Cost-benefit analysis Environmental and cultural resources

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Topics covered

- **Methods for valuing natural and cultural resources.**
- **Cost-benefit analysis.**
- **The choice of discount rate.**

OECD (2018), *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*, OECD Publishing, Paris.

The evolution of the concept of economic value

Value is no longer expressed (only) by market value (price) but by the **total well-being** (utility) produced.

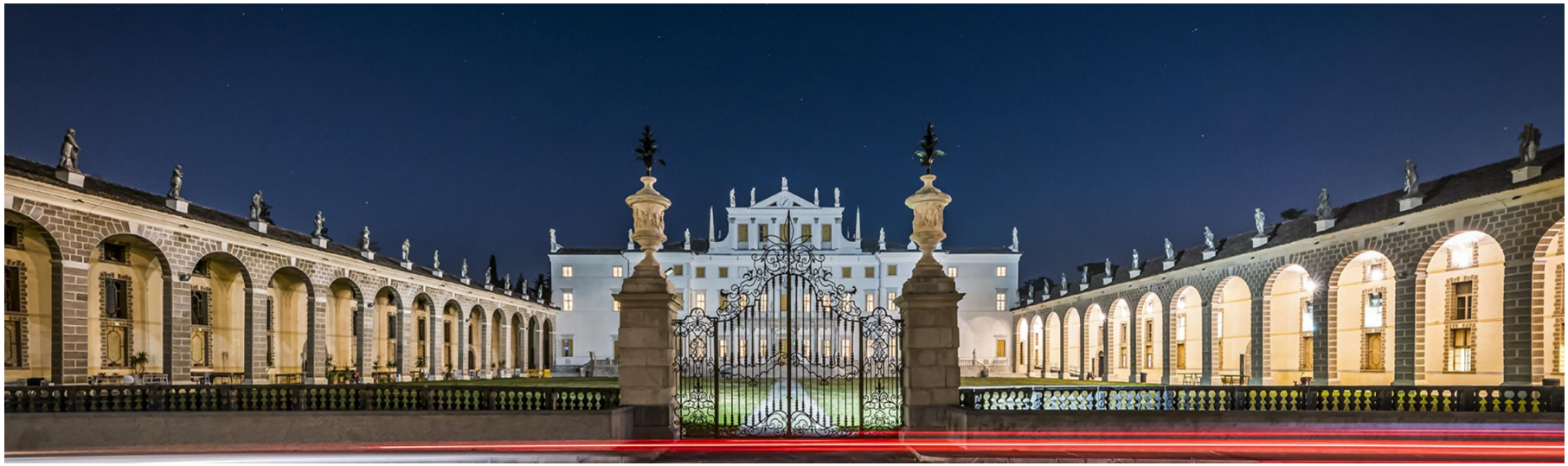
Well-being depends not only on the benefits deriving from the **use**, direct or indirect, of the good but is also linked to its values of "**non-use**".

Krutilla, J. V. (1967). Conservation reconsidered. *The American Economic Review*, *57*(4), 777-786.

The components of the total economic value

The Castle of Catajo

The components of the total economic value



Villa Manin

The components of the total economic value

The rhinoceros

The components of the total economic value

Value Type	Component	Genesis
Use value	Direct use	Real or virtual use
	Indirect Use	
	Option	Guarantee of future use at risk
Non-use or passive value	Bequest	Sensitivity towards future generations and living beings
	Existence	

The components of the total economic value

Type of good	Value			
	Use	Option	Existence	Bequest
Reproducible	Yes	No	*	No
Non-reproducible				
Non-substitutable	Yes	Yes	Yes*	Yes*
Substitutable	Yes	Yes**	Yes*-**	Yes**

* The extent of this component depends on ethical aspects
** The extent of these components depends on ethical aspects and surrogacy

The measurement of the value of public environmental goods

Value is a measure of the total welfare generated by the environmental good.

Measuring welfare requires the adoption of a given unit of measure.

The unit of measure depends on the context (purpose) of the valuation.

€ **Monetary valuations**
(cost-benefit analysis)

[-] **Non-monetary valuations**
(Multi-Criteria Analysis)

The measurement of the value of public environmental goods

The monetary measurement of the value of a public (environmental) good is equal to the amount of money needed to purchase/produce private goods capable of generating the same utility as the public good.

Assumptions

- Substitutability between private and public goods in the function of social welfare (purchase).
- Subrogation of the public good with an equivalent good for services produced (production).

The measurement of the value of public environmental goods

-

The change in well-being produced by the **negative change** of a public environmental good can be evaluated monetarily in the **maximum willingness to pay of consumers to avoid the worsening or in the willingness to accept a minimum compensation in order not to oppose the deterioration.**

+

The change in well-being produced by the **positive change** in a public environmental good can be evaluated monetarily in the **maximum willingness to pay of consumers to obtain the improvement or in the willingness to accept a minimum compensation to give up the improvement.**

The monetary measure of well-being
The Utility Function

$$U = f(I, \overline{p}, q, \overline{z})$$

U Utility

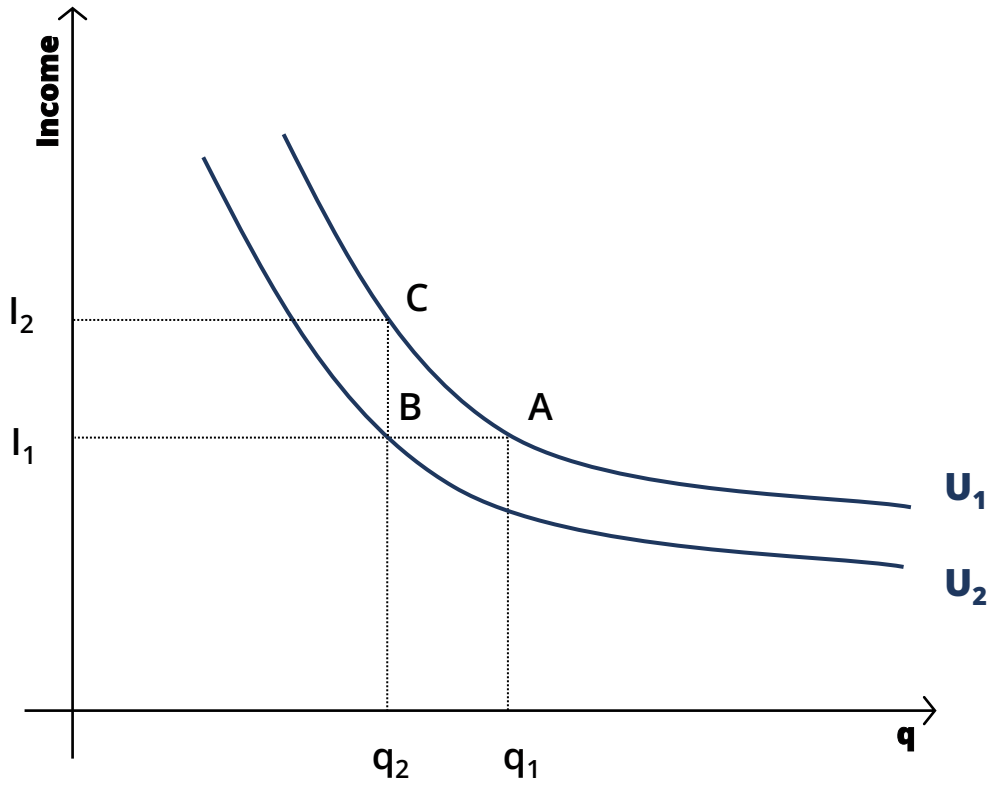
I Income

$\overline{p}$ Prices of private goods (constant)

q Public environmental good to evaluate

$\overline{z}$ Other public goods and services (constant)

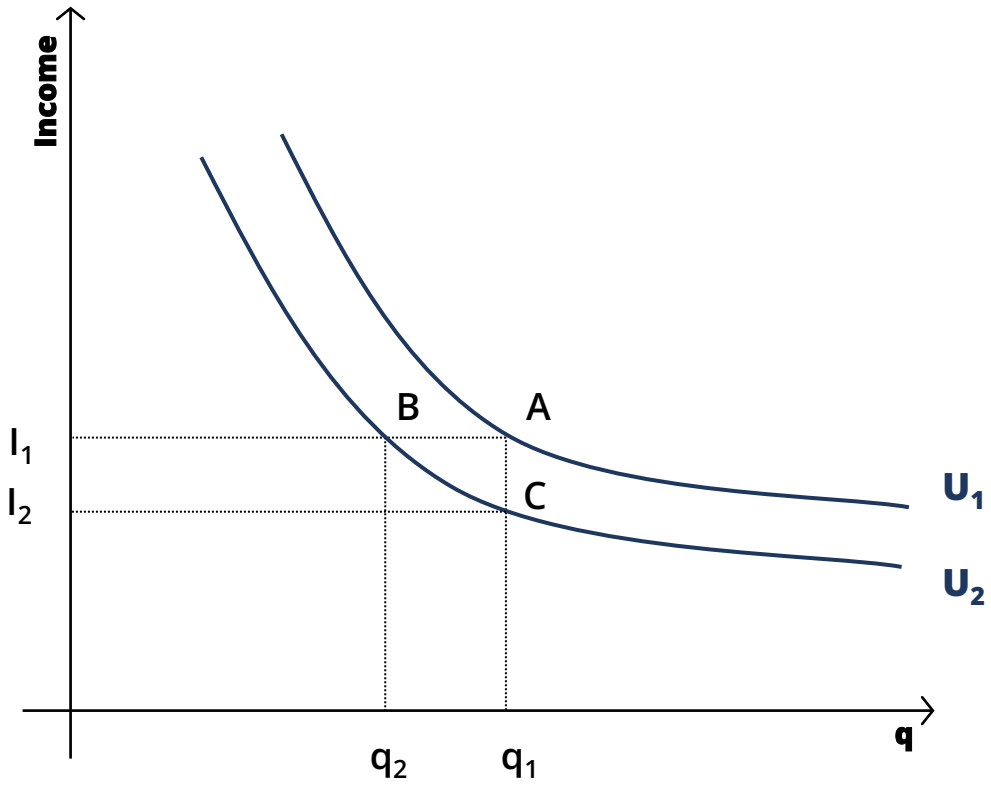
The monetary measure of lost well-being
Willingness to accept compensation



$\Delta I = (I_2 - I_1)$
is the minimum amount of money capable of compensating for the loss of utility produced by the negative change
$\Delta q = (q_1 - q_2)$
in the availability of public environmental good.

ΔI is also referred to as **Willingness to Accept Compensation - WTA**.

The monetary measure of lost well-being
Willingness to pay



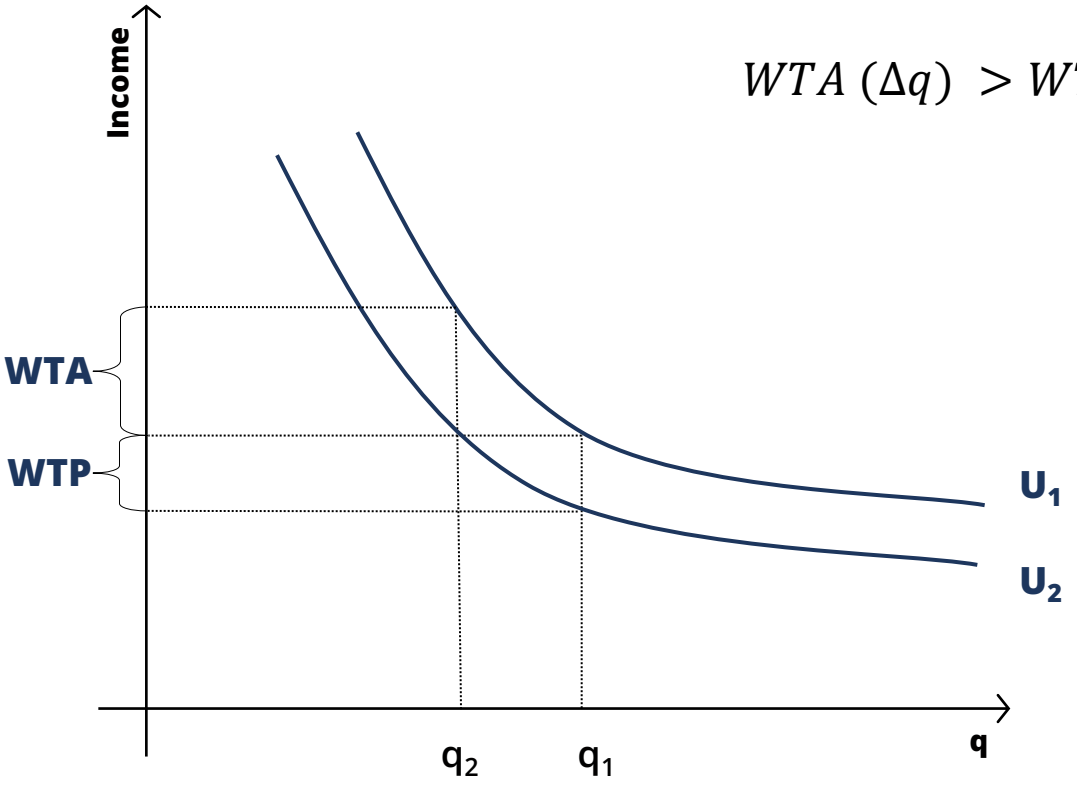
$\Delta I = (I_1 - I_2)$
it is the maximum amount of money consumers are willing to pay to avoid the loss of utility produced by the negative change
$\Delta q = (q_1 - q_2)$
in the availability of public environmental good.

