

# Quantitative tools for responsible quantification

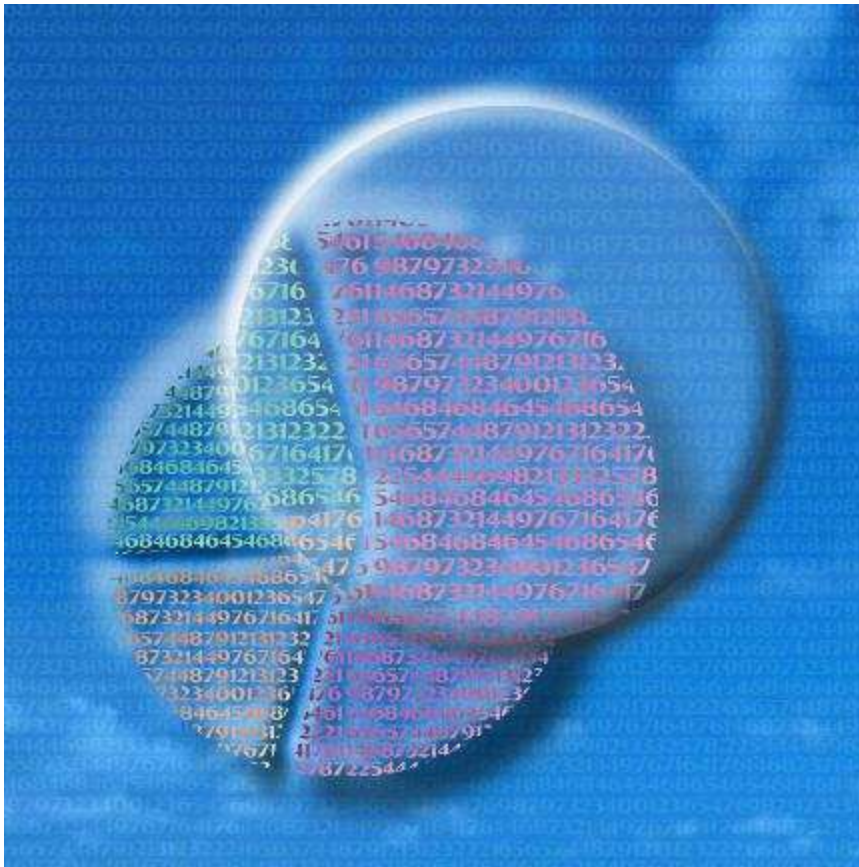
Andrea Saltelli

Centre for the Study of the  
Sciences and the Humanities  
(SVT), University of Bergen  
(UIB)

Course:

Theory of Science and Ethics,  
for the PhD students from the  
Faculty of Science and  
Mathematics of  
Bergen University

September 14, 2017





= more material on my web site



= discussion time

CAETERIS ARE  
NEVER PARIBUS

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andrea saltelli

@AndreaSaltelli

Sign and donate. What these people are doing is unique. [twitter.com/Jeroen\\_vdSluisj...](https://twitter.com/Jeroen_vdSluisj...)



24/11



andrea saltelli

@AndreaSaltelli

Lovely (also in the sense of 'of love') piece by an Italian scholar [@robertocalasso](https://twitter.com/robertocalasso):

[nybooks.com/articles/2016/...](https://nybooks.com/articles/2016/...)



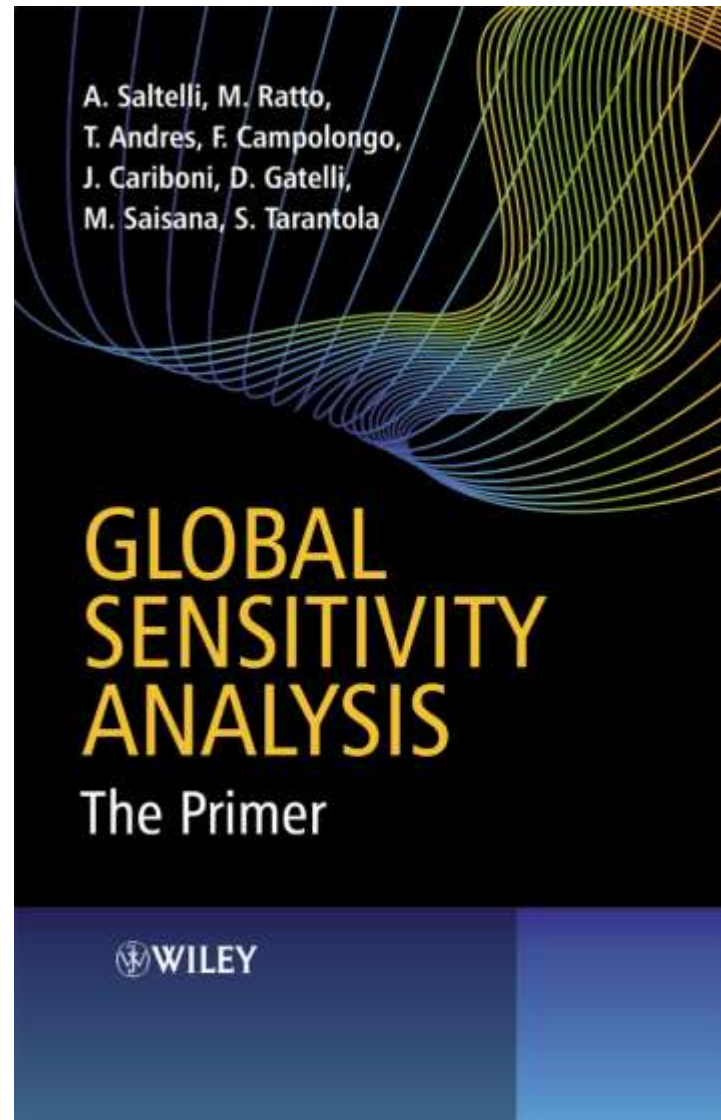
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sensitivity analysis, sensitivity auditing, science for policy, impact assessment



Sensitivity analysis book available on LibGen



## Sensitivity analysis

[Saltelli, A., Annoni, P., 2010, How to avoid a perfunctory sensitivity analysis, Environmental Modeling and Software, 25, 1508–1517.](#)

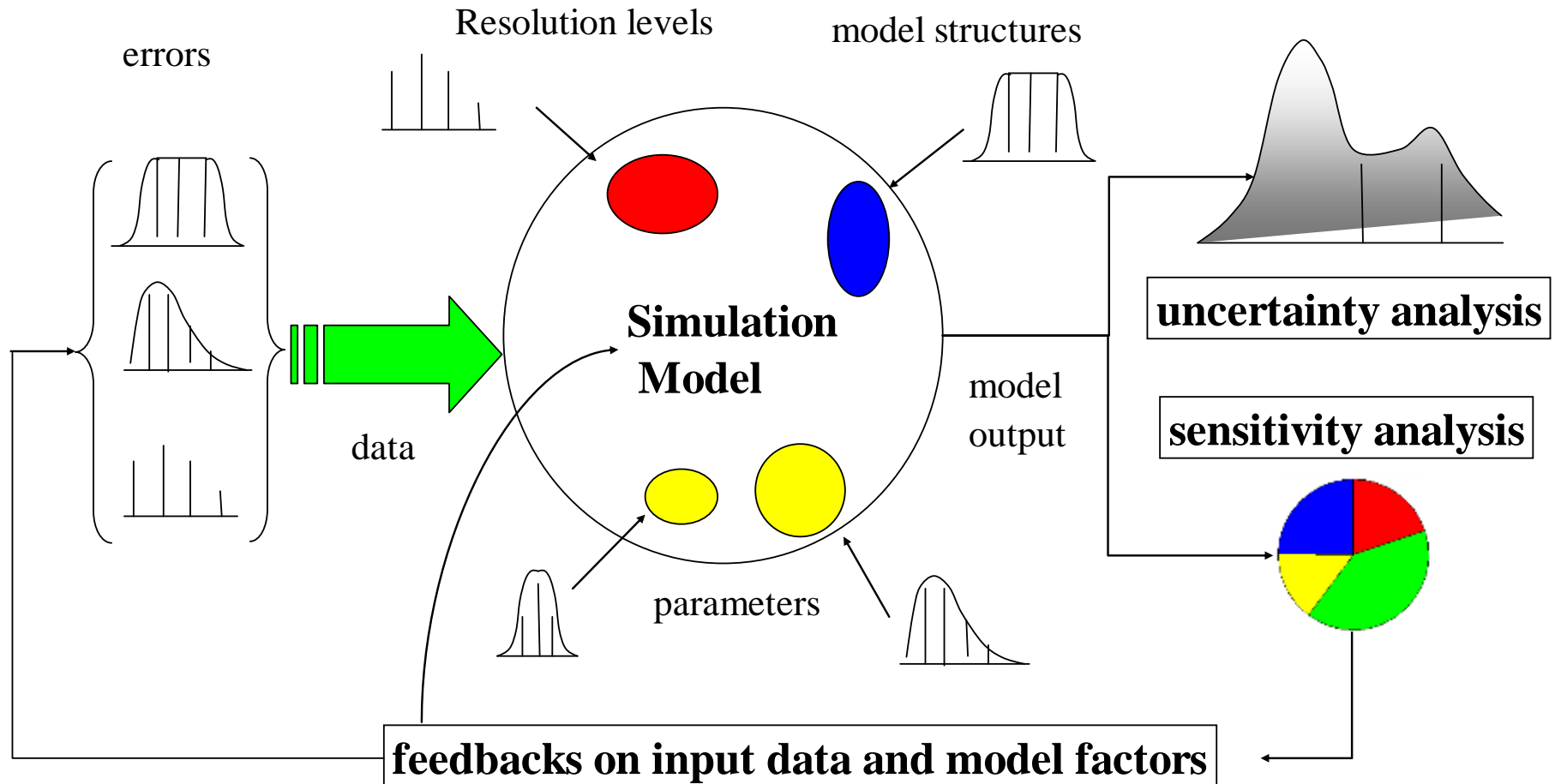
## Sensitivity auditing

[Saltelli, A., Funtowicz, S., 2014, When all models are wrong: More stringent quality criteria are needed for models used at the science–policy interface, Issues in Science and Technology, Winter 2014, 79–85.](#)

## Quantitative storytelling

[Andrea Saltelli, Mario Giampietro, 2017, What is wrong with evidence based policy, and how can it be improved? Futures, DOI: <http://dx.doi.org/doi:10.1016/j.futures.2016.11.012>.](#)

