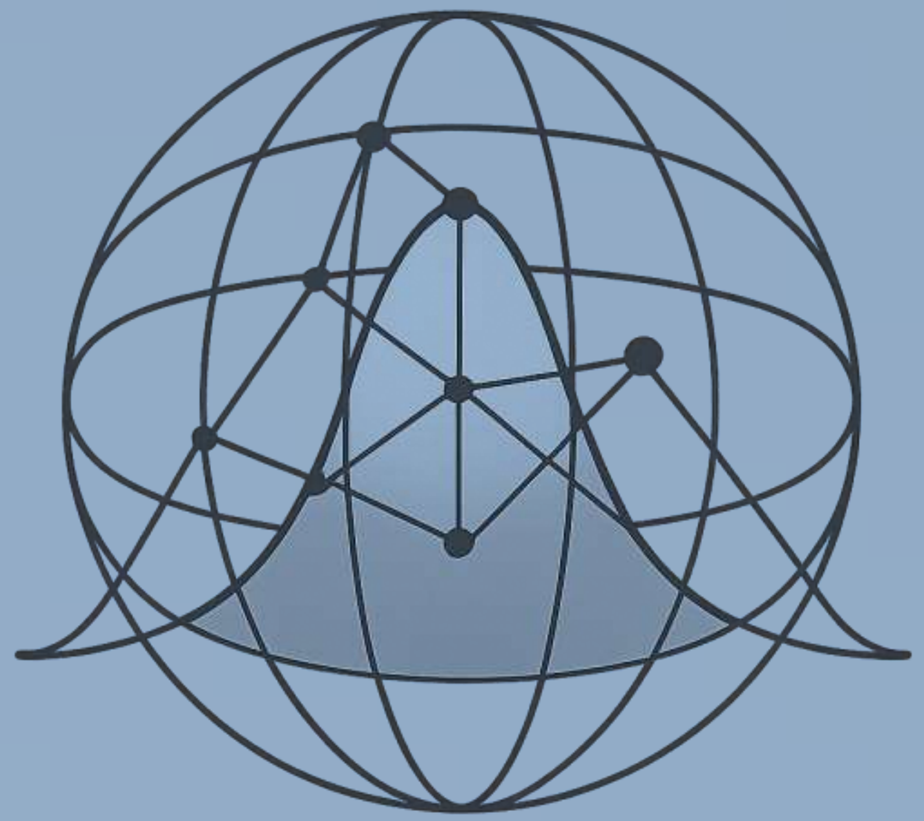
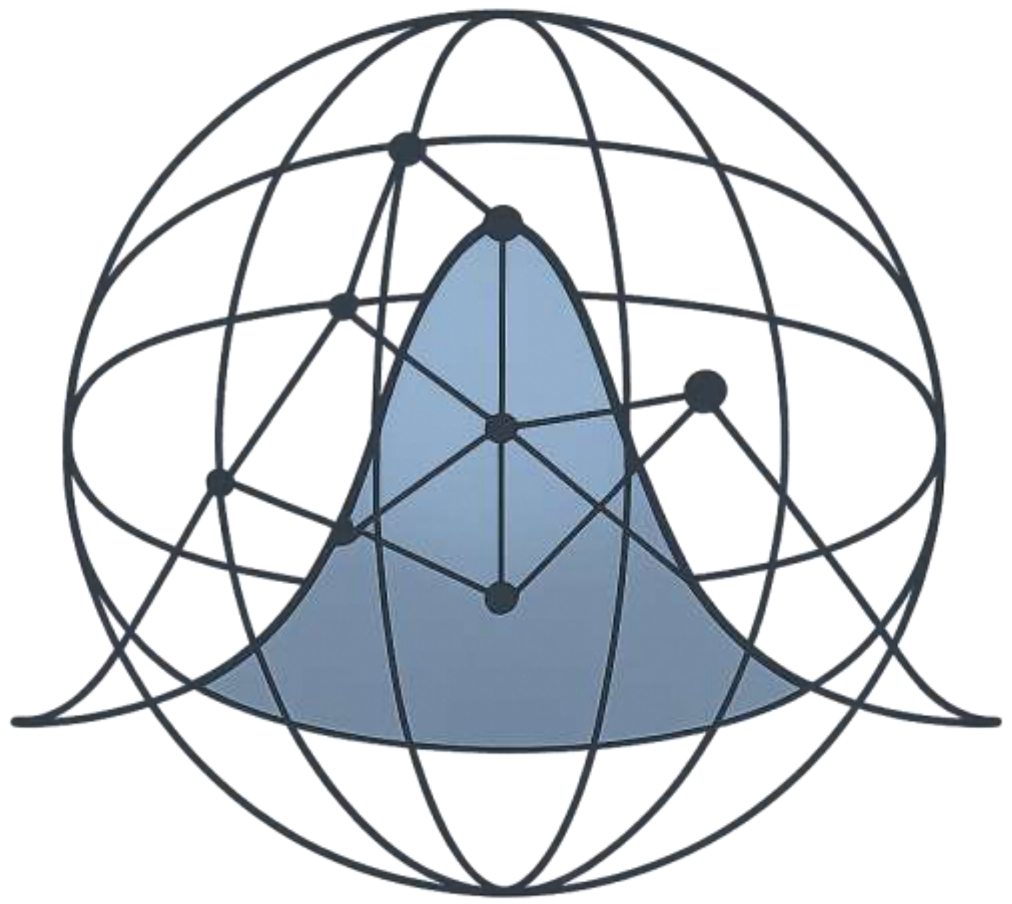
THE FUTURE OF PROBABILISTIC RISK ASSESSMENT: SCIENCE THAT BUILDS TRUST

From Uncertainty Quantification to Risk Governance



MOEZ SANAA
PRESENTATION

Outline

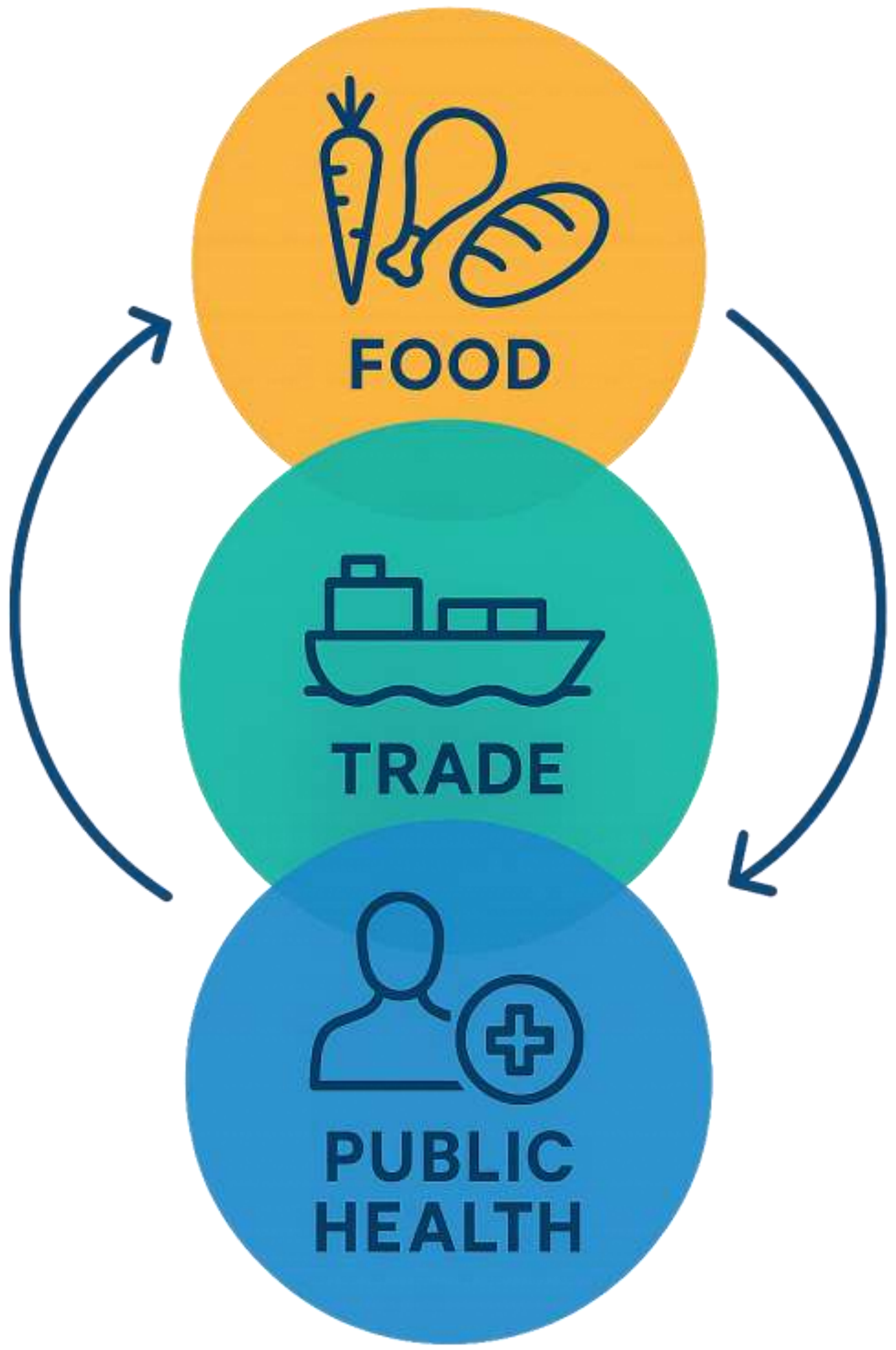


Probabilistic methods allow us to move from single points to population realities - to quantify variability, to explain uncertainty, and to visualize where risk truly lies. When regulators and stakeholders see the same uncertainty landscape, decisions become not only more accurate, but more legitimate.

