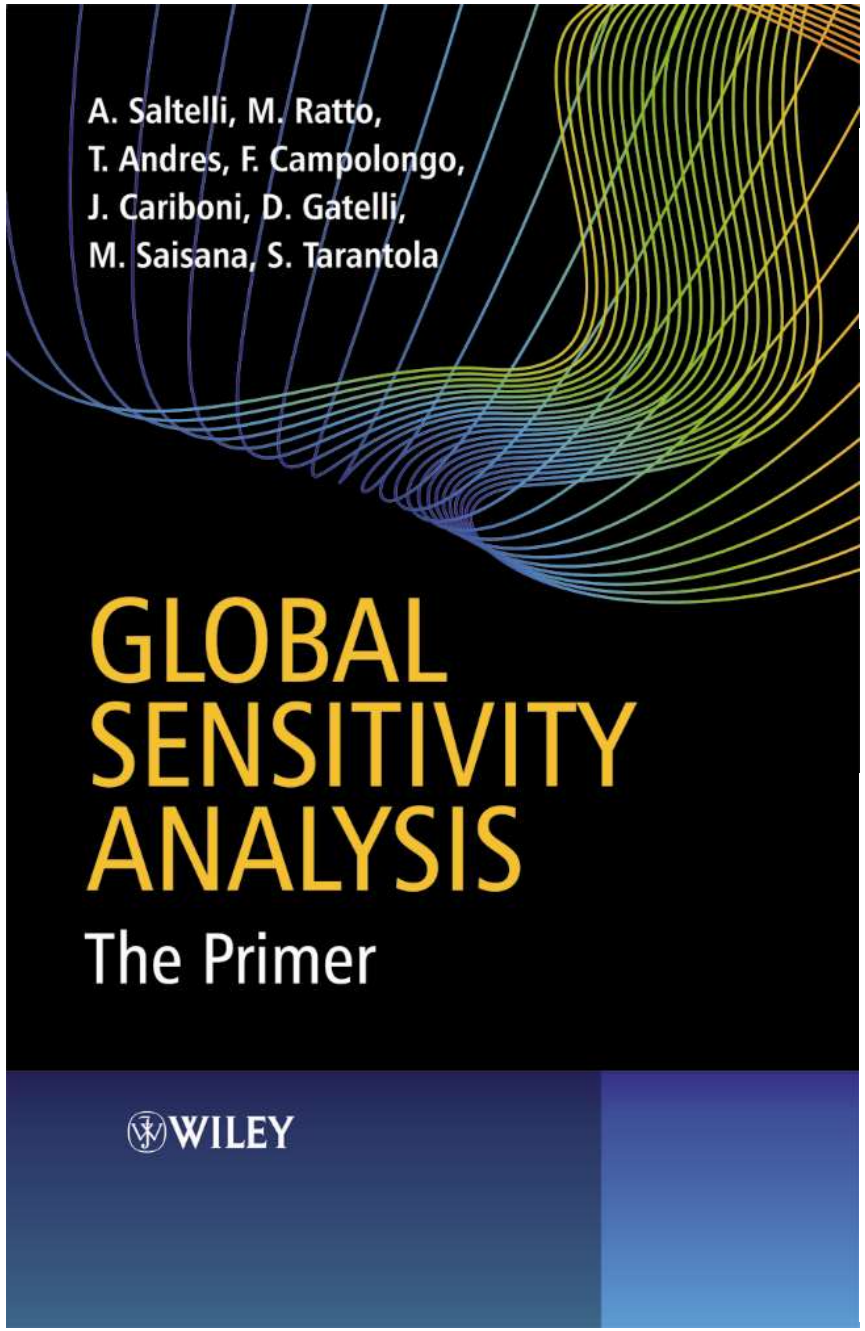


Exploratory modelling analysis (RAND corporation)

Explore (maybe too liberally) scenarios



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.



A handbook for sensitivity analysis, with exercises

(available online)

