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Trends in sensitivity analysis practice in the last decade

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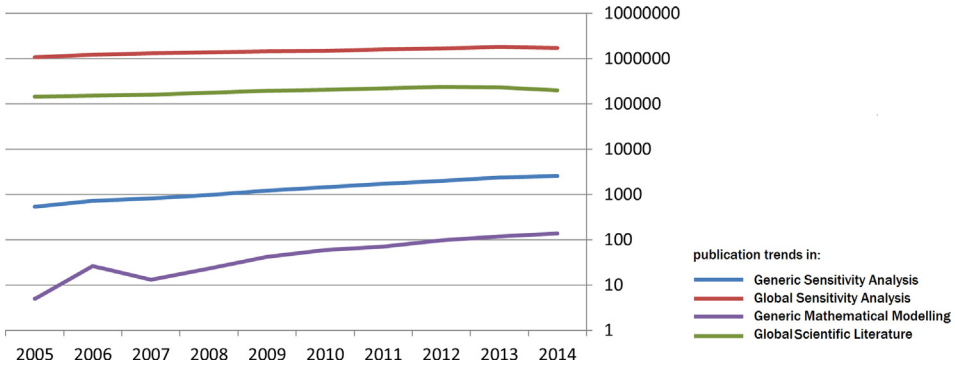
HIGHLIGHTS

- Sensitivity analysis is critical to gauge the relevance and plausibility of models.
- Sensitivity analysis is either overlooked or performed unsatisfactorily.
- We look at how things have changed over the last years performing bibliometric analyses.
- We see sign of improvements in the take up of global sensitivity analysis.
- Journals could play a role to improve responsible use of quantitative information.

GRAPHICAL ABSTRACT



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ABSTRACT

The majority of published sensitivity analyses (SAs) are either local or one factor-at-a-time (OAT) analyses, relying on unjustified assumptions of model linearity and additivity. Global approaches to sensitivity analyses (GSA) which would obviate these shortcomings, are applied by a minority of researchers.
By reviewing the academic literature on SA, we here present a bibliometric analysis of the trends of different SA practices in last decade. The review has been conducted both on some top ranking journals (Nature and Science) and through an extended analysis in the Elsevier's Scopus database of scientific publications.
After correcting for the global growth in publications, the amount of papers performing a generic SA has notably increased over the last decade. Even if OAT is still the most largely used technique in SA, there is a clear increase in the use of GSA with preference respectively for regression and variance-based techniques. Even after adjusting for the growth of publications in the sole modelling field, to which SA and GSA normally apply, the trend is confirmed. Data about regions of origin and discipline are also briefly discussed. The results above are confirmed when zooming on the sole articles published in chemical modelling, a field historically proficient in the use of SA methods.

1. Introduction

In "How to avoid a perfunctory sensitivity analysis", Saltelli and Annoni (2010) argued that the majority of published SAs were either local or one factor-at-a-time (OAT) analyses, relying on unjustified assumptions of model linearity and additivity. To the knowledge of the

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authors no dissent has been voiced in the literature against the paper's findings, which can be summarized as follow:

- Moving one factor at a time away from a fixed baseline in a multi-dimensional space of uncertain factors leaves the majority of that space unexplored. This is one of the consequences of the so-called curse of dimensionality, whereby the mass of a hyper-cube tends to concentrate in its edges and corners at increasing dimensionality – corners which are not visited if one moves factors away from their baseline one at a time.
- Further, moving one factor at a time leaves all interactions dormant as in order to activate them one needs to move more than one factor at a time, as known in statistical theory of the design of experiments. Experimental designs are in fact designed to efficiently uncover effects of various order e.g. main effects, second-order interactions, etc. Surprisingly many reported numerical experiments do not include a design at all.
- To obviate these shortcomings, global approaches to sensitivity analyses (GSA) are needed which are well described in the literature, but are applied by a minority of researchers.