ΔI it is also called Willingness to Pay - WTP.

The monetary measure of lost well-being

Change in the public environmental good	Property rights on the public environmental good	
	Right to *status quo*	**Right to changed situation**
Positive	Willingness to pay to get the benefit **WTP**	Willingness to accept compensation to forfeit the benefit **WTA**
Negative	Willingness to accept compensation to bear the loss **WTA**	Willingness to pay to avoid loss **WTP**

WTP and WTA are not the same thing



$$WTA\ (\Delta q)\ > WTP\ (\Delta q)$$

WTP and WTA are not the same thing

Types of good	WTA/WTP ratio	Standard error
Public	**10,4**	2,5
Health/Healthcare	**10,1**	2,3
Private	**2,9**	0,3
All goods	**7,2**	0,9

Horowitz, J. K., & McConnell, K. E. (2004). A Review of WTA/WTP Studies', Journal of Environmental Economics and Management, 44 (3), November, 426-47. *INTERNATIONAL LIBRARY OF CRITICAL WRITINGS IN ECONOMICS*, *177*, 387-408.

Why is willingness to pay normally used?

- It avoids **strategic behaviour**.
- It is **consistent** with the perception of property rights over public goods (non-excludable).
- The **uncertainty** affecting **WTA** estimates **is greater** than that characterising WTP estimates.
- It provides a **precautionary measure** of the change in welfare.

Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., & Schuman, H. (1993). Report of the NOAA panel on contingent valuation. *Federal register*, *58*(10), 4601-4614.

Evaluation methods

Valuation approach	Metodo di valutazione	
Change in well-being measured **indirectly** from the costs/effects of adaptations	Imputed preferences	Defensive expenditure Restoration cost
		Replacement cost / value
		Production function
	Revealed preferences	Hedonic pricing
		Travel cost models
Change in well-being valuated by **direct** estimation of willingness to pay	Stated preferences	Contingent valuation
		Choice experiments

Valuation methods: imputed preferences
Defensive expenditure / restoration cost

- The defensive expenditure / restoration cost method can be used when **individuals change their expenditure in response to a change in the state of the environmental resource**.
- The theoretical assumption underlying this method is that, **if individuals change their expenditure to offset the environmental change, then the change in welfare is at least equal to the change in expenditure.**
- This method is **widely used to assess negative changes** in the state of the environment.

Valuation methods: imputed preferences
Replacement cost

- Replacement cost/value is used **when costs are incurred/avoided to replace the services provided by the resource with substitutes capable of restoring individuals' initial level of utility**.
- In the Italian appraisal literature, the replacement cost of a good is defined as **the sum of the expenditures required to replace it with other goods capable of performing the same functions or providing the same utilities as the original good.**
- The method is widely **applied in the valuation of damage affecting non-market environmental goods and/or services** for which **substitution with private resources is conceivable or plausible** (and vice versa).

Valuation methods: imputed preferences
Production function

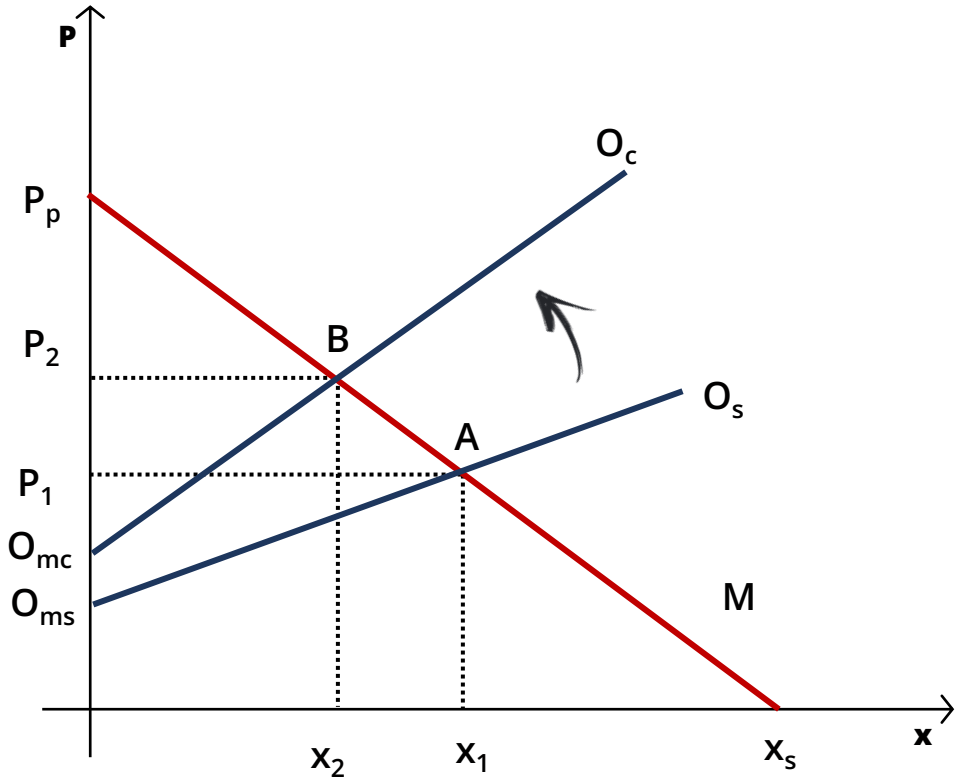
The approach is based on the **relationship** between **the endowment of an environmental resource and the productivity of an economic activity that uses that resource.**

Premises

- If the resource changes, then the cost functions (total, average, and marginal) of the related economic activities change.
- If the cost functions change, the market supply function changes and, consequently, so do producer and consumer surpluses.

Valuation methods: imputed preferences
Production function

Changes in well-being following the deterioration of an environmental resource that increases the production costs of product x.



Loss of consumer surplus

$P_1\ P_2\ B\ A$

Loss of producer surplus

$O_{ms}\ A\ P_1 - O_{mc}\ B\ P_2$

Loss of total surplus

$O_{ms}\ Omc\ B\ A$

Valuation methods: revealed preferences
Hedonic pricing method

Valuation methods: revealed preferences
Hedonic pricing method

- It is based on the possibility of establishing an **econometric relationship between the endowment of environmental goods and the market price of real estate** (land and houses) or wages.
- It is directly inspired by the concept of **complementary value**.
- It has important **theoretical limitations** (preconditions).
- It requires excellent **market information** to provide reliable estimates.

Valuation methods: revealed preferences
Hedonic pricing method

$$\max_x \left[U(X,Q) \left| I \geq \sum_{i=1}^{n} p_i \cdot x_i \, ; Q = g(\bar{Q}, x_k) \right. \right]$$

$$p_k = \varphi(z, q_1, \bar{Q})$$

$$V = |\varphi(z, q_1^s, \bar{Q}) - \varphi(z, q_1^c, \bar{Q})| = |p_k^s - p_k^c|$$

- V Monetary value of the change in the environmental good q_1
- X market goods
- Q Public environmental goods
- I Income
- p_i Prices of market goodsx_i
- $\overline{Q}$ Other environmental goods
- p_k Market good price x_k
- z intrinsic characteristics of the good x_k
- q_1 Environmental good to evaluate
- x_k market good whose value depends on the environmental good q_1
- s without environmental change
- c with environmental change

Valuation methods: revealed preferences
Hedonic pricing method

Prerequisites

- **Weak complementarity** between the environmental good and the market good.
- **A continuous range of combinations** between the private good and the environmental characteristic.
- **Equal information and transaction costs** in a market that must be **transparent and competitive.**
- **There must be no surpluses** connected with changes in the endowment of environmental resources

Valuation methods: revealed preferences
Hedonic pricing method

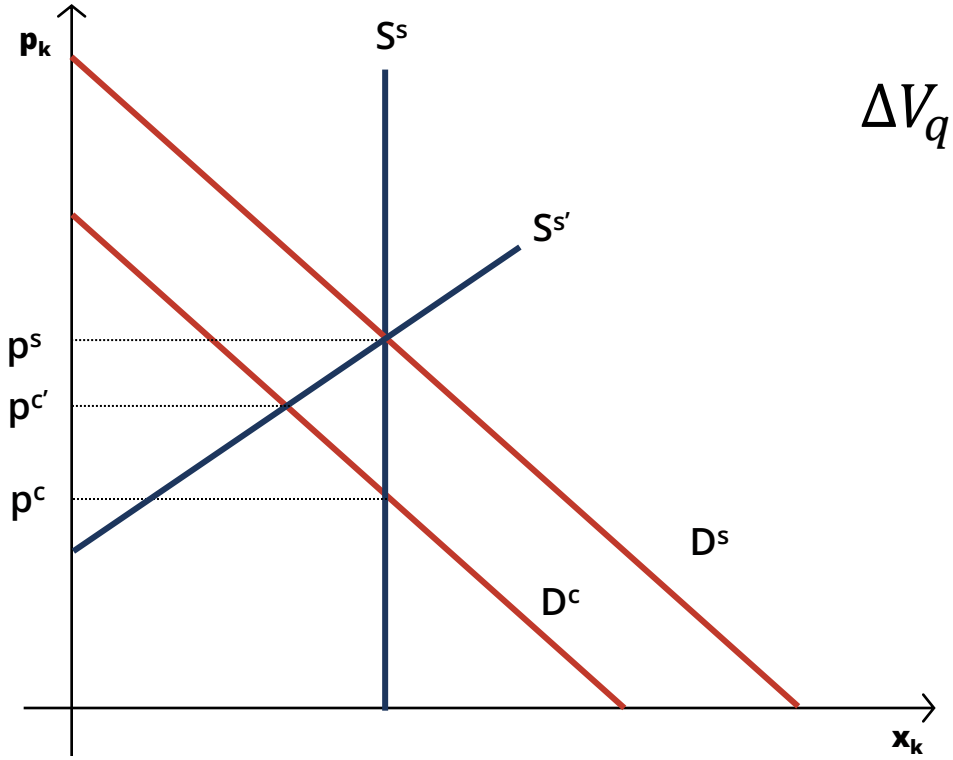
An **example** of strong and weak complementarity
(property values €/mq)

Strong complementarity		Green park	
		Present	Absent
Finishes	Excellent	4 000	-
	Ordinary	-	2 000

Weak complementarity		Green park	
		Present	Absent
Finishes	Excellent	4 000	2 500
	Ordinary	3 500	2 000

Valuation methods: revealed preferences
Hedonic pricing method

Rigid and elastic supply of the market good, and changes in price and buyers' surplus



$$\Delta V_q = p^s - p^c$$

Valuation methods: revealed preferences
Hedonic pricing method

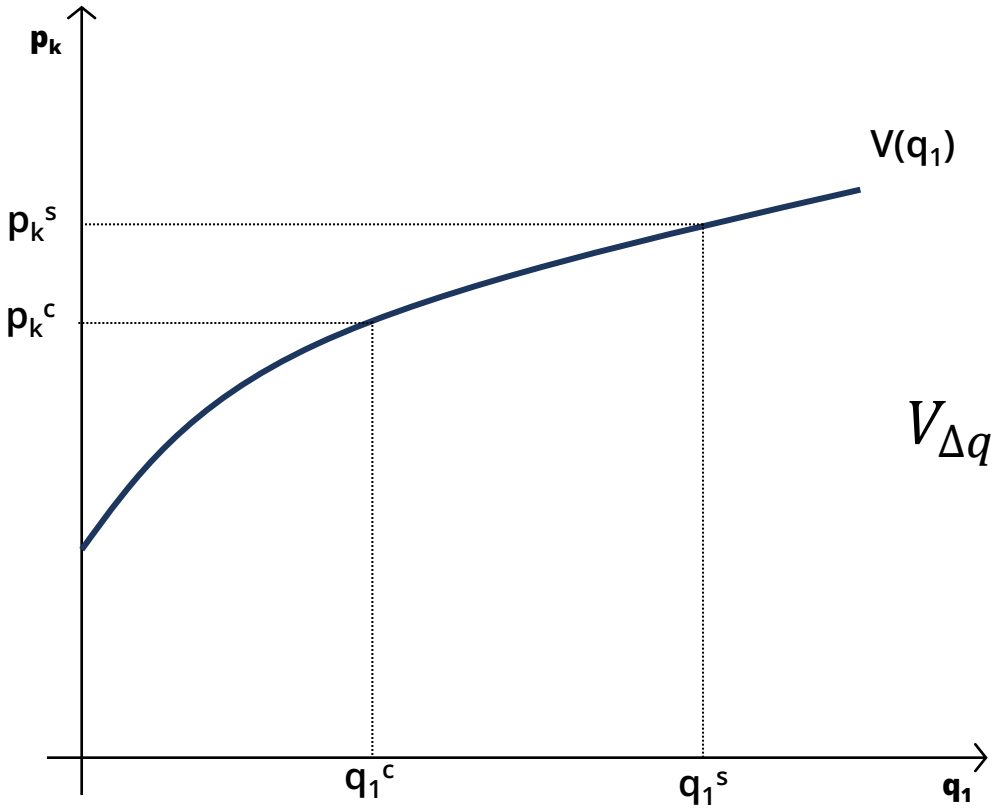
Estimating the value function

$$p_k = \varphi(z, q_1, \bar{Q})$$

- **Non-linear function** with respect to q_1
- The **substitution rate** between the characteristics is **independent of the price of the other goods**

