From climate risk to action:
Analysing adaptation decision robustness under uncertainty

Cecina Babich Morrow

Supervisors: Laura Dawkins, Dan Bernie, Dennis Prangle

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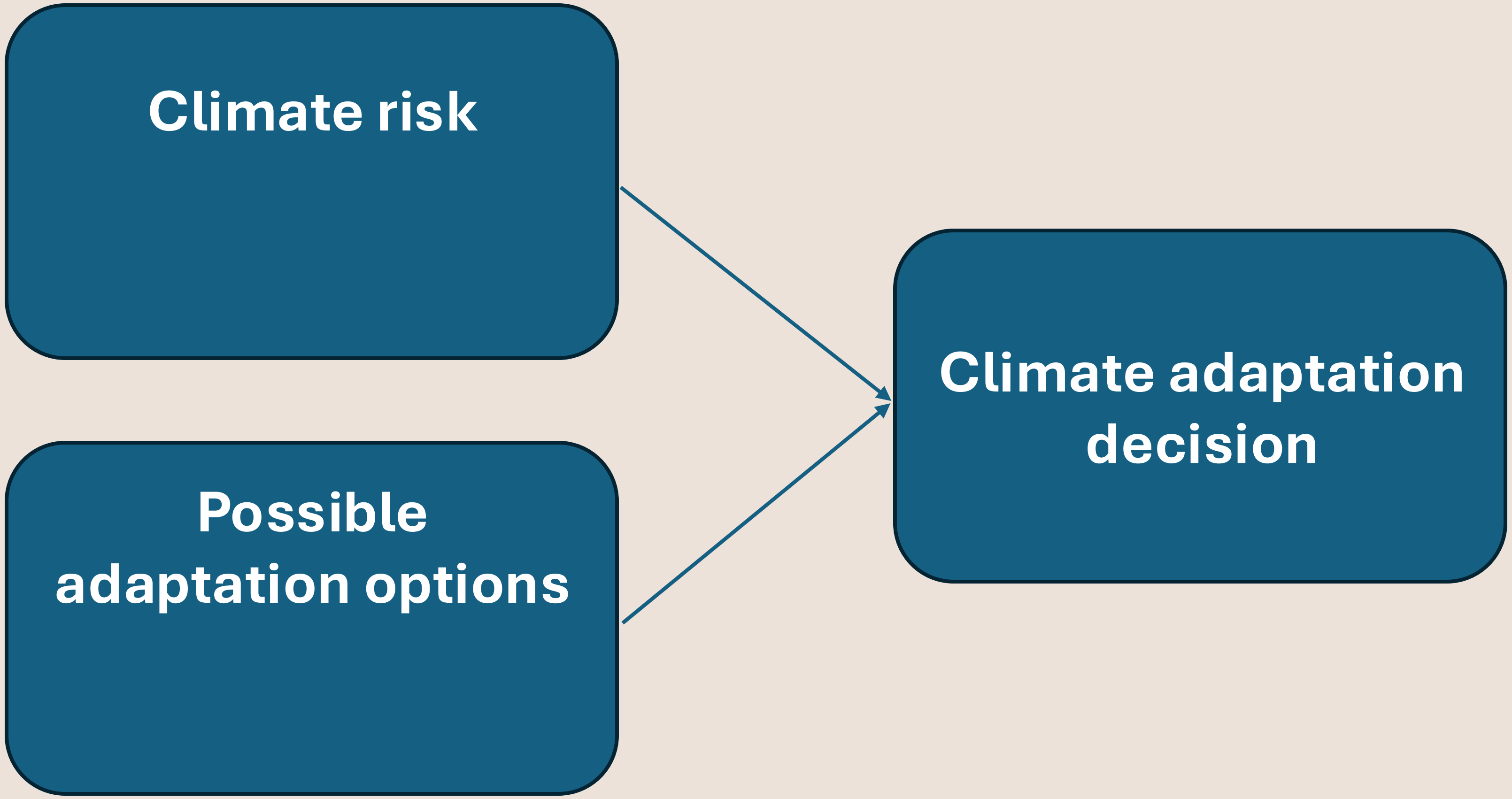
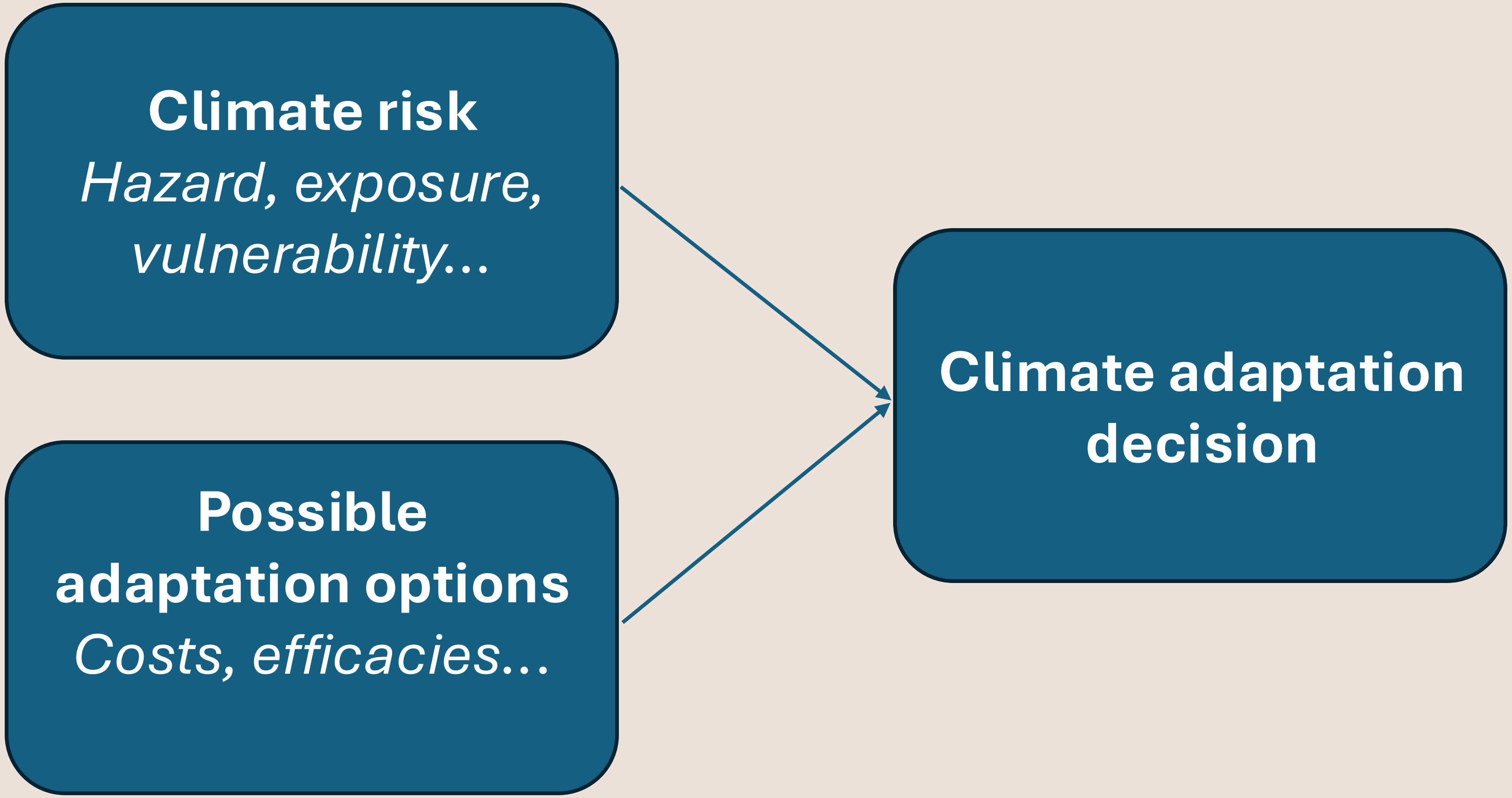
Met Office