# An engineer's vision of UA, SA



One can sample more than just factors

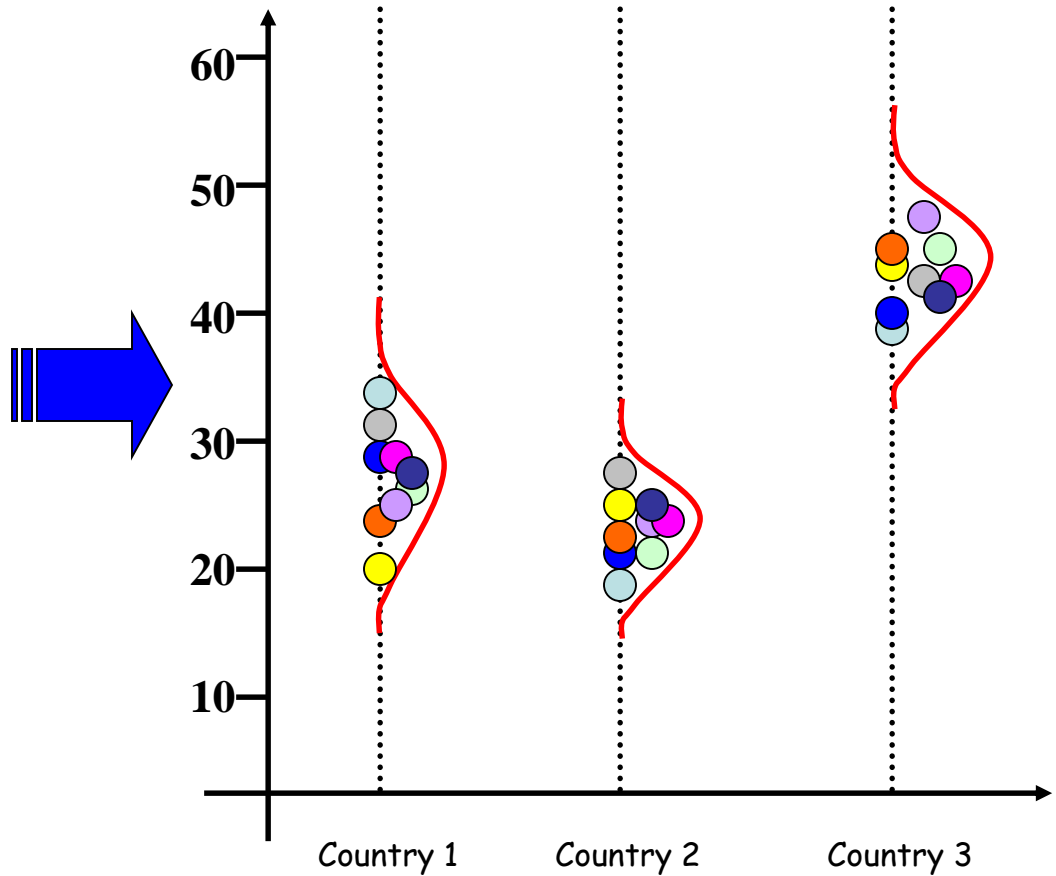
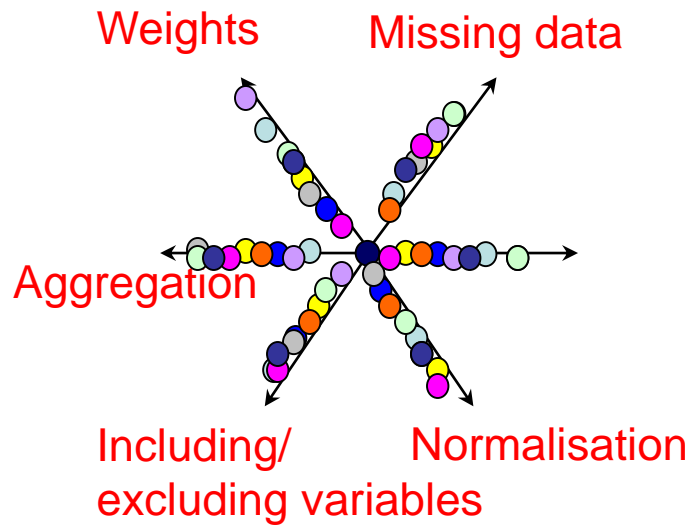
One can sample modelling assumptions

Example: The output is a composite indicator

Assumption	Alternatives
Number of indicators	<ul style="list-style-type: none"><li>▪ all six indicators included or one-at-time excluded (6 options)</li></ul>
Weighting method	<ul style="list-style-type: none"><li>▪ original set of weights,</li><li>▪ factor analysis,</li><li>▪ equal weighting,</li><li>▪ data envelopment analysis</li></ul>
Aggregation rule	<ul style="list-style-type: none"><li>▪ additive,</li><li>▪ multiplicative,</li><li>▪ Borda multi-criterion</li></ul>



## Space of alternatives



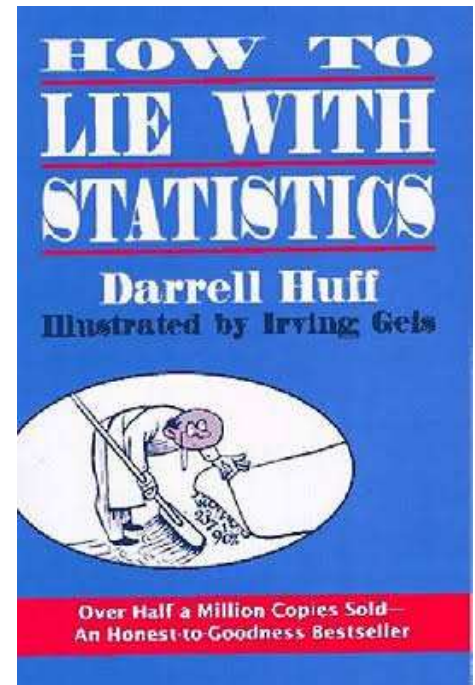
<http://ec.europa.eu/smart-regulation/>



Source: IA Toolbox, p. 391



Will any sensitivity analysis do the job? Can I lie with sensitivity analysis as I can lie with statistics?



Saltelli, A., Annoni P., 2010, How to avoid a perfunctory sensitivity analysis, *Environmental Modeling and Software*, **25**, 1508–1517.

# Why not just changing one factor at a time (OAT)?

<<“one-at-a-time” (OAT) approach is most commonly used in Commission IAs>>

Source: IA Toolbox, p. 391



*Better Regulation "Toolbox"*

Why not just changing one factor at a time (OAT)?

“Sensitivity analysis usually proceeds by changing one variable or assumption at a time, but it can also be done by varying a combination of variables simultaneously to learn more about the robustness of your results to widespread changes”.

Source: Office for the management and  
Budget of the White House (OMB),  
Circular A4, 2003

[https://www.whitehouse.gov/omb/circulars\\_a004\\_a-4/](https://www.whitehouse.gov/omb/circulars_a004_a-4/)

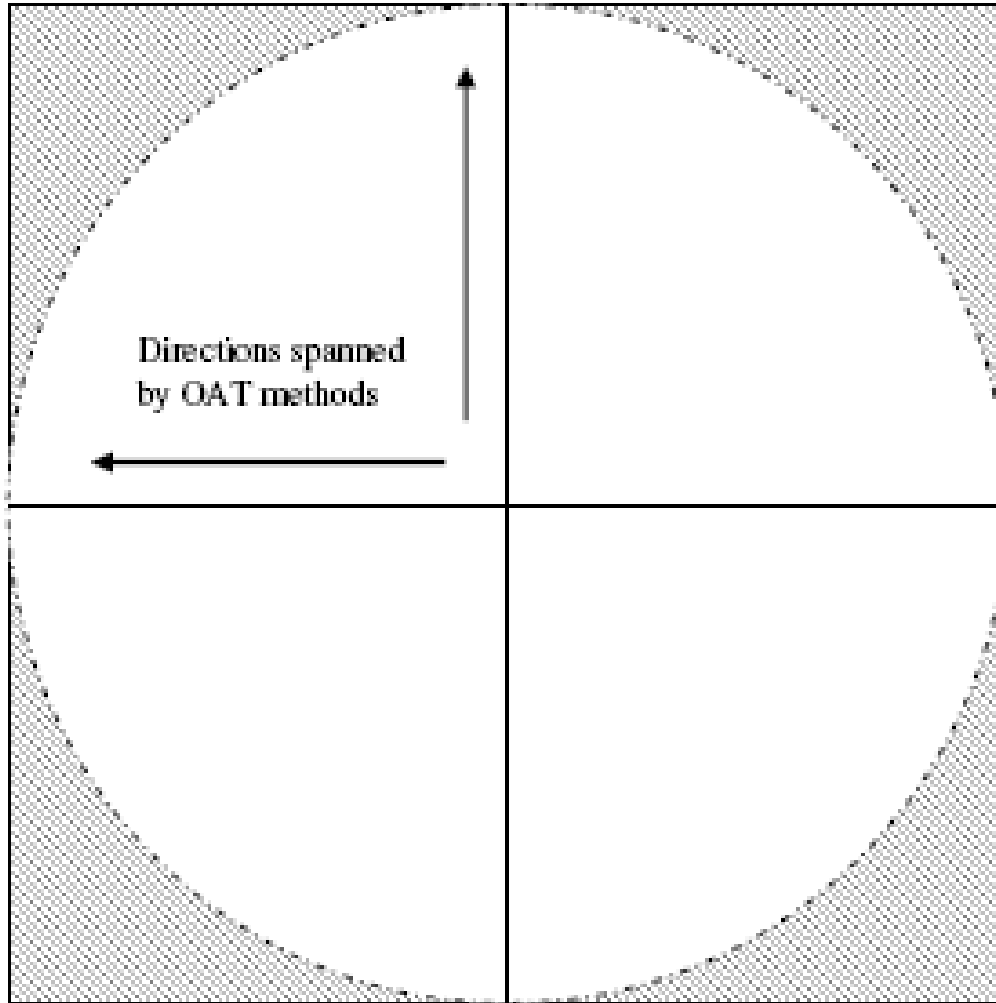


Why not just changing one factor  
at a time (OAT)?

Because it is a bad idea!