- **FARMING THE FUTURE**
- **THE EVOLUTION OF RISK THINKING**
- **THE SCIENCE BEHIND THE TRUST**
- **INSTITUTIONAL MOMENTUM**

FRAMING THE FUTURE

THE CONTEXT SHIFT



Food safety in the age of complexity

- Globalized supply chains → systemic vulnerabilities
- Climate and trade pressures → dynamic exposures
- Public expectations → transparency and accountability

The future of food safety will not be written in averages, but it will be shaped by the distributions that reveal our realities.

Moez Sanaa

Keynote on the future of Probabilistic Risk Assessment, 2025.

THE EVOLUTION OF RISK THINKING

FROM DETERMINISTIC TO PROBABILISTIC

DETERMINISTIC

- Fixed assumptions
- “Average consumer”
- Point estimates (ADI, TDI)

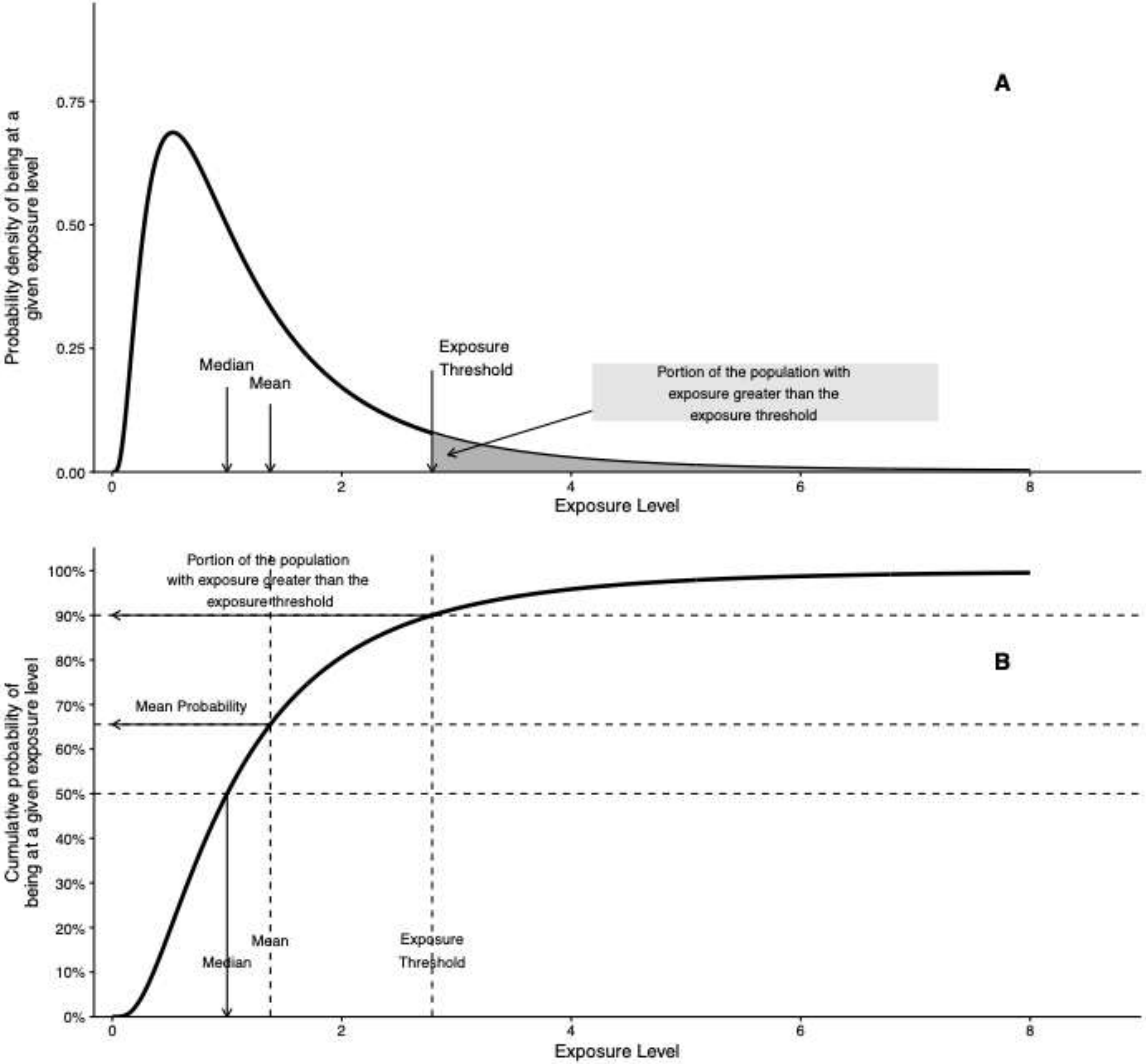
PROBABILISTIC

- Embraces variability (within and between individuals)
- Quantifies uncertainty
- Describe full exposure distributions

PROBABILISTIC

Probabilistic risk assessment (PRA) uses probability density(A) and cumulative probability (B) functions to represent how exposure varies across a population. It allows regulators to quantify the proportion of the population exceeding defined safety thresholds, offering a transparent basis for risk management decisions.

Theoretical example.
Figures generated using the
R *ggplot2* package.



T H E F U T U R E O F P R A

WHY PROBABILITY MATTERS

We don’t hide uncertainty —
we manage it intelligently

1. Variability – real differences in populations
2. Uncertainty – limits of our knowledge
3. Transparency – clarity on both

THE FUTURE OF PRA

UNDERSTANDING VARIABILITY VS UNCERTAINTY

"Variability is natural; uncertainty is informational. Probabilistic methods help us manage both."

Concept	What it Means	Example	How It's Treated
Variability	Real differences across foods, people, time	Differences in consumption by age/region	Represented explicitly by distributions
Uncertainty	Imperfect knowledge	Limited sampling measuring a contaminant in foods	Reduced by better data and sensitivity analysis

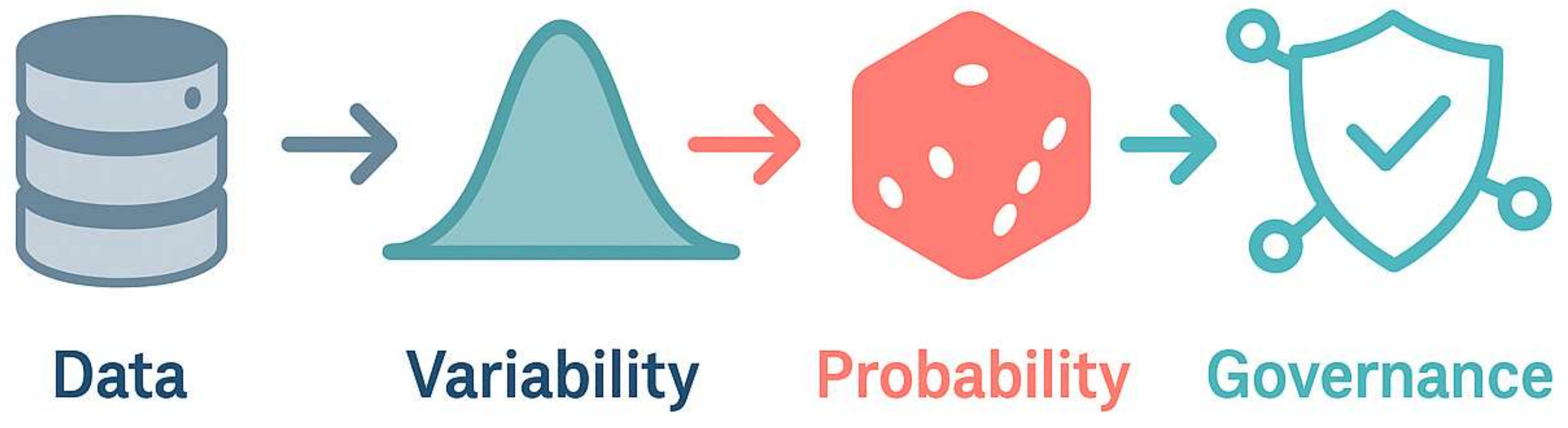
Risk Governance

Actors, Rules, Conventions, Processes, and Mechanisms concerned with how relevant risk information is collected, analyzed, and communicated and how management decision are made

REFRAMING THE RISK.