Valuation methods: revealed preferences
Hedonic pricing method

Environmental good and asset value



$$V_{\Delta q_1} = V_{q_1^s} - V_{q_1^c} = p_k^s - p_k^c$$

Valuation methods: revealed preferences
Hedonic pricing method

Estimating the demand function

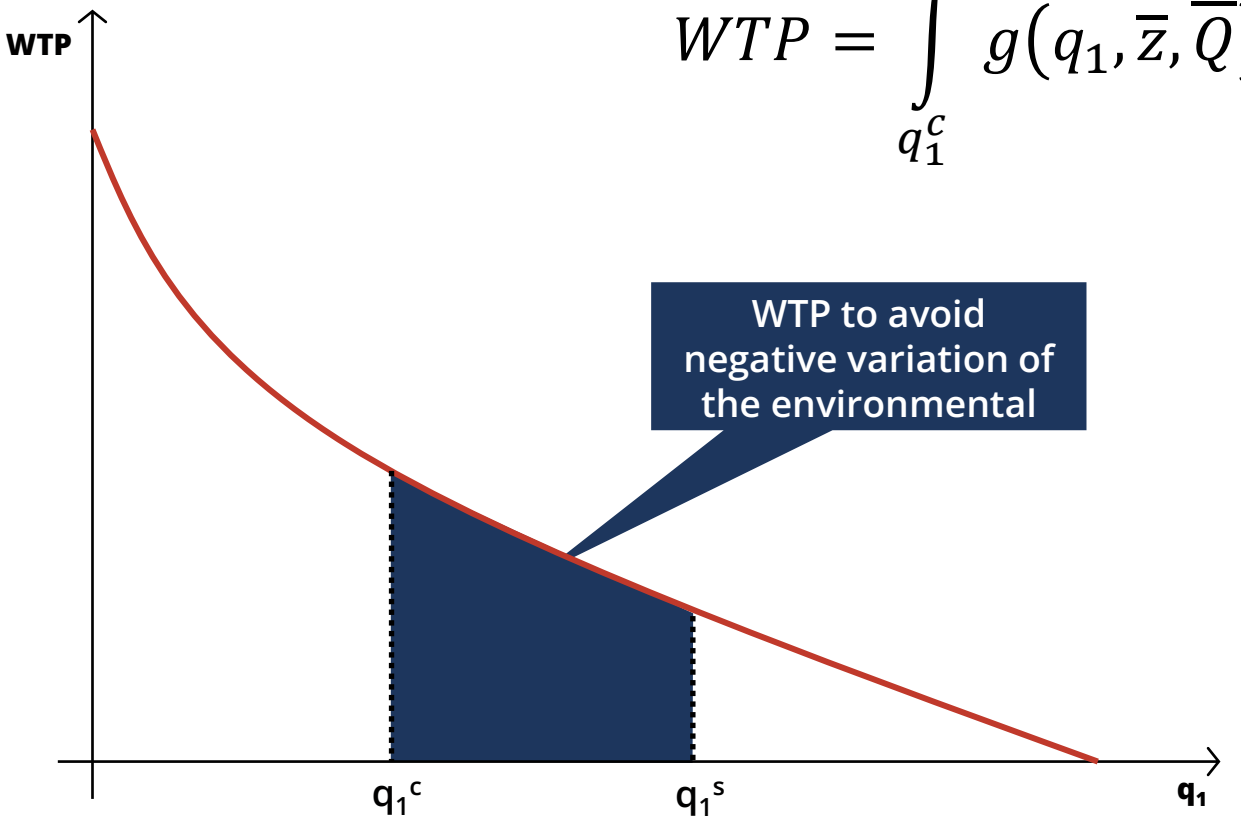
$$WTP_{q_1} = \frac{dV(q_1)}{d_{q_1}} = g(q_1, \bar{z}, \bar{Q})$$

WTP_{q_1} value of the change in the quality of the environment, i.e., differential rent produced by the environmental good

Valuation methods: revealed preferences
Hedonic pricing method

The demand function

$$WTP = \int_{q_1^c}^{q_1^s} g(q_1, \bar{z}, \overline{Q}) dq_1$$



Valuation methods: revealed preferences
Hedonic pricing method

An **example**: valuing the effect of public green space on property values and the effect of any change in it.

#	Price [€]	Floor area [m²]	Green area [%]
1	150 000	62	17
2	170 000	77	3
3	215 000	102	5
4	220 000	97	17
…	…	…	…
109	165 000	66	37
110	250 000	116	11

Valuation methods: revealed preferences
Hedonic pricing method

Sample characteristics under the purely illustrative hypothesis that value is influenced only by size and surrounding greenery.

Indicator	Total value [€]	Unit value [€/m²]	Floor area [m²]	Public green space [% of land]
Arithmetic mean	203 496	2 278.50	89.75	18.95
Median	200 000	2 272.73	88.00	18.00
Minimum	145 000	1 982.76	60.00	1.00
Maximum	270 000	2 500.00	120.00	40.00
Variance	1 089 583 222	11 733.97	270.44	129.89
Standard deviation	33 008.84	108.32	16.45	11.40
Coefficient of variation	16%	5%	18%	60%
Skewness	0.22	0.04	0.13	0.22
Kurtosis	- 0.99	- 0.41	- 1.10	- 1.14

Valuation methods: revealed preferences
Hedonic pricing method

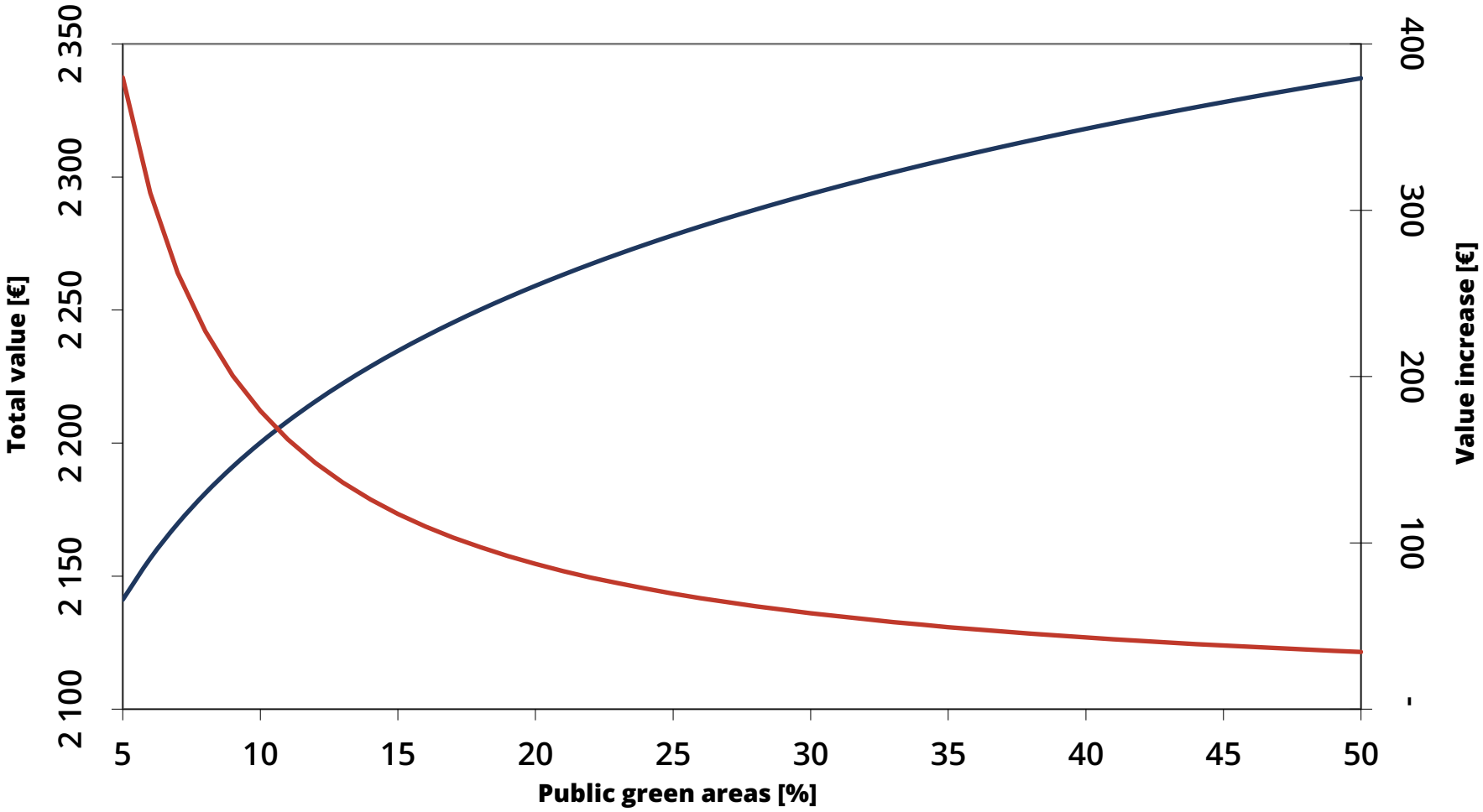
The value function

$$P = Int + b_1 Sup + b_2(\ln pct\ V)$$

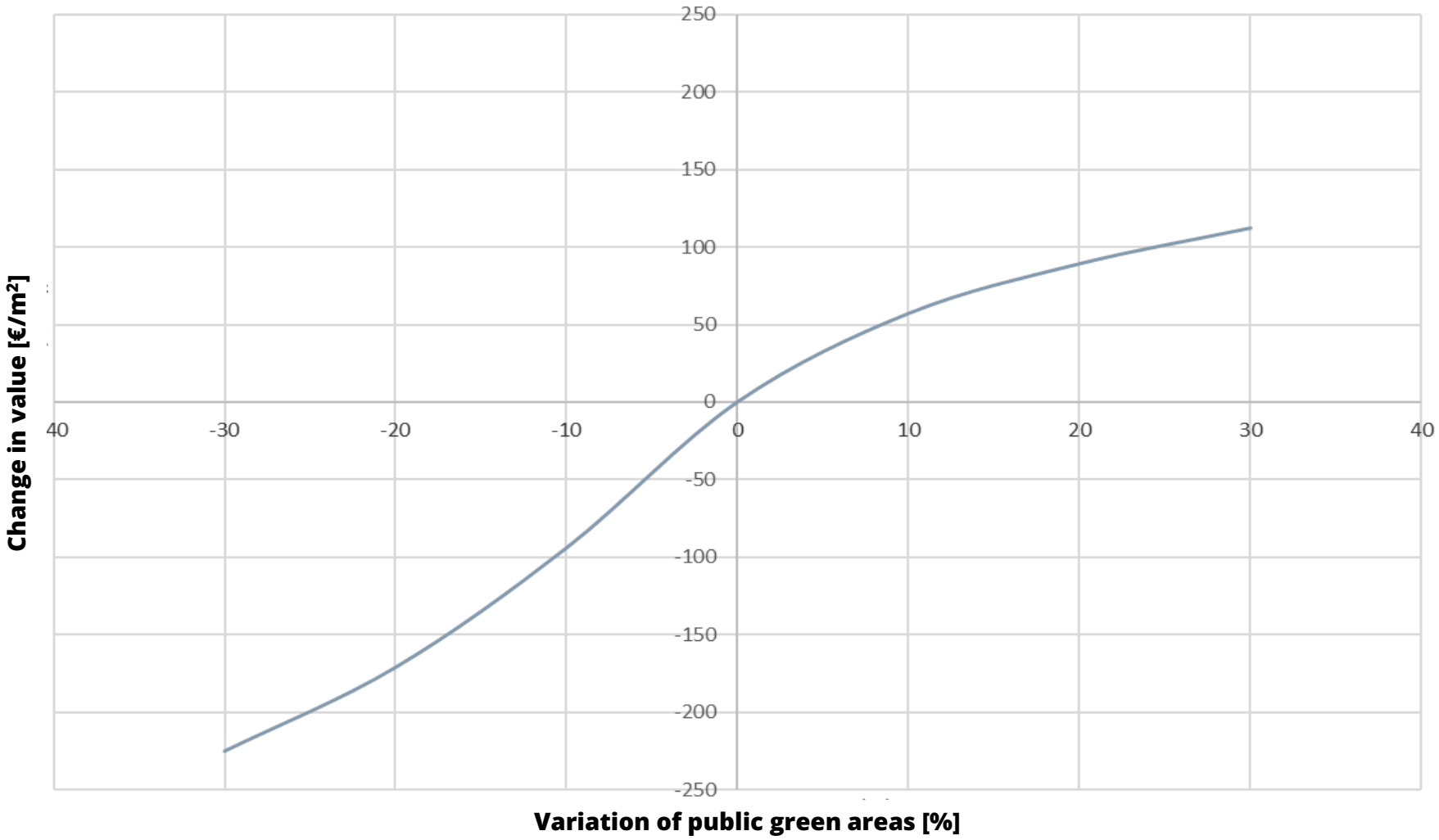
	Coefficients	Standard error	Stat t
Int	6 962.47	1 181.93	5.89
Sup	1 934,52	11.21	172.61
$\ln pct\ V$	8 510.67	224.07	37.98