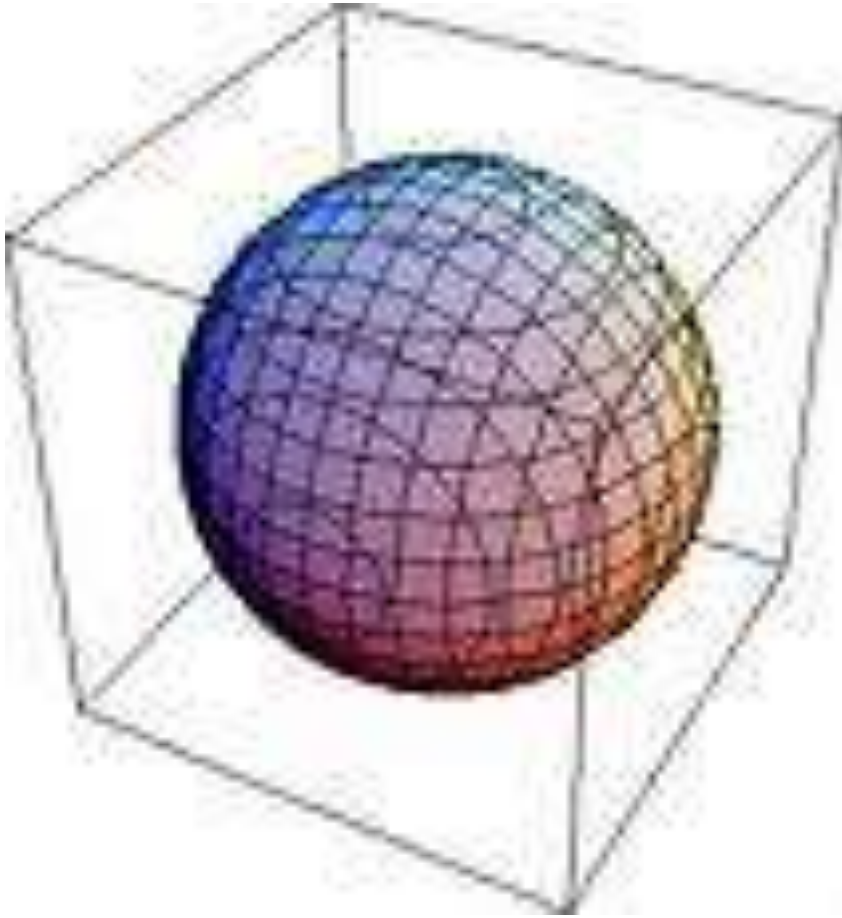
# OAT in 2 dimensions



Area circle / area  
square = ?

$\sim 3/4$

# OAT in 3 dimensions



Volume sphere /  
volume cube =?

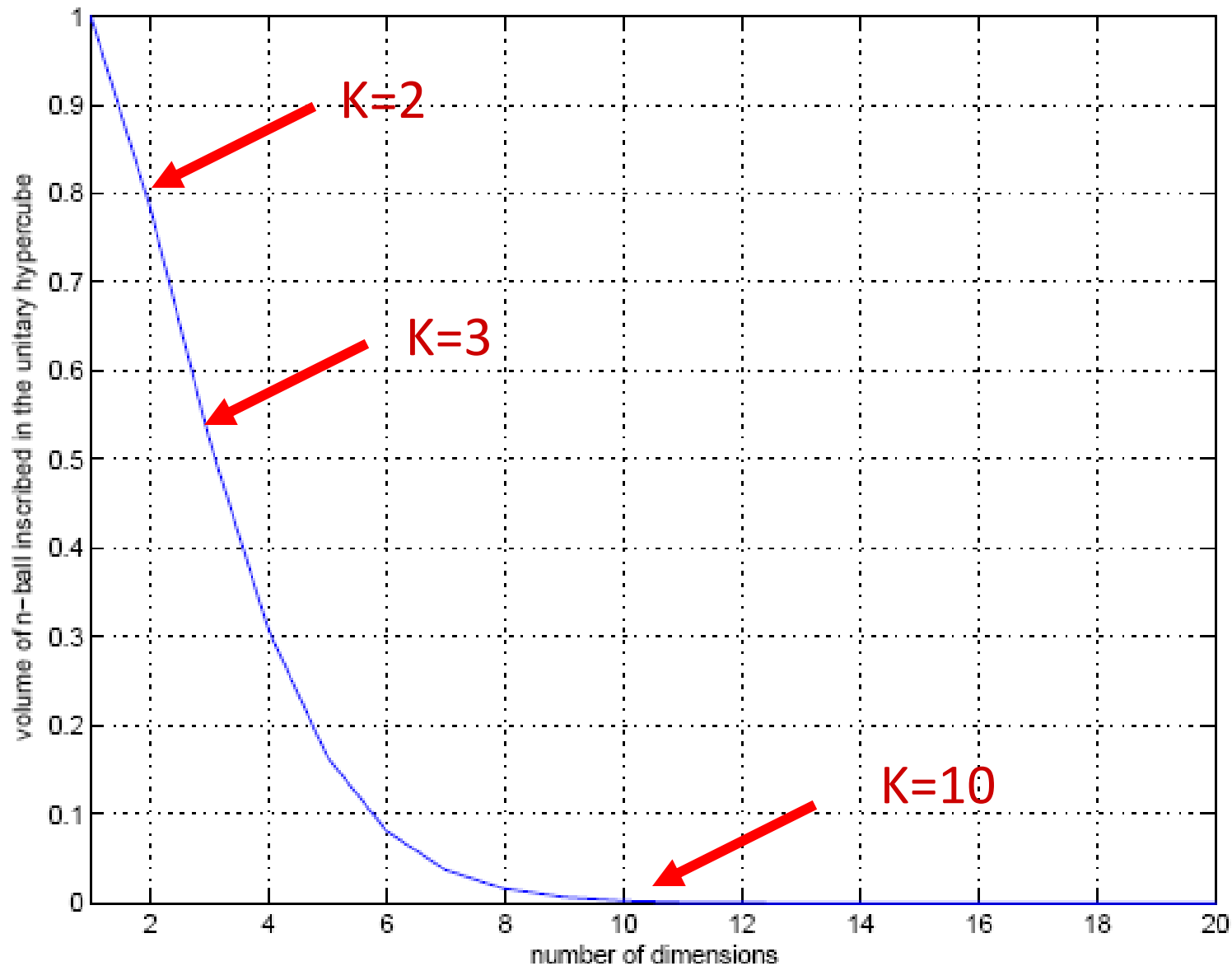
$\sim 1/2$

# OAT in 10 dimensions

Volume hypersphere / volume ten  
dimensional hypercube =? ~ 0.0025



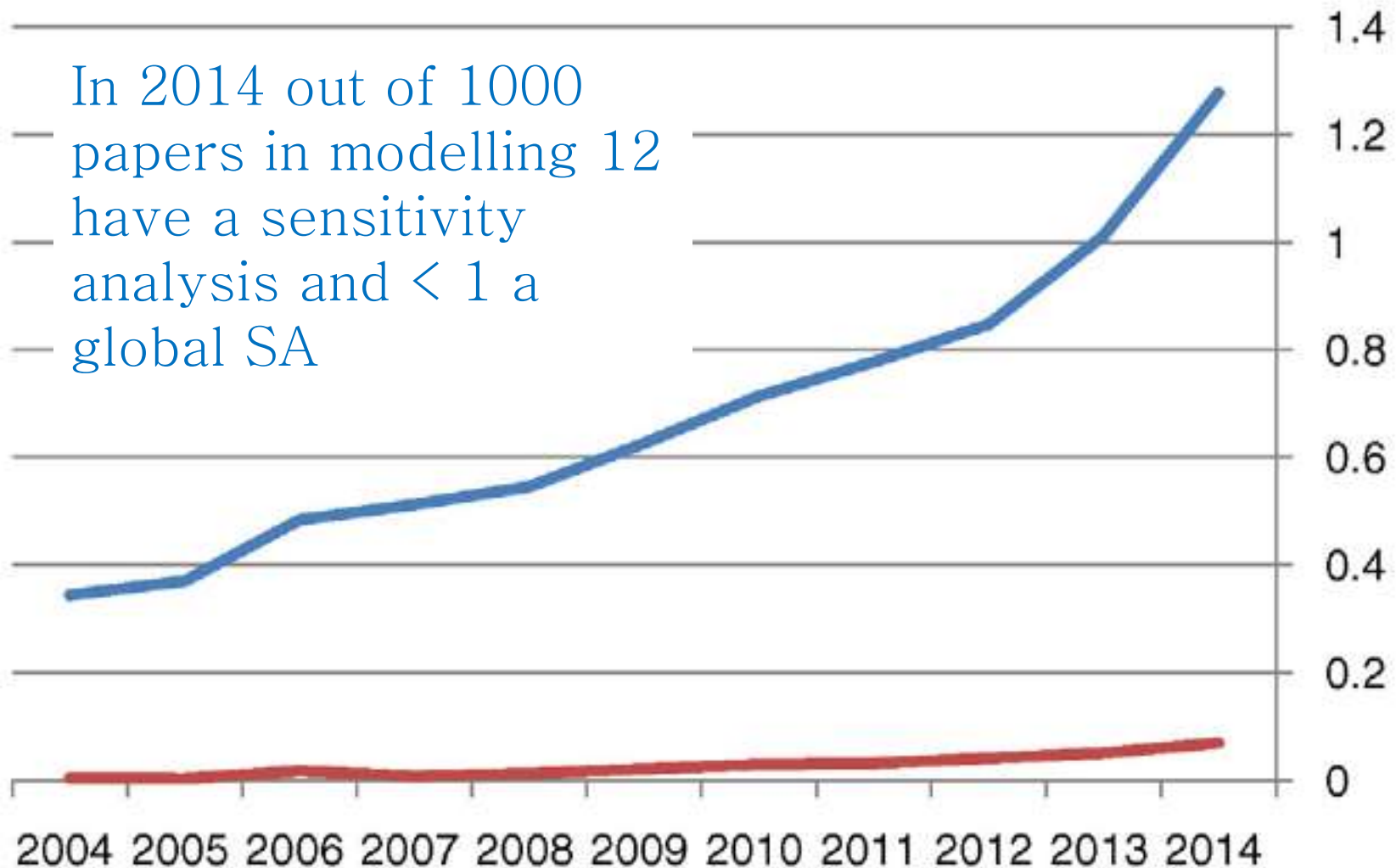
# OAT in $k$ dimensions



Bottom-line: once a sensitivity analysis is done via OAT there is no guarantee that either uncertainty analysis (UA) or sensitivity analysis (SA) is any good:

- ➔ UA will be non conservative
- ➔ SA may miss important factors

In 2014 out of 1000 papers in modelling 12 have a sensitivity analysis and < 1 a global SA



— TOT\_SA/TOT\_MOD (%)  
— TOT\_GSA/TOT\_MOD (%)

Ferretti, F., Saltelli A., Tarantola, S., 2016, Trends in Sensitivity Analysis practice in the last decade, Science of the Total Environment, <http://dx.doi.org/10.1016/j.scitotenv.2016.02.133>



# Secrets of sensitivity analysis

First secret: The most important question is the question.