THE FUTURE OF PRA

FROM CONTROL TO COMPREHENSION



VARIABILITY

variability doesn’t undermine safety — it refines it

THE SCIENCE BEHIND THE TRUST

Risk Governance

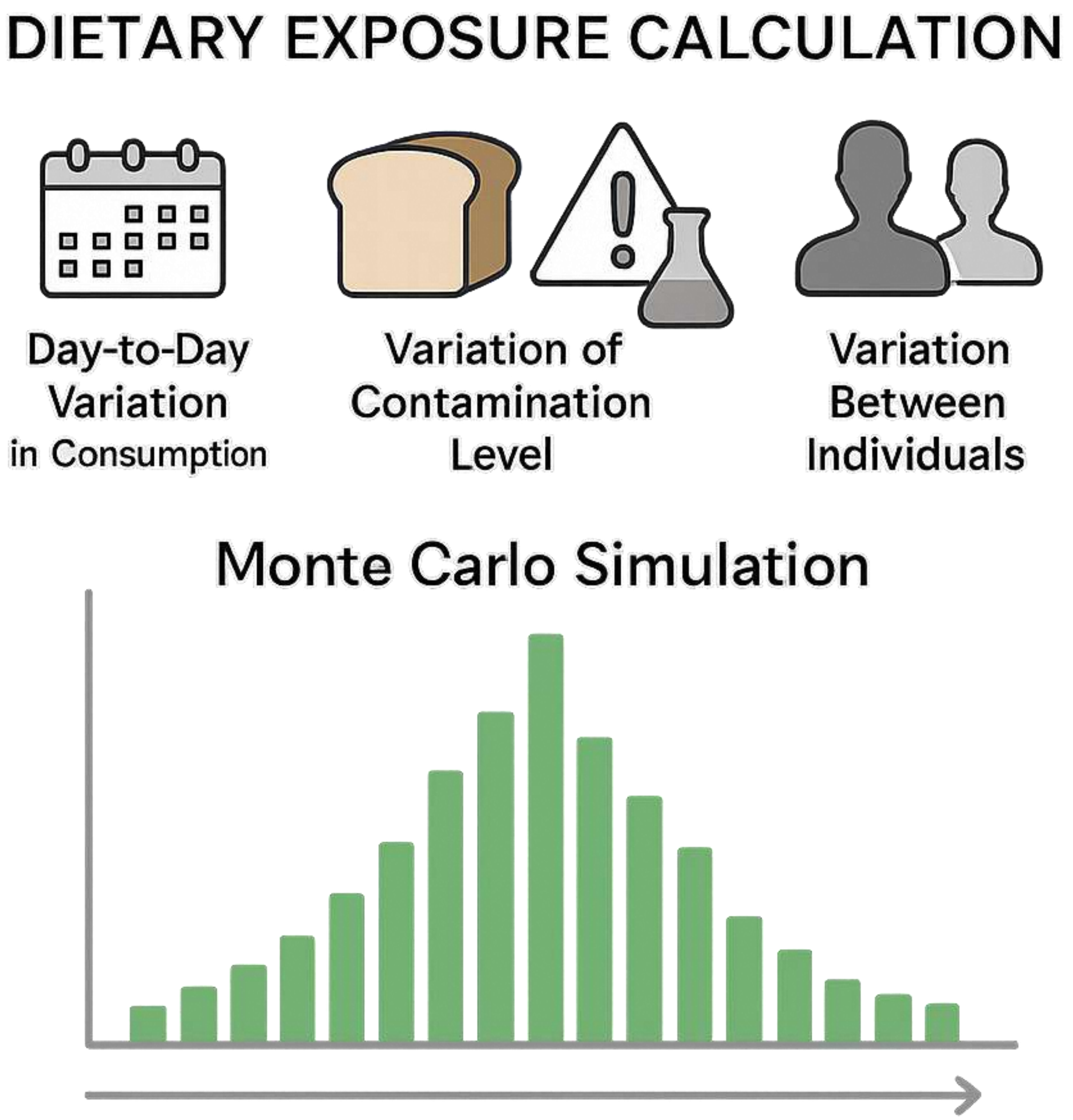
Actors, Rules, Conventions, Processes, and Mechanisms concerned with how relevant risk information is collected, analyzed, and communicated and how management decision are made

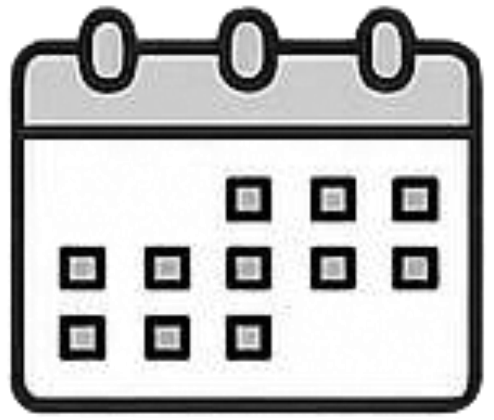
Transparency

REFRAMING THE RISK.