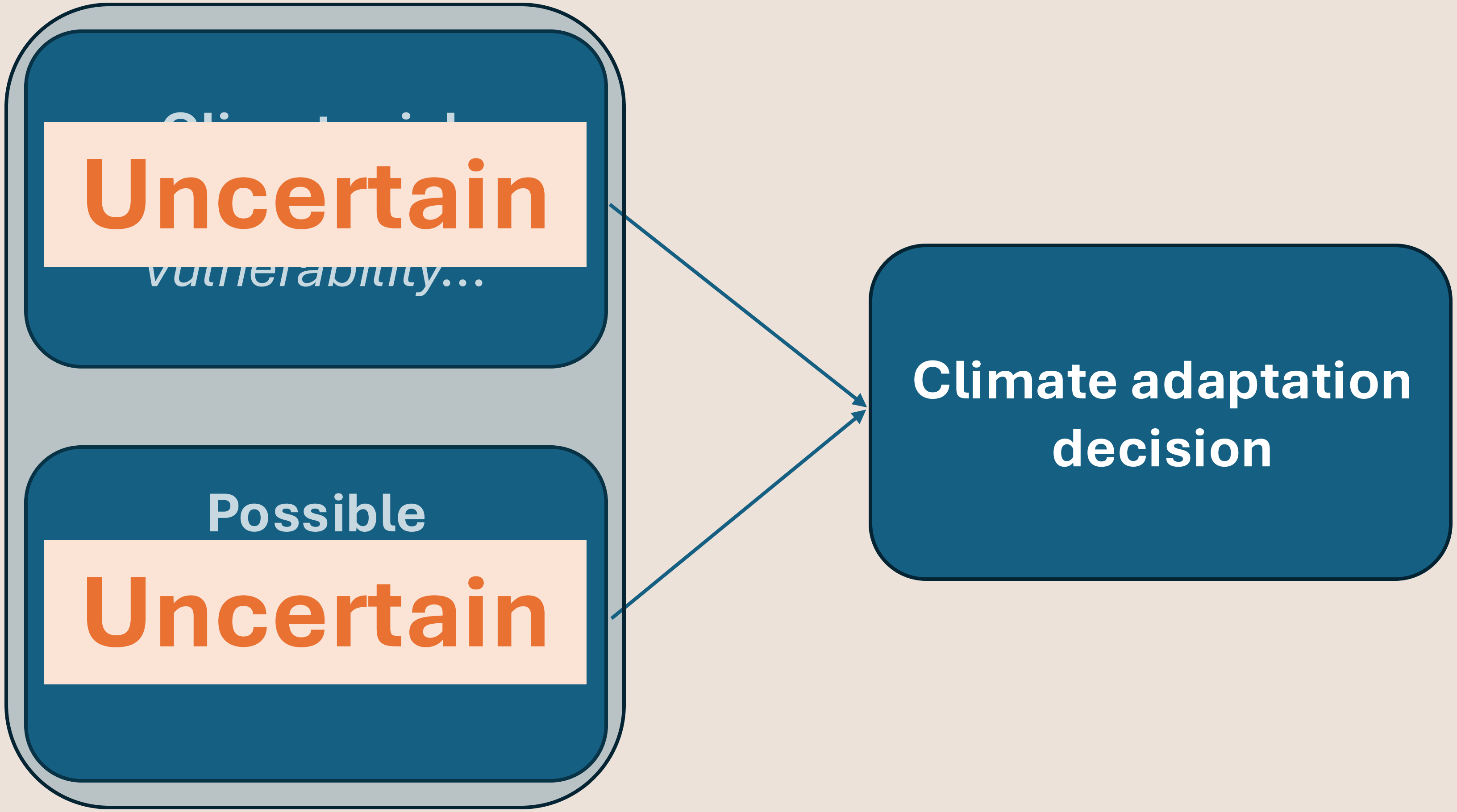
Climate adaptation decision-making



Climate adaptation decision-making

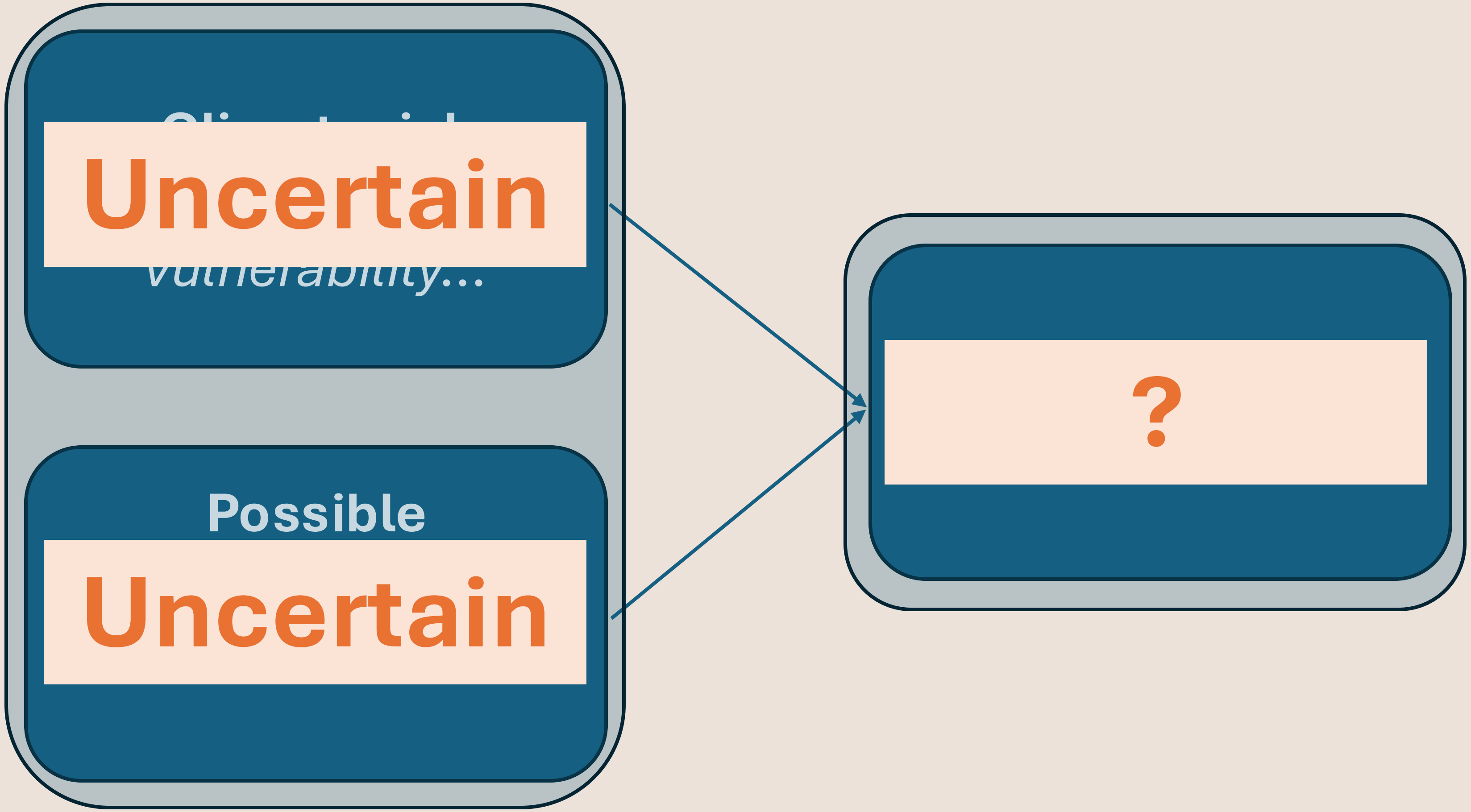


Climate adaptation decision-making



Climate adaptation decision-making

How can we make robust climate adaptation decisions?



When making adaptation decisions under uncertainty...

Where are different adaptation options most often optimal?

Are there regions where certain decisions dominate?

How **uncertain** is the optimal decision?

How does decision uncertainty relate to climate risk uncertainty?

Which inputs are the optimal decision **most sensitive** to?

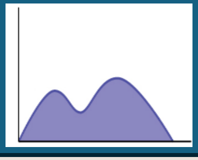
How does the sensitivity of the optimal decision vary spatially?