Corollary 1: Sensitivity analysis is not “run” on a model but on a model once applied to a question.

First secret: The most important question is the question.

Corollary 2: The best setting for a sensitivity analysis is one when one wants to prove that a question cannot be answered given the model

It is better to be in a setting of falsification than in one of confirmation (Oreskes et al., 1994 ).

[Normally the opposite is the case]

Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences,  
Naomi Oreskes, Kristin Shrader-Frechette, Kenneth Belitz, Science, New Series, Vol. 263,  
No. 5147 (Feb. 4, 1994), pp. 641-646.

Second secret: Sensitivity analysis should  
not be used to hide assumptions  
[it often is]



Third secret: If sensitivity analysis shows that a question cannot be answered by the model one should find another question/model which can be treated meaningfully.

[Often the love for the model prevails]

Badly kept secret:

There is always one more bug!

(Lubarsky's Law of Cybernetic  
Entomology)



And of course please don't ...

... run a sensitivity analysis where each  
factors has a 5% uncertainty



# Sensitivity auditing

# EC impact assessment guidelines: what do they say about sensitivity auditing ?



[http://ec.europa.eu/smart-regulation/guidelines/docs/br\\_toolbox\\_en.pdf](http://ec.europa.eu/smart-regulation/guidelines/docs/br_toolbox_en.pdf)

p. 392

... where there is a major disagreement among stakeholders about the nature of the problem, ... then sensitivity auditing is more suitable but sensitivity analysis is still advisable as one of the steps of 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.

[...]

The ultimate aim is to communicate openly and honestly the extent to which particular models can be used to support policy decisions and what their limitations are.

p. 393

“In general sensitivity auditing stresses the idea of honestly communicating the extent to which model results can be trusted, taking into account as much as possible all forms of potential uncertainty, and to anticipate criticism by third parties.”



# The rules of sensitivity auditing

Rule 1: Check against rhetorical use of mathematical modelling;

Rule 2: Adopt an “assumption hunting” attitude; focus on unearthing possibly implicit assumptions;

Rule 3: Check if uncertainty been instrumentally inflated or deflated.

# The rules of sensitivity auditing

Rule 4: Find sensitive assumptions before these find you; do your SA before publishing;

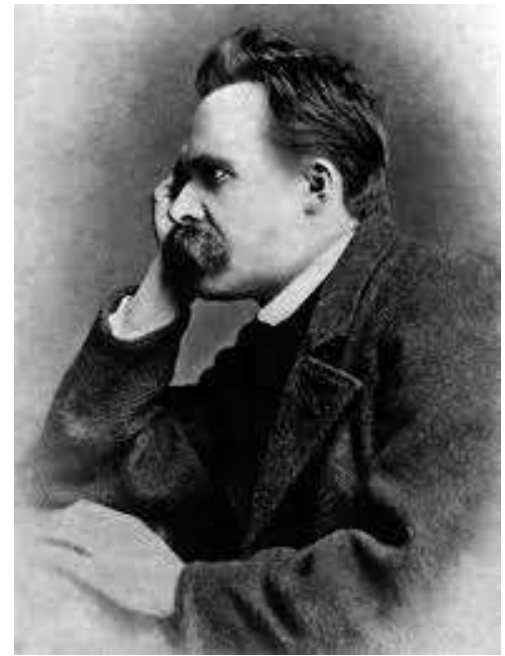
Rule 5: Aim for transparency; Show all the data;

Rule 6: Do the right sums, not just the sums right; the analysis should not solve the wrong problem;

Rule 7: Perform a proper global sensitivity analysis.

# Quantitative story-telling

“There is only a perspective seeing, only a perspective “knowing”; and the more affects we allow to speak about one thing, the more eyes, different eyes, we can use to observe one thing, the more complete will our “concept” of this thing, our “objectivity”, be.”



Friedrich Nietzsche, *Genealogy of Morals*, Third Essay.

# Frames

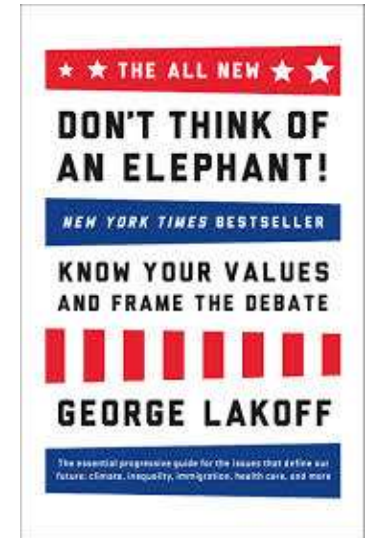
The expression ‘tax relief’ is apparently innocuous but it suggests that tax is a burden, as opposed to what pays for road, hospitals, education and other infrastructures of modern life (Lakoff, 2004).



George Lakoff

Lakoff, G., 2010, Why it Matters How We Frame the Environment, Environmental Communication: A Journal of Nature and Culture, 4:1, 70-81.

Lakoff, G., 2004-2014, Don't think of an elephant: know your values and frame the debate, Chelsea Green Publishing.



## Why Free Markets Make Fools of Us

Cass R. Sunstein

OCTOBER 22, 2015 ISSUE

*Phishing for Phools: The Economics of Manipulation and Deception*

by George A. Akerlof and Robert J. Shiller  
Princeton University Press, 272 pp., \$24.95



*The Rolls-Royce Silver Cloud — \$13,595*

“At 60 miles an hour the loudest noise in this new Rolls-Royce comes from the electric clock”

*An advertisement for Rolls-Royce from the late 1950s*

# Frames

For Akerlof and Shiller - against what the ‘invisible hand’ would contend - economic actors have no choice but to exploit frames to ‘phish’ people into practices which benefit the actors not the subject phished.



George Akerlof



Robert R. Shiller

Instead of Evidence-based policy: robust policy:

Test for:

- feasibility (compatibility with processes outside human control);
- viability (compatibility with processes under human control, in relation to both the economic and technical dimensions); and
- desirability (compatibility with a multitude of normative considerations relevant to a plurality of actors).



# Frames as hypocognition & Socially constructed ignorance

For Rayner (2012) “Sense-making is possible only through processes of exclusion. Storytelling is possible only because of the mass of detail that we leave out. Knowledge is possible only through the systematic ‘social construction of ignorance’ (Ravetz, 1986)”



Steve Rayner



Jerry Ravetz

Ravetz, J., R., 1987, Usable Knowledge, Usable Ignorance, Incomplete Science with Policy Implications, *Knowledge: Creation, Diffusion, Utilization*, 9(1), 87-116.

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 societies may use to deal with “uncomfortable knowledge”.

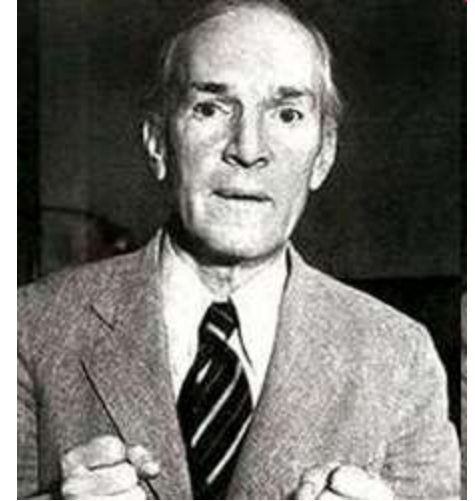
- Denial: “There isn’t a problem”
- Dismissal: “It’s a minor problem”
- Diversion: “Yes I am working on it” (In fact I am working on something that is only apparently related to the problem)
- Displacement: “Yes and the model we have developed tells us that real progress is being achieved” (The focus is now the model not the problem).

“Uncomfortable knowledge” can be used as a gauge of an institution’s health.

The larger the “uncomfortable knowledge” an institution needs to maintain, the closer it is to its ancient régime stage (Funtowicz and Ravetz, 1994).

## Why frames ‘stick’

“It is difficult to get a man to understand something when his salary depends upon his not understanding it.”



Upton Sinclair

Some examples:

Sensitivity analysis: the case of  
the Stern review



Contents lists available at ScienceDirect

## Global Environmental Change

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



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

Andrea Saltelli\*, Beatrice D'Hombres

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



HOME ABOUT ME



# The case of Stern's Review – Technical Annex to postscript



William Nordhaus,  
University of Yale



Nicholas Stern, London  
School of Economics

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

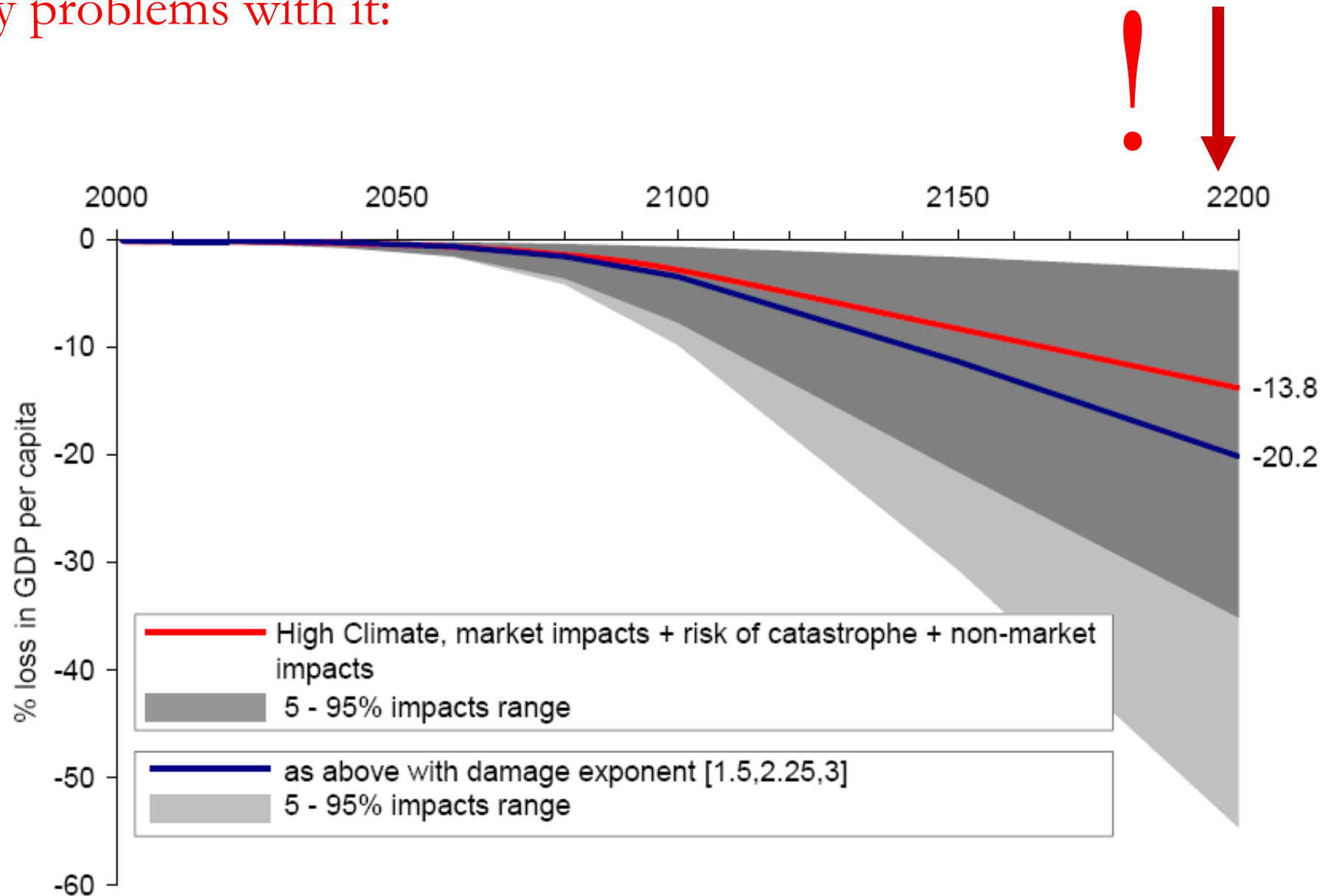
Nordhaus W., Critical Assumptions in the Stern Review on  
Climate Change, *SCIENCE*, 317, 201-202, (2007).