Valuation methods: revealed preferences
Hedonic pricing method

Total and **marginal** value function



Valuation methods: revealed preferences
Hedonic pricing method



Valuation methods: revealed preferences
Hedonic pricing method

✓

- Anchored in **real market facts**
- Theoretically **rigorous procedure**
- **Results that are easy to interpret** and communicate

HEDONIC PRICE.pdf

✗

- **Multicollinearity**
- **Omitted variables**
- **Market segmentation**
- **Expectations of change**
- **Restrictive assumptions**
- **Partial valuation**
- **High availability of market data**
- Statistically **complex method**

Valuation methods: revealed preferences
Travel cost models

The travel cost models **make it possible to derive the appreciation (WTP) for an environmental good**, usually a site-specific one, **from the expenditure** that users are willing to incur **to reach it**, and assume that they behave with respect to these expenses (travel cost) as they would with respect to the price of consumer goods.

Hotelling.pdf

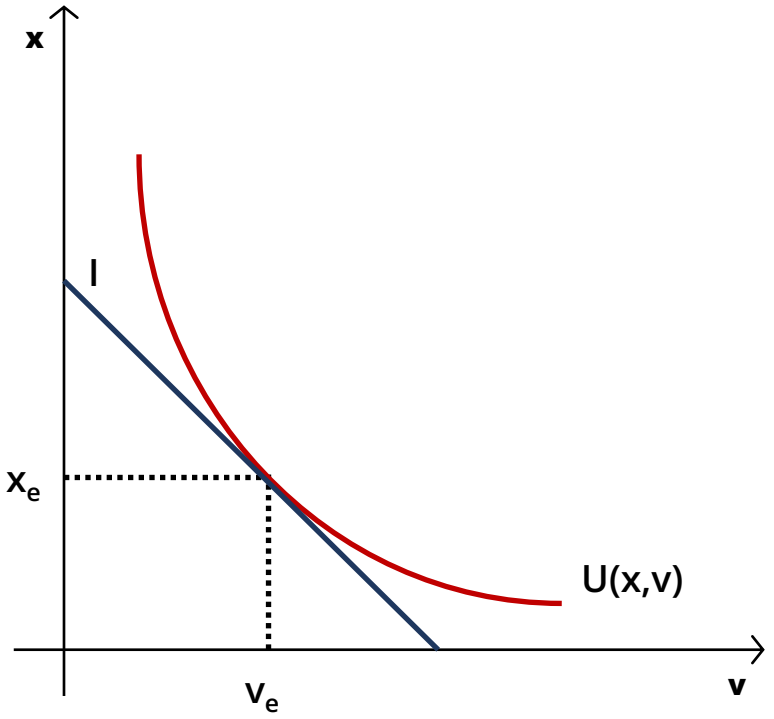
Valuation methods: revealed preferences
Travel cost models

$$\max U = f(x, v)$$

where

$$px + cv \leq I$$

- x Private good
- v Environmental site visits
- p Private good price
- c Cost per trip
- I Income



Valuation methods: revealed preferences
Travel cost models

Method variants	Data collection basis	Dependent variable
Zonal	Constant cost per trip zones	Population visit frequency
Individual	Individual	Individual visit frequency
Random Utility Model	Individual	Individual visit probability

Valuation methods: revealed preferences
Travel cost models

The stages of the "zonal" travel cost method

1. **Identification** of the site and its catchment area.
2. **Definition** of zones at different distances from the site to be valued.
3. **Collection of data** on population, number of visitors and cost per visit for each zone.
4. **Calculation** of the visit rate for each zone and relating it to the cost per visit.
5. **Estimation of the effect** of incremental additional per-visit costs on the frequency rate for each zone, and extension of the effect to the user population.
6. **Estimation of the demand function** of site users.
7. **Calculation of total surplus.**

Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

An example of estimating the value of a site (a spring-fed wetland) and the loss in annual value resulting from pollution that reduces the number of visitors for 5 years in a declining way.

Boundary conditions

- The site attracts mainly local visitors (catchment area within a radius of 100 km)
- The site is manned, with a single access.
- Access to the site is free of charge.
- Visits can be carried out on weekends and do not involve significant travel time (zero time value).
- The site has been polluted by a hydrocarbon spill that caused a loss of birdlife.
- The site has been remediated, but full "recovery" will take 5 years.

Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

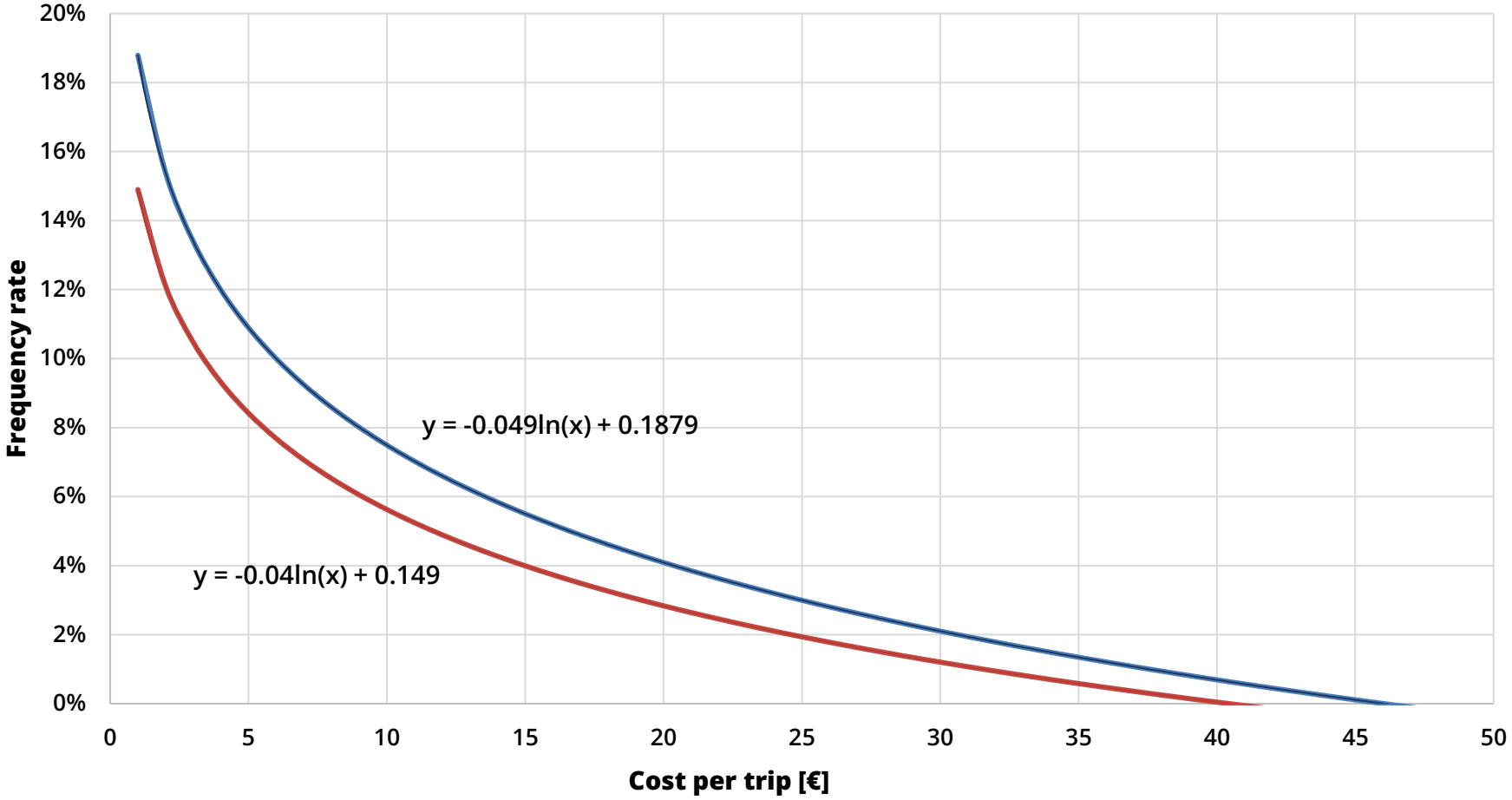
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

Data for the valuation

Distance from the site [km]	Cost per trip [€]	Population	Visits "without damage"	Visit rate "without damage" [%]	Visits "with damage"	Visit rate "with damage" [%]
10	5.2	10 000	1 254	12.54%	837	8.37%
20	5.4	30 000	2 361	7.87%	2 100	7.00%
30	8.1	100 000	5 224	5.22%	4 500	4.50%
40	10.8	1 500 000	47 649	3.18%	39 455	2.63%
50	13.5	50 000	905	1.81%	713	1.43%
60	16.2	2 500 000	47 712	1.91%	33 000	1.32%
70	18.9	400 000	4 069	1.02%	3 351	0.84%
80	21.6	30 000	414	1.38%	190	0.63%
90	24.4	3 000 000	13 003	0.43%	8 543	0.28%
100	27.1	60 000	553	0.92%	30	0.05%
		7 680 000	**123 144**		**92 719**	

Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The frequency rate **without** and **with** damage



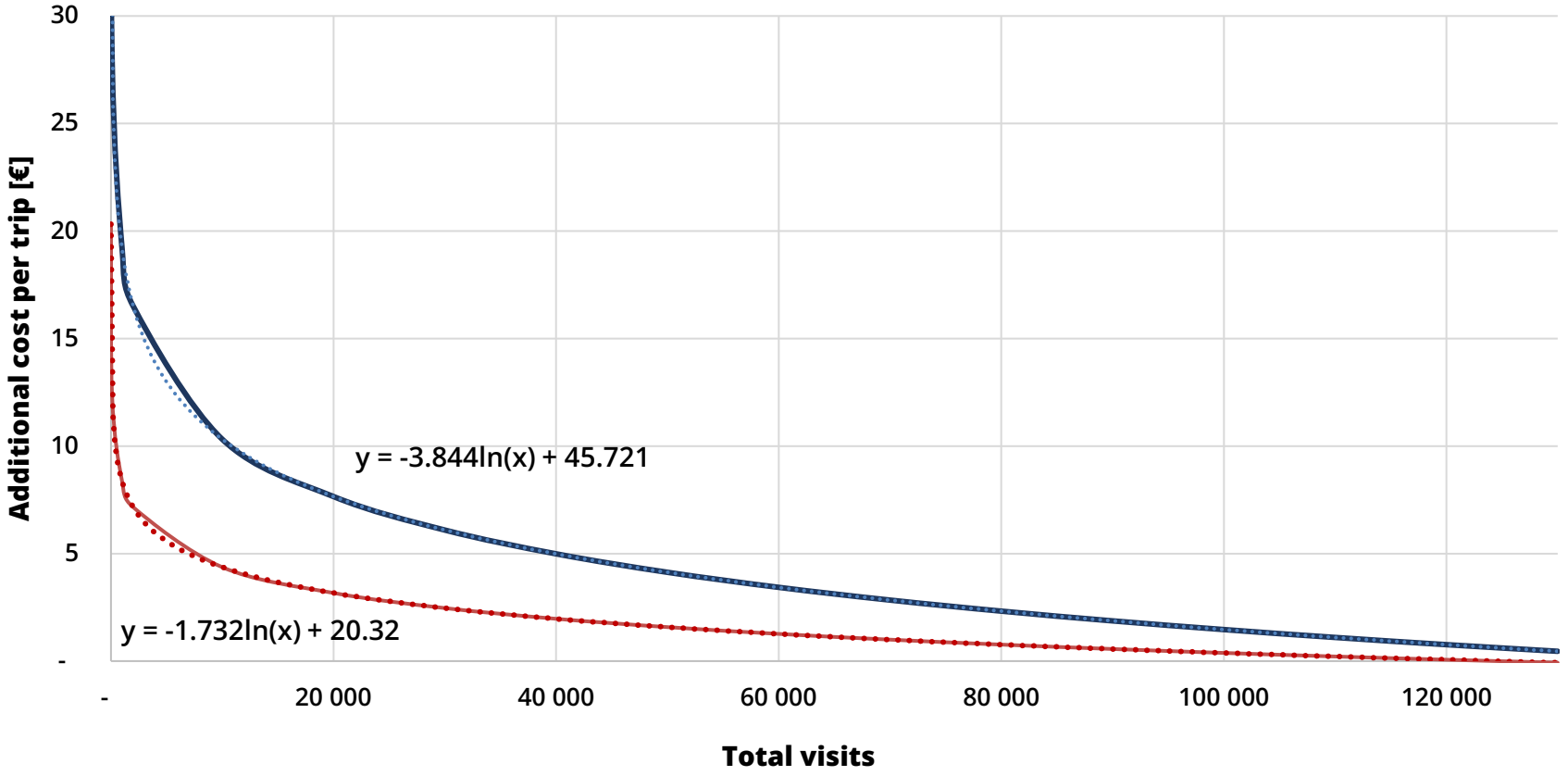
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The effect of the additional cost (for example €5/visit) on frequency rates and total visits

