Lecture 5:
Solving a social compromise decision problem
The Cost-Benefit Analysis (CBA)

MICS Algorithmic Decision Theory

University of Luxembourg

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Plan

1. What is Cost–Benefit Analysis (CBA)
   - CBA Definition
   - Illustrative Applications
   - History

2. Principles of CBA
   - Choose investment projects
   - CBA : an extension of financial auditing
   - Economic Foundations

3. CBA applications in public transports
   - Traffic forecasting
   - Travel time reductions
   - Improving road safety

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CBA Definition

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- The Cost–Benefit Analysis is a financial-economic (quantitative) approach for solving social choice problems, based on balancing societal costs against societal benefits.

Commentary

- *This decision aid technique is essentially used for evaluating and/or comparing large public sector equipment projects.*
- *The algorithmic idea is very simple : A project should only be undertaken if its societal benefits outrank its societal costs.*

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Illustrative applications

Economic development :

- Choosing an investment strategy in a developing country
- Allocating budgets to government agencies
- Choosing a policy of energy supply

Transports :

Public health :

Illustrative applications

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Transports :

- Choose the actual trajectory of a highway
- Develop an urban tramway
- Reorganize the public transports in a city

Public health :

- Choose the actual site for a new hospital
- Decide on a disease prevention policy
- Choose therapy standard for a given disease

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- Establish pollution norms
- Approve or not genetically modified food
- Establish a plan for reducing CO_2 emissions

National Education :

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- The CBA mostly developed after the big depression of the thirties and during the reconstruction years after Second World War II.
- First applications concern water supply management in the South-West of the USA.
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Optimal choice of investment projects

- The natural starting point of CBA is given by a classical investment problem.
- Indeed, an investment may be considered as an actual expenditure at today's date (the costs) from which one expects to earn future incomes (the benefits).

Example

- A SME acquires a new production equipment for 1 000 000€. The company pays cash 400 000€ and the rest amount is financed with a mortgage that foresees ten annuities of 80 000€ to be paid at the end of each year.
- The company expects to earn with new equipment following incomes at the end of the next ten years: 150 000€/year in the first three years, then 140 000€ during the next five years and eventually 100 000€ during the last years of the investment project.
- Will the investment project be profitable when assuming a discount rate of 7%?

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Commentary

- *To quantify an investment projects requires the choice of a temporal horizon wherein to set the accounting of costs and benefits.*
- *Usually the life time of an investment is reasonably taken as global time period for evaluating an investment project.*
- *Slicing the overall life time into equal sub-periods, years or semesters for instance, is somehow arbitrary and may depend on the trade-offs between the time depth and the complexity of the evaluation model.*

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Definition

- Suppose now that a given project is evaluated on T periods of equal length.
- The consequences of the investment project are evaluated in each of these time periods.
- Let's denote b_t the benefits, and c_t the costs, appearing in each period $t = 0, 1, ..., T$.
- The net income in each period is $a_t = b_t - c_t$.
- Note that these evaluations have to be expressed in a same currency (here supposedly in €).

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- *Comparing two net incomes from different times, even if expressed in the same currency, requires to discount future net incomes to a same present period, usually the starting period* $t = 0$ *of the investment project.*
- *Suppose there exists a capital market where the company may borrow money at a fixed interest rate of* $i\%$*.*
- *If you borrow today* $1€$ *for one time period, you will have to reimburse* $(1 + i)€$ *at the end of the period.*
- *Inversely, if you get an income of* $1€$ *at the end of the period, you may borrow* $\frac{1}{(1+i)}€$*.*
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Definition (The Present Net Value of a project)

The Net Present Value (NPV) of project is defined as follows :

$$NPV = \sum_{t=0}^{T} \frac{a_t}{(1+i)^t} = \sum_{t=0}^{T} \frac{(b_t - c_t)}{(1+i)^t}$$

- If $NPV > 0$, the project's benefits outrank its costs, the investment project appears to be profitable.
- If, however, $NPV \leq 0$, the investment will not be profitable.
- If $NPV = 0$, the company will be indifferent between undertaking or not this investment project.

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Commentary

In this approach, following working hypotheses are made :

- *The life time of the project is given.*
- *This duration is divided into T periods of equal length.*
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Commentary

- *Societal Investment projects concerned with CBA are much more complex than simple company investment projects.*
- *Nonetheless, CBA may be seen as an extension of classical financial auditing. In CBA :*
  - *Costs and benefits are evaluated following a societal perspective.*
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An extension of financial auditing – continue

Definition (Net Present Value of a societal project)

- We denote $b_t = (b_t^1, b_t^2, ..., b_t^r)$ the r components of the benefits and

  we denote $c_t = (c_t^1, c_t^2, ..., b_t^s)$ the s components of the costs,

  evaluated in units specific to each component at each period t.

- We denote p_j the price of one unit of societal benefit of the component $j = 1, ..., r$ and

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  Theses conversion prices are supposed independent of period t, i.e. constant over the time life of the project.

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The Net Present Societal Value *NPSV* of a project is defined as :

$$NPSV = \sum_{t=0}^{T} \frac{(\bar{b}_t - \bar{c}_t)}{(1+i)^t} = \sum_{t=0}^{T} \frac{\sum_{j=1}^{r}(p_j \cdot b_t^j) - \sum_{k=1}^{s}(p'_k \cdot c_t^k)}{(1+i)^t}.$$

- If $NPSV > 0$, the project, should it be implemented, is going to augment social welfare.