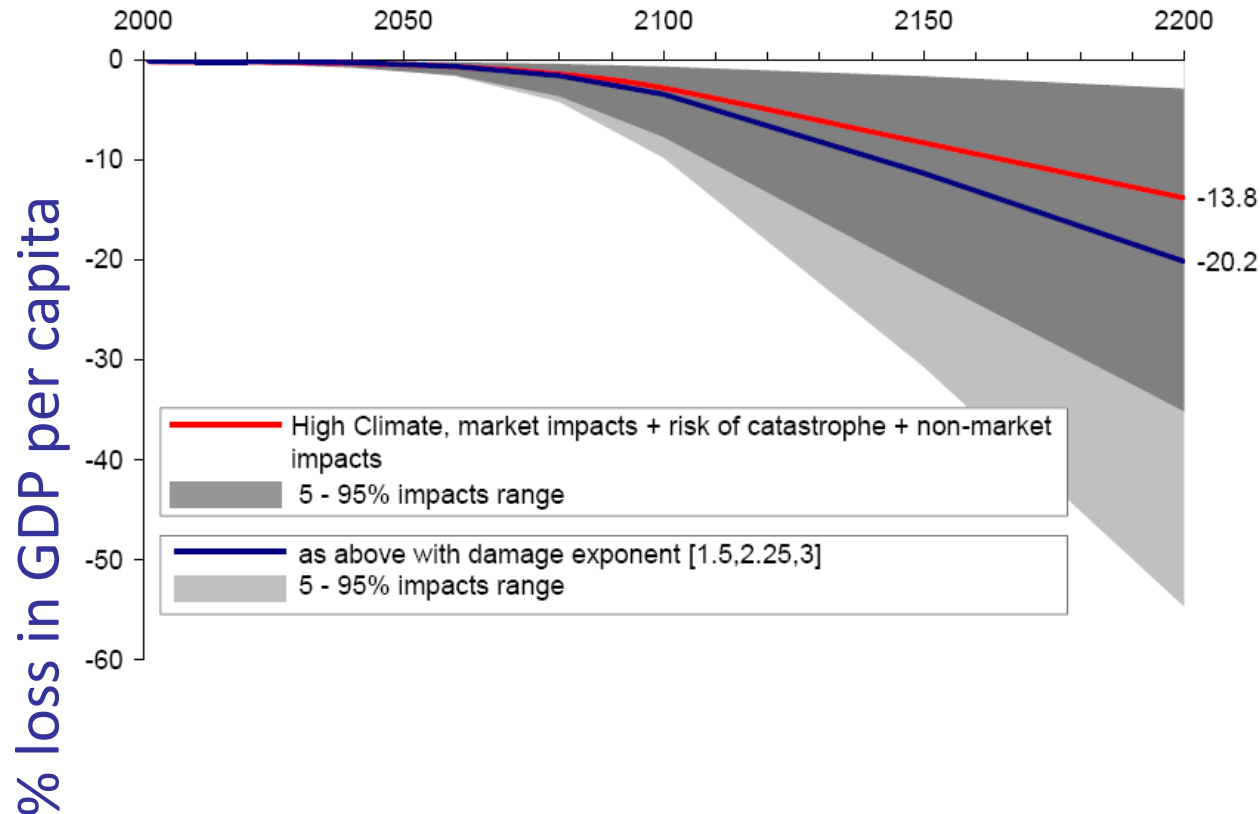
## The Stern - Nordhaus exchange on *SCIENCE*

- 1) Nordhaus falsifies Stern based on ‘wrong’ range of discount rate
- 2) Stern’s complements its review with a postscript: a sensitivity analysis of the cost benefit analysis
- 3) Stern infers: My analysis shows robustness’

My problems with it:

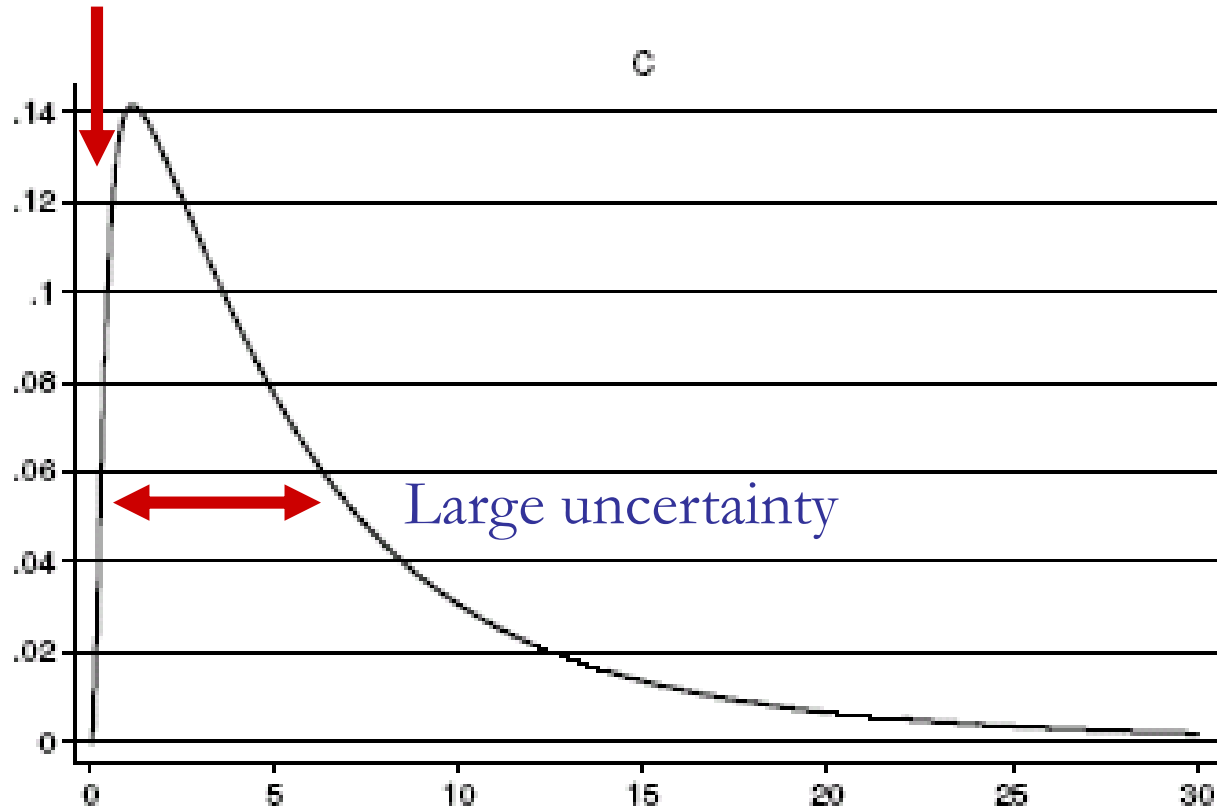


... but foremost Stern says:  
changing assumptions → important effect  
when instead he should admit that:  
changing assumptions → all changes a lot