Example: Heat-stress in the UK

Bayesian Decision Analysis framework

Framework for decision-making under an uncertain state of nature

Θ : expected annual days of work lost to heat stress



$\mathcal{D}$: decisions

- d_1 : do nothing
- d_2: modify working hours
- d_3: buy cooling equipment

L(θ,d)
loss function

$\mathcal{L}$: losses

- *Financial*
- *Non-financial*

U(L(θ,d))
utility function

$\mathbb{R}$
Relative utility of each adaptation given level of heat stress

d^*
Optimal adaptation decision in each location

Bayes optimal decision

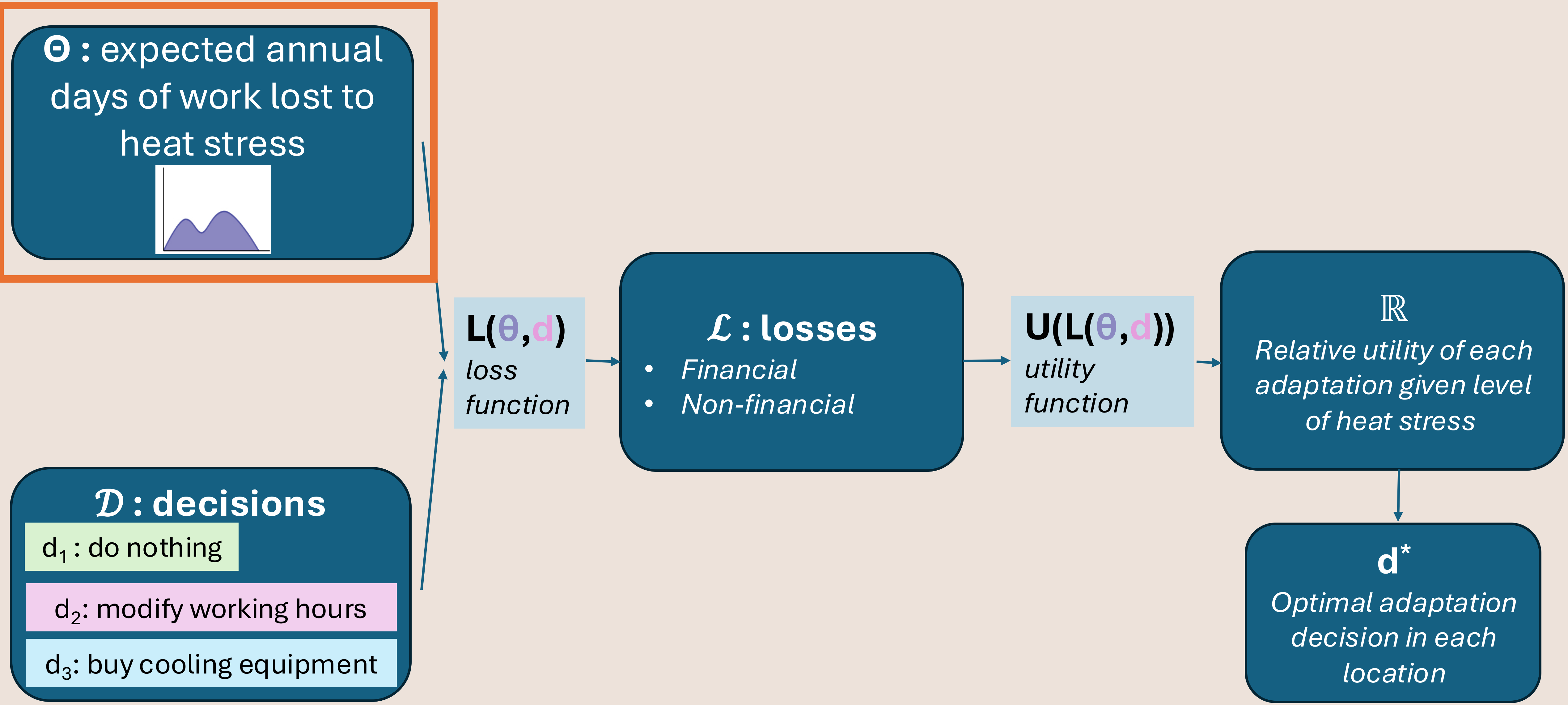
Select the decision that maximises expected utility:

Bayes decision under utility U

Select the decision d^* such that

$$d^* = \arg\max_d \sum_{\theta \in \Theta} U[L(\theta, d)]p(\theta) = \arg\max_d \bar{U}(d)$$

