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

CBA Definition

Definition

- 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.*

Illustrative applications

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

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 certain diseases

Illustrative example – continue

Environment :

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

National Education :

- Choose the site of a new secondary school building
- Establish a developing plan for public research
- Evaluate a further University Campus in the country

European policy :

- Brexit : Leaving or remaining in the EU
- New intellectual property rights
- Harmonising or not fiscal policies

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.

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% ?

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.*

Optimal choice of investment projects – continue

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 €).

Optimal choice of investment projects – continue

Commentary

- *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 $\frac{1}{(1+i)}$€.*
- *Indeed, at the end of the period you will have to reimburse : $\frac{1}{(1+i)} \cdot (1 + i) = 1$€.*

Optimal choice of investment projects – continue

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.

Optimal choice of investment projects – continue

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.*
- *All consequences of the project are expressed in a same currency (€).*
- *A homogeneous capital market with am apparent interest rate is assumed to exist.*
- *Effects of uncertainty and imprecision on future consequences are neglected.*
- *Possible other contextual constraints like project synergies, limited budgets, etc are ignored.*

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 :*
  - *Costs and benefits are evaluated following a societal perspective.*
  - *Costs and benefits are not necessarily evaluated in monetary units. In such a case, one uses adequately chosen conversion prices.*
  - *The discounting rate has to be chosen from a societal perspective.*

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

  we denote p'_k the price of one unit of societal cost of component $k = 1, .., s$.

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

An extension of financial auditing – continue

Definition (Net Present Value of a project – continue)

- We denote $\overline{b}_t$ the societal benefits generated by the project at period t.

$$\overline{b}_t = \sum_{j=1}^{r} (p_j \cdot b_t^j)$$

- We denote $\overline{c}_t$ the societal costs generated by the project at period t.

$$\overline{c}_t = \sum_{k=1}^{s} (p'_k \cdot c_t^k)$$

An extension of financial auditing – continue

Definition (Net Present Value of a project – continue)

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

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

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

Net Present Societal Value of a project – critics

Commentary

- *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 ?*
  - *Is it always possible to measure costs and benefits in monetary units ?*
  - *How to choose a reasonable societal discounting rate ?*

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 $i = 1, ..., n$.

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 $dW > 0$.

Economic Foundations – continue

- 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.

Economic Foundations – continue

- 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 $i = 1, ..., n$.

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

Economic Foundations – critical review

Commentary

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.*
- *The economy is in equilibrium : initial distribution of income is assumed to be optimal.*

CBA applications are problematic

Commentary

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)*
- *The presence of numerous externalities (pollution generated by a new motorway for instance)*
- *Very large time lives of societal projects (storage of nuclear waste for instance)*

CBA applications are problematic – continue

Commentary

- *Very unevenly distributed impact of the societal projects on different individuals (new airport location for instance)*
- *Overwhelming presence of uncertainty (technological changes, future prices, long term impacts etc)*
- *The difficulty of evaluating impacts on cultural goods (monuments and historical sites for instance)*

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.
- And the conversion of such travel time reductions into may monetary units may represent up to 50% of the expected benefits from these projects.

Traffic forecasting

Example (continue)

- 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.
- Moreover, usually, traffic forecast models do not take into account foreseeable modifications of the traffic habitude following the effective implementation of the new road equipment.

CBA applications in public transports

Example (Travel time reductions)

- 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).
- Difficult commensurability problems may soon appear with this approach.

Travel time reductions

Example (continue)

- 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 ?
- Around Paris, the conversion prize is 13.7€ / hour ! ?

CBA applications in public transports

Example (Improving road safety)

- A substantial category of benefits expected from a road equipment project consists in improving rad safety.
- Based on traffic figures forecast after the implementation of the project, one has to estimate the expected reduction of the number of deaths and seriously injured caused by future road accidents.
- These reductions have again, to be translated into monetary units.

Improving road safety

Example (continue)

- The conversion rates used in France are the following

(instruction cadre 2004) :	death	1 500 000	€
	seriously injured	225 000	€
	other injured	33 000	€

Improving road safety

Example (continue)

- Value of a life in Europe (2002) :

Country	CBA prize of life	
Denmark	628 147	€
Finland	1 414 200	€
France	600 000	€
Germany	406 672	€
Portugal	78 230	€
Spain	100 529	€
Sweden	984 940	€
UK	935 149	€

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.
- The economic foundations of the CBA are, in fact, inadequate.
- CBA may not, hence, figure as a reliable policy analytics approach.

Advantages of CBA

- It is a decision aid approach well established and fine tuned for over 50 years supported by many theoretical and practical studies.
- CBA stresses the necessity for following a consistent and systematic evaluation of the consequences of the decision alternatives.
- CBA illustrates that costs and benefits to be taken into account in a decision project may be very diverse and essentially incommensurable.
- The algorithmic logic of balancing pros (benefits) and cons (costs) is very convincing.
- It is a purely quantitative and totally transparent decision aiding algorithm.

Disadvantages of CBA

- Effectively supporting a decision maker confronted to a non trivial decision problem requires a richer evaluation model than simply converting all consequences into commensurable monetary units.
- CBA is essentially used in a practical decision aiding context that doesn't fit with the economic foundations of the approach.
- CBA's monetary approach reduces the eventual description of the apparent preferences of the decision maker to the comparison of a single net present societal value. This does not allow to effectively express the otherwise rich preference structures occurring in these public investment projects.
- Additivity of the NPSV may be doubtful. Are all costs and benefits really mutually preferentially independent one from another ?

Disadvantages of CBA – continue

- Using conventional conversion prizes hides away non explicit weighing of certain costs and benefits.
- Assuming a strictly homogeneous society with respect to the consequences of a societal investment project is not realistic and therefore not convincing.
- Using a single and constant discounting rate over the long time lives of societal investment problems is hardly admissible.
- The idea that a societal preference effectively exists may be questioned. And if such preferences do exist, they will certainly appear neither to be necessarily complete nor transitive, as is required by a single value modelling.
- Taking into account in a CBA neither the uncertainty, nor, the imprecision of the evaluations does not allow to formulate robust and convincing decision recommendations.

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.
- [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.

Amartya Sen, The Idea of Justice, Allen Lane London, 2009