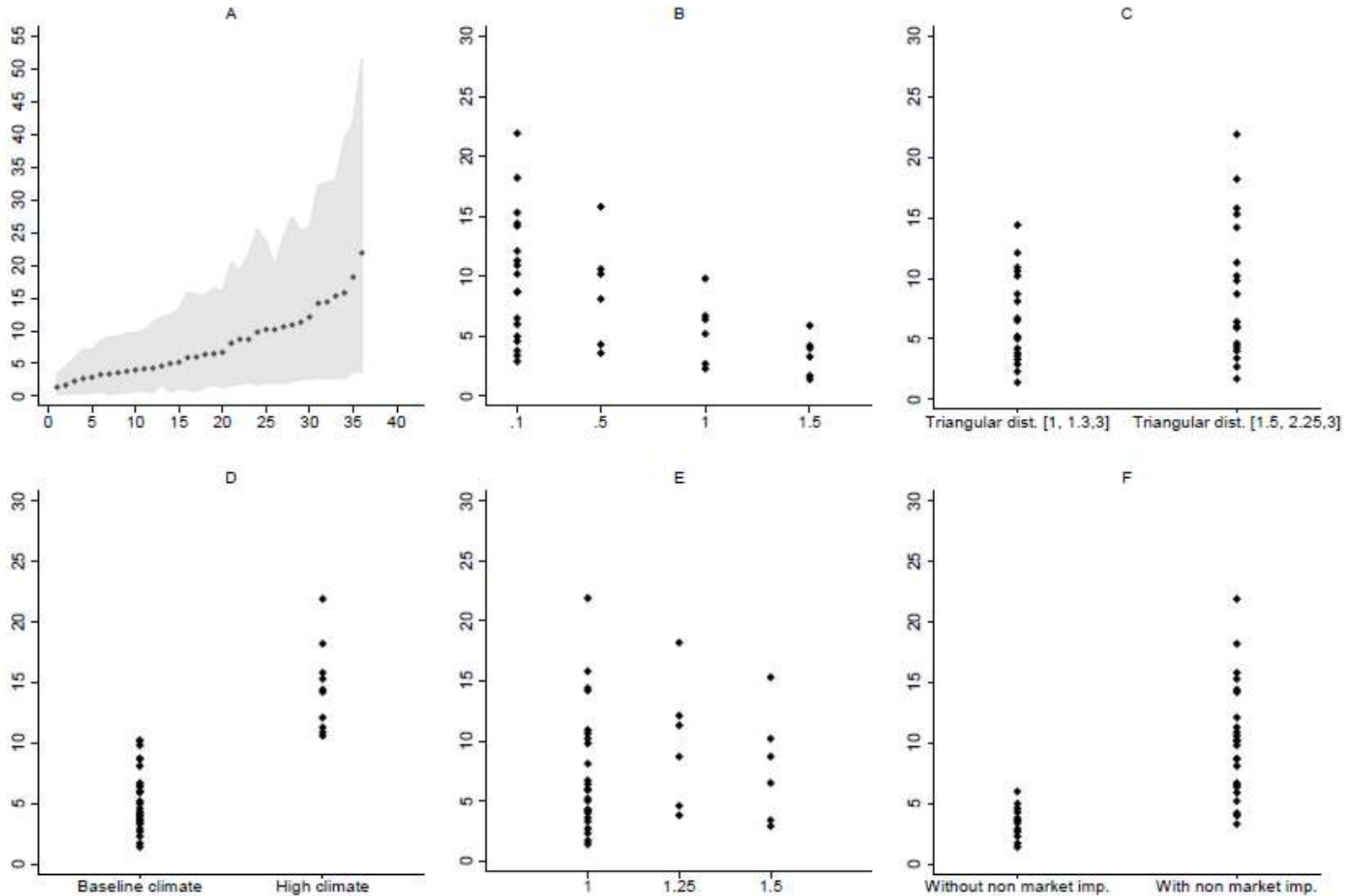
# How was it done? A reverse engineering of the analysis

Missing points

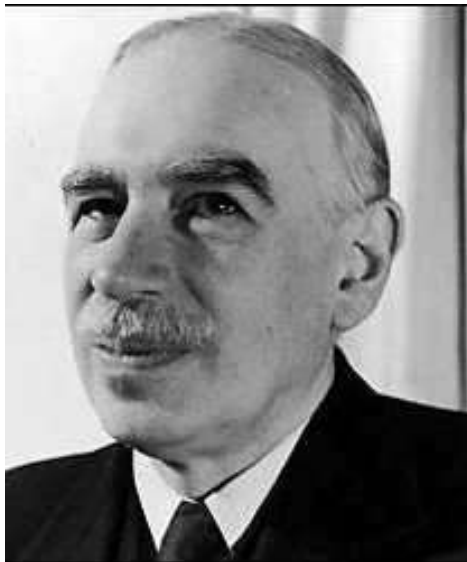


% loss in GDP per capita

# Sensitivity analysis here (also by reverse engineering)



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



... precisely wrong

From: Saltelli, A., D'Hombres, 2010, Sensitivity analysis didn't help. A practitioner's critique of the Stern review, *GLOBAL ENVIRONMENTAL CHANGE*, 20, 298–302.

Some examples:

Sensitivity auditing: the OECD  
PISA study

---

# Do PISA data justify PISA-based education policy?

PISA-based  
education  
policy



International Journal of  
Comparative Education and  
Development  
Vol. 19 No. 1, 2017  
pp. 1-17

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2396-7404

DOI 10.1108/IJCED-12-2016-0023

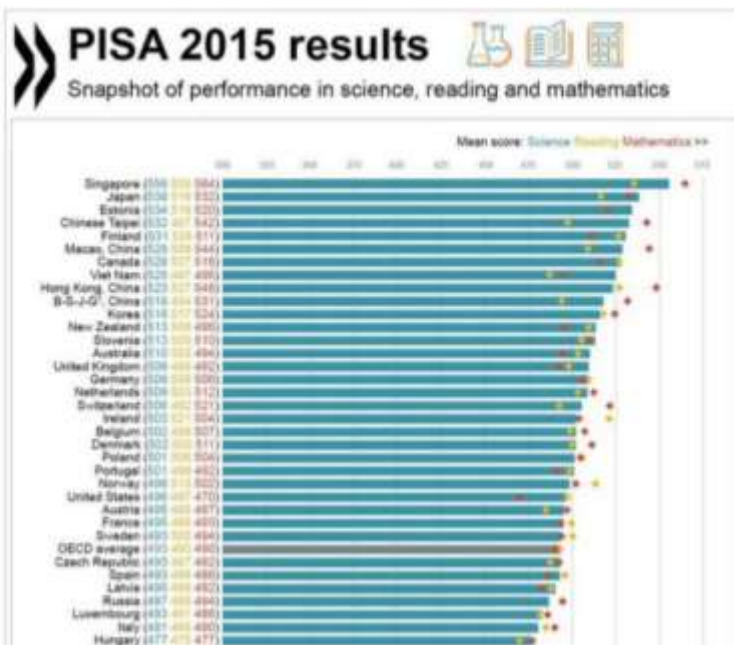




## International PISA tests show how evidence-based policy can go wrong

June 12, 2017 3:55pm AEST

Chemistry class at the Dong Tien Secondary School, Thai Nguyen Province, Vietnam. Asian Development Bank/Wide, CC BY-SA



A condensed version of the article

With PISA the OECD gained the centre-stage in the international arena on education (see Porter's book) policies, which led to important controversies

<http://www.theguardian.com/education/2014/may/06/oecd-pisa-tests-damaging-education-academics>

the **guardian**

## OECD and Pisa tests are damaging education worldwide - academics

In this letter to Dr Andreas Schleicher, director of the OECD's Programme for International Student Assessment, academics from around the world express deep concern about the impact of Pisa tests and call for a halt to the next round of testing



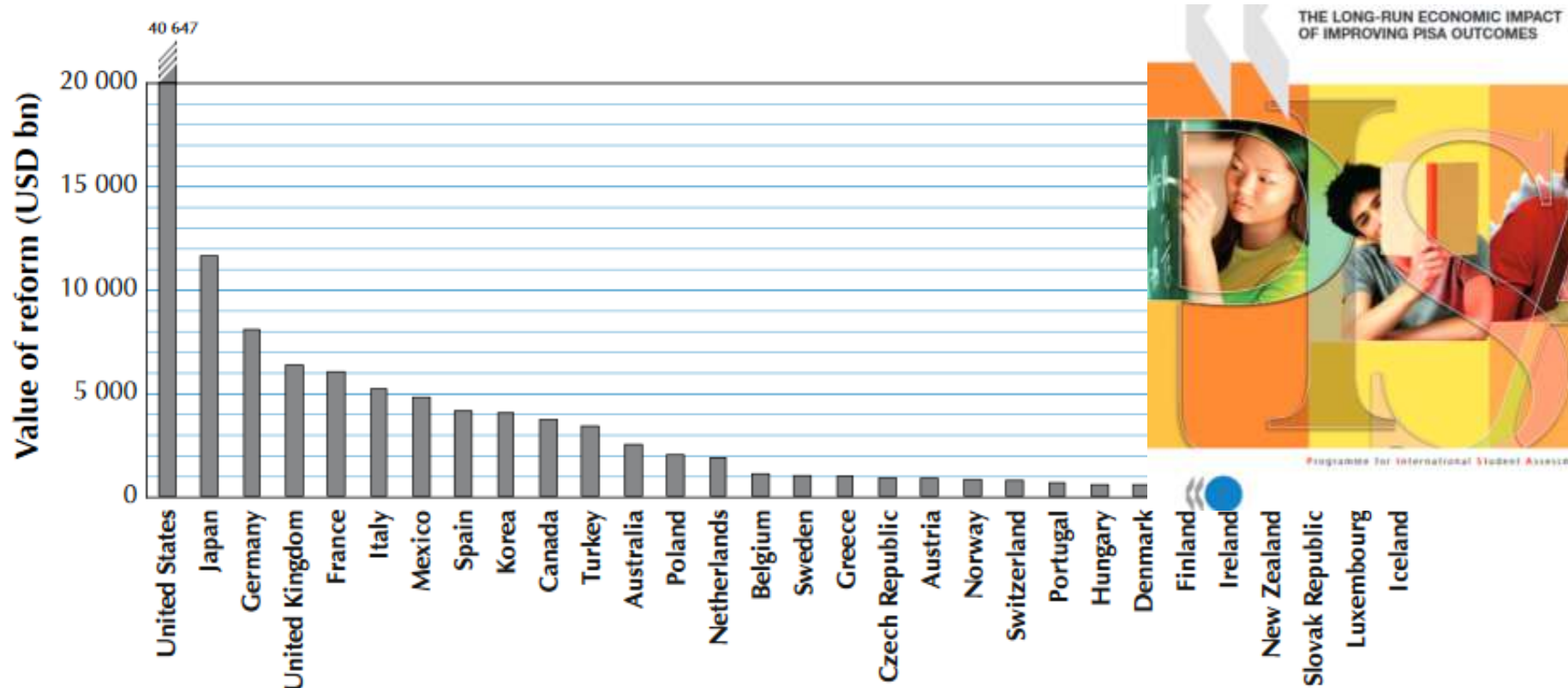
① School children in Sichuan province in China. Academics say the OECD should develop alternatives to league tables and find more meaningful ways of reporting assessment, taking account of different cultures. Photograph: James Zeng Huang/Corbis Sygma

## Critical remarks by the 80 signatories of the letter:

- Flattening of curricula (exclusion of subjects)
- Short-termism (teaching to the test)
- Promoting “life skills to function in knowledge societies”
- Stressing the student
- ... ➔ Stop the test!
- A more participatory run of the study would be advisable

**Figure 1**

**Present value of Scenario I (improve student performance in each country by 25 points on the PISA scale) in billion USD (PPP)**



Note: Discounted value of future increases in GDP until 2090 due to reforms that improve student performance in each

<http://www.oecd.org/edu/school/programmeforinternationalstudentassessmentpisa/thehighcostofloweducationalperformance.htm>

# PISA's daring quantifications:

“If every EU Member State achieved an improvement of 25 points in its PISA score (which is what for example Germany and Poland achieved over the last decade), the GDP of the whole EU would increase by between 4% and 6% by 2090; such an 6% increase would correspond to 35 trillion Euro”

Our study identifies both technical and normative issues:

1) Non response bias (what students are excluded; PISA non-response for England: the bias turned out to be twice the size of the OECD declared standard error in 2003.