Uncertainty in risk



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L(θ,d)
loss function
ℒ : losses
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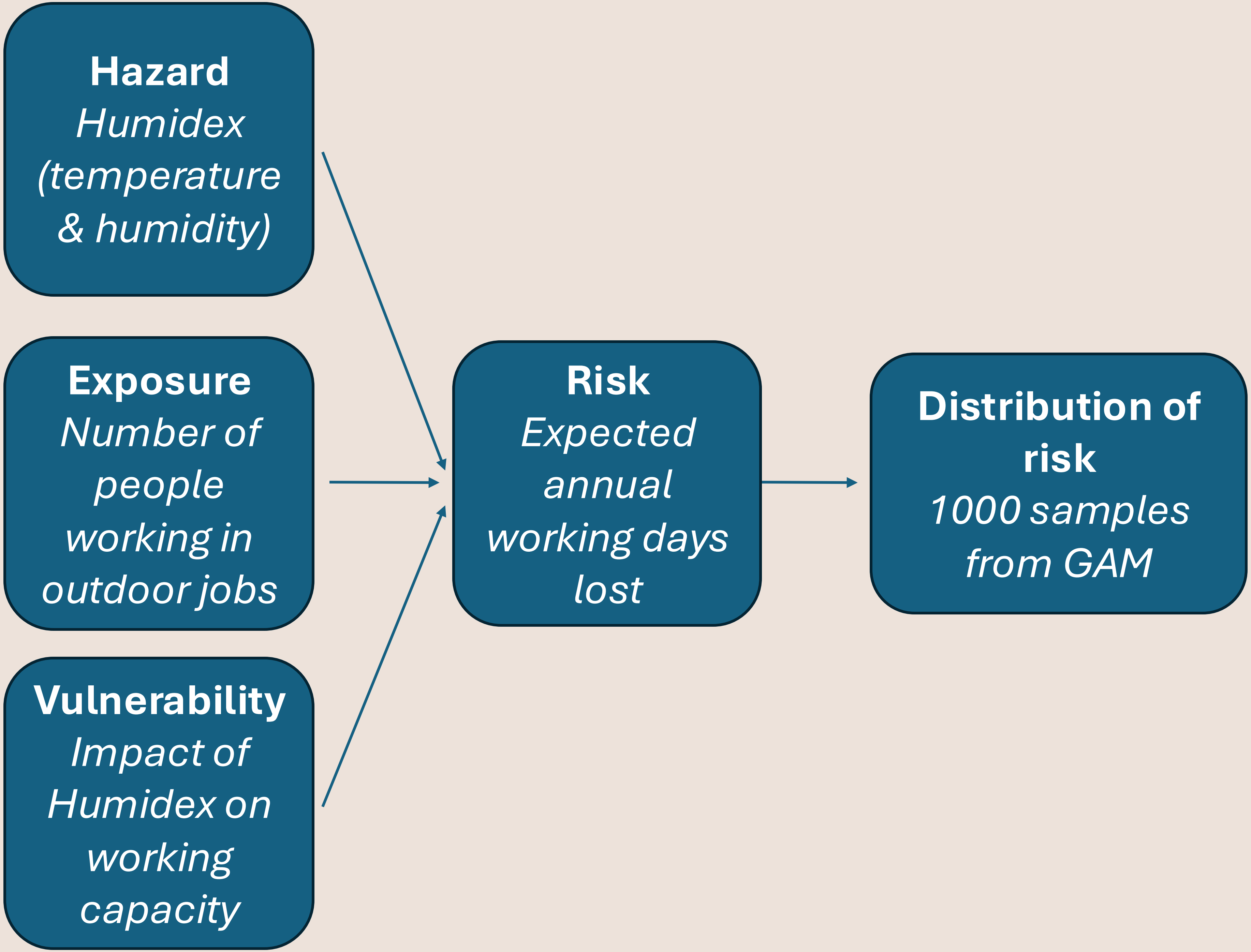
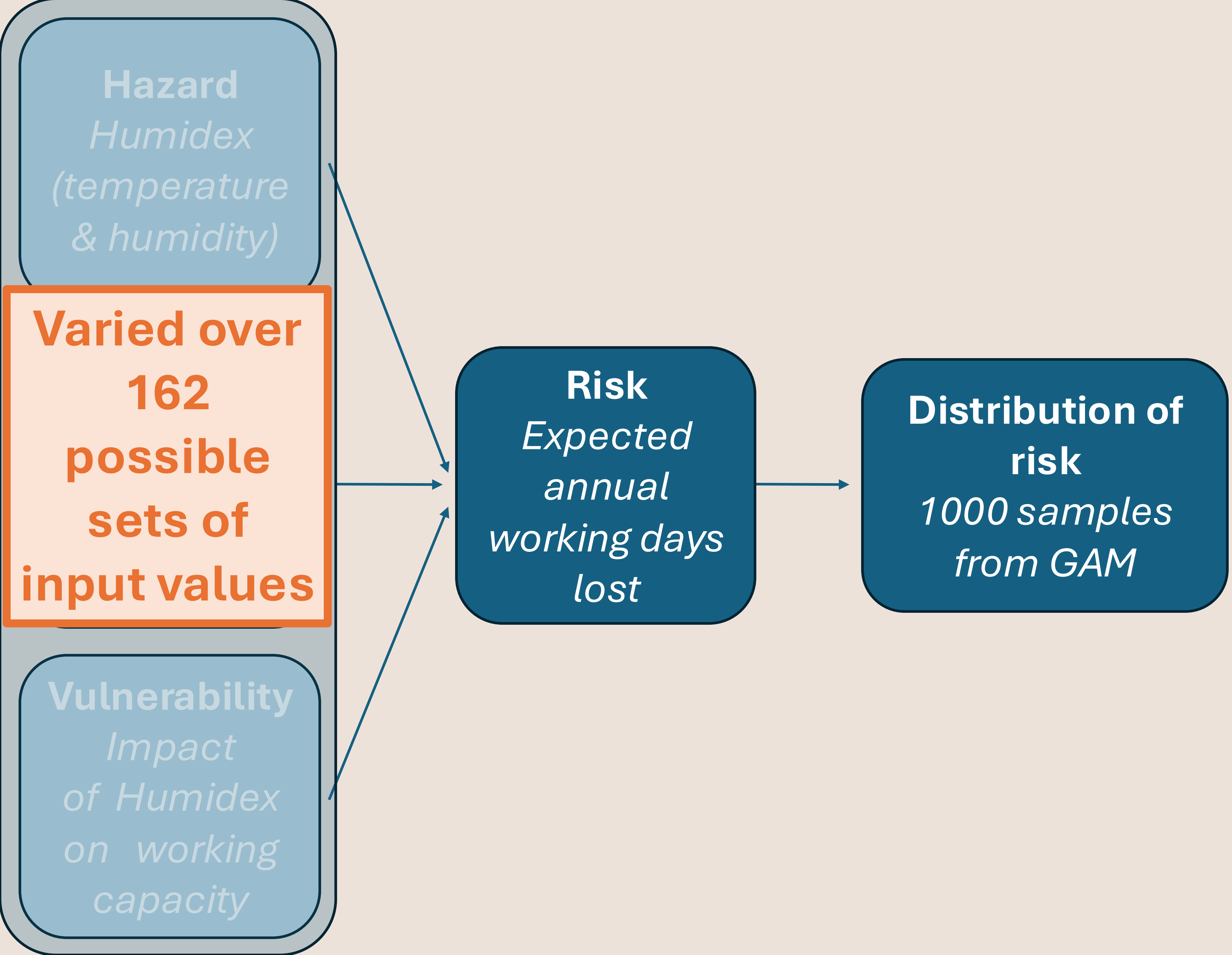


Quantifying uncertainty

Following Dawkins et al. 2023:

- Input hazard, exposure, and vulnerability data
- Apply a risk assessment model to each climate model ensemble member
- Generate 1000 samples of risk per location using Generalised Additive Models (GAMs)

