INDRAPRASTHA INSTITUTE of INFORMATION TECHNOLOGY DELHI

ARTPARK
AI & Robotics Technology Park, I-Hub @ IISc

RESPONSIBLE USE OF MODELS IN COMPLEX SYSTEMS

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Overview

1 Why Models Matter

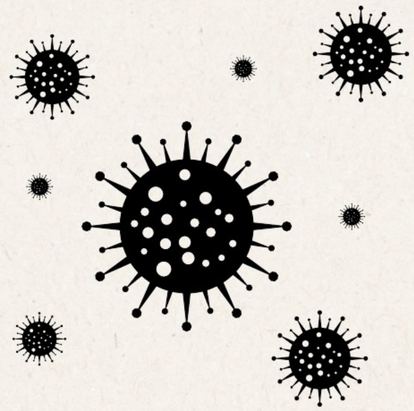
2 Reproducibility & Transparency

3 Uncertainty & Sensitivity Analysis

4 Ethics & Communication

Why Models Matter (And When They Go Wrong)

- Models simplify complex systems to help us understand, predict, and decide.
- Used in diverse fields for high stakes decision-making (eg: Covid-19 pandemic)
- Every model carries assumptions, simplifications, and value judgements.



Why Models Matter (And When They Go Wrong)

- Reinhart & Rogoff (2010): Excel spreadsheet error in economic model → used to justify austerity, later discredited.
- Ferguson’s Covid model (2020): Opaque code and assumptions → widespread influence, then public backlash and scepticism.

Why Models Matter (And When They Go Wrong)

A **model** is an abstract description of a **system** that uses precise **language** to describe its behaviour or inter-relationships.

Eg: Epidemiology, Population Dynamics, Climate Dynamics

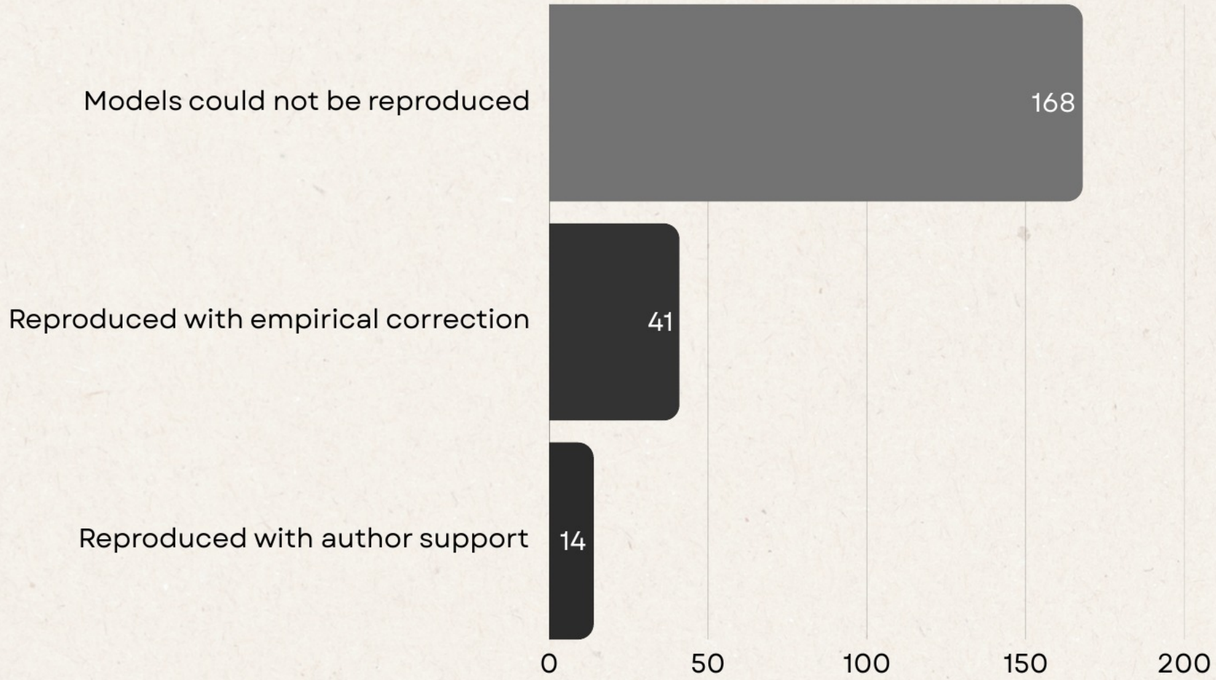
Eg: Equations

Model Reproducibility

Summary of a study by EMBL researchers on BioModels

455 kinetic models among which the mathematical equations of 389 models were analysed