1.6 EXERCISES

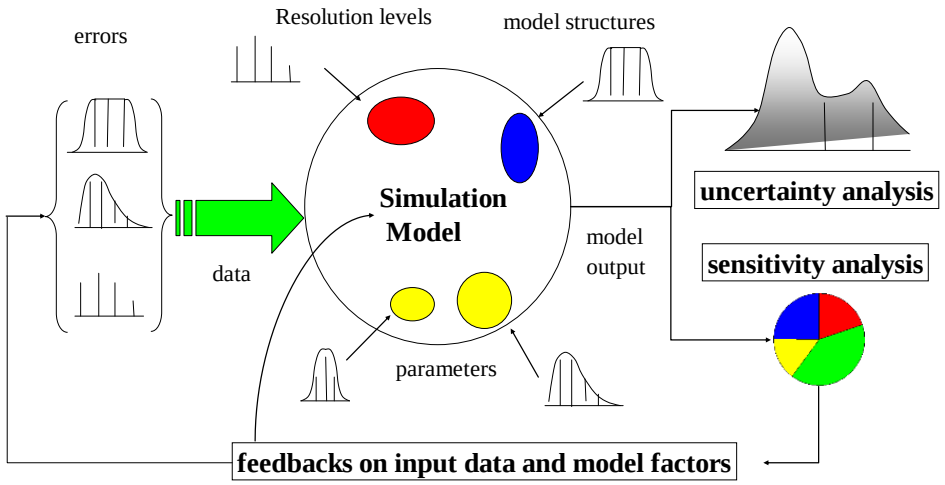
1. Prove that

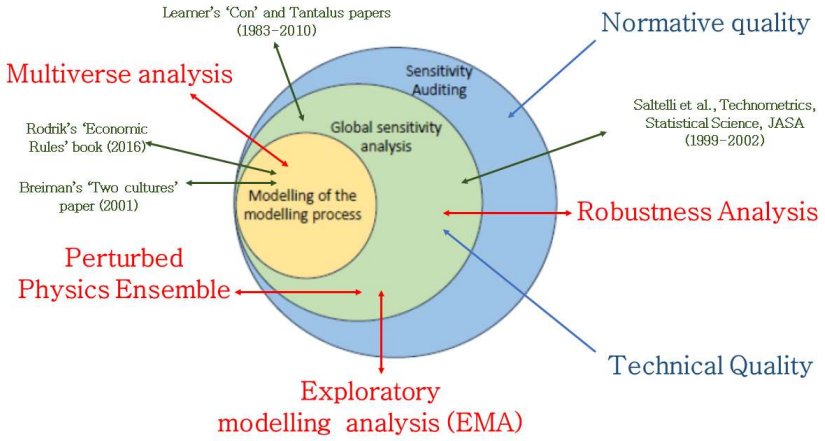
$$V(Y) = E(Y^2) - E^2(Y).$$

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.

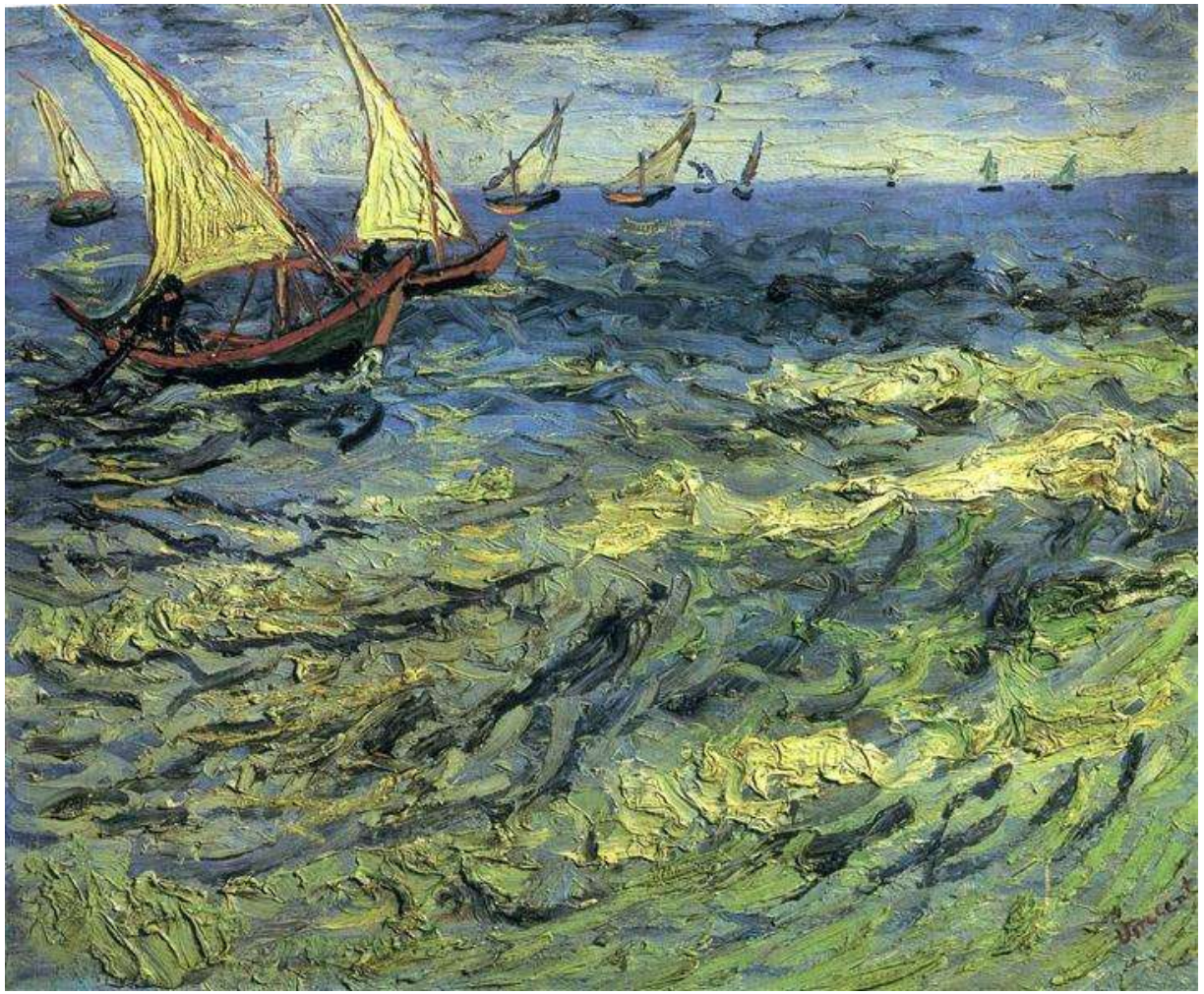
PART IV — MODELLING THE MODELLING PROCESS

Modelling of the modelling process, another name for multiverse analysis, can be seen as an instance of global sensitivity 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.

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

- **Multi-analyst studies** examine social epistemology — how scientific communities generate variability.
- **Multiverse analyses** examine statistical robustness — how conclusions depend on modelling choices.