THE FUTURE OF PRA

CONSIDERING VARIABILITY

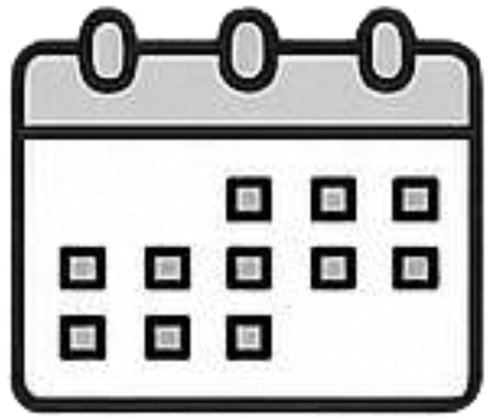




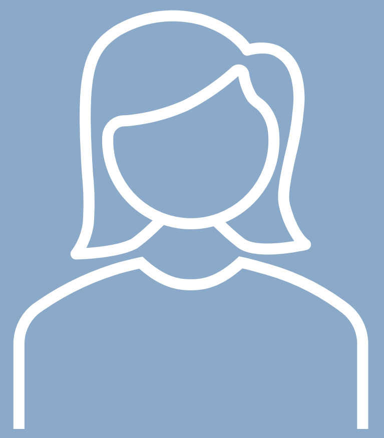
Day-to-Day Variation in Consumption

Individual1

	DAY1	DAY2	DAY3
	172	166	225
	27	23	0
	197	187	171
	254	225	222

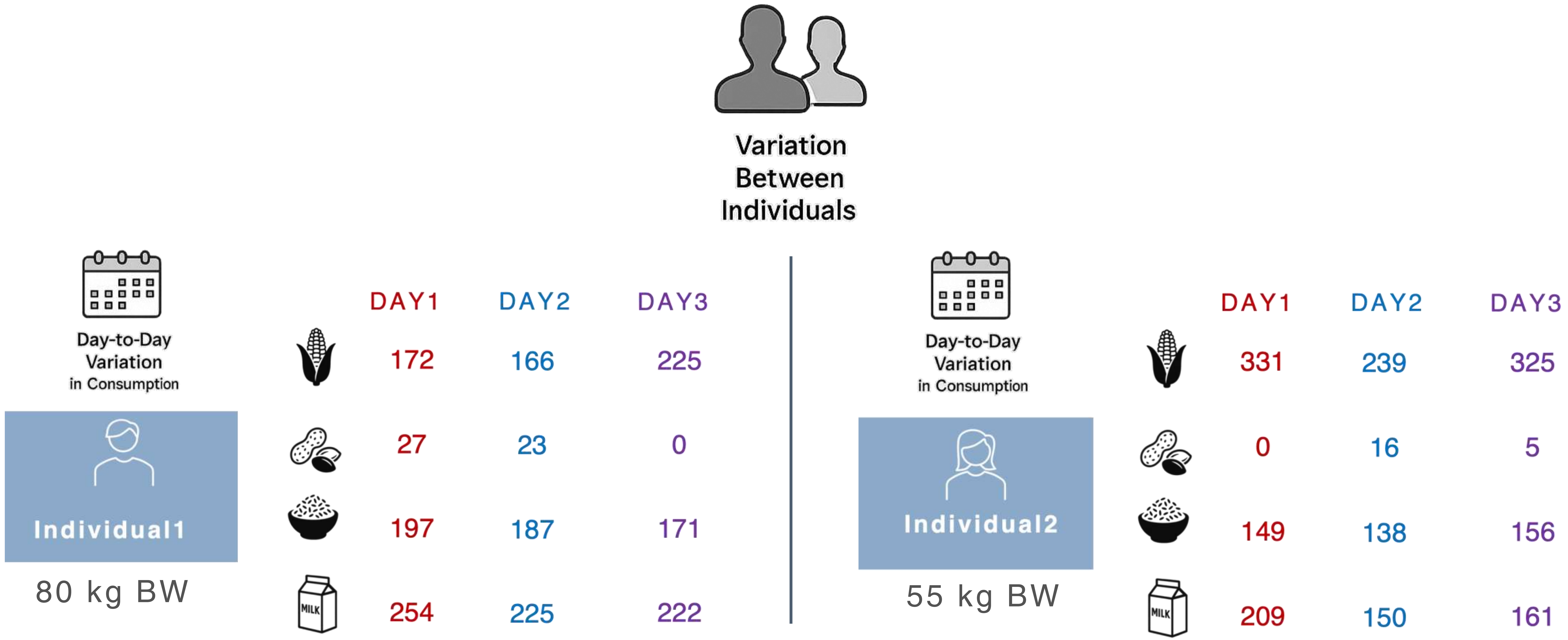


Day-to-Day
Variation
in Consumption

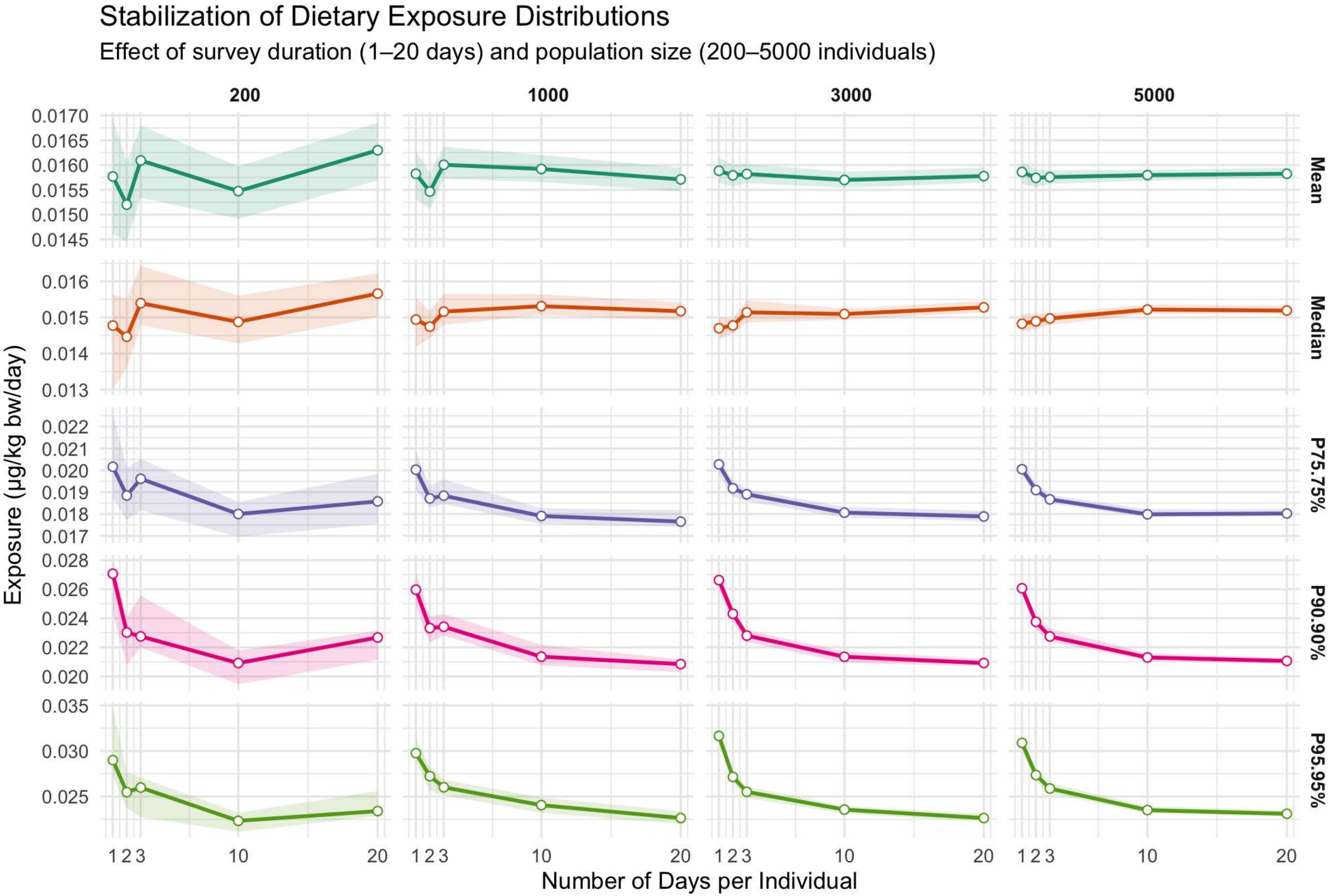


Individual2

	DAY1	DAY2	DAY3
	331	239	325
	0	16	5
	149	138	156
	209	150	161

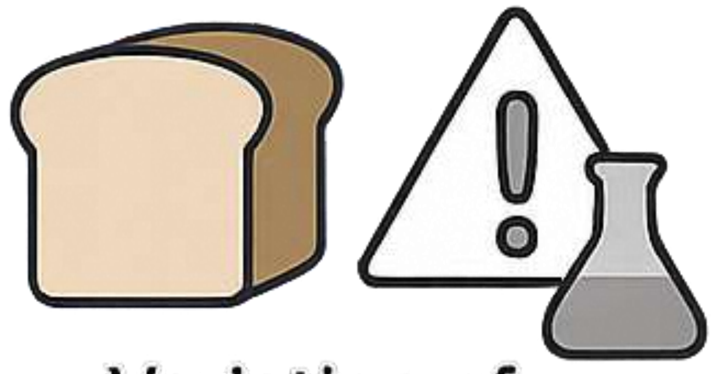


Variation Between Individuals
Day-to-Day Variation in Consumption
Individual1
80 kg BW
DAY1 DAY2 DAY3
172 166 225
27 23 0
197 187 171
254 225 222
Day-to-Day Variation in Consumption
Individual2
55 kg BW
DAY1 DAY2 DAY3
331 239 325
0 16 5
149 138 156
209 150 161
MILK
MILK



Stabilization of Dietary Exposure Distributions
Effect of survey duration (1–20 days) and population size (200–5000 individuals)
200
1000
3000
5000
Mean
Median
P75.75%
P90.90%
P95.95%
Exposure (µg/kg bw/day)
Number of Days per Individual
1 2 3
10
20
0.0170
0.0165
0.0160
0.0155
0.0150
0.0145
0.016
0.015
0.014
0.013
0.022
0.021
0.020
0.019
0.018
0.017
0.028
0.026
0.024
0.022
0.020
0.035
0.030
0.025

SOURCE OF VARIABILITY IN FOOD CONTAMINATION



Primary Production

- Geographical origin of raw materials
- Soil and water contamination levels
- Agriculture practices (pesticides use, type, usage, timing, fertilizer use)
- Animal feed composition and contamination
- Animal health and metabolism affecting residue levels
- Seasonal variation in crop or animal products
- Climatic factors (temperature, humidity, rainfall)

Post-Harvest & Processing

- Post-harvest handling and drying conditions
- Storage duration and conditions (temperature, humidity, aeration)
- Processing efficiency (washing, blanching, roasting, milling, …)
- Degradation or transformation of chemicals during processing
- Mixing of products with different contamination levels
- Cross contamination during transport, processing or packaging
- Equipment cleanliness and maintenance variability
- Batch-to-batch differences in industrial production

Distribution and Retail

- Variation in supplier or brand contamination profiles
- Differences in transport and storage conditions along the supply chain
- Mixing of products from multiple origins in retail lots
- Duration of storage before sale or consumption

Purchasing and Consumption

- Brand loyalty – consistent purchase from specific brands with distinct contamination profiles.
- Preference for organic foods – reduced synthetic residues but possible higher natural contaminants.
- Food sourcing habits – local, seasonal, or niche products with variable contamination control levels.
- Storage and Preparation conditions

LIMITATIONS OF USING A SINGLE AVERAGE CONTAMINATION LEVEL

Key message

Current exposure assessments often assume one average contamination value for all foods of the same category and all consumers - but this ignores how contamination varies in the real world.