233 out of 455 models (51%) directly reproduced the simulation results in the original manuscript



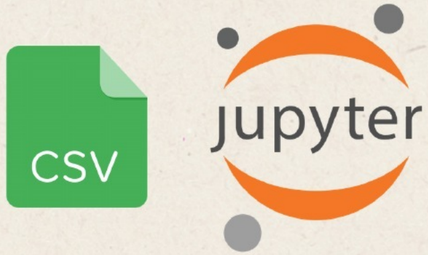
https://www.ebi.ac.uk/biomodels/reproducibility

Model Reproducibility

Reproducibility = ability to independently recreate results using the same data, code, assumptions, parameters, initial conditions.

Differ from replicability (similar result, different data) and robustness (same conclusion under variation).

Example:



Versions change, environment is different.

Tracks model configuration, parameters, and package versions.

Best Practices for Model Reproducibility

System Aspects

- Version Control
- Testing
- Reproducible Environment

Model Aspects

- Data version
- Parameter configuration
- Initial conditions and seeding
- Logging (instead of printing and checking)

Managing Sensitive Data Projects

Types of sensitive data: Personally Identifiable Information (PII), economically sensitive data, critical infrastructure data, surveillance data.

Inner source projects: Inner source is the use of open source software development best practices and open source-like culture within an organisation for the development of a non-open source output.

Tools

- Trusted Research Environment (TRE) or secure cloud workspace.
- Use anonymised or synthetic data for development.
- Model cards and technical appendix.

Transparency Beyond Code

Reproducibility ≠ Full transparency

Three critical judgements

- Which variables to include? (What's considered relevant?)
- What assumptions to make? (Simplifications, causal links, etc.)
- What futures to imagine? (Scenarios, time horizons, behaviours)

Transparency means exposing not only the model, but the **modelling process**.

Why We Must Test Our Modelling Assumptions

- Not all assumptions influence results equally.
- **Sensitivity analysis** asks: *“Which inputs, assumptions, or uncertainties most influence model outcomes?”*

Why this matters:

- Prevents false confidence in results.
- Helps to identify gaps and prioritise data collection.
- Builds credibility and trust.

What is Sensitivity Analysis?

Systematic study of how variations in model inputs affect outputs.

Key types:

- Local SA: Change one input at a time near a fixed point.
- Global SA: Explore full input space, all combinations (more realistic).

How not to do sensitivity analysis?

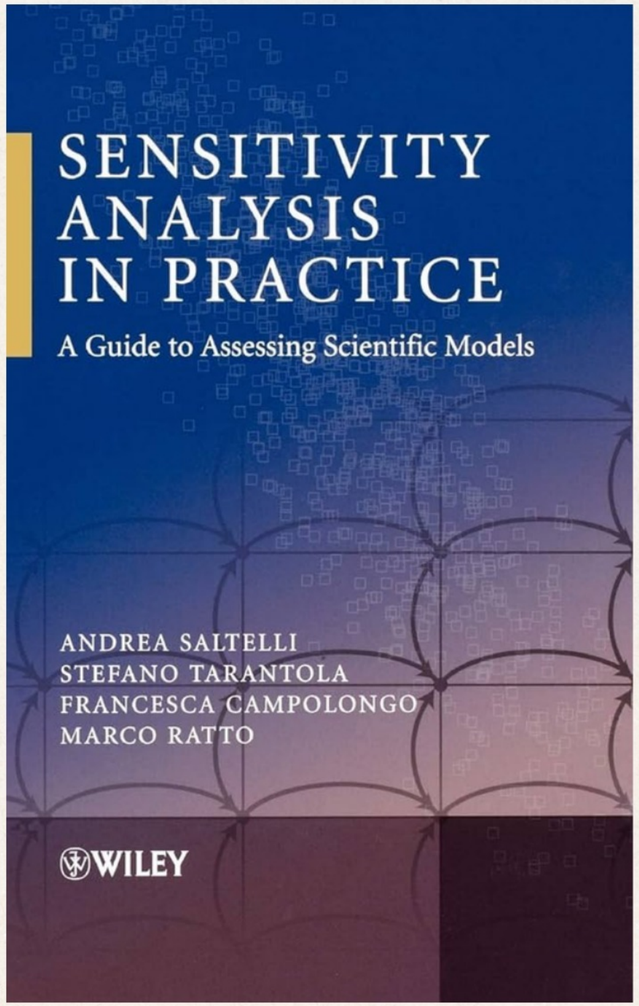
- Only changing one input at a time (OAT) when parameters are interdependent – misses important interactions between variables.
- Testing narrow ranges of parameters and ignoring edge cases.
- Undefined goals or unclear decision criteria.