Back to the garden

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*

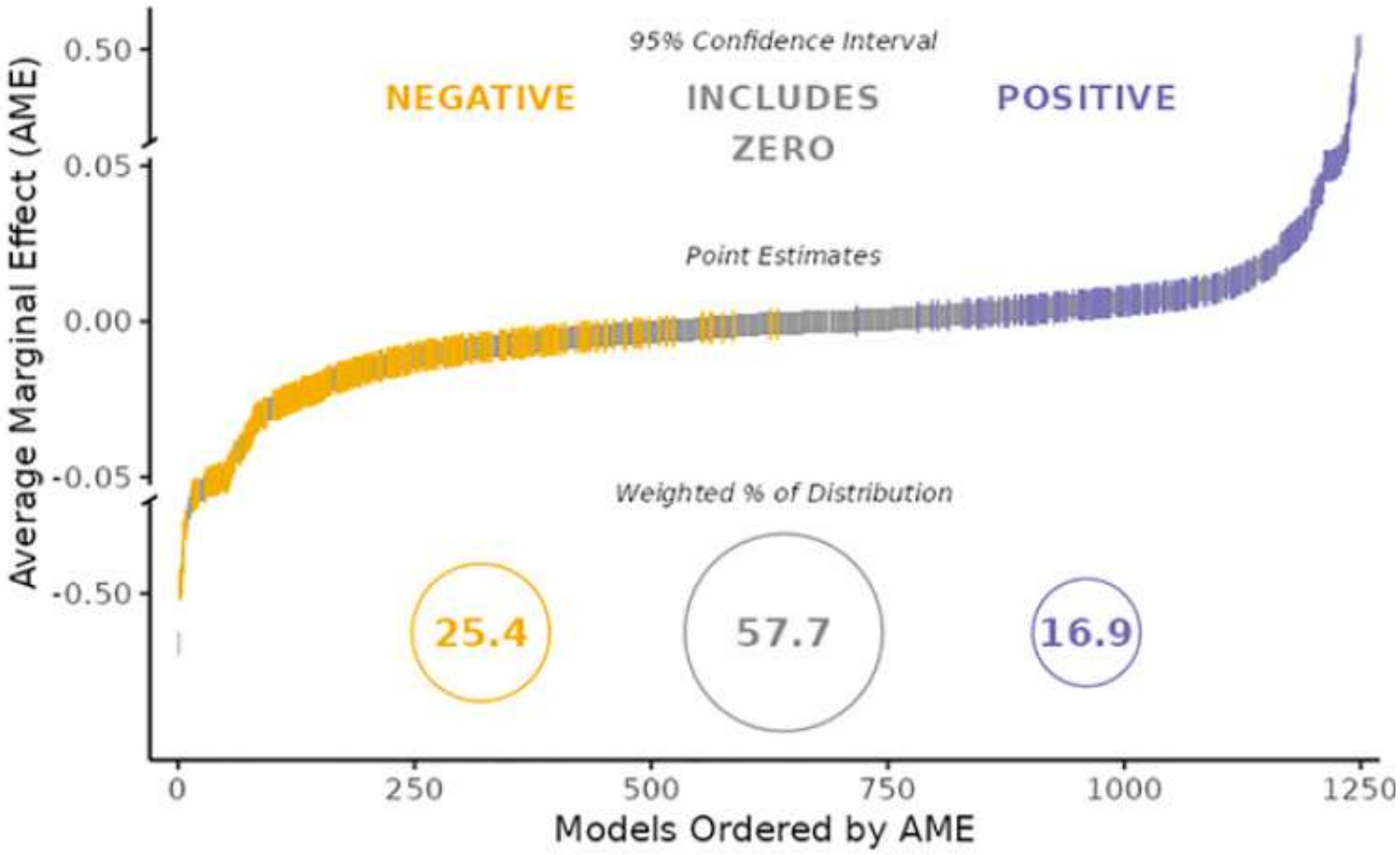
Andrew Gelman† and Eric Loken‡

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

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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

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/

Simulate different paths using triggers

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

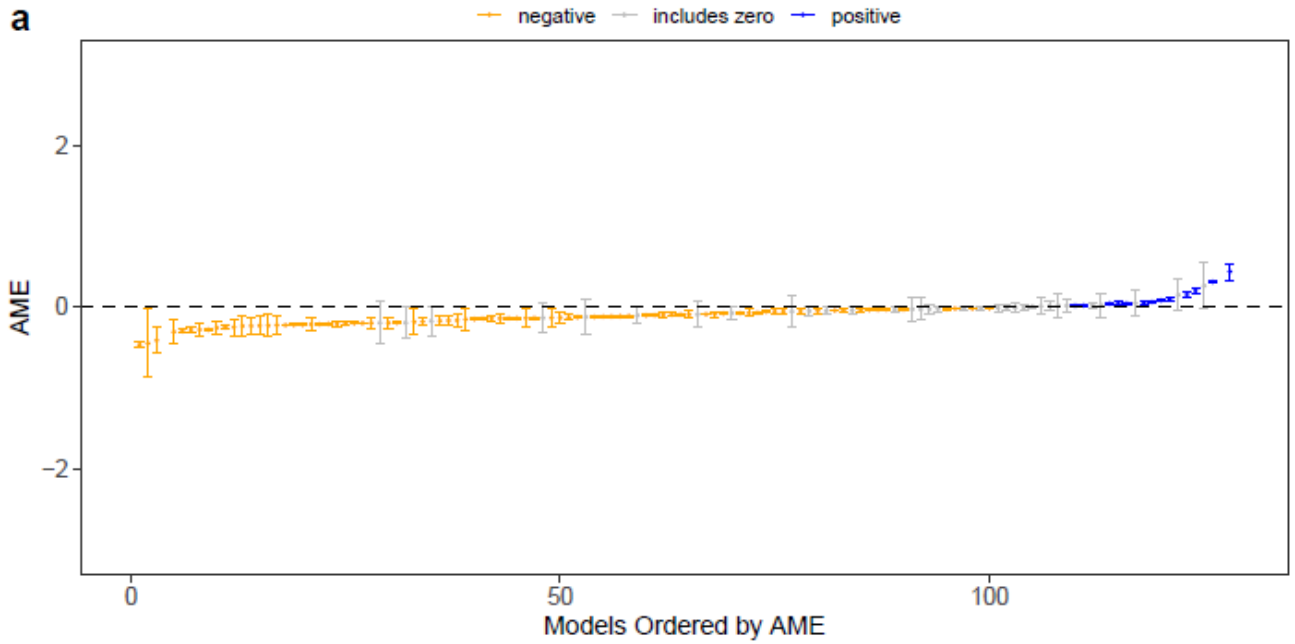
Table 1. Descriptions of variables included in the analysis.

