

Lecture 5:

Solving a social compromise decision problem

The Cost-Benefit Analysis (CBA)

MICS Algorithmic Decision Theory

University of Luxembourg

1^{er} avril 2019



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

- *The 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

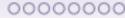
Economic development :

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

Transports :

Public health :

- Choosing a policy of energy supply
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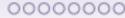
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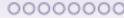
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Transports :

• Choose the actual trajectory of a highway

Public health :

• Choosing the best location for a hospital



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Transports :

- Choose the actual trajectory of a highway
- Develop an urban tramway

Public health :

- Choose the location of a hospital
- Develop a vaccination strategy



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- Reorganize the public transports in a city

Public health :

- Choose the location of a hospital
- Develop a vaccination strategy
- Choose the location of a waste treatment plant



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- Develop a new disease prevention policy
- Choose therapy standard for certain diseases



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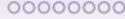
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Illustrative example – continue

Environment :

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

National Education :

European policy :



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- Brexit : Leaving or remaining in the EU
- New individual or company
- Exporting or not local policies



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History

- **Origin** : Jules Dupuit (French engineer, 1804–1866) and Alfred Marshall (British economist, 1842–1924)
- 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.
- It is in the UK and the Common Wealth that the CBA approach is at present most used.

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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 requires a new production equipment for 1.000.000 €. The company pays cash 400.000 €, and the rest amount is financed with a mortgage that forces her to make of 80.000 € to be paid at the end of each year.
- The investment project is profitable when the investment returns are higher than the cost of the investment. The SME expects to have a net cash flow of 200.000 € during the first two years and 300.000 € during the last years of the investment period.
- Will the investment project be profitable when assuming a discount rate of 7%?

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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.
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Optimal choice of investment projects – continue

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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- 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 $t = 0, 1, \dots, T$.
- The net income in each period is $a_t = b_t - c_t$.
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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 $(1 + i)\text{€}$ at the end of the period.*
- *Inversely, if you get an income of 1€ at the end of the period, you may borrow $\frac{1}{(1+i)}\text{€}$.*
- *Indeed, at the end of the period you will have to reimburse :*

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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.
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- If, however, $NPV \leq 0$, the investment will not be profitable.
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Optimal choice of investment projects – continue

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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.*
- *All consequences of the project are expressed in a same currency (€).*
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CBA : an extension of financial auditing

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 :*

1. *Costs and benefits are evaluated following a societal perspective.*

2. *Costs and benefits do not necessarily materialize in monetary value. If not, a cost, not immediately shown, can be taken into account.*

3. *The discounting rate has to be chosen from a societal perspective.*

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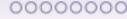
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An extension of financial auditing – continue

Definition (Net Present Value of a societal project)

- We denote $b_t = (b_t^1, b_t^2, \dots, b_t^r)$ the r components of the benefits and
we denote $c_t = (c_t^1, c_t^2, \dots, c_t^s)$ 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 $j = 1, \dots, r$ 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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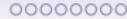
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- If $NPSV > 0$, the project, should it be implemented, is going to augment social welfare.

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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 ?)*
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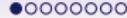
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Economic Foundations

- Consider an economy over a certain time span.
- Each individual $i = 1, \dots, n$ is supposed to have completely ordered preferences on all potential consumption baskets.
- The preferences of individual i are revealed by a utility function $U_i(q_{i1}, q_{i2}, \dots, q_{im})$ where q_{ij} represent the quantity of good $j = 1, \dots, m$ consumed by individual i .
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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 $j = 1, \dots, m$ 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 $U_{ij} = \frac{dU_i}{dq_{ij}}$.

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- The existence of a market for all goods $j = 1, \dots, m$, on which operate the individuals $i = 1, \dots, n$ 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 $j = 1, \dots, m$, $U_{ij} = \lambda_i p_j$.
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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 $i = 1, \dots, n$.

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The overall Utility W may thus be normalised such that $\lambda_i W_i = 1$ for all individual i .

Economic Foundations – continue

- The societal impact hence becomes :

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

- Societal effects of the project are measured as the sum over individuals of the marginal variation of their consumption evaluated at market prices.
- In this simplified economic reasoning it is reasonable to model variations of social welfare in terms of monetary units using market prices.
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The actual limitations of the simple economic model are evident :

- *Only marginal variations of the economy are taken into account.*
- *Only a single time period is considered.*
- *The economy is closed : there is no public sector and no foreign trade.*
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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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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

CBA applications in public transports

Example (Traffic forecasting)

- In France, the yearly investment in public transports is around 1.5 billion €.
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- 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.
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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.
- Therefore, the conversion into **standard travel time units** takes into account : comfort, day-time, weather conditions, difficulty of the travel, road conditions, etc).
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- Linearity of time may easily be contested.
- Is losing one hour per day for one individual equivalent to losing one minute a day for 100 individuals?
- How to convert travel time reductions into monetary units?
- Around Paris, the conversion prize is 13.7€ / hour!?

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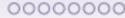
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- A substantial category of benefits expected from a road equipment project consists in improving road safety.
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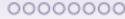
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Example (continue)

- The conversion rates used in France are the following

	death	1 500 000	€
(instruction cadre 2004) :	seriously injured	225 000	€
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Country	CBA prize of life	
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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.
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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**.
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- 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.
- [However], whether we are deciding between buying different commodity baskets, or making choices about what to do on a holiday, or deciding for whom to vote for in an election, we are **inescapably involved in evaluating alternatives with non-commensurable aspects**.

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