Living with Climate Variability and Change: Understanding the Uncertainties and Managing the Risks

The Theory of Decision Making

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Two Main Topics:

- Different types of **uncertainties**
- Different types of **decisions** to be made

with respect to climate variability

and change

Four Parts of the Talk

1. Examples for different types of uncertainties and decisions and classification
2. Normative approaches to predict uncertain events and to make decisions under uncertainty
3. Strengths and weaknesses of the normative approaches
4. Conclusions and recommendations

1a. Different Types of Uncertainties

- **Uncertainties** mean: missing knowledge about future events (dimensions: scope rsp. damage; probability rsp. likelihood)
- **Types** of uncertainties with respect to climate variability and change:

  Type A: future **manifestation** of climate indicators like temperature increase/ precipitation/ sea level rise etc.

1a. Different Types of Uncertainties

Type B: future **relationships** between CO_2 increase and environmental effects like ocean acidification, soil degradation, bio-diversity losses etc.

Type C: future **costs** of climate change induced environmental effects like the destruction of coastal areas, the degradation of maritime ecosystems, migration etc.

1a. Different Types of Uncertainties

- Different types of uncertainties can be **classified** according to

  (i) the **fields** concerned (natural vs. social science)

  (ii) the **type** of missing knowledge (climate input vs. environmental or socio-economic output vs. relationships)

  (iii) the **amount** of missing knowledge (uncertainty, ambiguity, pure risk; degree of belief)

1a. Different Types of Uncertainties

- Why do these classifications **matter**?

They matter because they show **who** has to bring in **which** information in order to reduce the uncertainties.

They matter because one can see which **types of decision procedures** can be applied

1b. Different Types of Decisions

- Climate related **decisions** have to be made on many different levels:

  Type 1: **Individual** decisions like farmers' crop decisions

  Type 2: **Group** decisions like settlement of families

  Type 3: **Political** decisions like the decisions of voters which political (environmental) program to prefer or of politicians which (environmental) strategy to pursue on national and international level

1b. Different Types of Decisions

- Different types of decisions can be **classified** according to:

  (i) the type of **decision-maker** (individual, group, voter, politician)

  (ii) the **time horizon** (long, middle, short term)

  (iii) the **scope** (local, regional, national, global)

1b. Different Types of Decisions

- Why do these classifications matter?

  They matter because they emphasize the **relevance** of making good decisions.

  The more relevant (aggregate level, long term, global) a decision is the more **it pays** to improve climate related decisions

  They show **different needs** for forecast products and decision rules

2a. Normative Approaches to Predict Uncertain Events

Relevant questions are:

- **What** will happen in the future?
- **How likely** is it?
- **When** will it happen?
- **Where** will it happen?

=> **Rational predictions** are based upon a model

2a. Normative Approaches to Predict Uncertain Events

What will happen?

- Classical normative approaches assume that there is an **observation history** (y_t, y_{t-1}, y_{t-2},….) available in order to predict y_{t+1}, y_{t+2},….;

  hereby y mostly represents **outcomes** (c)

- **Techniques** in order to predict just one y_t are numerous

2a. Normative Approaches to Predict Uncertain Events

What will happen?

- **Prominent techniques** are for instance Least Square methods (minimizing the mean square deviation) or Maximum Likelihood estimates (if all variables are jointly normally distributed)
- These techniques typically imply assumptions about the distribution functions of the variables

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- The likelihood of the predicted outcome can be guessed from the error terms of the econometric models
- However, classical **normative decision models** require more precise probability information
- They also require separable outcome and probability information

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- **Probabilities p** are used for drawing inferences from inadequate information
- Probabilities can be interpreted on the basis of **relative frequencies** of events in repeated trials.
- For a countably infinite series of trials the relative frequency tends in the limit to p
- **Not applicable** for short records or extreme events

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- A probability p can also be interpreted as a **degree of belief**; it expresses the credibility of a certain thought about the future event
- One is concerned with reasonable degrees of belief relative to evidence; therefore this approach can be called a **rationalist** one (Laplace 1795, Keynes 1921)

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- A statement of probability can also be one's own assessment of the extent to which one is confident of a proposition (Ramsey 1926, de Finetti 1937, Savage 1954). This can be called a **subjective** approach
- Various methods to determine such probabilities (questioning, graphical, relative heights etc.)

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- Objective, rationalist and subjective probabilities follow the same **mathematical rules** like normalization, non-negativity, additivity, independence, conditional probability etc.