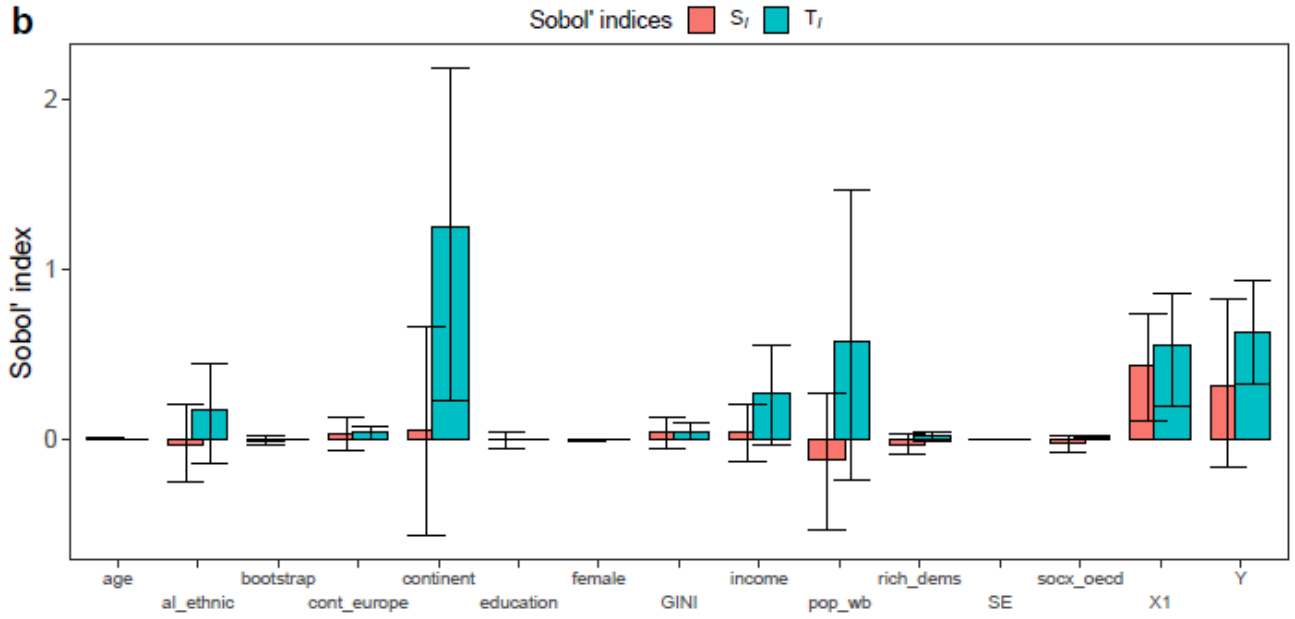
Leamer Reloaded: A Long-Neglected Suggestion Is Rediscovered To Apply Global Sensitivity Analysis To A Quantification Before Publishing It

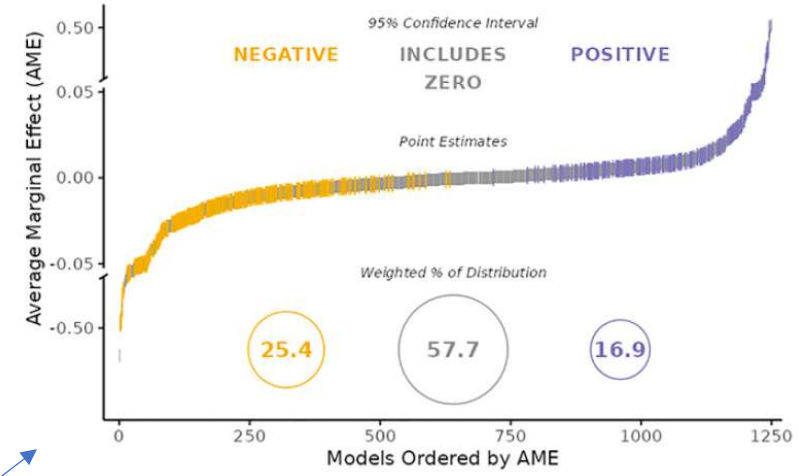
Andrea Saltelli*[1,2], Alessio Lachi[3,4], Arnald Puy[5], and Nate Breznau[6]