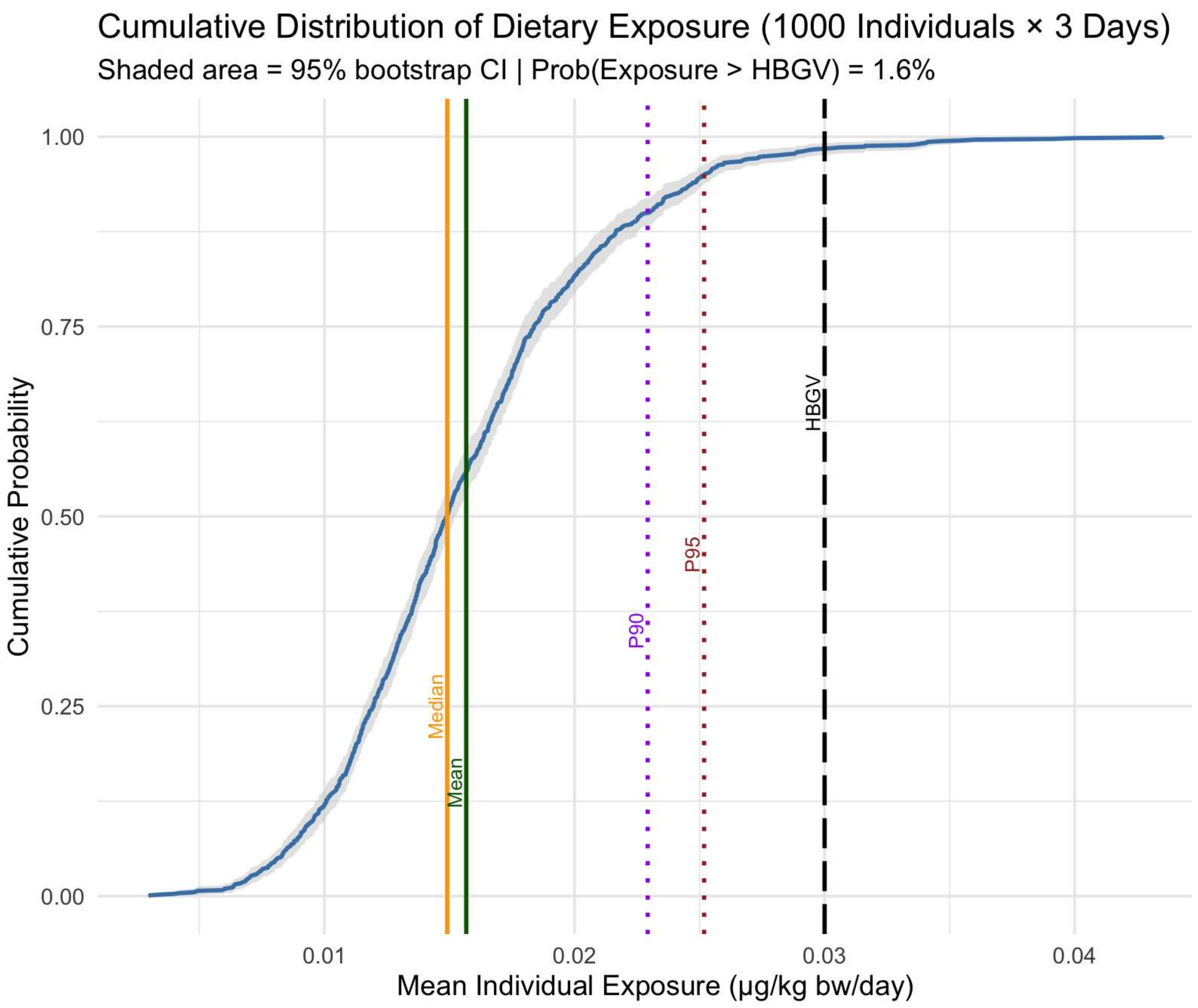
A

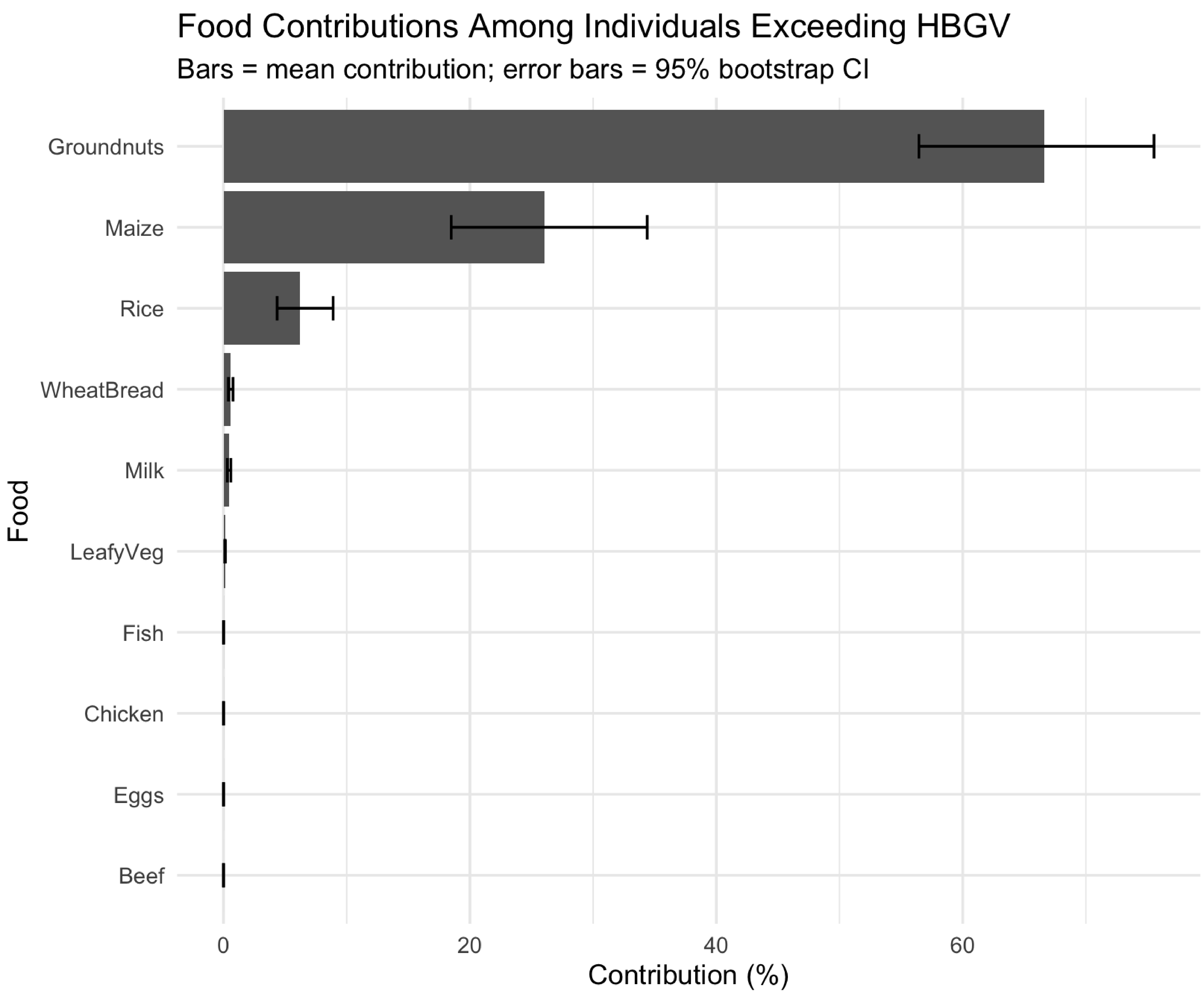
Using one mean contamination level simplifies assessment but undermines accuracy - realistic exposure estimation must reflect variability across individuals, foods, and time.

MAIN ISSUES

- Ignores variability - contamination differs by batch, source, season, and storage.
- Assumes stability over time - uses a snapshot even though contamination changes across years or decades.
- Masks high exposures - fails to identify individuals regularly consuming more contaminated foods.
- Reduces realism - treats the food system as static while it is dynamic and heterogeneous.
- Biases chronic exposure - may smooth random variation but misses long-term shifts in contamination trends.

OUTPUTS INCLUDING UNCERTAINTY





Relative vs. Absolute Burden

Chemical exposure effects (e.g., cancers, neurotoxicity, developmental outcomes) may have low prevalence but high severity
Each case representing a major lifelong burden or DALY loss.

ALOP

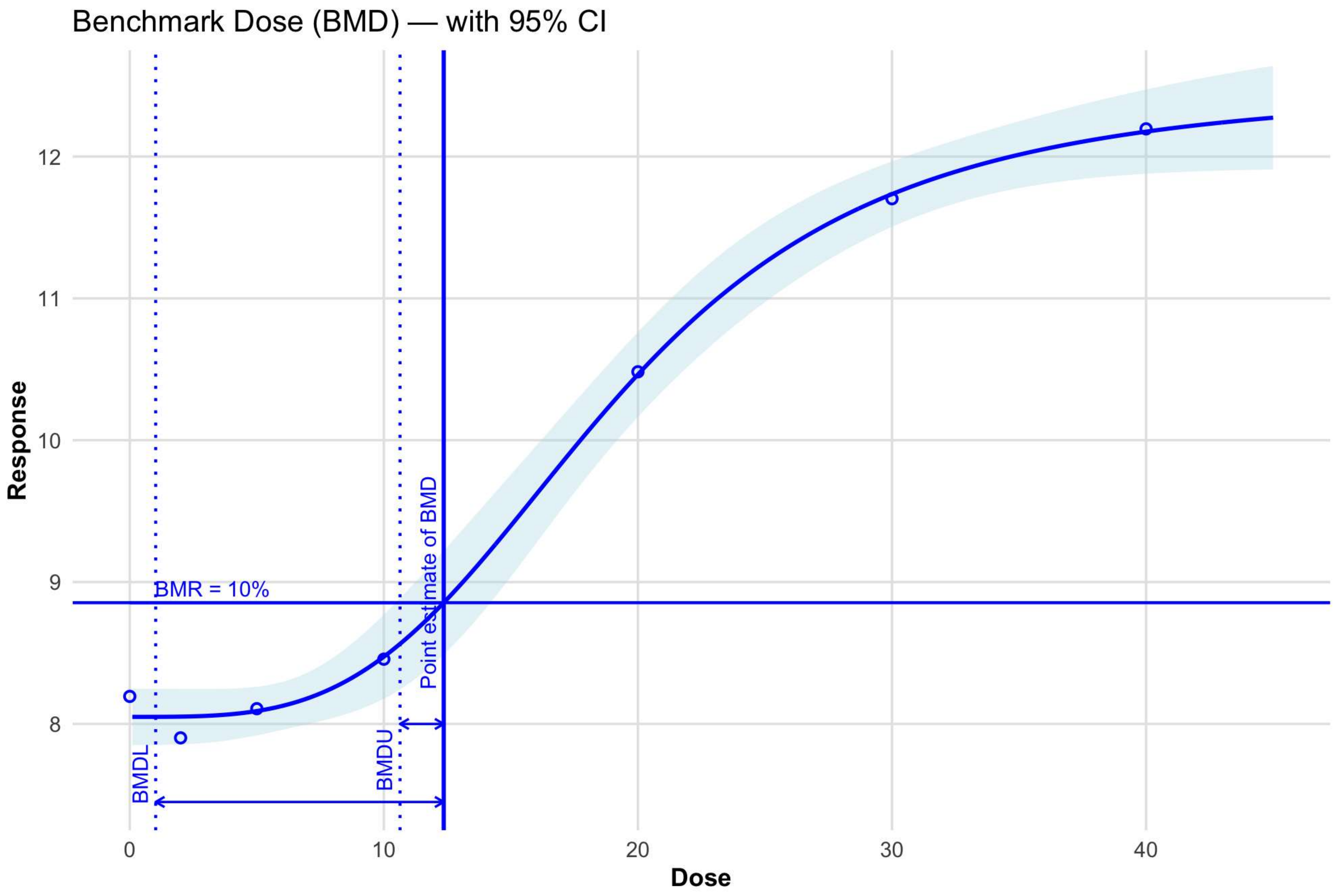
While 1% may seem small next to NCD prevalence, for involuntary and preventable exposures with potentially severe outcomes, it represents a meaningful and actionable public health concern.

Health Outcome	Typical Prevalence	Public Health Interpretation
Hypertension	25–35%	Common, chronic, multifactorial
Diabetes (Type 2)	8–10%	High and rising globally
Cancers (any type)	0.5–2% incidence	Considered high because of lethality
Chemical exposure exceeding HBGV	0.5–5%	Critical for regulatory action despite low prevalence

USE THE DOSE RESPONSE MODELS

The full dose–response model gives a clearer picture of population risk, while an HBGV shows only a single threshold and hides the gradient of potential effects.