2. Literature review

The literature review has initially been conducted by querying the databases of the high impact factor journals Science and Nature - whose impact factors in 2013 were 31.48 and 42.351 respectively (Thomson Reuters, http://thomsonreuters.com/journal-citation-reports, April 2015).

Search entries were set to exactly match the string "sensitivity analysis" anywhere in the text body for publications from 2005 to 2014. The retrieved documents have been thereafter individually scrutinized to assess their relevance for this research.

Approximately 30% of the raw database-return has been excluded because the content of the articles was found not related to the topic of sensitivity analysis of model output.

A pool of 66 publications was eventually used for the investigation (see Appendix for the searches' specification).

In most of the cases the articles could successfully be categorized into either OAT or GSA. In a few other cases an objective classification was not possible because the term "sensitivity analysis" was used generically in a context of uncertainty estimation.

For example, in Lentink et al. (2007) the sentence [*Sensitivity analysis: The performance maxima occur at the same wing configuration when we change body drag coefficient (2100%, 1200%), body weight (623%) and add the tail's contribution to lift (620% of wing lift)…*] clearly points to an OAT approach. In Carslaw et al. (2013) the sentence [*Here we carry out a variance-based sensitivity analysis of a global aerosol model to attribute the uncertainty in the aerosol first indirect forcing to uncertainties in the emissions and processes that control changes in aerosol over the industrial period…*] clearly refers to a GSA technique. Other less clear cut cases such as the one in Moreno et al. (2010), in which the model sensitivity seems to be conducted graphically, have been classified under the category "other".

2.1. Overall shares of SAs in top journals

The only inference permitted by Table 1 is that there still is dominance of OAT-type articles.

2.2. Overall shares of GSA in Elsevier's journals

An additional investigation in all Elsevier's journals using Scopus bibliometric search tools (www.scopus.com) enables a more extended review, although an article-by-article analysis is here clearly impractical. The queries adopted in this search are available in the appendix.

We performed various searches from 2005 onward to respectively assess:

1. The total number of articles (reviews, conference papers and letters have been excluded for comparability reasons). [TOT_PUB].
2. The total number of articles matching the string "sensitivity analysis" anywhere in the text body. The query also includes control strings to filter out entries not relevant to mathematical modelling. [TOT_SA].
3. The total amount of articles in 2 matching also GSAs methods (metamodel, high dimensional model representation, variance based, moment independent, elementary effect, regression). [TOT_GSA]=TOT_SA AND (technique_1 OR technique_2 OR … technique_N).
4. The total amount of articles in 1 also matching "modelling" or equivalent among the key words. [TOT_MOD].

Results are plotted in Fig. 1 on a logarithmic scale: GSA (violet line) seems to be gaining a slow but constant growing consensus.

2.3. GSA in the modellers' community

To assess their relevance, trends need to be adjusted by the global growth in publication they refer to. Fig. 2 presents the trends of TOT_SA and TOT_GSA over the global amount of documents published. Both trends clearly show the progressive community's interest in the area of SA (approximations fit linearly).

A similar trend in the number of SAs and GSAs is registered also relatively to the sole pool of publications on modelling (to which SA and GSA normally apply), after normalizing TOT_SA and TOT_GSA against the total number of publications in modelling TOT_MOD. Note how TOT_SA/TOT_MOD (blue line, left chart) is apparently undergoing a consistent expansion in the last couple of years.

Table 1
Articles in Science and Nature (own calculations).

Category	Description	Number of articles										Total
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
One factor at a time (OAT)	SA performed by changing one input at a time while keeping the others at their baseline nominal values	6	5	5	5	3	3	3	–	2	6	39
Global SA (GSA)	SA performed by changing all the inputs simultaneously	2	–	1	–	–	1	1	1	4	–	10
Other	SA mentioned in contexts not related to uncertainty quantification or not involving model-based calculations.	2	1	1	1	2	2	2	2	1	3	17
	Total documents on SA	10	6	7	6	5	6	6	3	7	9	66
Total articles published	The total number of articles published in Science and Nature.	4109	4014	3768	3796	3587	3539	3581	3538	3397	3273	36,602

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