OSF

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



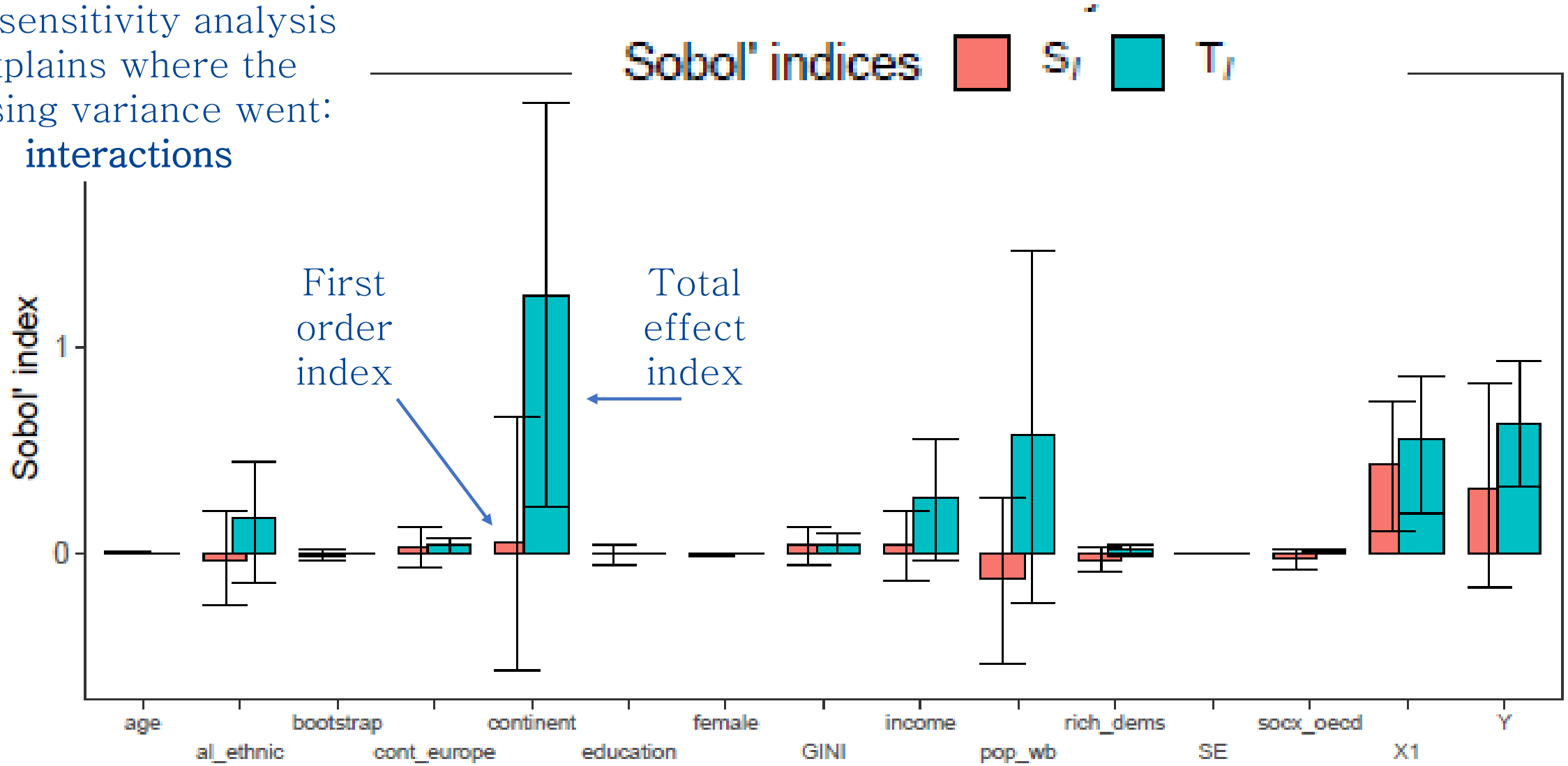




Uncertainty analysis broadly reproduces the results of the multi-analyst experiment

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

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

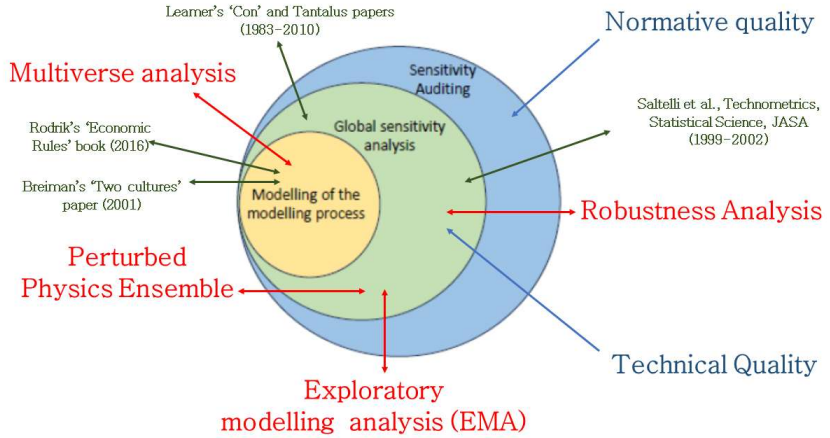


Modelling of the modelling process and multiverse analysis tells us how sensitive conclusions are to the paths taken …

… But was the right garden entered in the first place?

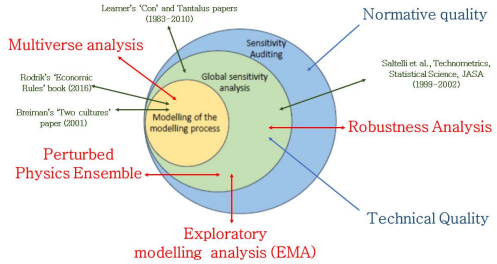
PART V — SENSITIVITY AUDITING

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

1. Check against rhetorical use of mathematical modelling
2. Adopt an ‘assumption hunting’ attitude
3. Detect garbage in, garbage out (GIGO)
4. Find sensitive assumptions before they find you
5. Aim for transparency
6. Do the right sums
7. Focus the analysis on the key question answered by the model, exploring the entire space of the assumptions holistically