DR

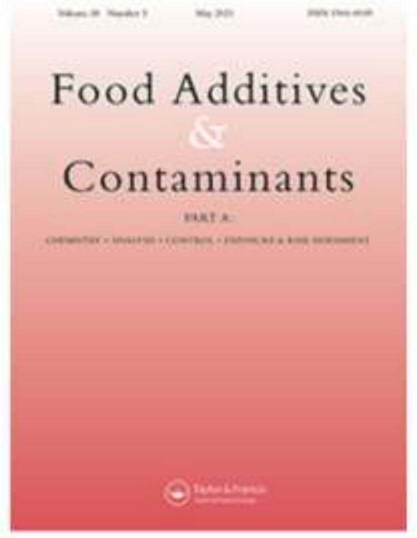


CASE STUDY WITH INFANT CEREAL

INFANT CEREALS (RICE VS OAT) AND TWO CONTAMINANTS (INORGANIC ARSENIC, AFLATOXINS)

PROBABILISTIC ELEMENTS

- Contamination
  - Distributions fitted to iAs and aflatoxin measurements
  - Parametric bootstrap to generate uncertainty in mean concentrations
- Consumption (NHANES)
  - Each infant has their own intake + body weight
  - Captures real variability across 1,041 infants
- Dose–response models
  - Inorganic arsenic: FDA model-averaged cancer functions
  - Aflatoxins: JECFA cancer potency modeled as Pert distribution
- Two-dimensional Monte Carlo
  - Inner loop: variability across infants
  - Outer loop: uncertainty in contaminant levels & dose–response



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Food Additives & Contaminants: Part A

ISSN: 1944-0049 (Print) 1944-0057 (Online) Journal homepage: www.tandfonline.com/journals/tfac20

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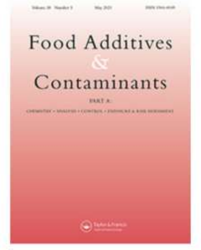
THE FUTURE OF PRA

CASE STUDY WITH INFANT CEREAL



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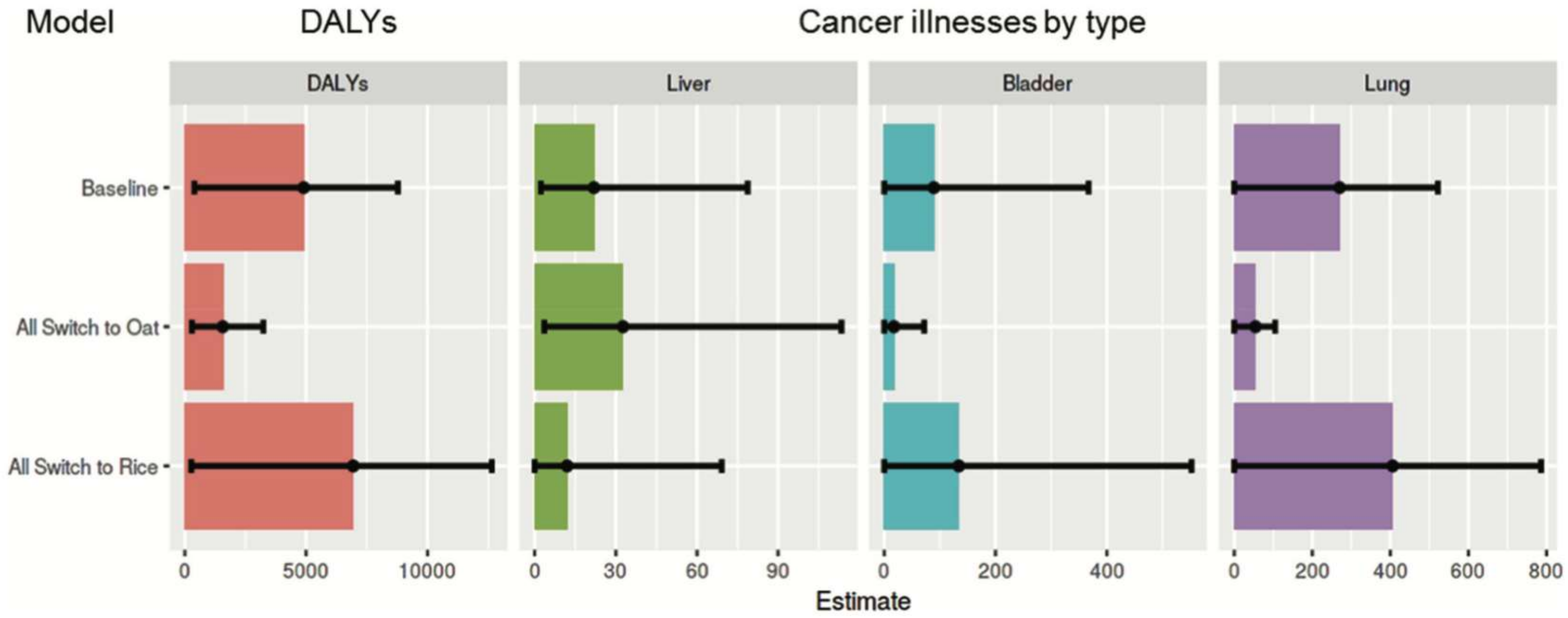
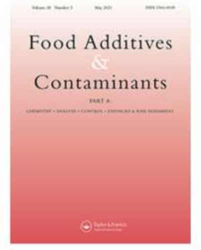


Table 2. Median number of cancer illnesses per year and DALYs for the total U.S. population and 90% uncertainty CI.

		Number of cancer illnesses by type				
Model		Liver	Bladder	Lung	Total	DALYs
Baseline exposure		21 (2, 87)	92 (0, 376)	270 (0, 531)	397 (25, 762)	4,921 (414, 9,071)
100% switch to oat	Absolute	31 (3, 121)	18 (0, 74)	55 (0, 108)	111 (26, 222)	1,513 (312, 3,356)
	Relative to baseline	1.60	0.21	0.21	0.29	0.35
100% switch to white rice	Absolute	11 (0, 72)]	139 (0, 566)	405 (0, 799)	575 (18; 1,126)	6,942 (326; 12,931)]
	Relative to baseline	0.61	1.50	1.50	1.40	1.40

CASE STUDY WITH INFANT CEREAL



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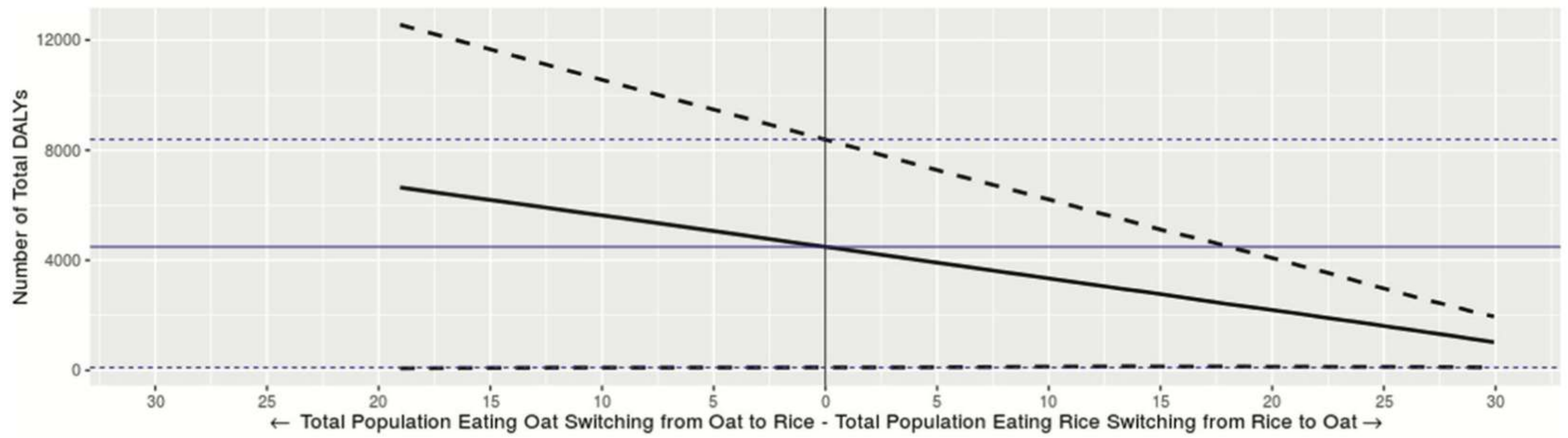


Figure 5. Predicted total cancer illnesses as percent shift in consumption from oat to white rice (left) and from white rice to oat (right). Straight blue line represents the median estimated baseline value (including the lower and upper 90% confidence interval of the baseline in the blue dotted lines) and the straight black line represents the median predicted value as a result of the shift (including the lower and upper 90% confidence interval of the prediction in the black dotted lines).