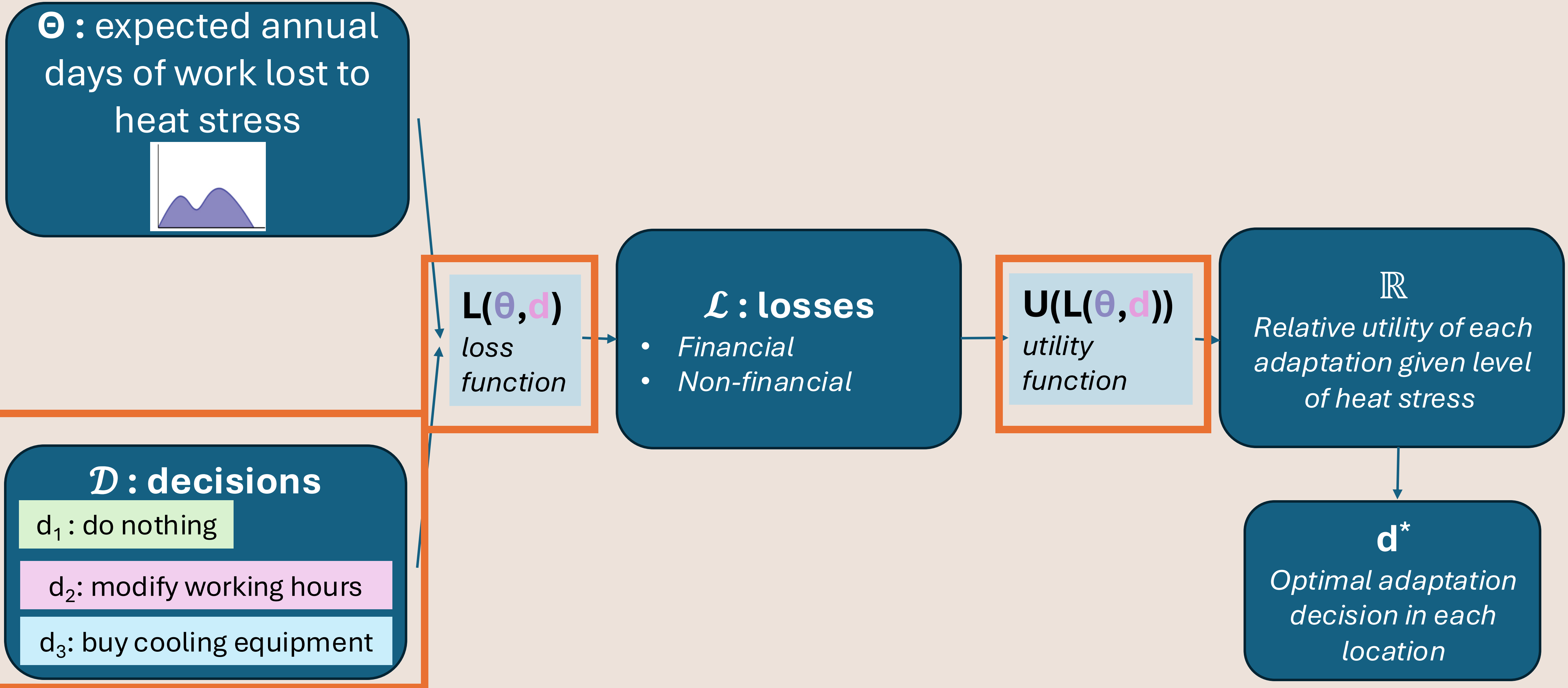


Uncertain risk-related inputs

Sample the risk for each combination of plausible values for 5 risk-related inputs:

- Hazard: calibration method, warming level
- Exposure: exposure model
- Vulnerability: function parameters

Uncertainty in decision attributes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Optimal adaptation decision in each location

Loss functions

$L(\theta,d)$: $\Theta \times \mathcal{D} \rightarrow \mathcal{L}$ is the loss of making decision d if the true state of nature is θ

For a location j, GAM sample n, and decision i:

Financial loss:

$$L_1(\theta_{jn}, d_i) = (\text{cost per person per year}_i \times \text{number of people}_j) + (\text{cost per day of work} \times (1 - \%\ \text{effectiveness}_i) \times \theta_{jn})$$

Non-financial loss:

$$L_2(\theta_{jn}, d_i) = 10 - s_i \text{ where } 0 \le s_i \le 10$$

Utility function

$U(L(\theta,d))$: $\mathcal{L} \to \mathbb{R}$ represents the relative value of each decision

For a location *j*, GAM sample *n*, and decision *i*:

Financial utility	**Non-financial utility**
$U_1(L_1(\theta_{jn}, d_i)) = 1 - \frac{L_1(\theta_{jn}, d_i)}{\max_{n',i'} L_1(\theta_{jn'}, d_{i'})}$	$U_2(L_2(\theta_{jn}, d_i)) = 1 - \frac{L_2(\theta_{jn}, d_i)}{10}$

Overall utility function:

$$\boxed{U(\theta_{jn}, d_i) = k_1 U_1(L_1(\theta_{jn}, d_i)) + k_2 U_2(L_2(\theta_{jn}, d_i))}$$ where $k_1, k_2 \geq 0$, $k_1 + k_2 = 1$

Uncertain decision-related inputs

Financial loss:

$L_1(\theta_{jn}, d_i)$ = (cost per person per year$_i$ × number of people$_j$)

+ (cost per day of work × (1 – % effectiveness$_i$) × θ_{jn})

Non-financial loss:

$L_1(\theta_{jn}, d_i) = 10 - s_i$

Utility:

$$U(\theta_{jn}, d_i) = \boxed{k_1} U_1(L_1(\theta_{jn}, d_i)) + \boxed{k_2} U_2(L_2(\theta_{jn}, d_i))$$