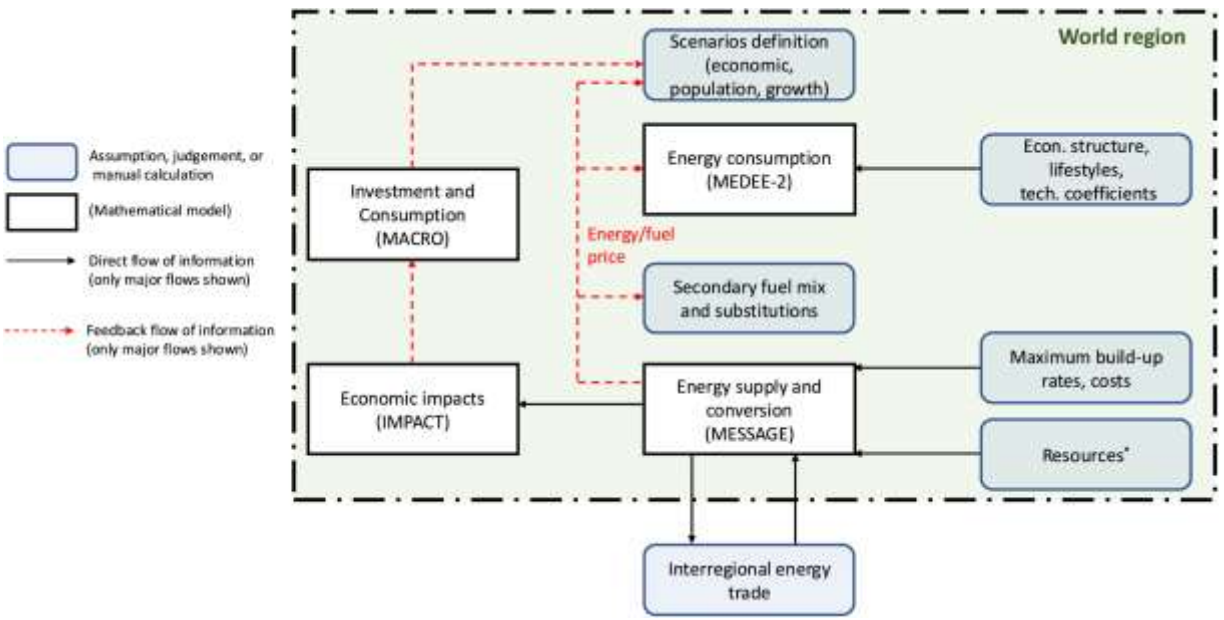


Verbatim from

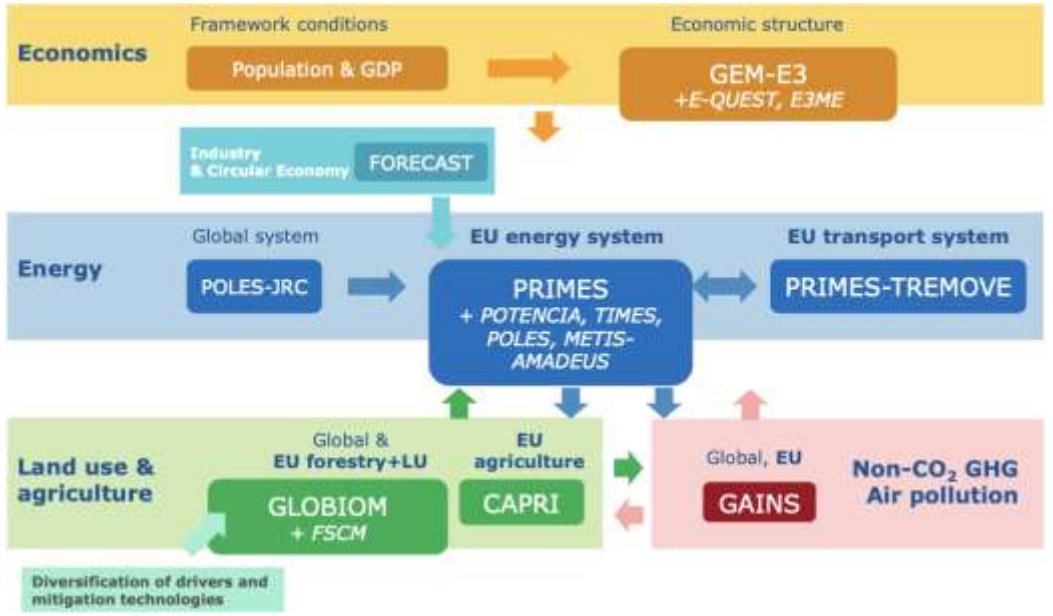
An illustration of rule 1 is given next

- We contrast a 1980s energy study and a 2024 EU impact assessment on emissions.
- Auditing reveals persistent flaws when models are used to inform policy.

IIASA 1980's



EC 2024



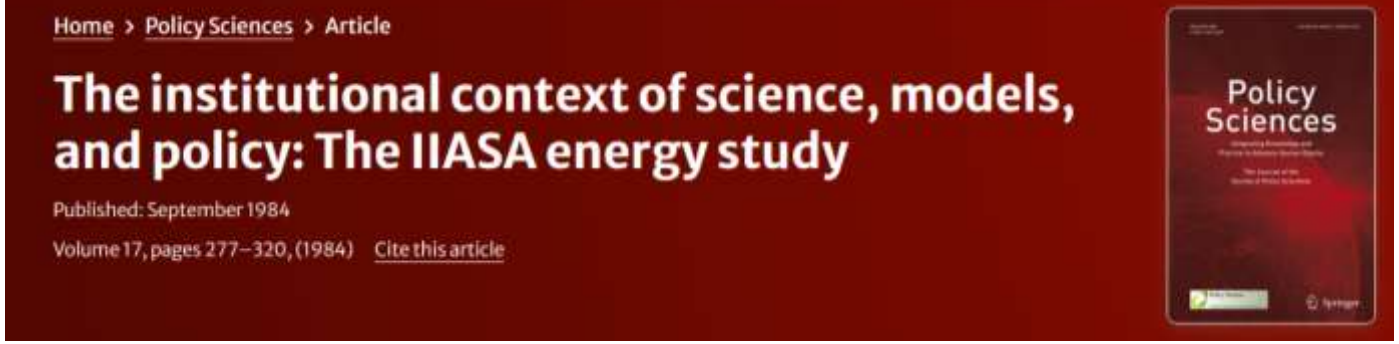
The rhetoric of the concatenated suite of models