2) Non open data, which makes SA impossible

Our study identifies both technical and normative issues:

3) Flattening curricula (do all countries wish to prosper by becoming knowledge societies?)

4) Power implications: power in the use of evidence. OECD (unelected officers and scholars) becoming a global super-ministry of education

Some examples:

Sensitivity auditing/Quantitative  
storytelling: scenarios for food  
security



DISCUSSION PAPER

# Problematic Quantifications: a Critical Appraisal of Scenario Making for a Global ‘Sustainable’ Food Production

Andrea Saltelli<sup>1,2,3</sup>  • Samuele Lo Piano<sup>1</sup>

Accepted: 4 August 2017 / Published online: 15 August 2017  
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## Pathways Leading to a More Sustainable and Healthy Global Food System

Volume 7 | Issue 5 | Page 10-12 | September 2016

By Krishna Bahadur KC, Evan D.G. Fraser, Samantha Pascoal, Goretty Dias, Trudi Zundel



Purchase



“What follows is a hypothetical executive summary from an imagined Food and Agriculture Organization (FAO) report on the state of the world’s food systems, written from the perspective of the 2050s”

<https://www.thesolutionsjournal.com/article/pathways-leading-sustainable-healthy-global-food-system/>

# Executive Summary: FAO State of World Agriculture in 2050 Draft Report


“[...]this FAO report presents evidence that the international food system of the second half of the 21st century is more sustainable than the food system of the late 20th or early 21st centuries.



[...] today more people are being fed on less land and agriculture is requiring fewer inputs”

# Executive Summary: FAO State of World Agriculture in 2050 Draft Report

Three digits



“[...] despite there being 10 billion people on the planet, today agriculture requires 438 million hectares\* less land than it did in 2015, yet produces more adequate nutrition for all.”

\*Authors' estimate

This [438 Mha] figure was arrived at by assuming that:

- Agriculture shifts away from over production of cereals, oils, and sugars, but increases fruit and vegetables;
- Agricultural yields increase  $\sim 1\%/y$  between now and 2050.
- Protein consumption shifts from 86% animals and 14% plants to 50% animal and 50% plant.

*“Please contact the authors for references etc. pertaining to these calculations”*



## Our study:

- Gain in number of hectares: three significant digits (438 millions)?
- Balancing hectares growth and population growth (our computation) results in no change in food per capita at planetary scale.

## Our study:

- Neglect of diminishing returns and ecosystem stress (fertilizers, pesticides)
- More adults (higher caloric intake) in 2050 population
- Can one educate citizens globally? The case of tobacco

In conclusion the

“mismatch between what the world needed for everyone to enjoy a nutritious diet and what the world was actually producing”

is the substitution of a political problem with a technical one



Some examples:

Sensitivity

auditing/Quantitative

storytelling: Golden Rice's  
story

Speaking of Science

# 107 Nobel laureates sign letter blasting Greenpeace over GMOs

By Joel Achenbach June 30

<https://www.washingtonpost.com/news/speaking-of-science/wp/2016/06/29/more-than-100-nobel-laureates-take-on-greenpeace-over-gmo-stance/>



While Greenpeace and other organizations oppose genetically engineered food, more than 100 Nobel laureates are taking a stand on the side of GMOs. Here's a look at each side's arguments. (Jenny Starrs/The Washington Post)

“While Greenpeace and other organizations oppose genetically engineered food, more than 100 Nobel laureates are taking a stand on the side of GMOs. Here's a look at each side's arguments. (Jenny Starrs/The Washington Post)”

From the Noble laureates' letter:

“Greenpeace has spearheaded opposition to Golden Rice, which has the potential to reduce or eliminate much of the death and disease caused by a vitamin A deficiency (VAD), which has the greatest impact on the poorest people in Africa and Southeast Asia.

[...] a total of one to two million preventable deaths occur annually as a result of VAD, [...] VAD itself is the leading cause of childhood blindness globally affecting 250,000 – 500,000 children each year. Half die within 12 months of losing their eyesight”

From the Noble laureates' letter:

“[...] Opposition based on emotion and dogma contradicted by data must be stopped.

How many poor people in the world must die before we consider this a "**crime against humanity**"?"

# Opposing evidence on Golden Rice

Nutritionally: not enough beta carotene

Golden rice not authorized yet

More politically viable alternative successful

Dangerous colour

Low yield of the modified variety ...

<http://www.ecowatch.com/greenpeace-to-nobel-laureates-its-not-our-fault-golden-rice-has-failed-1896697050.html>



“What climate, vaccines and GMOs have in common”

<https://theconversation.com/forcing-consensus-is-bad-for-science-and-society-77079>

Some examples:

Sensitivity auditing/Quantitative  
storytelling: The Ecological  
Footprint

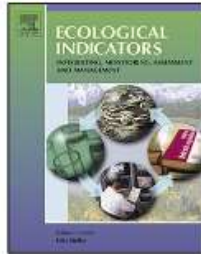




Contents lists available at [ScienceDirect](#)

## Ecological Indicators

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



### Footprints to nowhere

Mario Giampietro<sup>a,c</sup>, Andrea Saltelli<sup>b,\*</sup>

<sup>a</sup> *Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain*

<sup>b</sup> *Institute for the Protection and Security of the Citizen (IPSC), The European Commission, Joint Research Centre, TP 361, 21027 Ispra, VA, Italy*

<sup>c</sup> *Catalan Institution for Research and Advanced Studies (ICREA), Passeig Lluís Companys, 23, 08010 Barcelona, Spain*



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Giampietro, M., and Saltelli, A., 2014, Footprints to nowhere, Ecological Indicators, 46, 610–621.

Goldfinger, S., Wackernagel, M., Galli, A., Lazarus, E., Lin, D., 2014, Footprint facts and fallacies: A response to Giampietro and Saltelli (2014) “Footprints to Nowhere”, 46, 622–632.

Giampietro, M., and Saltelli, A., 2014, Footworking in Circles, Ecological Indicators, 46 (2014) 260–263.

Alessandro Galli , Mario Giampietro , Steve Goldfinger, Elias Lazarus, David Lin, Andrea Saltelli , Matthis Wackernagel , Felix Müller, 2016, Questioning the ecological footprint , Ecological Indicators, 69, 224–232.

All the story . . .



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# How many Chinas does it take to support China?

 CHINA 2.5   

What about some other countries?

 FRANCE 1.6  

 INDIA 1.8  

 U.S.A. 1.9  

 EGYPT 2.4   

 GREECE 3.1    

 U.K. 3.5    

 ITALY 4.0    

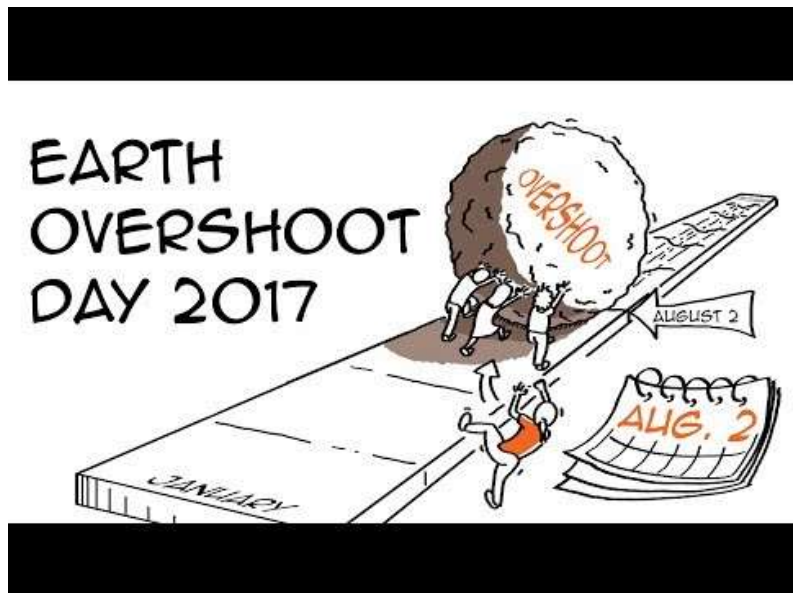
 SWITZERLAND 4.2     

 QATAR 5.7      

 JAPAN 7.1       

 WORLD 1.5  

Based on two “accounts (biocapacity and footprint) representing the supply and demand of renewable biological resources, and the area of forest required to offset human carbon emissions (the carbon footprint)” the EF tells mankind how many planets are being used