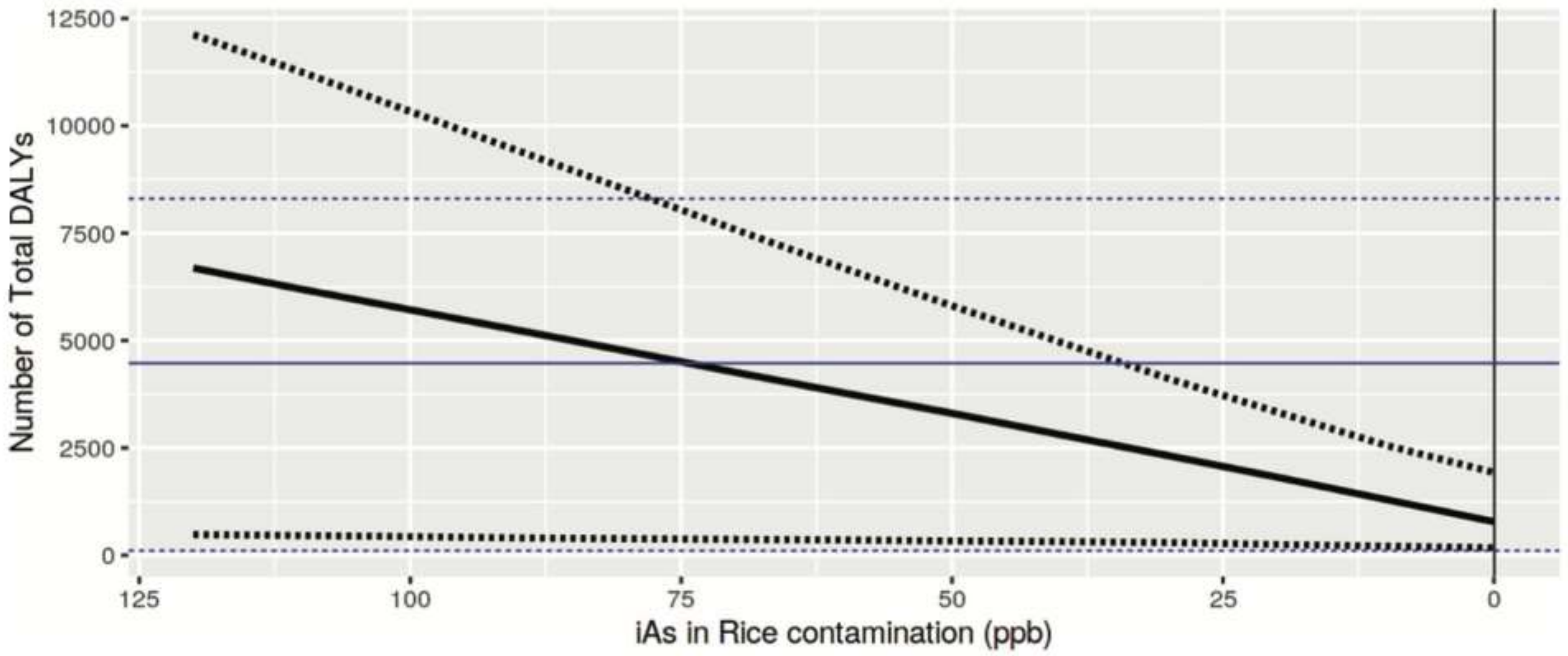
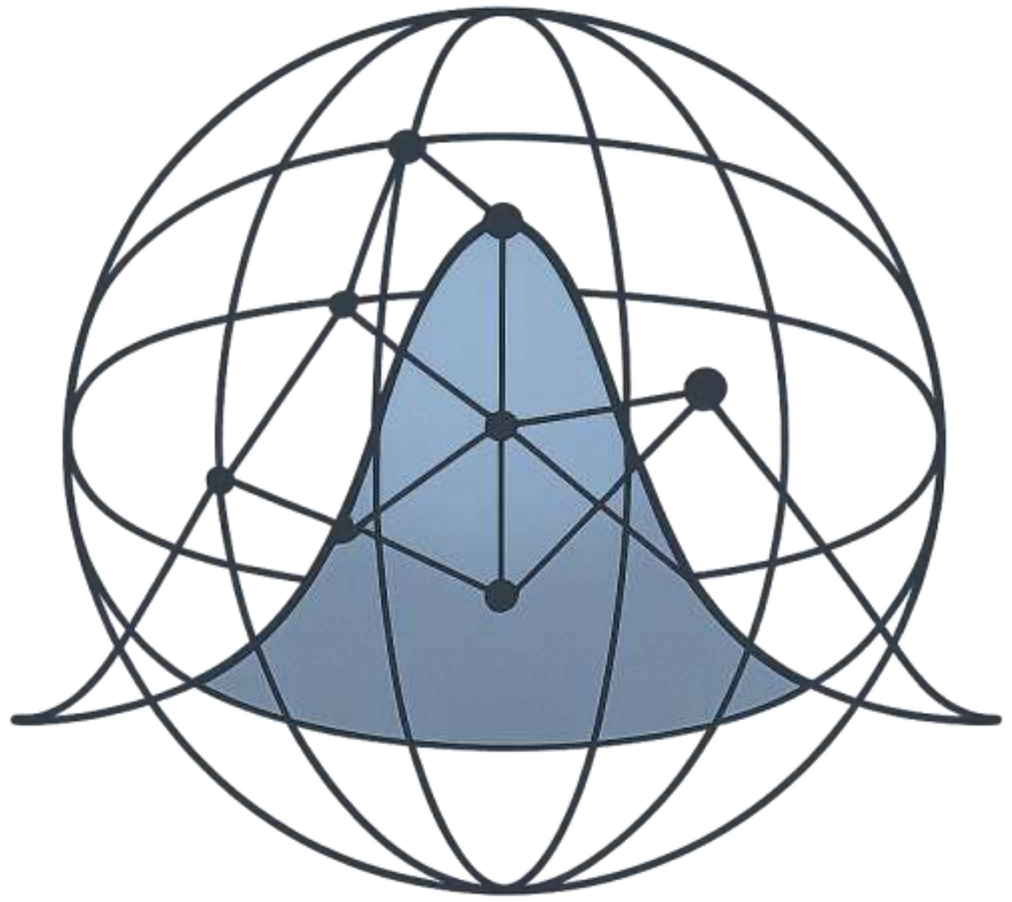


Figure 6. Predicted number of total DALYs as a function of iAs concentration in infant white rice cereal. Where the straight blue line is the median baseline value (including the lower and upper 90% confidence interval of the baseline in the blue dotted lines) and the straight black line is the median predicted value as a result of the change in concentration (including the lower and upper 90% confidence interval of the prediction in the black dotted lines).

INSTITUTIONAL MOMENTUM

INTERNATIONAL ORGANIZATIONS

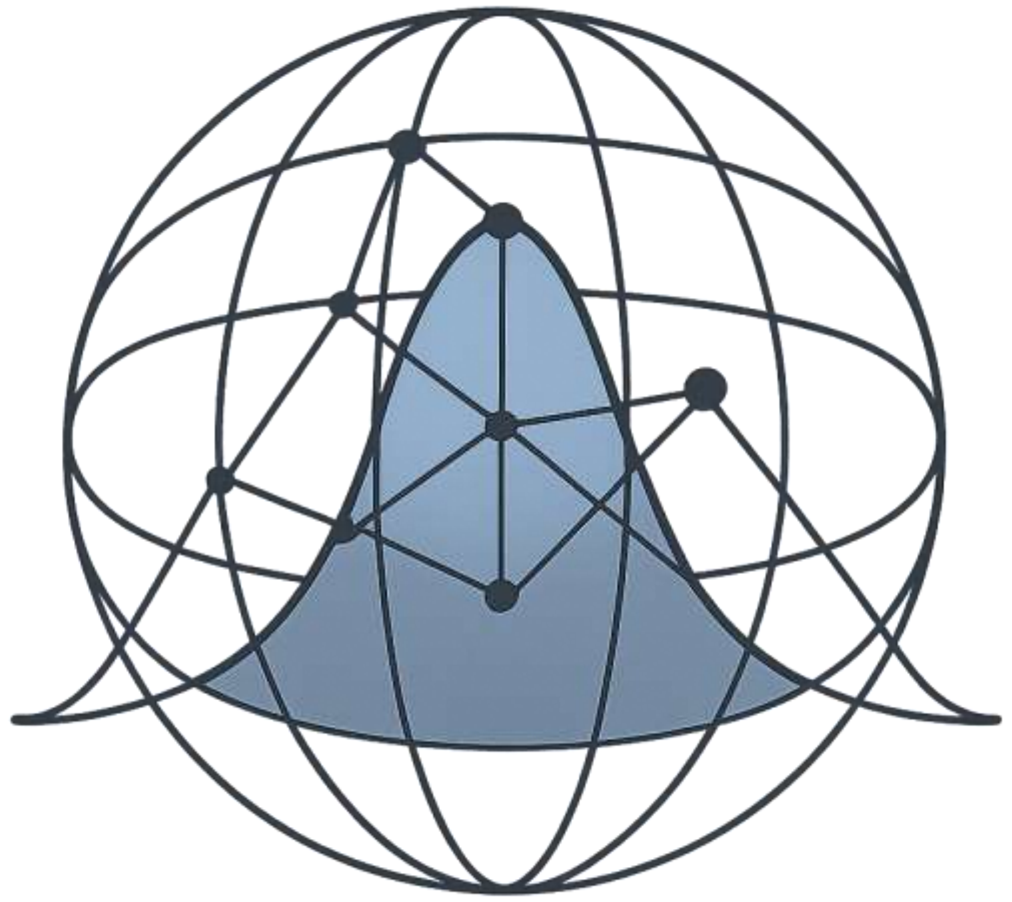


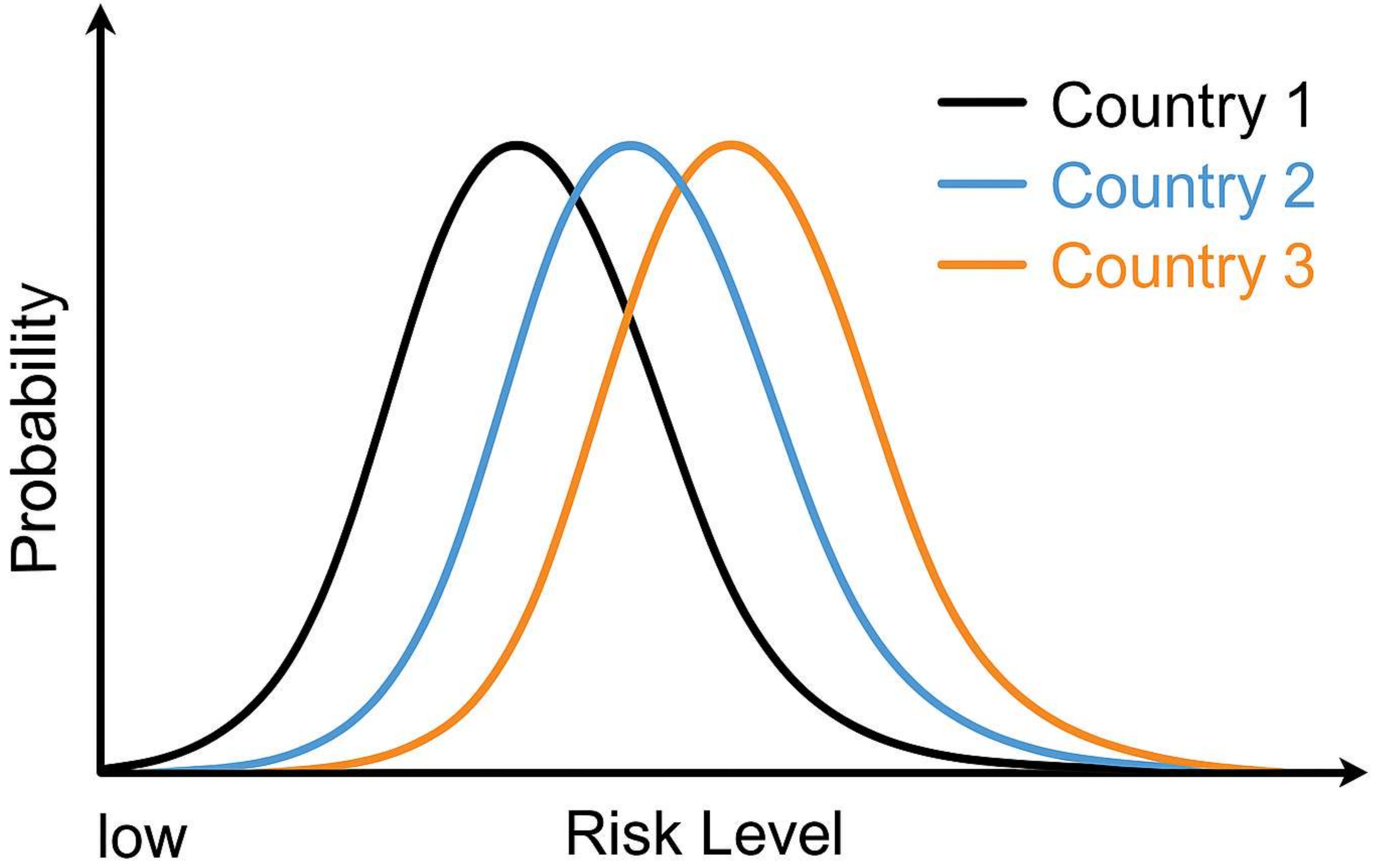
Integrating variability/Uncertainty into global scientific advice.