Home › Policy Sciences › Article

The institutional context of science, models, and policy: The IIASA energy study

Published: September 1984

Volume 17, pages 277–320, (1984) Cite this article



Brian Wynne (and others such as William Keepin) debunked in the early 80's the off-the-mark model-based energy future, declared as 'scientifically prescribed' by analysts at IIASA …

A fast breeder reactor (a crucial ingredient of the energy mix predicted for the year 2030 by IIASA) is today an amusement park in the Netherlands

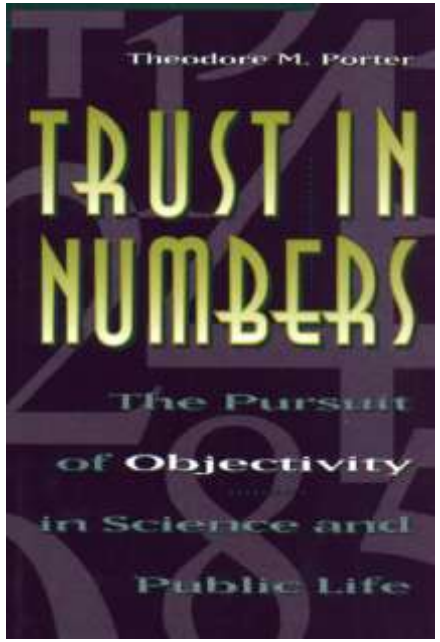
Applying sensitivity auditing to different cases:

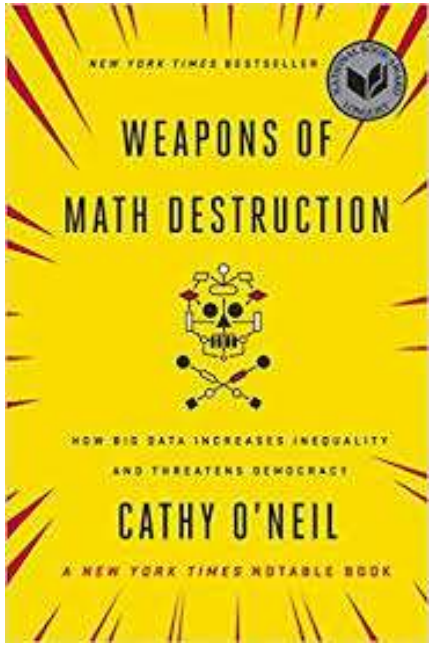
- Nutrition and Public Health
- Sustainability, Ecological Footprint (EF)
- Global Hydrological Models
- Sociohydrology, Coupled Human and Water Systems (CHAWS)
- Food Security
- Education, Programme for International Student Assessment (PISA) test

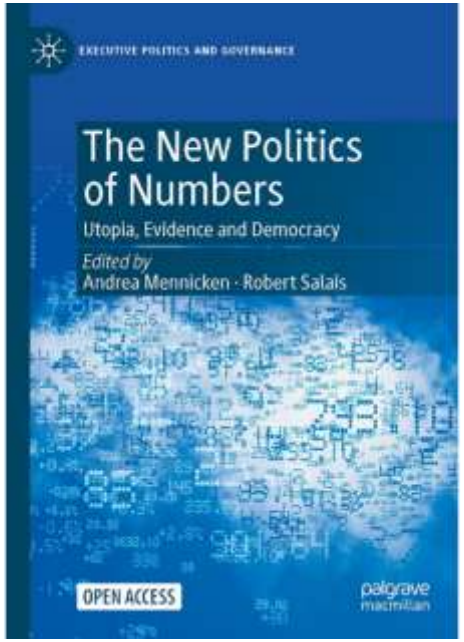
The same pattern appears:

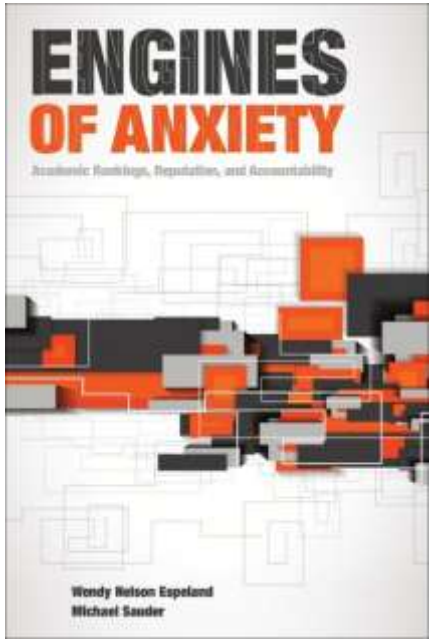
- the most consequential choices are often not numerical;
- they concern problem framing, indicator selection, omitted variables, boundary choices, and implicit values