Distance from the site [km]	Population	Cost per trip + €5 [€]	Visit rate "without damage" [%]	Visits "without damage"	Visit rate "with damage" [%]	Visits "with damage"
10	10 000	10,2	5,08%	423	3,87%	329
20	30 000	10,4	4,98%	1 243	3,79%	966
30	100 000	13,1	3,62%	3 010	2,70%	2 290
40	1 500 000	15,8	2,51%	31 351	1,81%	23 020
50	50 000	18,5	1,58%	658	1,06%	449
60	2 500 000	21,2	0,78%	16 162	0,41%	8 748
70	400 000	23,9	0,07%	232	0,00%	-
80	30 000	26,6	0,00%	-	0,00%	-
90	3 000 000	29,4	0,00%	-	0,00%	-
100	60 000	32,1	0,00%	-	0,00%	-
	7 680 000			**53 078**		**35 802**

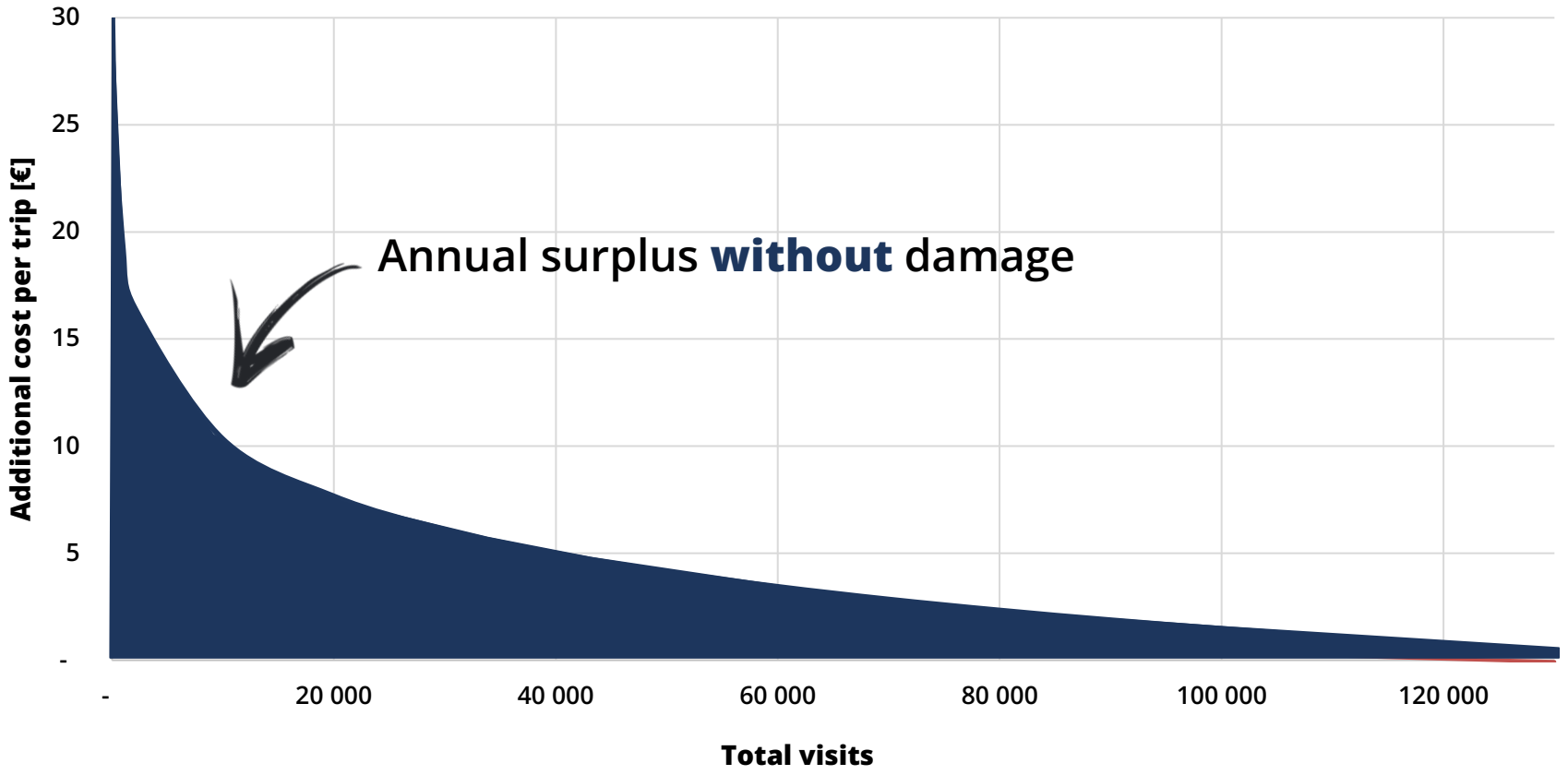
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

By simulating the total number of visits for incremental additional costs (€1, €2, €3, €4, …) I obtain the demand function **without** and **with** damage.



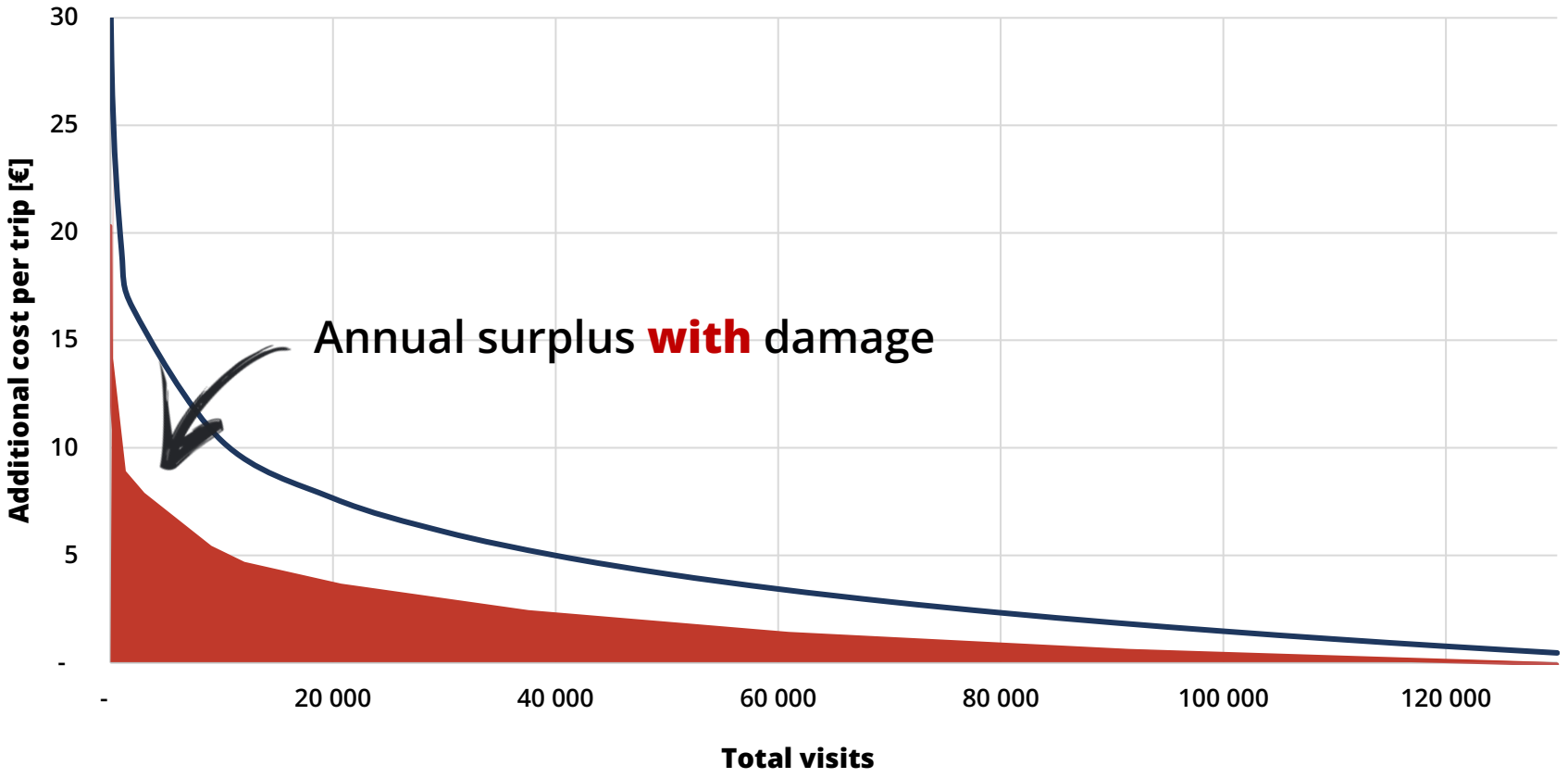
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The demand function **without** and **with** damage



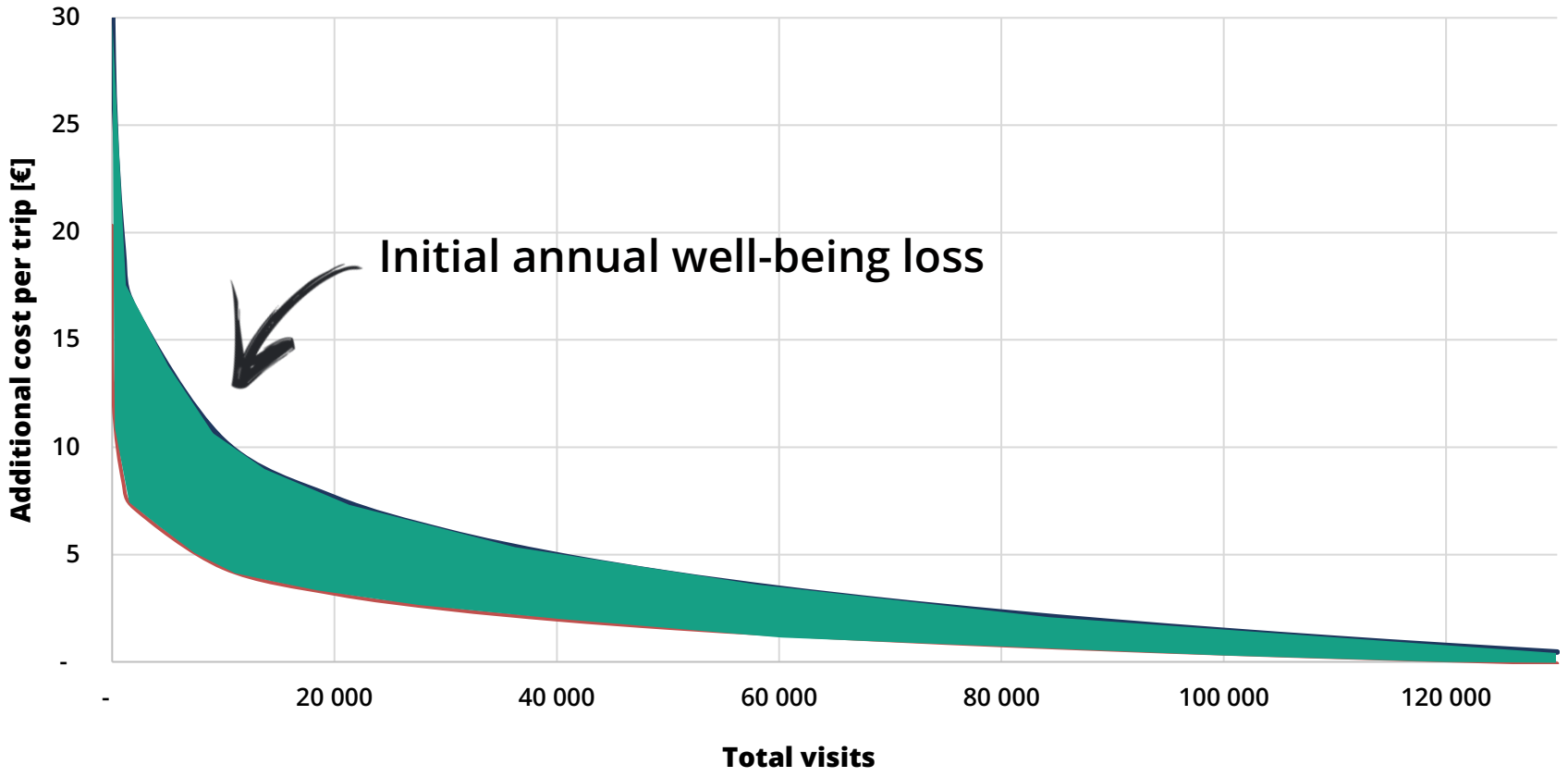
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The demand function **without** and **with** damage



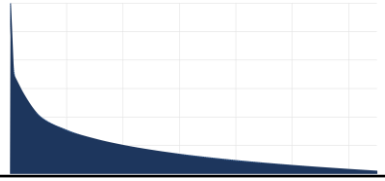
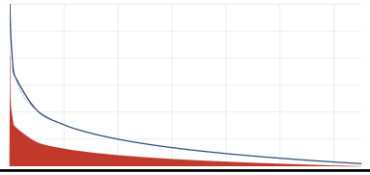
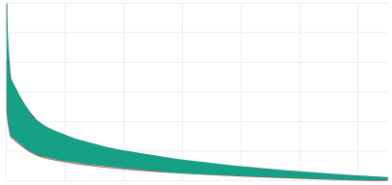
Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The demand function **without** and **with** damage



Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The estimate of the **well-being loss** suffered by users in the **first year** is obtained by calculating the difference between the integral, from 0 to the maximum number of visits, of the demand functions **without** and **with** damage.