Varied by taking 200 samples from a range of plausible values

Overall process

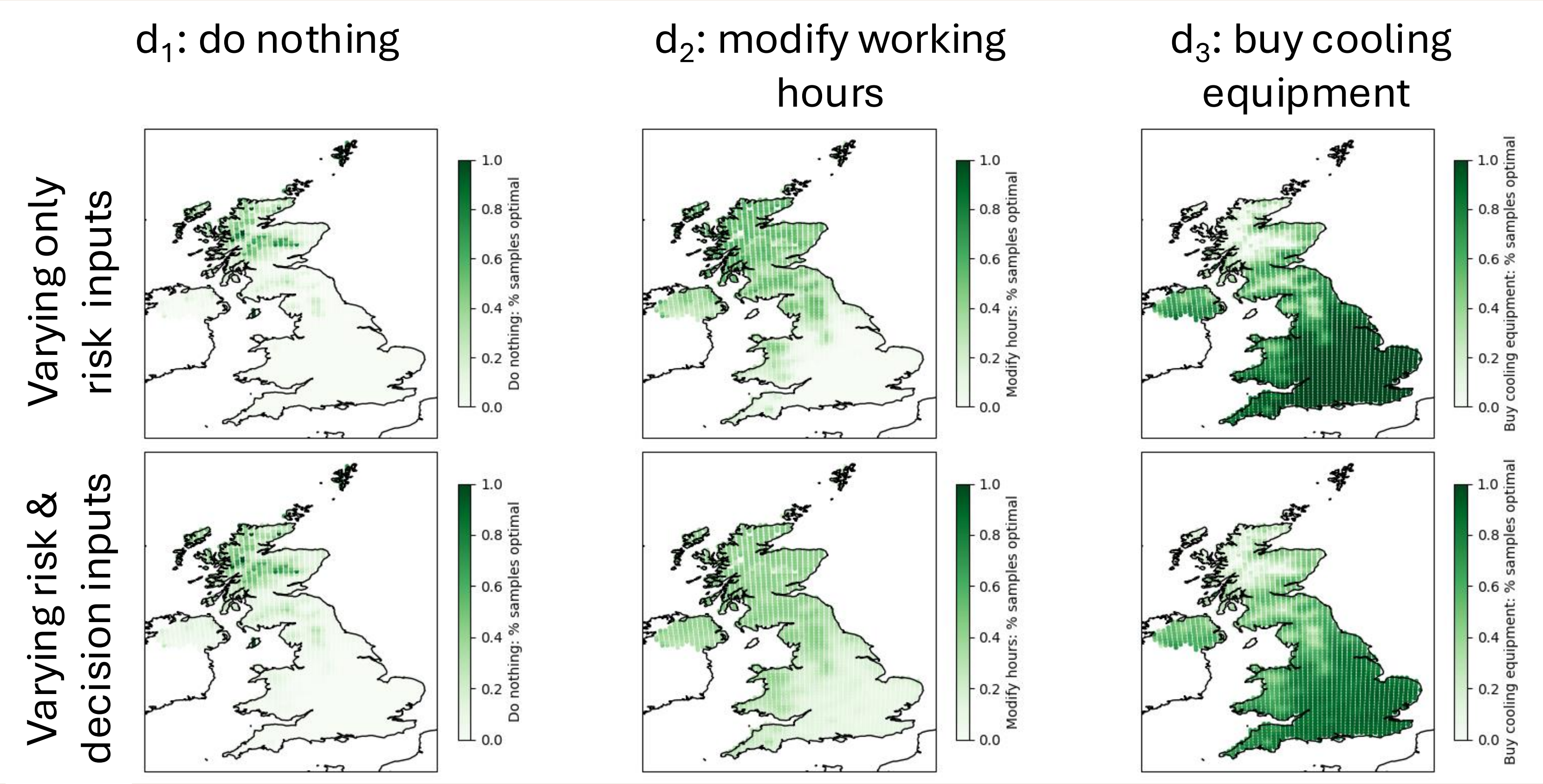
- Vary the risk-related inputs across a range of 162 combinations →
  record the optimal decision in each location
- Vary both risk-related and decision-related inputs across a range of 162 × 200 = 32,400 combinations →
  record the optimal decision in each location
- Characterise the uncertainty of the optimal decision & its sensitivity to each input

Results

Where are the different adaptation options most often optimal?

Optimal decision by location

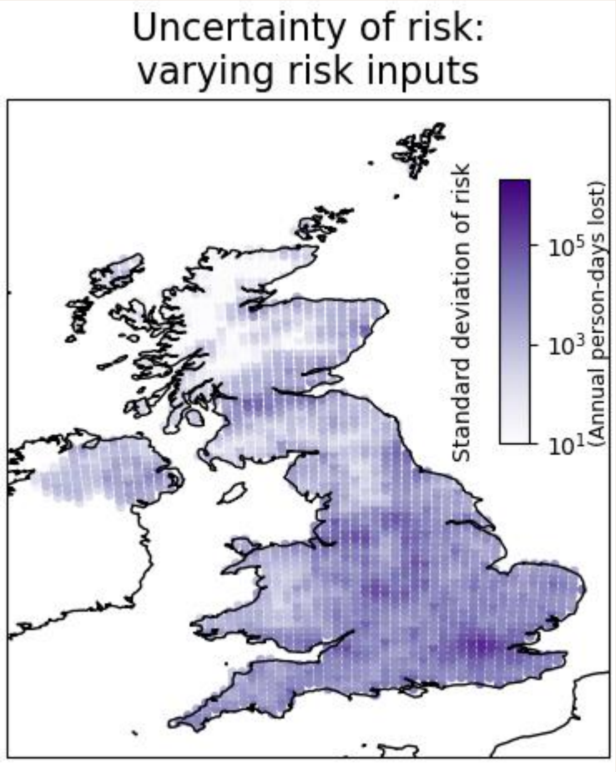
- **Spatial** distribution of where certain decisions are more often optimal
- We are less certain in the decision when varying risk **and** decision-related inputs