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- Based on the so-called **Bayesian theorem** new pieces of evidence can be incorporated in prior probability distributions
- One calculates the probability of an event as **conditional** probability (conditional on the new piece of evidence)
- This can be called “reasonable **learning**” from experience

2a. Normative Approaches to Predict Uncertain Events

How likely is it?

- In many cases we have **quantitative** probabilities
- Probabilities may also have **qualitative** character

  (ordering of probabilities; fuzzy probability information)

2a. Normative Approaches to Predict Uncertain Events

When will it happen?

- The normative approaches just concentrate on **one future** point in time
- Yet, increasing climate variability and climate change have a long **multi-period time horizon**
- Predictions have to be made and are made until 2050/2100/even2300 from a natural science point of view

2a. Normative Approaches to Predict Uncertain Events

When will it happen?

- A prominent technique to make long range predictions is the **scenario technique**
- Combining different parameter constellations (highly probable, medium, less probable)
- This technique is for instance applied by **IPCC**; examples are A1, B2 etc. scenarios with differing assumptions about demographic behavior, consumption patterns etc.

2a. Normative Approaches to Predict Uncertain Events

When will it happen?

- Given a set of assumptions about future developments of explanatory variables and given a model for the relationship between explanatory and explained variables => the **time path** of the explained variable is predicted (embedded in **confidence bands**)
- **Different time paths** for different sets of assumptions

2a. Normative Approaches to Predict Uncertain Events

Where will it happen?

- Normative models to predict uncertain events typically do not have a **spatial component**
- However, with respect to climate variability and climate change it matters where exactly the sea level rises or the temperature increases most.

2a. Normative Approaches to Predict Uncertain Events

Where will it happen?

- **GIS models** can give the necessary information about the past and present situation in specific areas of the world
- Together with spatial models this information can be used in order to make spatial predictions
- These predictions are typically embedded in **confidence bands**

2b. Normative Approaches to Make Decisions Under Uncertainty

Some Basic Principles:

- To decide means to **choose** from a set of alternatives
- Decision theory is concerned with **rationality** in choice (decisions one should make, based on some axiomatic footing)
- Decision theory mostly refers to **individual decisions**
- Decision theory mostly sees just **one future point in time** and **just one location**

2b. Normative Approaches to Make Decisions Under Uncertainty

Each decision problem has 4 components

- Set A of possible **actions** or activities a
- Set Z of possible future **states of the world** z
- Set P of information p on the **probability** of different future states of the world
- Set C of possible future **consequences** c or **outcomes** of future consequences of an action or alternative

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Matrix:

The elements have

to be constructed!

States of the world / Actions	z_1	z_2
	p_1	p_2
a_1	c_{11}	c_{12}
a_2	c_{21}	c_{22}

2b. Normative Approaches to Make Decisions Under Uncertainty

Climate change related **example**:

- A farmer has to decide on the type of crop on which he specializes during the next 10 -20 years (a1 and a2)
- Future states of the world are: no change in precipitation (z1) and heavy decrease in precipitation (z2); p1 and p2
- In z1 (z2) cases consequences will be good (low) harvest/high (low) income, differing for a1 and a2
- Choose a1 or a2?

2b. Normative Approaches to Make Decisions Under Uncertainty

Some basic **assumptions**:

- The decision-maker is **well informed** about the key components of the decision problem
- We assume here that the decision-maker has just **one goal**, i.e. we do not deal with multiple criteria decision problems

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 1 – **Expected Utility** Model **EU**:

- Based on Bernoulli (1738; St.Petersberg Paradox): people do not generally base their decisions on expected values of outcomes
- Modern version by John von Neumann and Oskar Morgenstern (1944)
- Assumption that the individual has **preferences** over the set of consequences or outcomes

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 1 – **Expected Utility** Model **EU**:

- The preference relation R is complete and transitive and can be represented by a utility function $u(c_i)$:

  $u(c_1) \geq u(c_2)$ if and only if c_1 R c_2

- Classical representability theorem by Debreu 1954 (for certainty!)