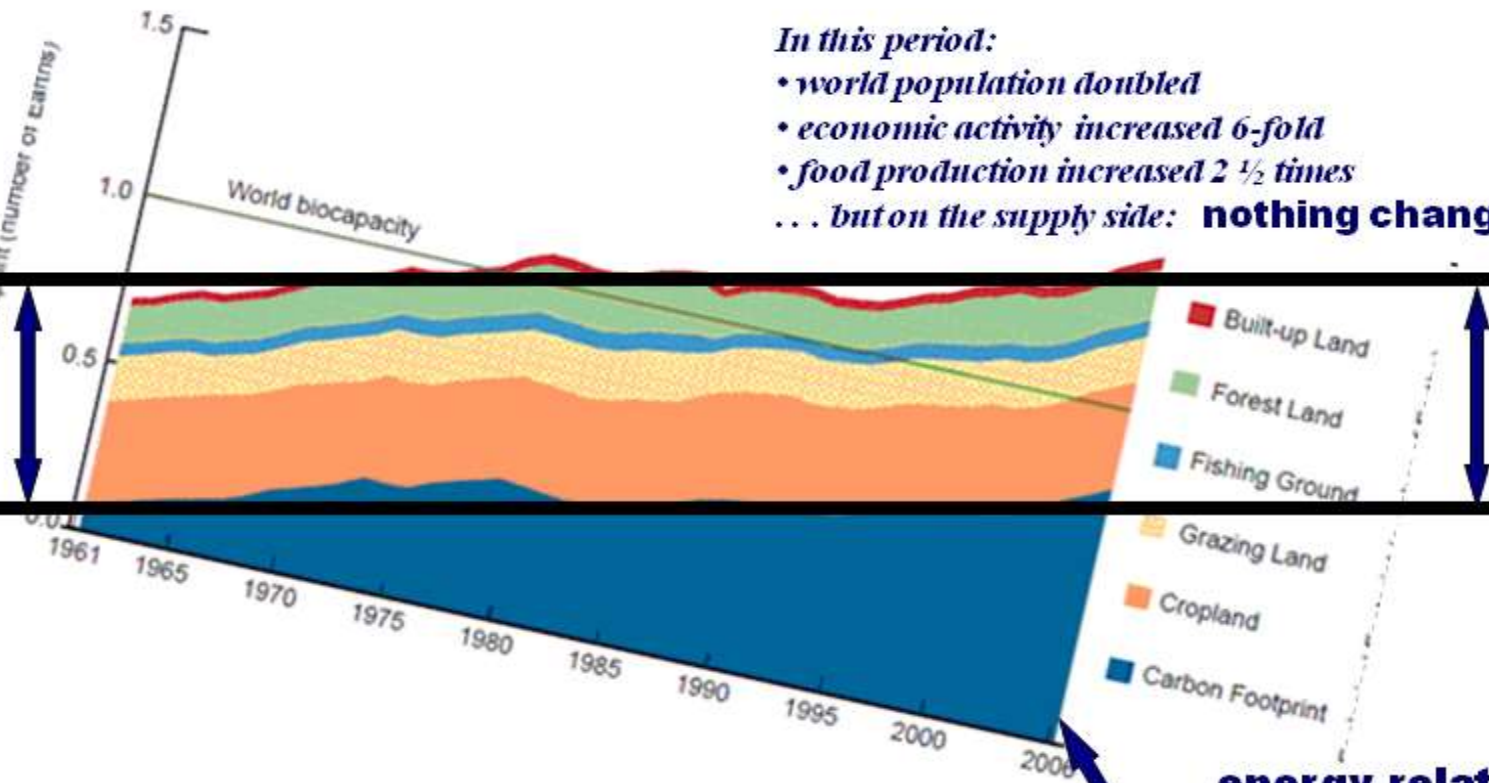


# The change of world footprint in time (1961-2006)

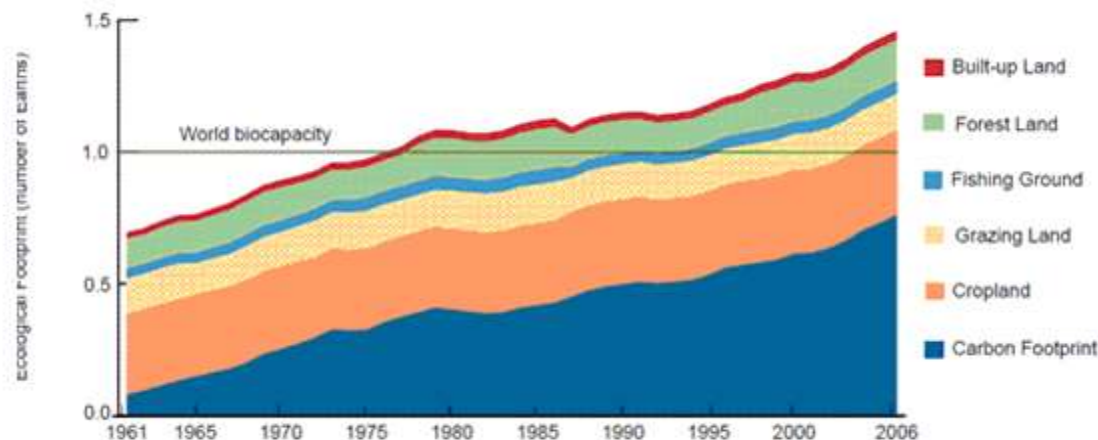
*In this period:*

- world population doubled
- economic activity increased 6-fold
- food production increased 2 ½ times
- ... but on the supply side: **nothing changed!**

**non-energy  
related  
biocapacity  
demand**



**energy related  
biocapacity  
demand**



*the only measured change in EF  
is generated by a very creative  
protocol convert ing energy use  
into hectares of planet ...*



The footprint is almost entirely driven by energy consumption, which corresponds to carbon emission which are in turn sequestered by forests; [...] Carbon sequestration rate is hence what drives the results

But this number could be made negative as well as infinity depending on what number one picks ... it is totally volatile

# Is the EF a rhetorical device?

- The implausible accuracy (Earth overshoot day = August 2! )
- Offsetting a flow with a stock (Kg of CO<sub>2</sub> per year versus square meters of land)
- The anti-trade bias (CMEPSP, 2009, p. 71)
- The total dependence upon energy related pressures
- Paradoxical policy implications (e.g. in Agriculture)

Giampietro and Saltelli, Op. cit.

CMEPSP (2009). Commission on the Measurement of Economic Performance and Social Progress, URL: [http://www.stiglitz-sen-fitoussi.fr/documents/rapport\\_anglais.pdf](http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf) last accessed June 2014.

# Is the EF a rhetorical device?

- The EF is inconsistent with its stated purpose of measuring demand on ecosystems
- The EF depends mostly from a dimensionally flawed energy emissions assessment
- One cannot accept EF's flaws on the ground that the EF has normative virtues; EF's rhetoric muddles the sustainability debate



“EF measurements, as currently constructed and presented, are so misleading as to preclude their use in any serious science or policy context.[...], less than half the area of the United States planted with eucalypts could essentially give us an EF equal to one Earth—an approach that no ecologist would recommend.”

Blomqvist L, Brook BW, Ellis EC, Kareiva PM, Nordhaus T, et al. (2013a) Does the Shoe Fit? Real versus Imagined Ecological Footprints. PLoS Biol 11(11): e1001700. doi:10.1371/journal.pbio.1001700.

See also follow up:

Rees WE, Wackernagel M (2013) The Shoe Fits, but the Footprint is Larger than Earth. PLoS Biol 11(11): e1001701. doi:10.1371/journal.pbio.1001701

Blomqvist L, Brook BW, Ellis EC, Kareiva PM, Nordhaus T, et al. (2013b) The Ecological Footprint Remains a Misleading Metric of Global Sustainability. PLoS Biol 11(11): e1001702. doi:10.1371/journal.pbio.1001702.

Some examples:  
Quantitative storytelling: Cost  
Benefit Analyses

The myth of scientific quantification via risk or cost benefit analyses, including of the impact of new technologies, has been at the hearth of the critique of the ecological moment (e.g. Schumacher, 1973; Winner, 1986; Funtowicz and Ravetz, 1994)

E. F. Schumacher, 1973, *Small Is Beautiful. Economics as if People Mattered*, Penguin Perennial,

Winner, L., 1986. *The Whale and the Reactor: a Search for Limits in an Age of High Technology*. The University of Chicago Press, 1989 edition.

Funtowicz, S.O. and Ravetz, J.R. (1994). The worth of a songbird: Ecological economics as a post-normal science. *Ecological Economics* 10(3), 197–207.

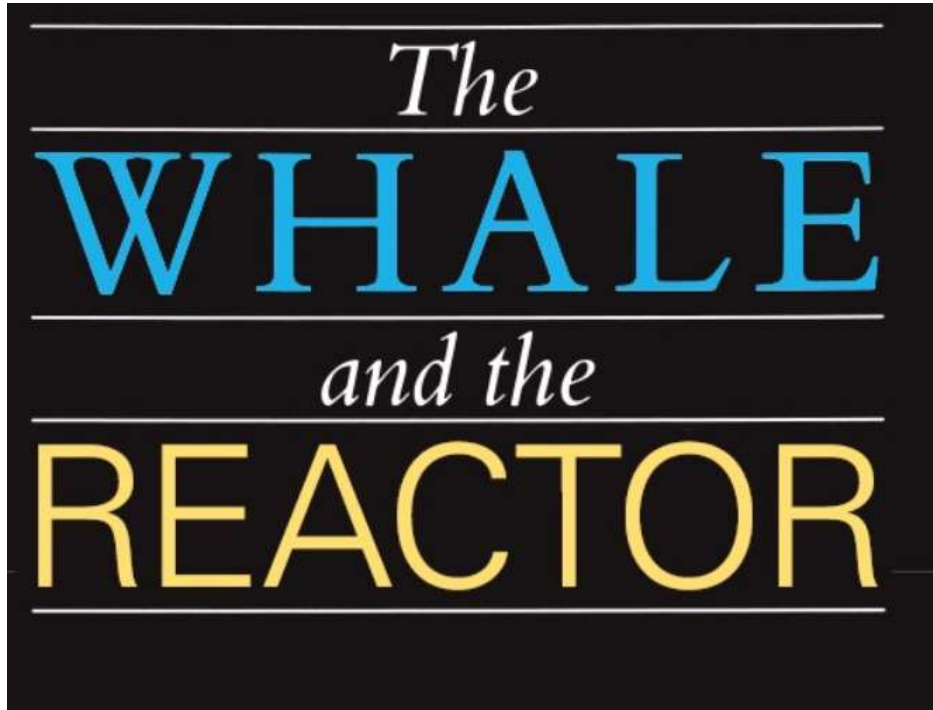
[...] quality is much more difficult to 'handle' than quantity, just as the exercise of judgment is a higher function than the ability to count and calculate.



Ernst Friedrich  
"Fritz"  
Schumacher

Quantitative differences can be more easily grasped and certainly more easily defined than qualitative differences: their concreteness is beguiling and gives them the appearance of scientific precision, even when this precision has been purchased by the suppression of vital differences of quality.

Most analyses offered as input to policy are framed as cost benefit analysis or risk analyses



Langdon Winner

Winner, L., 1986. *The Whale and the Reactor: a Search for Limits in an Age of High Technology*. The University of Chicago Press, 1989 edition.

Read chapter 8

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# 8

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## ON NOT HITTING THE TAR-BABY



Langdon Winner

On not falling into the trap of CBA  
and risk analyses

Winner, L., 1986. *The Whale and the Reactor: a Search for Limits in an Age of High Technology*. The University of Chicago Press, 1989 edition.



Consume GMO because they are safe.





## GMO as a food scare

The Economist, Vermont v science, The little state that could kneecap the biotech industry, May 10th 2014



## Citizens' worries (Marris, 2001, excerpts)



- Who decided that they should be developed and how?
- Why are we not given an effective choice about whether or not to buy and consume these products?
- Do regulatory authorities have sufficient powers and resources to effectively counter-balance large companies who wish to develop these products?

Marris, C., Wynne, B., Simmons P., and Weldon, S. 2001. Final Report of the PABE research project funded by the Commission of European Communities, Contract number: FAIR CT98-3844 (DG12 – SSMI), December 2001.

US National Academy of Sciences report on genetically engineered crops:

“Products of new technologies should be regulated not only on the basis of their benefit–risk profiles, but also on their societal context and need”

Hunter, J., Duff, G., Science, GM crops—lessons from medicine, 353, 1187 (2016)



# END

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