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- *The same operational difficulty as before, that is estimating the net present value of a financial investment project, remains (time life of the project ?, discounting rate ?)*
- *Following difficulties appear furthermore :*
  - *How to evaluate costs and benefits of a project from a societal perspective ?*
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Economic Foundations

- Consider an economy over a certain time span.
- Each individual $i = 1, .., n$ is supposed to have completely ordered preferences on all potential consumption baskets.
- The preferences of individual i are revealed by a utility function $U_i(q_{i1}, q_{i2}, ..., q_{im})$ where

  q_{ij} represent the quantity of good $j = 1, ..., m$ consumed by individual i.
- Social welfare is supposed to be defined by a function $W(U_1, U_2, ..., U_n)$ aggregating the preferences of all the individuals $i = 1, ..., n$.

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Economic Foundations – continue

- A project is considered as an external perturbation of the economy modifying in fact the quantities of goods $j = 1, .., m$ consumed by each individual i.
- These modifications are supposed to be marginal, not influencing by the way the prices of the goods.
- The impact of the project is thus given by the derivative of the global welfare function W :

$$dW = \sum_{i=1}^{n} \sum_{j=1}^{m} W_i U_{ij} dq_{ij}$$

where $W_i = \frac{dW}{dU_i}$, and $U_{ij} = \frac{dU_i}{dq_{ij}}$.

- Social welfare will improve if $dW > 0$.

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- The existence of a market for all goods $j = 1, ..., m$, on which operate the individuals $i = 1, ...n$ before the impact of the project in order to maximise their utility guarantees an equilibrium situation such that for each individual i and all goods r and s :

$$\frac{U_{ir}}{U_{is}} = \frac{p_r}{p_s}$$

where p_r and p_s represent the equilibrium prices of both goods r and s.

- If we choose a specific good as exchange money, we obtain for each good $j = 1, ..., m$, $U_{ij} = \lambda_i p_j$.
- λ_i is the marginal utility variation of individual i when consuming a unit of this exchange money, that is the marginal utility of income of individual i.

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- The societal impact of the project becomes :

$$dW = \sum_{i=1}^{n} \lambda_i W_i \sum_{j=1}^{m} (p_j \cdot dq_{ij}).$$

$\lambda_i W_i$ represents the increase in social welfare following a marginal increase of the income of individual i.

- Under the hypothesis that, before the project, the distribution of societal income is optimal, the $\lambda_i W_i$ are constant over all individuals $i = 1, ..., n$.

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- *NPSV* - the Net Present Social Value may indeed by seen as an extension of formula (*).

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Economic Foundations – critical review

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The actual limitations of the simple economic model are evident :

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Applications of CBA are usually characterised by :

- *Non-marginal variations of social welfare (constructing the tram in Luxembourg for instance)*
- *The presence of numerous public goods for which no market price is available (Education, health services, etc)*
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CBA applications in public transports

Example (Traffic forecasting)

- In France, the yearly investment in public transports is around 1.5 billion €.
- CBA is at present the standard evaluation approach of these investment projects.
- A crucial and essential part in these CBA is devoted to estimating the changes in traffic that will be induced with a project. Most of the benefits appear as travel time reductions.
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- Potential travel time reductions are directed related to the traffic estimations expected after the implementation of the project.
- Time life of a road equipment project may be very long. However, the traffic forecasts cannot go very very far ahead of the starting date of the project.
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- Taking travel time reduction into account is not evident at all.
- A minute in a crowded bus is not equivalent to a minute comfortably sitting in a half-empty bus.
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- Linearity of time may easily be contested.
- Is loosing one hour per day for one individual equivalent to loosing one minute a day for 100 individuals ?
- How to convert travel time reductions into monetary units ?
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- A substantial category of benefits expected from a road equipment project consists in improving rad safety.
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- The conversion rates used in France are the following

(instruction cadre 2004) :

death	1 500 000	€
seriously injured	225 000	€
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- Value of a life in Europe (2002) :

Country	CBA prize of life	
Denmark	628 147	€
Finland	1 414 200	€
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Concluding

- The conversion prizes used in CBA for evaluating costs and benefits of certain public goods are completely arbitrary (noise reduction, pollution reduction, improving road safety, etc)
- The complexity of the evaluation model is problematic.
- Uncertainty and imprecision associated with many costs and benefits measures is problematic.
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- CBA stresses the necessity for following a consistent and systematic evaluation of the consequences of the decision alternatives.
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- Assuming a strictly homogeneous society with respect to the consequences of a societal investment project is not realistic and therefore not convincing.
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What exactly is commensurability ?

- Two distinct objects can be taken to be commensurable if they are measurable in common units.
- Non-commensurability is present when several dimensions of value are irreducible to one another.
- In the context of evaluating choice, commensurability requires that, in assessing its results, we can see the values of all the relevant results in exactly one dimension – measuring the significance of all the distinct outcomes in a common scale – so that deciding what would be best, we need not go beyond '*counting*' the overall value in that homogeneous metric.
- Since the results are all reduced to one dimension, we need do no more than check how much of that '*one good thing*', to which every value is reduced, is provided by each respective option.
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