	Annual surplus [€]	
Without damage	676 380	
With damage	446 801	
Initial annual well-being loss	229 579	

Valuation methods: revealed preferences
Travel cost: the Cervara Oasis

The estimate of the total well-being loss is obtained by assuming a time horizon (5 years in the example) to eliminate the damage, a damage decay function (linear in the example), and an appropriate discount rate.

	Year					Total
	1	2	3	4	5	
Damage [€]	229 579	172 184	114 790	57 395	28 697	**602 645**
Present value [€] (r = 3,5%)	221 815	160 736	103 534	50 016	24 162	**560 263**

Valuation methods: revealed preferences
Travel cost models

✓

- A **widely accepted method** because it is based on standard economic techniques for measuring value on the basis of price
- It is based on **actual rather than hypothetical behaviour**
- **Easy to apply** and relatively inexpensive
- **The results are easy to interpret** and communicate

✗

- It measures **only the use value** of current users
- **Difficulty in disaggregating costs in multipurpose trips**
- **Controversial definition of the opportunity cost of time**
- **Not applicable when use does not require travel**

TCM south africa.pdf

Valuation methods: stated preferences

Exxon Valdez oil tanker

Valuation methods: stated preferences

A survey in which a **hypothetical market** for the environmental good is simulated and the consumer states their **willingness to pay** to avoid the (negative) change or achieve the (positive) change in the state of the good.

Type of survey

- Personal (on site, off site)
- Postal
- Telephone
- Internet

Valuation methods: stated preferences

The **sample** must be **representative of the reference population** in order to minimise errors in estimating willingness to pay

True WTP ≠ sample WTP

Sampling biases

- Imprecise knowledge of the population
- Non-response (postal, internet)
- Temporal selection (telephone)
- Self-selection (postal, internet)

Valuation methods: stated preferences

Questionnaire structure

- **Description of the good** (location, quantity, quality, time horizon, indirect benefits)
- **Definition of changes** (quantitative/qualitative variations and direct/indirect effects)
- **Definition of the hypothetical market** (rights, use, and payment vehicle)

Valuation methods: stated preferences

Questionnaire structure

- **Elicitation of WTP**
  - Open-ended response
    How much would you be willing to pay for XXXX?
  - Payment cards
    Which of the listed amounts (XX, YY, ZZ, etc.) would you be willing to pay for XXXX?
  - Closed-ended response
    Would you be willing to pay €XX for XXX?
  - Closed-ended response with iteration
    Would you be willing to pay €XX for XXX? And €YY?

Valuation methods: stated preferences

Questionnaire structure

- Respondent's **socio-economic characteristics**
  - Age
  - Educational qualification
  - Occupation, income
  - Preferences
- **Considerations on the interview**
  - Understanding
  - Degree of cooperation
  - Presence of strategic behaviour

Valuation methods: stated preferences

Content validity

- Did respondents actually evaluate the good we intended to evaluate?
- Accurate description of the scenario being valued.
- Plausible payment system.
- Importance of developing and calibrating the questionnaire through focus groups and pre-tests.

Valuation methods: stated preferences

Robustness of the estimates

- **Convergence**
  Is the WTP estimated through CV consistent with that assessed by other methods?
- **Internal validity**
  It is tested through regression analysis between WTP and the respondent's individual characteristics. The estimated coefficients for income, education, etc. must be consistent in sign and magnitude with those expected.
- **Repeatability**
  If CV were repeated, would we obtain the same values?

Valuation methods: stated preferences

Biases in WTP estimates

- **Random responses**
  Ignorance about the good to be valued, interviewer incapacity, poorly designed questionnaire, random WTP estimates.
- **Strategic responses**
  The respondent answers according to the desired outcome, with an unpredictable effect on the WTP estimate.
- **Inconsistent responses (whole/part)**
  WTP does not vary with the magnitude of the proposed change, warm-glow benevolence, overestimation of WTP.

Valuation methods: stated preferences

Biases in WTP estimates

- **Protest / contrary responses**
  respondents assign a value to the good but do not agree with the payment, thereby negatively affecting the estimated WTP.
- **Acquiescent responses**
  a desire to please the interviewer, imperfect assessment of the impact of the proposed amount on one's income; acquiescence artificially increases the estimated WTP.

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

Example of estimating the loss in value of a natural site resulting from pollution that compromises its ecological characteristics.

Boundary conditions

- Access to the site is free of charge.
- The site is a wetland and is very popular with day-trippers, birdwatchers, school groups.
- The site was significantly damaged by a hydrocarbons spill from a deteriorated tank with permanent loss of birdlife, fish fauna and temporary contamination of surface waters and banks.
- The site is expected to be fully restored in 5 years.

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

The survey

- Sample composed of 500 **web respondents using a self-administered questionnaire**.
- **Respondents are distributed uniformly with respect to population density**.
- The interview **describes the site, its natural features, the damaging event, and all its consequences for the quality and the environmental and recreational services provided**.
- **Respondents are asked to answer yes or no as to their WTP** for a varying amount to finance preventive measures against the occurrence of the spill.

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

The question about willingness-to-pay

In view of the negative effects on the Cervara Oasis natural site following the hydrocarbon spill, would you be willing to pay XX to create a fund financing protective interventions capable of preventing similar events at this site?

Population
7 680 000

Number of interviews
500

	Bid amount [€]									
	0.25	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**1.75**	**2**	**2.25**	**2.5**
Number of respondents offered the bid amount	50	50	50	50	50	50	50	50	50	50

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

In **closed-ended questionnaires** (yes/no), the estimate of mean WTP is obtained through a **logistic regression that estimates the probability of an affirmative response** (mean WTP = WTP with 50% probability).

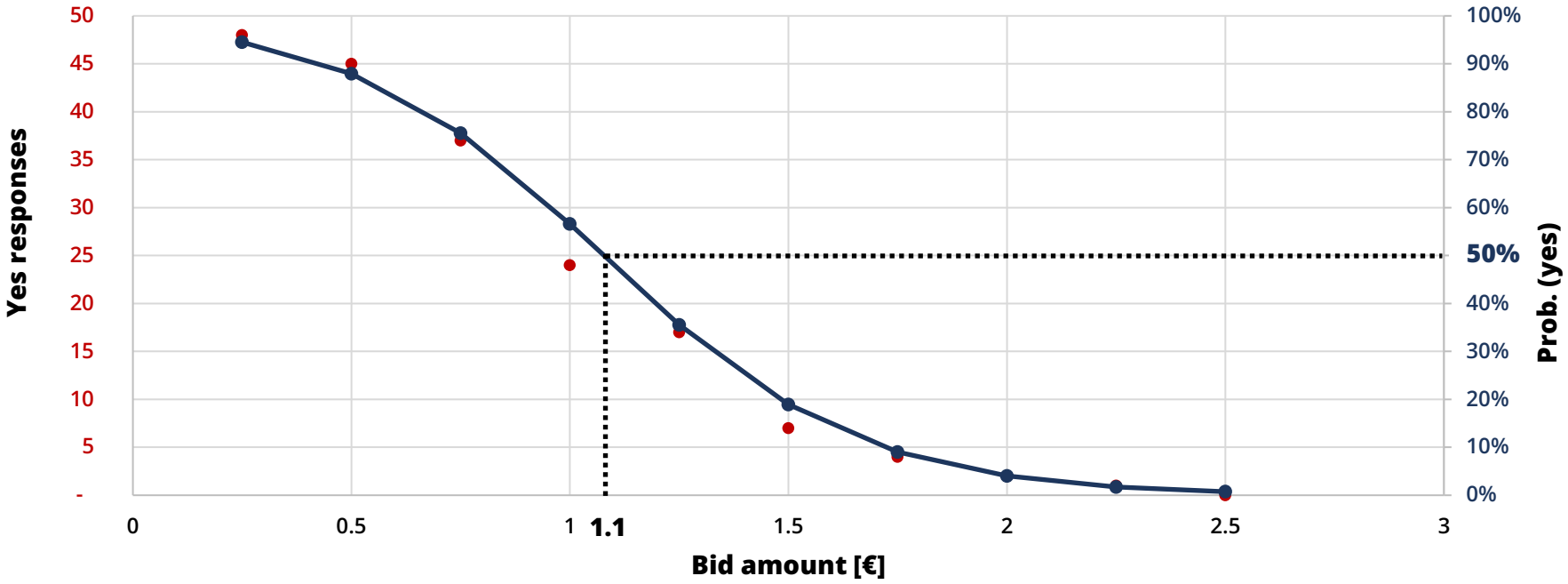
Bid amount	Yes responses	Observed percentage	Estimated percentage
0.25	48	96%	95%
0.5	45	90%	88%
0.75	37	74%	76%
1	24	48%	57%
1.25	17	34%	36%
1.5	7	14%	19%
1.75	4	8%	9%
2	2	4%	4%
2.25	1	2%	2%
2.5	-	0%	1%

$$p(\text{yes}, x) = \frac{e^{a+bx}}{1 + e^{a+bx}}$$

x bid amount

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

Responses obtained



Average WTP	1.10 € per person
Population	7 680 000 inhab.
Total WTP	**8 448 000 €**

Valuation methods: stated preferences
Contingent valaution: the Cervara Oasis

Comparison between contingent valuation and the travel cost method.