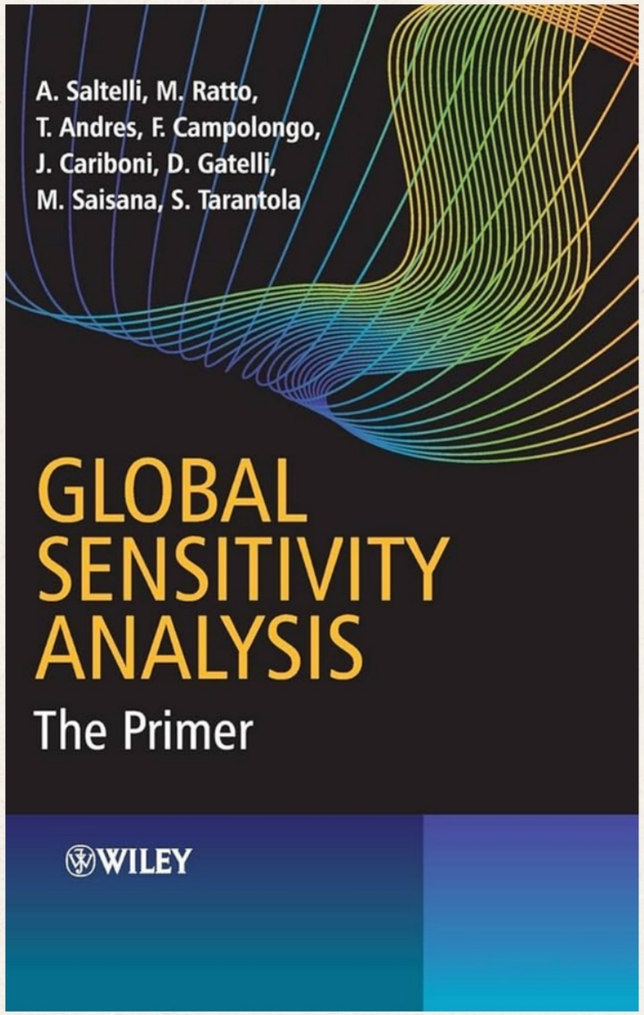
Sensitivity Analysis

Key methods

Method	Description	When to Use
One-at-a-Time (OAT)	Sequential variations in one parameter at a time while holding others constant.	Simple and quick, but only works when parameters are independent.
Morris Method	Random sampling of inputs with statistical analysis of results.	Use for preliminary screening or when computational cost is high.
Sobol' Indices	Uses variance decomposition to calculate first-order and total-order indices.	Best for high-dimensional models with complex interactions.

Sensitivity Analysis: Suggested readings



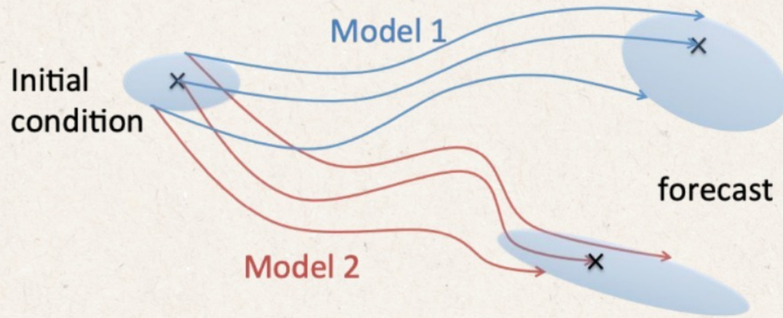


Beyond Input Variation: Categorising Uncertainty in Models

Types of uncertainty:

- Aleatory (Stochastic): Inherent randomness in the system
- Epistemic: limited or imperfect knowledge about the system being modelled.
- Parametric: values of input parameters.
- Structural: model's form, equations, or logic.