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 1 – **Expected Utility** Model **EU**:

- Mainly three axioms which characterize rationality under **uncertainty** imply that the preference relation R has an expected utility representation E U(a_j)
- Following the EU-principle then means **rationality:**

(1) $$EU(a_j) = \sum_{i=1}^{N} p_i \cdot u(c_{ji}), with \sum_{i=1}^{N} p_i = 1$$

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 1 – **Expected Utility** Model **EU**:

- The axioms are the ordering axiom (transitive and complete)/ the continuity axiom/ the independence axiom
- Additional assumption: probabilities are perceived in an objective way
- But: Subjective Expected Utility Model (**SEU**) as **the** model for decision-making under uncertainty

2b. Normative Approaches to Make Decisions Under Uncertainty

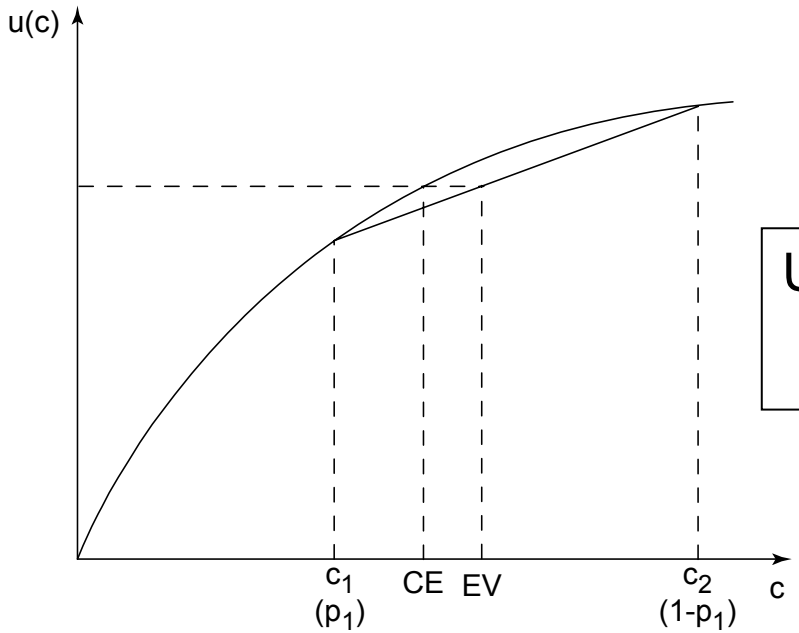
Decision Model 1 – **Expected Utility** Model **EU**:

- Additional assumption: **probabilities and utility** functions are **independent and separable**
- Further models: **Rank Dependent Expected Utility** Models (Quiggin 1982) as descriptive models with more explanatory power => Presentation E.U.Weber

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 1 – **Expected Utility** Model **EU**:

- A concave utility function implies risk aversion



$$U(p_1c_1+(1-p_1)c_2) > p_1\,U(c_1)+(1-p_1)\,U(c_2)$$

$$CE < EV$$

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 2 – **Risk/Return** Models **R/R**:

- Postulate: individual preferences over risky alternatives depend on the return value RV and the riskiness R; **no separability of outcome and probability**
- Value V of an alternative a_j:

  (4) $V(a_j) = g(RV,R)$

- g compensatory or lexicographic?

2b. Normative Approaches to Make Decisions Under Uncertainty

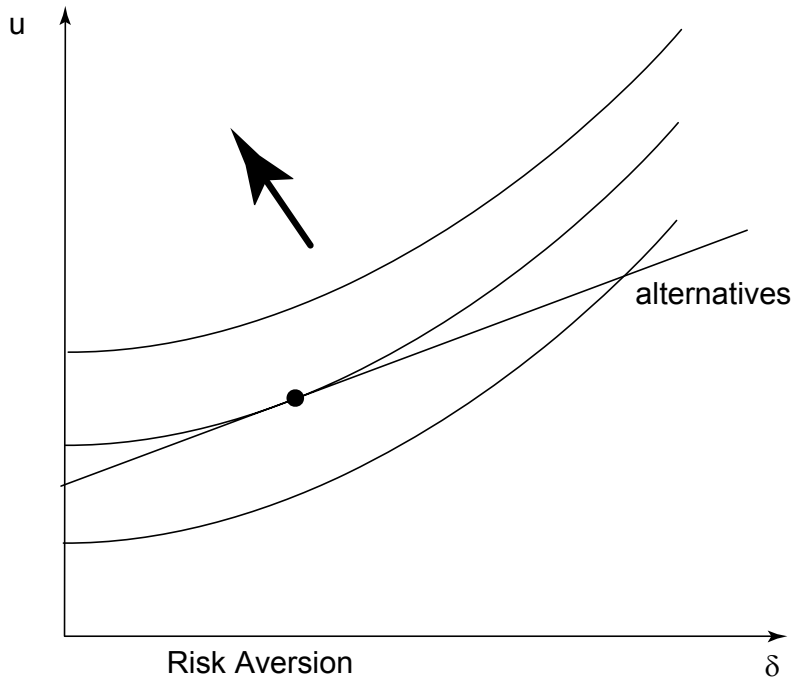
Decision Model 2 – **Risk/Return** Models **R/R**:

- RV normally measured as Expected Value EV
- R measured as Standard Deviation (Markowitz 1959; (μ,δ) -model)/ Perceived Risk etc.....
- Under certain conditions the Expected Utility model EU (or the Bernoulli model) and the (μ,δ) – model give the same results

2b. Normative Approaches to Make Decisions Under Uncertainty

Decision Model 3 – **Risk/Return** Models **R/R**:

- Markowitz model:



3a. Strengths and Weaknesses of the Normative Approaches

Normative **Prediction** Approaches:

- They tell us which information input and which assumptions you need in order to make **rational** predictions => good benchmark
- They do not tell us which assumptions to choose or how much to invest in improving the information input

  => weakness?

3a. Strengths and Weaknesses of the Normative Approaches

Normative **Prediction** Approaches:

- They are able to incorporate **experts' knowledge**

  => strength

- They allow for the incorporation of **new evidence**

  =>strength

- They mostly neglect **time horizon** and **spatial** effects

  => weakness

3b. Strengths and Weaknesses of the Normative Approaches

Normative **Decision** Models:

- They tell us how a **rational** decision-maker should behave => good benchmark
- They have a **clear analytic basis** and can be easily updated => strength
- The cost and benefits of generation/acquisition of **additional information** can be assessed => strength

3b. Strengths and Weaknesses of the Normative Approaches

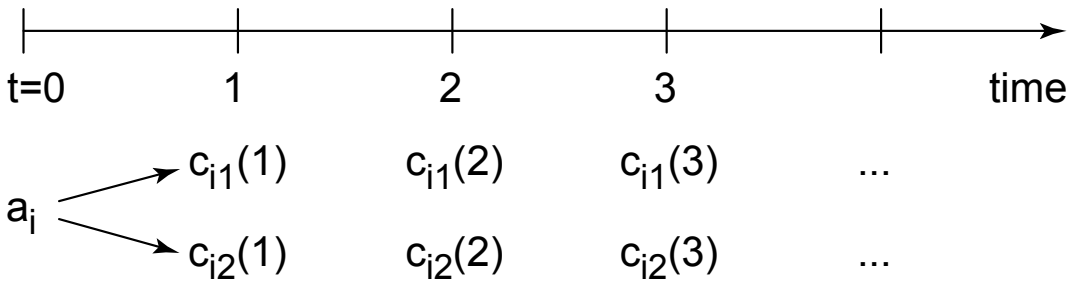
Normative **Decision** Models:

- They do **not explain** why people make the decisions we can observe => weakness
- For **predictions of decisions**: can we expect decision-makers to be nearly rational?
- They assume knowledge of **quantitative probabilities** => weakness

3b. Strengths and Weaknesses of the Normative Approaches

Normative **Decision** Models:

- They typically focus on just **one future point** in time => weakness
- Possible future consequences of an action have to be considered over several periods of time (discounting?)



3b. Strengths and Weaknesses of the Normative Approaches

Normative **Decision** Models:

- They typically consider one **individual** decision-maker => weakness
- They do not consider the **process (the interactions)** evolving while decisions are made => weakness
- They typically assume that there is sufficient knowledge about the **outcomes** => weakness

4. Conclusions and Recommendations

Conclusions:

- Normative **prediction** approaches are important since they help to structure the information requirements
- The normative **decision model** is still important since it helps to structure the decision situation and to serve as relatively simple benchmark
- In order to make reliable **predictions** on future decision behavior **descriptive models** seem to be more appropriate

4. Conclusions and Recommendations

Recommendations:

- Use normative **prediction** approaches to identify information requirements
- Don' forget to add time-path and spatial predictions
- Use the normative **decision models** to identify information requirements for predicting decisions or helping decision-makers
- Don't forget to consider **psychological approaches**

4. Conclusions and Recommendations

Recommendations:

- A well structured **interdisciplinary cooperation** (natural scientists, social scientists) has to be established in order to make **sustainable predictions and decisions** related to increasing climate variability and climate change