Valuation method	Amount [€]	Estimated value
Contingent Valuation	8 448 000	Total economic value
Travel cost	560 263	Direct use value
Difference	7 887 737	Other values (indirect use, option, bequest, existence)

Valuation methods: stated preferences

✓

- Based on **consumer utility theory**
- It is the only method for estimating **non-use values**
- It is **widely used**
- **Refined over time** to eliminate biases and make the method more realistic

✗

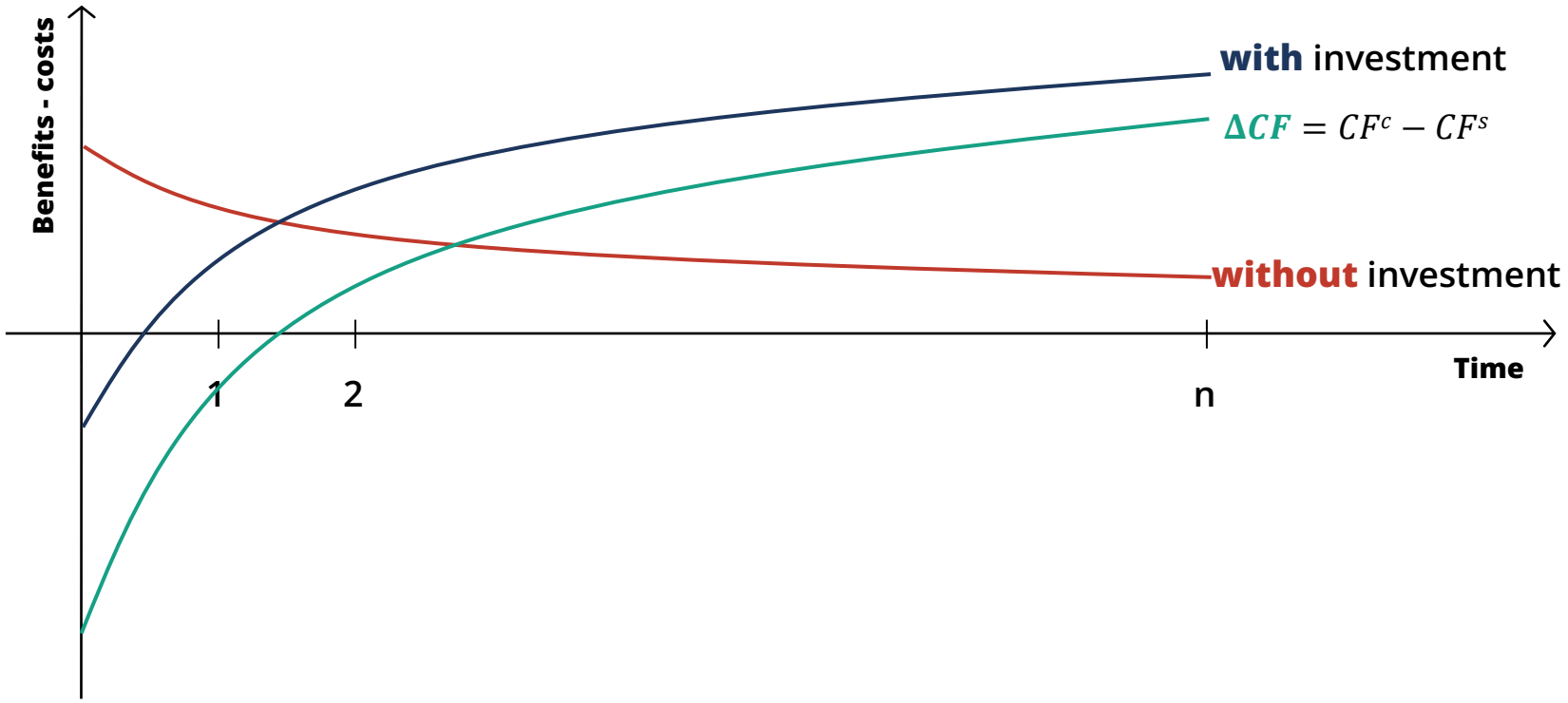
- **Difficult to validate** non-use value estimates
- **WTP is correlated with the level of knowledge of the good** (limited knowledge of how ecosystems function)
- **Credibility** of survey-based valuations
- **Costly** to implement

Valuation methods and estimated values

Valuation method		Estimated values
Imputed preferences	Defensive expenditure Restoration cost	Use
	Replacement cost / value	
	Production function	
Revealed preferences	Hedonic pricing	Use, option
	Travel cost models	Use
Stated preferences	Contingent valuation Choice experiments	Use, option, existence, bequest

Constructing the cash flow

The valuation of the costs and benefits of the investment takes as its reference the situation that would occur in the absence of the investment. The valuation therefore considers the **differential effect: differential costs vs differential benefits.**



The choice of the discount rate

The choice of the discount rate plays a **fundamental role in estimating the present value** of a future cash flow.

$$V_0 = V_n \frac{1}{(1+r)^n}$$

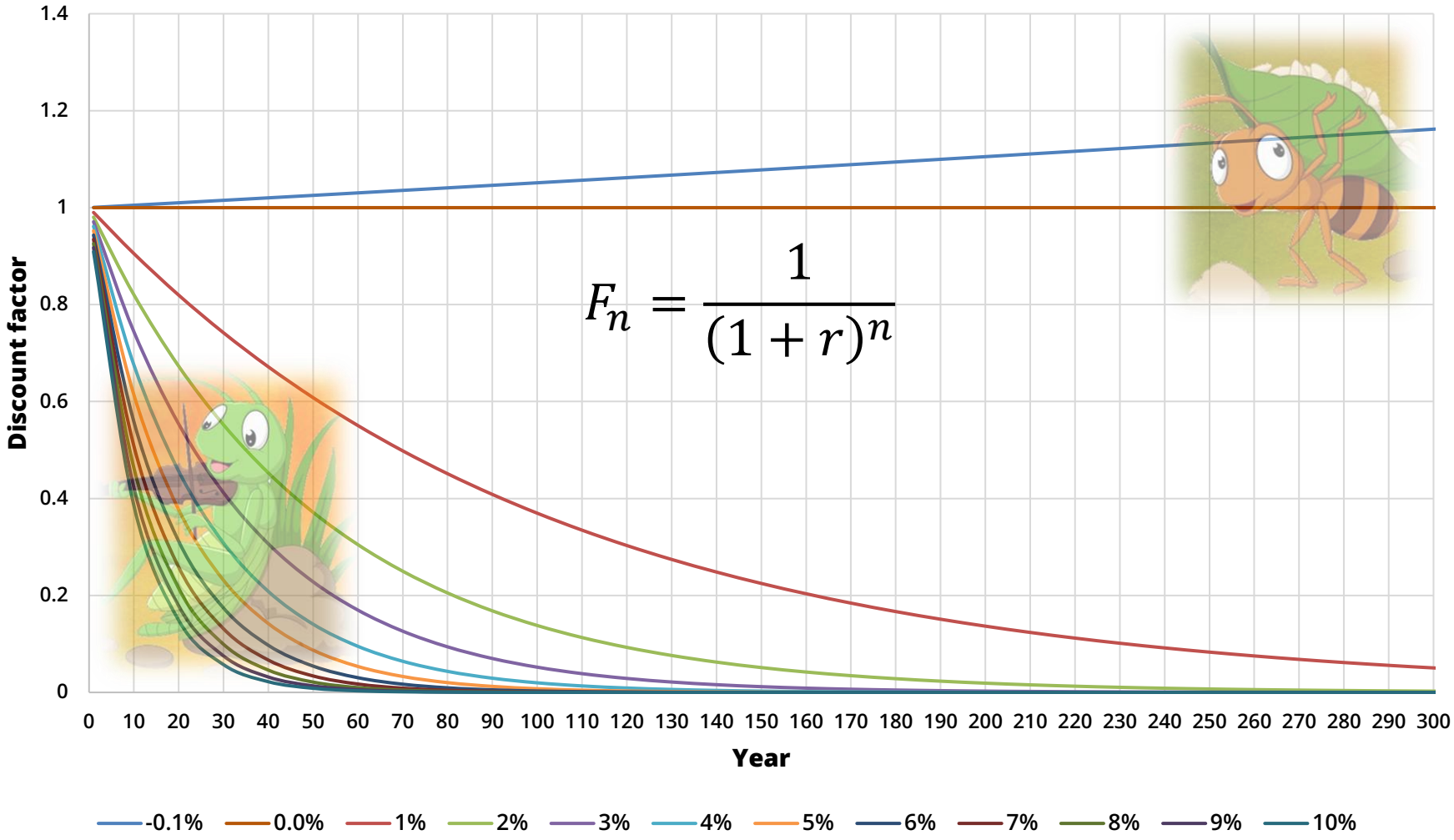
Discount factor for period n

V_0 present value

V_n future value at time n

r discount rate

The choice of the discount rate



The choice of the discount rate

1. The **theoretical foundations** of discounting in social and environmental valuations (the reason for discounting):
    - **The opportunity cost of capital**
    - **Time preferences**
2. Recent proposals: **zero**, **dual rate** and **declining discount rates over time**.
3. The choice of the rate in the **practice of some countries**.

The choice of the discount rate
Theoretical foundations

The opportunity cost of capital

- Because **capital is scarce**, investing in one project means giving up investment in the best alternative use.
- This forgone return is **the opportunity cost of capital**: the return lost from the most profitable alternative use.
- At the aggregate level, projects can be ranked according to their **rates of return**.
- At the margin, this rate of return is the **social opportunity cost** of capital, denoted by r, and it can be used as one basis for choosing the **discount rate** in public project and policy appraisal.

The choice of the discount rate
Theoretical foundations

Time preferences

$$W = \int_0^{\infty} U\big(c(t)\big)e^{-\rho t}dt$$

W	intertemporal social welfare
$U(c(t))$	instantaneous utility derived from per capita consumption at time t
ρ	pure rate of time preference (impatience)
$e^{-\rho t}$	discount factor

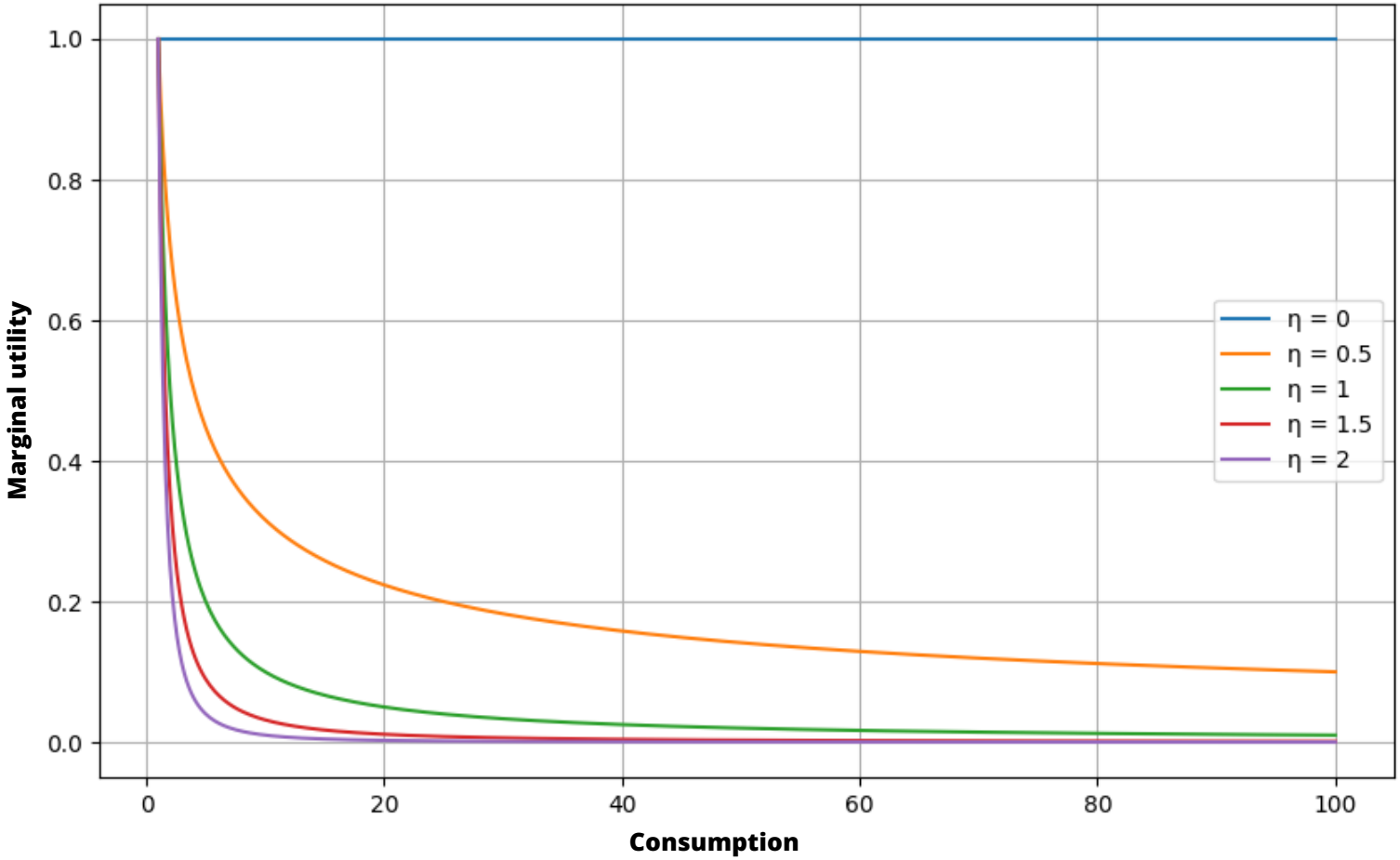
$$r = \rho + \eta g_c(t)$$

r	discount rate
η	elasticity of the marginal utility of consumption
$g_C(t)$	expected rate of growth (or decline) in per capita consumption

Ramsey, F. P. (1928). A mathematical theory of saving. *The Economic Journal*, *38*(152), 543-559.

The choice of the discount rate
Theoretical foundations

η elasticity of the marginal utility of consumption



The choice of the discount rate
Theoretical foundations

Some premises

- The **pure rate of time preference of society is lower than that of the individual** ('immortal society').
  low ρ
- **'Super-responsability' towards future generations.**

$$\rho = 0$$

- **Public choices affected by low risk and uncertainty** due to the law of large numbers.
  low ρ

Perman, R. (2003). *Natural resource and environmental economics*. Pearson Education.

The choice of the discount rate
Zero discounting

Hypothesis based on ethical considerations

- **Intergenerational equity against the "tyranny of the present"** that limits the development of future generations.
- ***Property rights* of future generations**.
- **Strong sustainability**: absence of substitutability in the social welfare function between natural capital and the other types of capital.