"Hawkmoth effect"



Erica L. Thompson and Leonard A. Smith (2014)

Hawkmoth Effect

Implications for decision-making

- Outputs must reflect real-world uncertainty, not just model-internal variation.
- Seeking ever more detailed outputs can delay action; instead, focus on robustness and transparent caveats.

Implications for model development

- Splitting models by purpose (understanding vs. decision) reduces pressure to "improve" all metrics.
- Decision models can focus on relevant variables, expert judgement, and adequacy-for-purpose.

Science When Stakes Are High

Post-Normal Science applies when:

- Facts are uncertain (e.g., models disagree, data is sparse)
- Values are in dispute (e.g., health vs. economy)
- Decisions are urgent (e.g., during a pandemic or climate crisis).

In such cases, science must go beyond "getting the right answer" to:

- Support deliberation under uncertainty.
- Include stakeholders and affected communities.
- Make assumptions and limitations explicit.

NUSAP

A Framework to Communicate Numbers with Their Context

Element	What It Describes	Example
Numeral	The number/result	“23%”
Unit	The measurement unit	“of cases prevented”
Spread	Range or statistical uncertainty	“±5%”
Assessment	Expert judgement on robustness	“Moderate confidence”
Pedigree	Evaluation of how the number was derived	“Based on expert elicitation with limited data”

Further reading: *Uncertainty and Quality in Science for Policy (Silvio Funtowicz and Jerome Ravetz)*

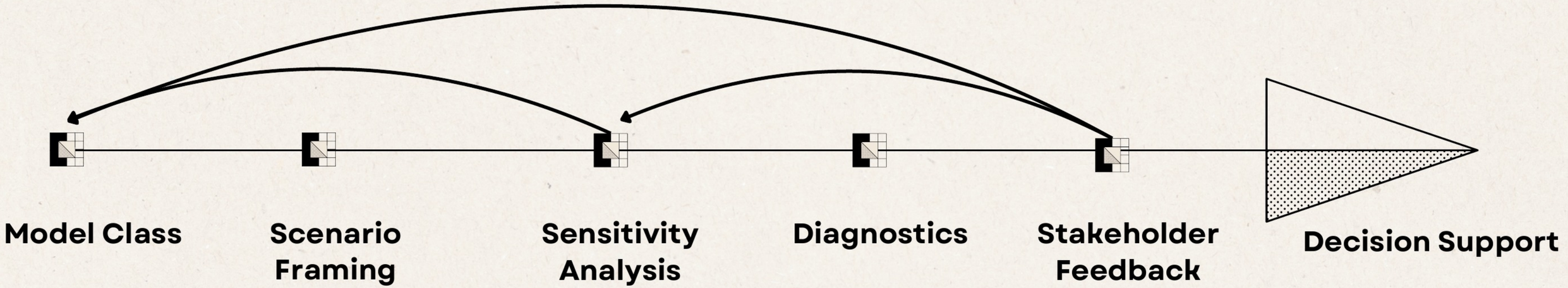
Modelling as a Value-Laden Activity

Modelling is not a neutral technical exercise; it involves normative assumptions at multiple stages – including problem framing, model selection, and output interpretation.

Key questions for practitioners:

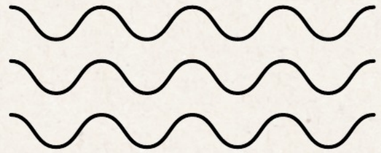
- What normative frameworks guide our model design?
- Whose perspectives are represented or omitted?
- What are the ethical implications of inaction or overconfidence based on model outputs?

Translating Outputs into Dialogues



Models support deliberation, not dictate decisions.
The best use of a model is to provoke better questions.

Communicating Models



- Clarify Purpose: Define the model's use – is it exploratory, predictive, or decision-supportive? Reveal what it cannot do.
- Show Structure: Diagrams and walkthroughs help reveal logic, feedbacks, and boundaries.
- Provide qualitative summaries, such as risk narratives or decision pathways, instead of raw outputs.