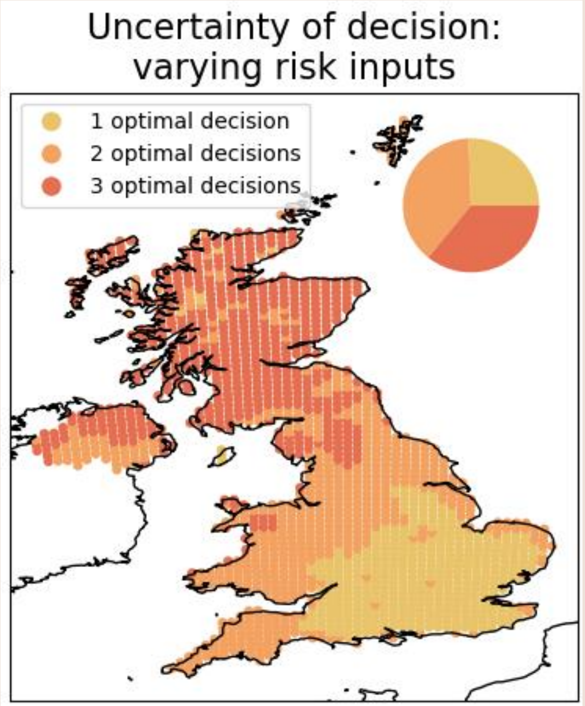


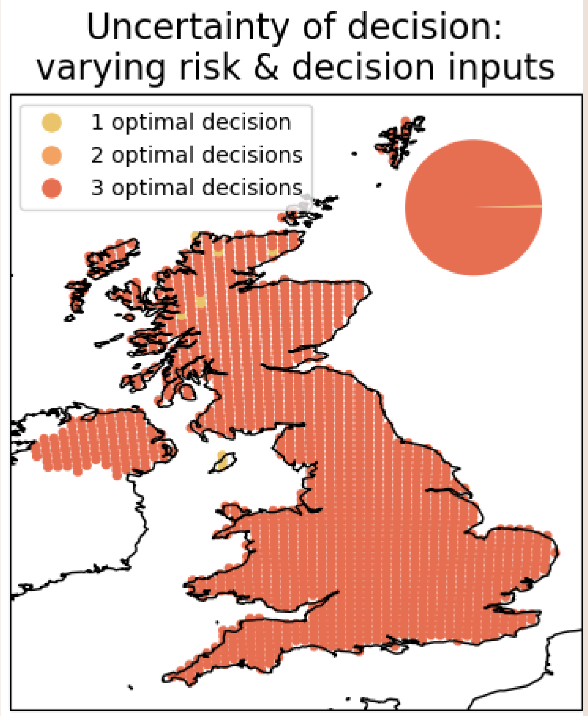
How uncertain is the optimal decision?

Decision uncertainty

- High uncertainty in climate risk **does not** necessarily translate into high uncertainty in decision
- When accounting for uncertainty in both risk and decision inputs, the decision becomes **far more uncertain**



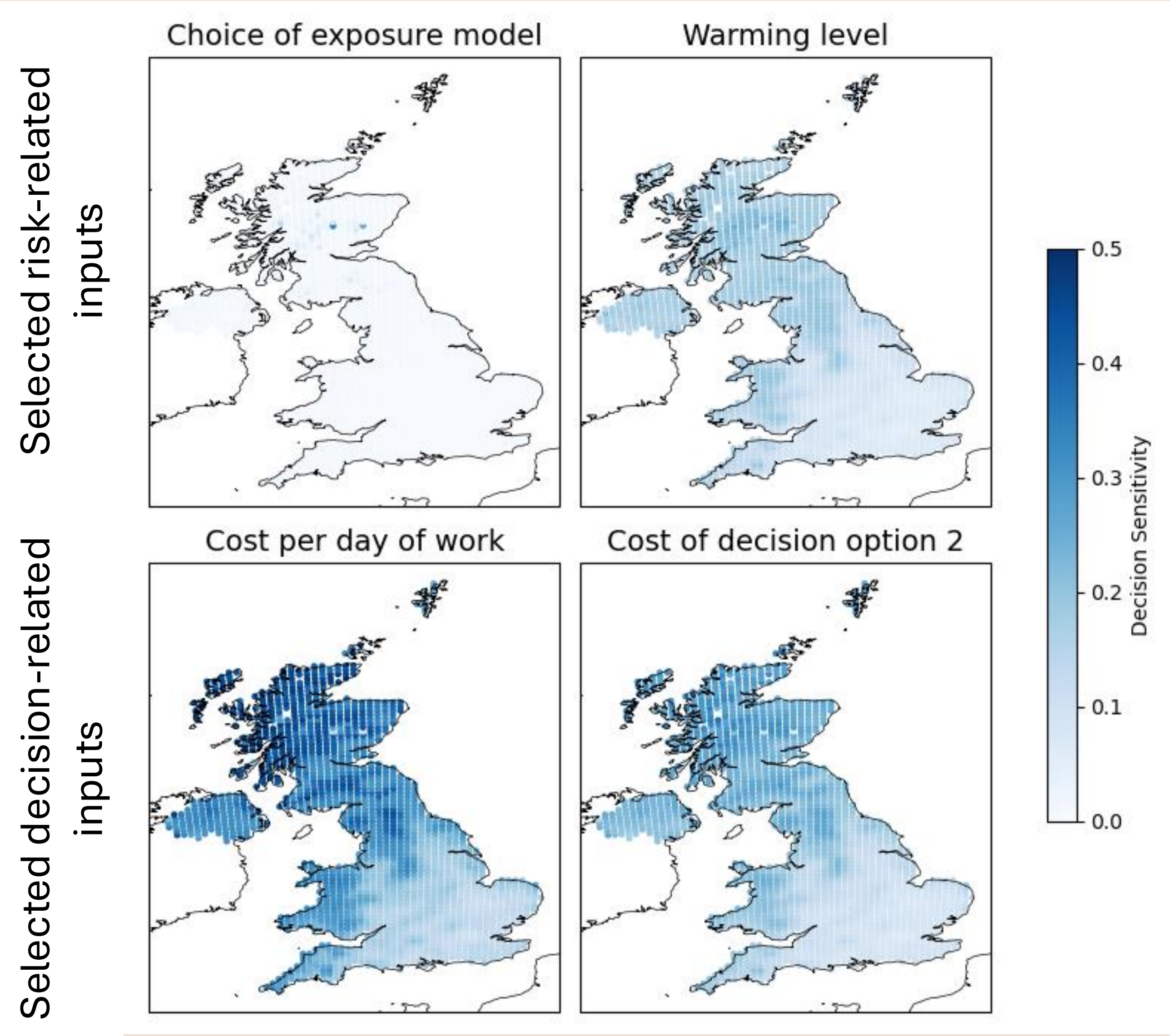




Which inputs is the optimal decision most sensitive to?

Decision sensitivity

- The decision is often more sensitive to **decision-related inputs** than to risk-related inputs
- Sensitivity to many inputs **varies regionally**



Conclusions

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- Uncertainty and sensitivity analysis should be performed on adaptation decisions, not only on climate risk
- Decisions can be less sensitive to risk-related inputs than they are to decision-related ones
- Uncertainty and sensitivity analyses should be performed on a local basis

What's next?

- Real-world application: electricity distribution network operator
- Theoretical extensions: value of information and sequential decision-making

Questions?

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Cecina Babich Morrow [a], Laura Dawkins [b], Francesca Pianosi [c], Dennis Prangle [a], Dan Bernie [b d]