Implications

- **Risk of continuously postponing development** and placing all societies at the limits of subsistence.
- If income grows over time, there is a risk of a '**tyranny of the future**' (richer) over the present generation (poorer)

Oxera, A. (2002). Social Time Preference Rate for Use in Long-term Discounting. *The office of the Deputy Prime Minister, Department for transport and Department for the Environment, food and rural affairs, London*.

The choice of the discount rate
Dual rate discounting

Hypothesis based on the observation that, **as income rises**, **appreciation** (WTP) **for environmental goods and services** (superior goods) **increases relative to other consumption** (private goods).

The utility flows generated by environmental goods must be discounted at **a discount rate r' lower than the rate r used for other goods** (market goods).

U.S. Federal Register, 15 CFR part 990, (1996) Natural Resource Damage Assessment, Final rule, Department of Commerce.

The choice of the discount rate
Declining discount rates over time

Hypothesis based on the observation that intertemporal choices are affected by **uncertainty** regarding:

- **stability and growth of future income** (Gollier, 2002)
- **future discount rates** (Weitzman, 1998)

To **take these uncertainties into account** it is necessary to adopt a **rate that declines over time.**

Gollier, C. (2002). Discounting an uncertain future. *Journal of public economics*, *85*(2), 149-166.

Weitzman, M. L. (1998). Why the far-distant future should be discounted at its lowest possible rate. *Journal of environmental economics and management*, *36*(3), 201-208.

The choice of the discount rate
Declining discount rates over time

$$F_n^* = \sum_i \frac{1}{(1+r_i)^n} \cdot p_i \qquad F_n^* = \frac{1}{(1+r^*)^n} \qquad r_n^* = \frac{1 - \sqrt[n]{F_n^*}}{\sqrt[n]{F_n^*}}$$

F_n^* certainty-equivalent discount factor

r_i the i-th discount rate with probability p_i

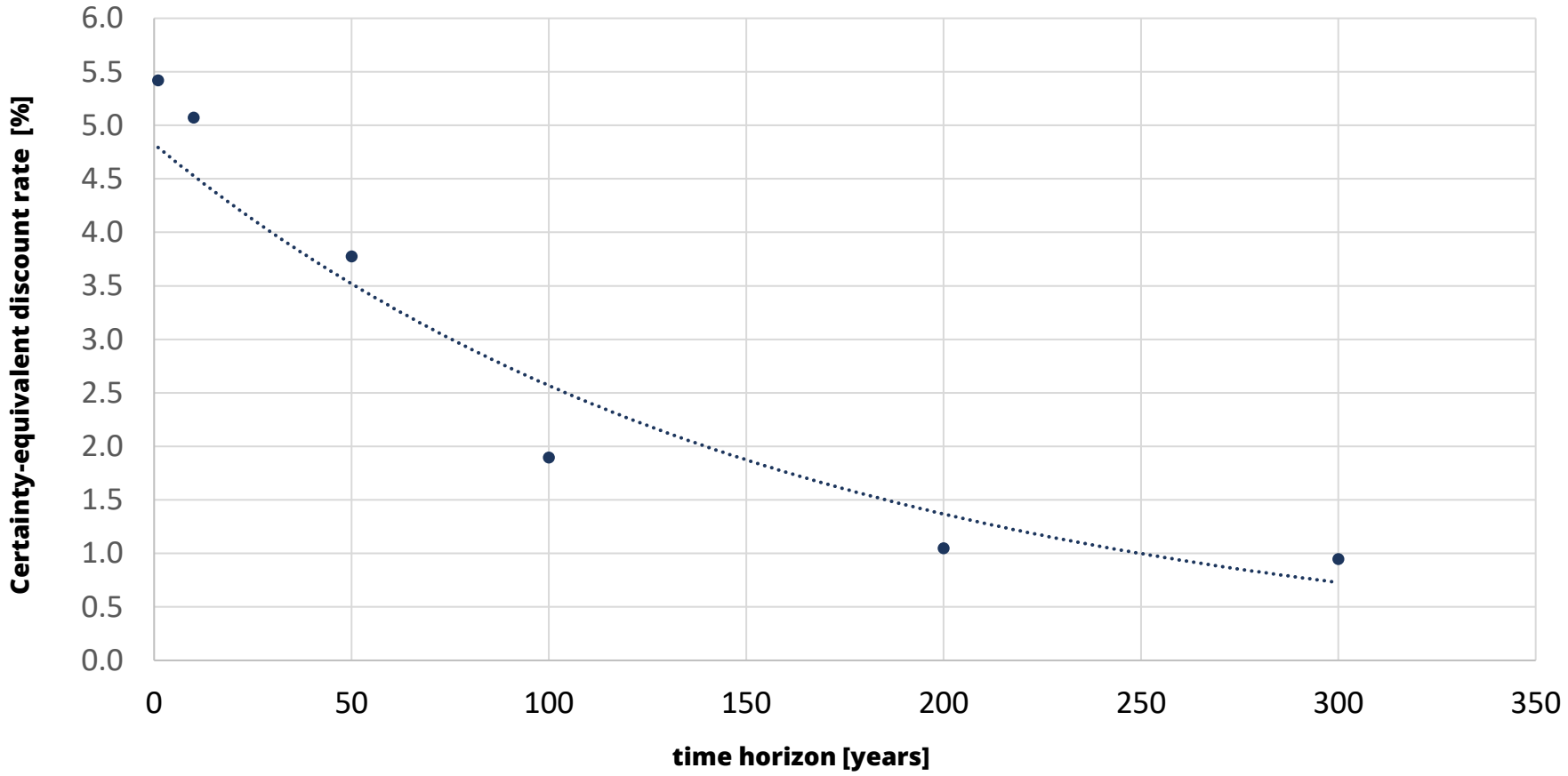
r_n^* certainty-equivalent discount rate for year n

The choice of the discount rate
Declining discount rates over time

Rate (%)	Probability p_i	Time horizon n = 10		50		100	
		Discount factor	Weighted factor	Discount factor	Weighted factor	Discount factor	Weighted factor
1	0.1	0.9053	0.0905	0.6080	0.0608	0.3697	0.0370
2	0.1	0.8203	0.0820	0.3715	0.0372	0.1380	0.0138
3	0.1	0.7441	0.0744	0.2281	0.0228	0.0520	0.0052
4	0.1	0.6756	0.0676	0.1407	0.0141	0.0198	0.0020
5	0.1	0.6139	0.0614	0.0872	0.0087	0.0076	0.0008
6	0.1	0.5584	0.0558	0.0543	0.0054	0.0029	0.0003
7	0.1	0.5083	0.0508	0.0339	0.0034	0.0012	0.0001
8	0.1	0.4632	0.0463	0.0213	0.0021	0.0005	0.0000
9	0.1	0.4224	0.0422	0.0134	0.0013	0.0002	0.0000
10	0.1	0.3855	0.0386	0.0085	0.0009	0.0001	0.0000
Certainty-equivalent discount factor			**0.6097**		**0.1567**		**0.0592**
Certainty-equivalent discount rate for year %			**5.0722**		**3.7763**		**2.8672**

The choice of the discount rate
Declining discount rates over time

Certainty-equivalent discount rate and time horizon



The choice of the discount rate
Current practice

United Kingdom (The Green Book, 2026)

Table 3.A Declining discount rate regime

Year	1-30	31-75	76-125
Social Time Preference Rate	3.500%	3.000%	2.500%
Health discount rate	1.500%	1.286%	1.071%

Source: HM Treasury

3.4 Practitioners should conduct additional sensitivity analysis when an appraisal has a time horizon beyond 50 years. They should initially discount values using the relevant discount rates set out in Table 3.A. They should then discount values using a variant of the discount rate in which pure time preference (δ) is excluded. These discount rates are set out in Table 3.B, with discount factors supplied in Table A.3.

Table 3.B Reduced long-term discount rates for sensitivity testing

Year	1-30	31-75	76-125	126-200	201-300	301+
Reduced STPR for (δ = 0)	3.00%	2.57%	2.14%	1.71%	1.29%	0.86%

Source: HM Treasury

The choice of the discount rate
Current practice

European Union (Economic Appraisal Vademecum 2021-2027)

Social discount rate	According to Annex III to Regulation No 2015/207, a social discount rate of 5 % will be used for major projects in cohesion countries and 3 % for the other Member States	Member States are free to establish and use their own country-specific social discount rate (see Section 2.3); 3 % can be used in the absence of a national approach

In this regard, a forthcoming publication (Catalano et al., 2021) presents estimations of the SDR at the national level for a sample of countries and can be a useful reference. Based on their calculations with updated data (including forecasts of economic growth rates), the SDR would currently range from a maximum of 8.13 % for Estonia to 0.80 % for Italy (calculated following the SRTP method), with an EU average of 3.6 % and a median value of 2.8 %.

As a matter of simplification, in the absence of national values, 3 % SDR can be taken as a reference point for EU-funded projects in 2021–2027.

What is the cost-benefit analysis?

Why use Cost-Benefit Analysis in environmental policy?

- **Cost-Benefit Analysis (CBA) is used to compare the benefits and costs of environmental projects and policies in monetary terms.**
- **It is useful for evaluating changes in environmental quality**, for example: water quality, new public forests, household recycling.
- CBA helps us **understand whether a policy is socially desirable and economically efficient.**
- Economic benefits and costs do not tell us everything that matters, but they still **provide very useful information for decision-making.**
- One central and controversial issue in CBA is the **discounting of future costs and benefits.**

What is the cost-benefit analysis?

CBA, welfare economics, and the Kaldor-Hicks criterion

- CBA consists of three steps:
  - **identifying** the relevant impacts of a project or policy
  - **valuing** them in terms of their effects on social well-being
  - **comparing** benefits and costs in monetary terms.
- The reference criterion is the **Kaldor-Hicks Compensation Test**: a policy is justifiable if the winners could compensate the losers and still remain better off.
- CBA helps **allocate scarce resources across alternative uses**, but compensation is usually potential, not necessarily actual.

What is the cost-benefit analysis?

Step 1: Project/policy definition

- **The object** and the **time horizon** of the analysis must be specified.
- It is also necessary to define **whose welfare** is being considered: it's the issue of standing in CBA. In many cases **standing** is national, but in some cases the relevant population is difficult to define.
- Step 1 also requires us to draw a **boundary around the project**: that is, to decide which costs, benefits, and alternatives are included in the analysis.
- For **climate policies**, the issue of standing is especially important because benefits and costs may be **global**, not only national.

What is the cost-benefit analysis?

Step 2: Identify the physical impacts of the project/policy

- The second step is to identify the outcomes of the project in **physical magnitudes**.
- These changes are not always known with **certainty**: they often have to be predicted or estimated.
- Once physical impacts have been identified and quantified, we must ask which of them are **relevant for the CBA**.
- An impact is relevant if it affects the quantity/quality of resources available or the welfare of households and firms, even when the **effects are non-market.**

What is the cost-benefit analysis?

Step 3: Valuing impacts

- The general principle is to value impacts in terms of **marginal social cost or marginal social benefit**.
- Under certain conditions, **market prices are a good first approximation** of marginal benefit and cost values.
- However, **markets may fail**, and for many environmental goods no observable market exists.
- For environmental goods such as biodiversity or river water quality, we can use the methods already seen in the course.

What is the cost-benefit analysis?

Step 4: Discounting costs and benefits

- Once expressed in monetary terms, cost and benefit flows must be converted into **present value** PV.
- This requirement comes from the **time value of money and time preference**.
- In general, a **benefit received sooner** is worth more than an identical one received later; similarly, a **future cost** is less burdensome than an immediate cost.
- Discounting uses a **discount rate** r.
- The present value of a cost or benefit X_t received at time t is:

$$PV(X_t) = X_t[(1+r)^{-t}]$$

What is the cost-benefit analysis?

Step 5: Applying the Net Present Value test

- CBA can also be used to **rank competing alternatives.**
- The criterion applied is the **Net Present Value** (NPV).
- The NPV test asks **whether the sum of discounted benefits exceeds the sum of discounted costs**.

$$NPV = \sum_{t=0}^{T} B_t(1+r)^{-t} - \sum_{t=0}^{T} C_t(1+r)^{-t}$$

- Decision rule:
  - **accept** the project if **NPV > 0**
  - **rank multiple projects** according to their NPV
  - **do not recommend** projects with **NPV < 0**

What is the cost-benefit analysis?

Step 6: Sensitivity analysis

An Illustrative CBA.pdf

- The NPV test tells us about the effectiveness of a project **given the data and assumptions** used in the calculations.
- **If the data change**, the results of the **NPV** test **change** as well.
- The main reason is **uncertainty**: in CBA the analyst must make predictions about future physical flows and future values.
- When **environmental** impacts are involved, **uncertainty** may be even greater.
- The essential final stage is therefore **sensitivity analysis**, that is, recalculating NPV after changing **key parameters**.

The end

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