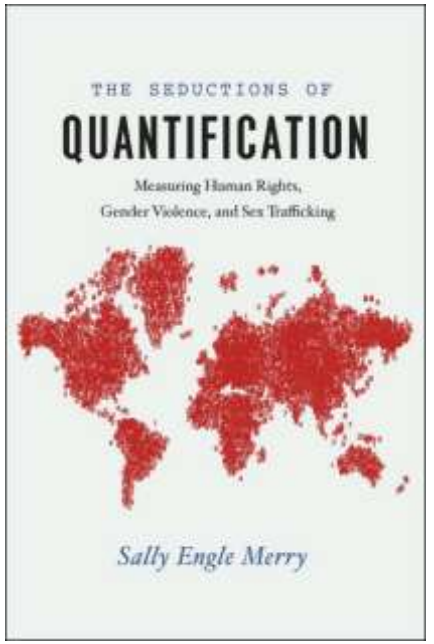
The rhetoric of quantification is a recurring topic in sociology of quantification











What would help

A model should not be used for policy unless:
- Its **sensitivity** to key assumptions has been explored
- Its structural and **framing** choices have been made explicit and tested
- **Affected parties** have had the opportunity to identify which assumptions matter to them

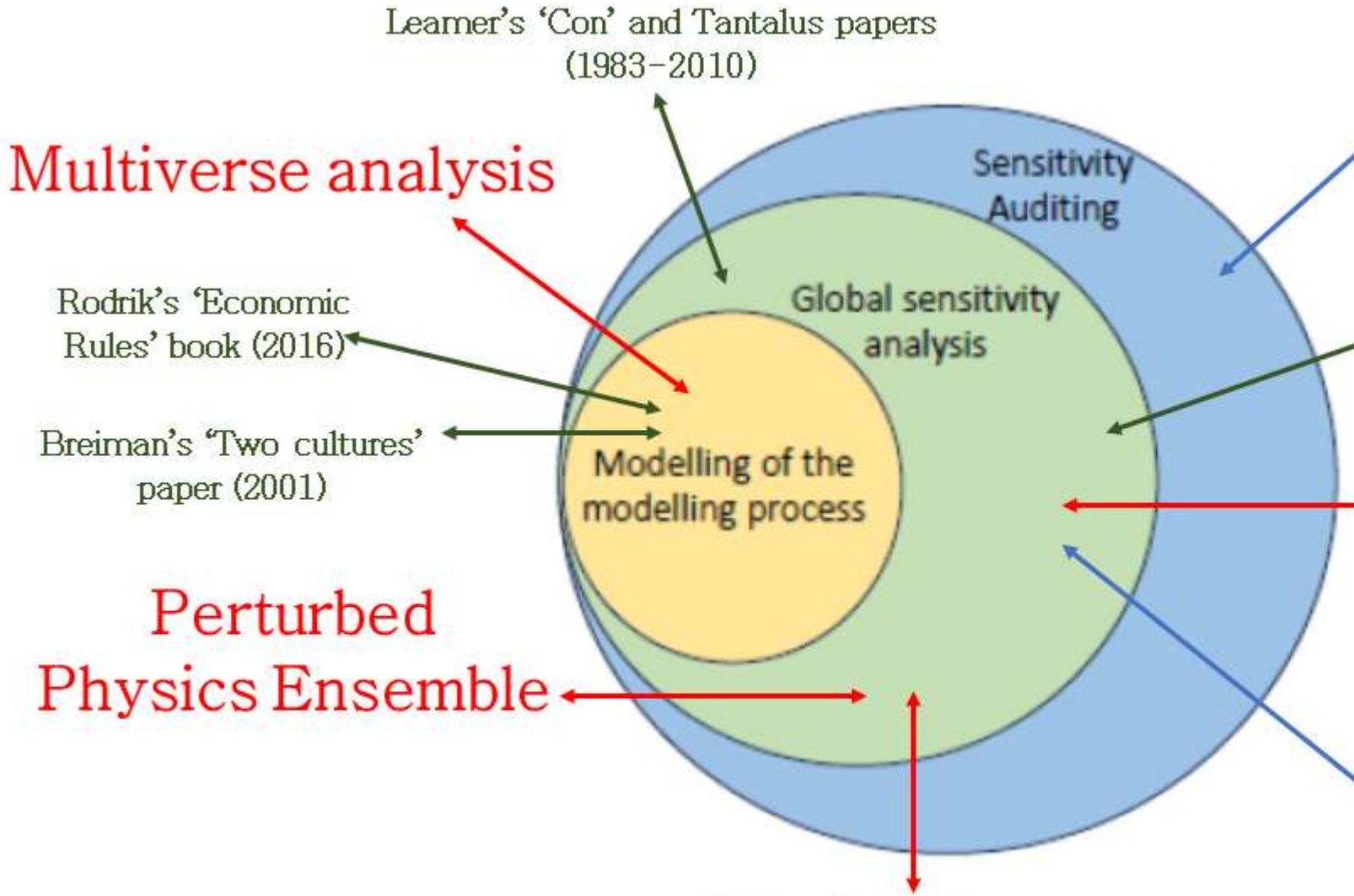
Global sensitivity analysis

Modelling of the modelling process

Sensitivity auditing

Alternatives: Statactivism and counter-modelling

- Statactivists: societal mobilisation around alternative numbers
- Countermodelling: building models that respond to different framings
- Critical friends: engaging with modelling communities from within
- Observatories: permanent watchdog institutions for quantification


Learner's 'Con' and Tantalus papers
(1983-2010)
Normative quality
Multiverse analysis
Sensitivity
Auditing
Saltelli et al., Technometrics,
Statistical Science, JASA
(1999-2002)
Rodrik's 'Economic
Rules' book (2016)
Global sensitivity
analysis
Breiman's 'Two cultures'
paper (2001)
Modelling of the
modelling process
Robustness Analysis
Perturbed
Physics Ensemble
Technical Quality
Exploratory
modelling analysis (EMA)

END

DIGRESSION — ECONOMICS AND SOCIOLOGY OF QUANTIFICATION

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

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

IIPP UCL Institute for Innovation and Public Purpose

WORKING PAPER
WP 2021/05

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