Building interoperability and coherence.

- **JECFA AND JMPR ADOPTING PROBABILISTIC EXPOSURE MODELS**
- **SHARED DATA STRUCTURES FOR DISTRIBUTION-BASED MODELLING**
- **CAPACITY-BUILDING FOR COUNTRIES TO GENERATE NATIONAL VARIABILITY DATA**
- **SUPPORT FOR NATIONAL MODELLING CAPACITY**

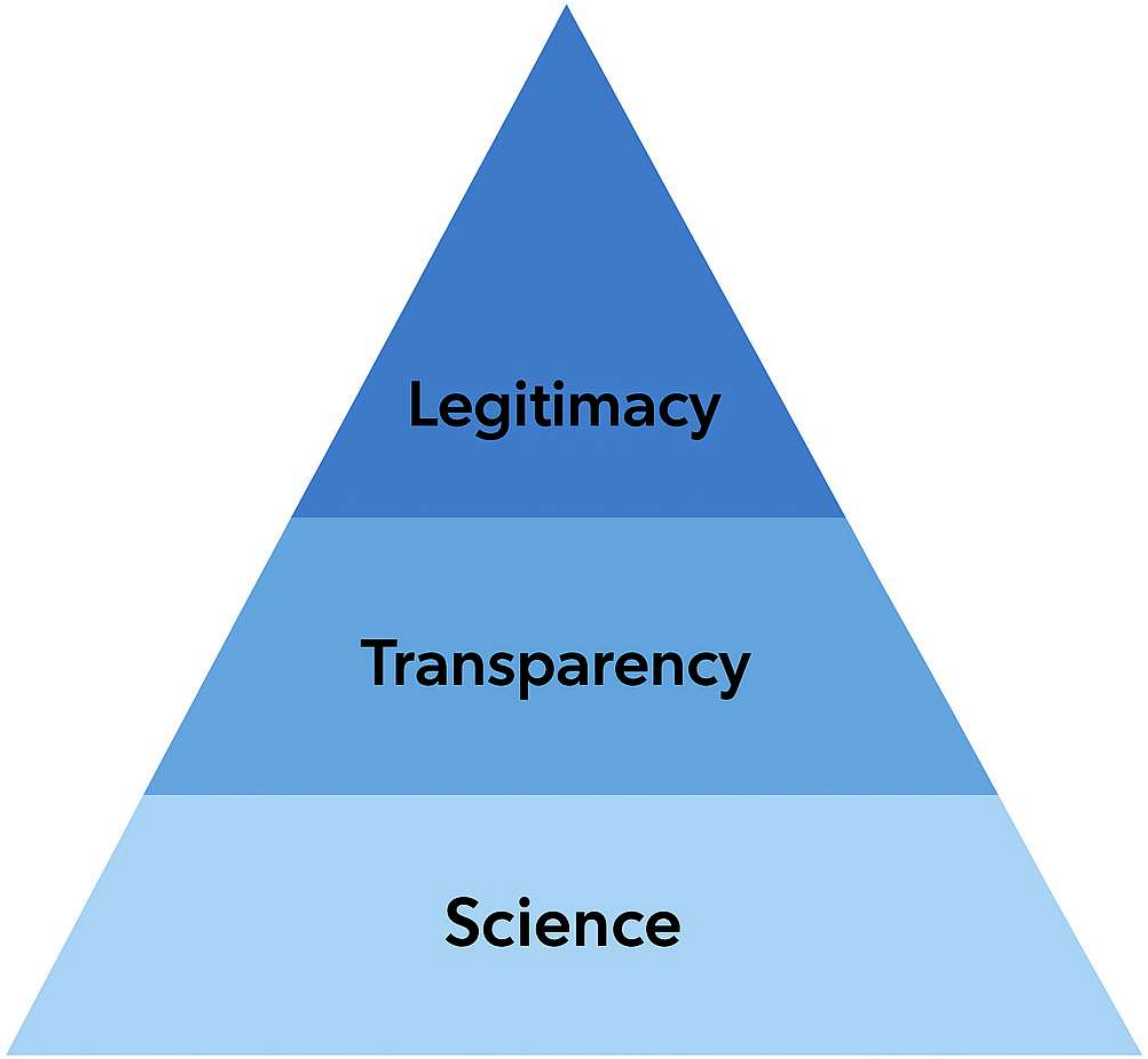
GLOBAL ALIGNMENT, LOCAL RELEVANCE





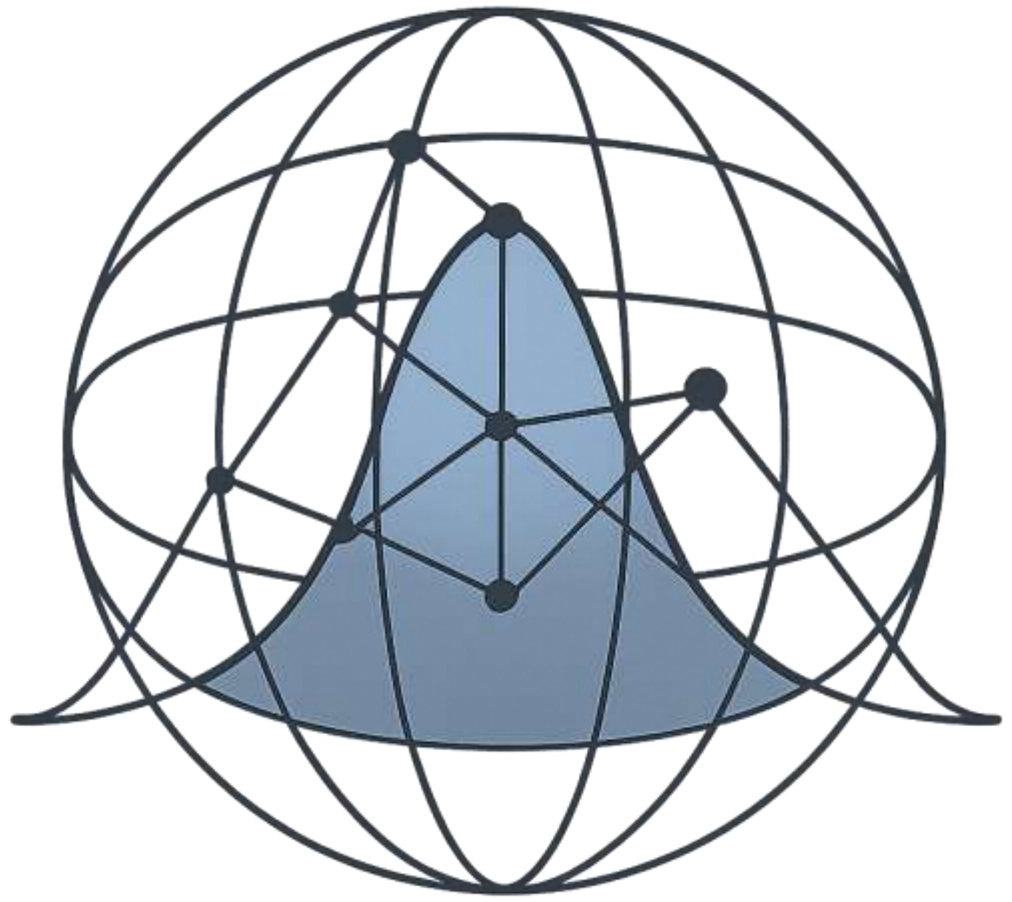
Different data, same science and shared trust.

POLICY RELEVANCE AND RISK GOVERNANCE



- SCIENTIFIC UNDERSTANDING OF VARIABILITY
- TRANSPARENT QUANTIFICATION OF UNCERTAINTY
- EVIDENCE-INFORMED, PROPORTIONATE DECISIONS
- PUBLIC LEGITIMACY

THE PROMISE OF PROBABILISTIC THINKING



Traditional Approach	Probabilistic Approach
One number fits all	Population spectrum
Manage to threshold	Manage to distribution
Hide uncertainty	Communicate uncertainty
Compliance	Confidence

"By embracing variability, we reveal equity. By embracing probability, we build trust."

M O E Z S A N A A

T H A N K S