

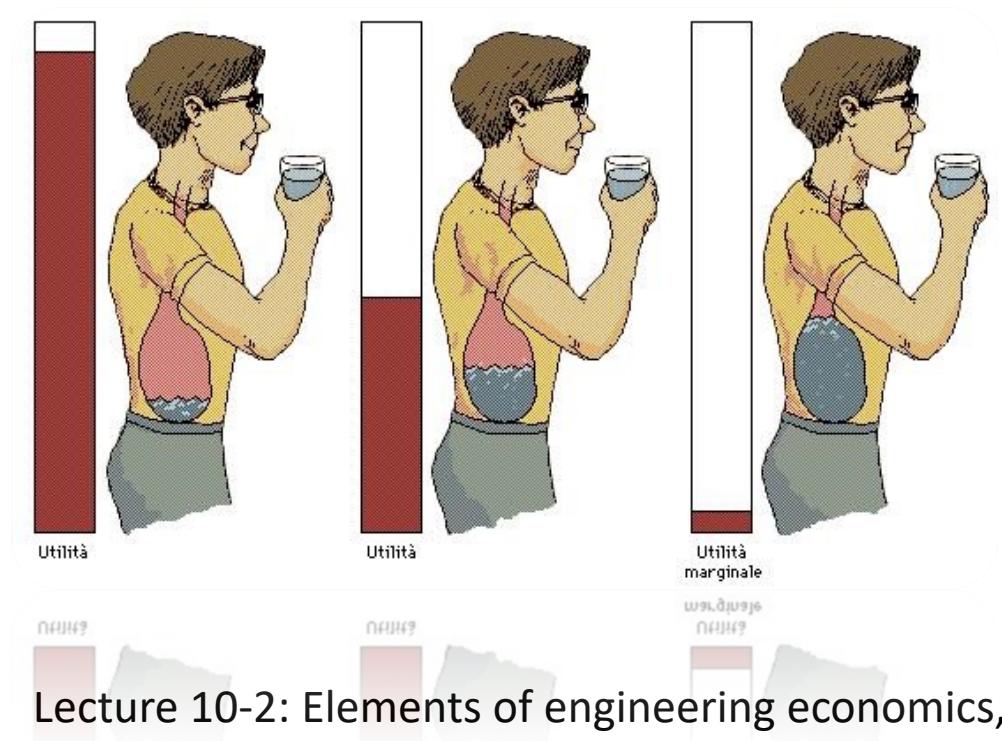
# Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course

**Prof. P. Perona**

Platform of hydraulic constructions



Lecture 10-2: Elements of engineering economics,  
Marginal analysis

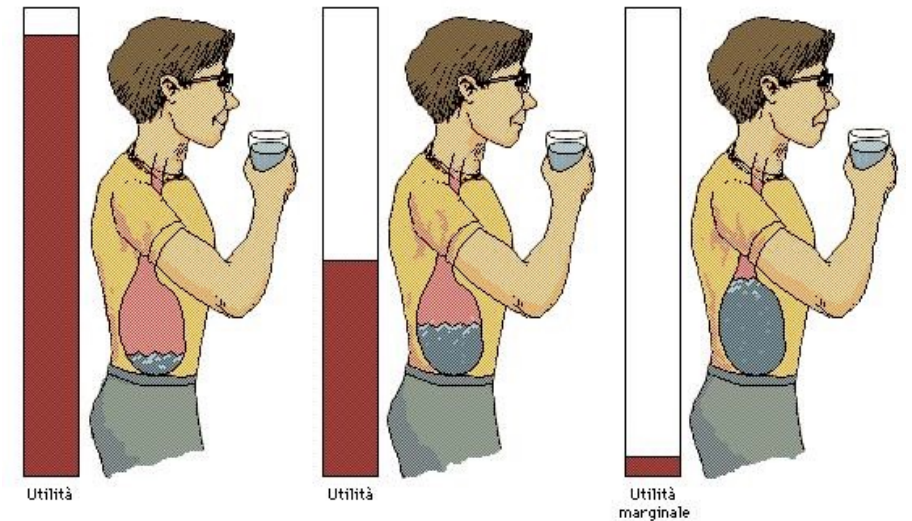


# Marginal analysis

- Aristoteles (*Πολιτικά*) writes  
...external goods have a limit, like any other instrument, and all things useful are of such a nature that where there is too much of them they must either do harm, or at any rate be of no use...

(Economists often criticize this viewpoint...but we are not economists)

**What is marginal analysis in economic theories?**



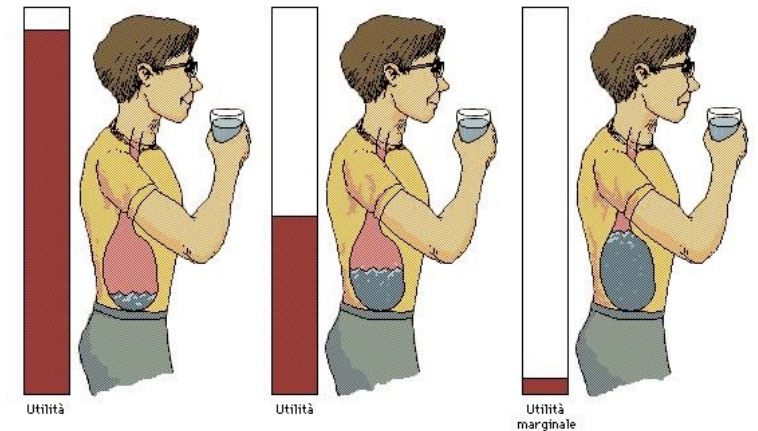
Marginal analysis assesses the concept of utility of a given good in relation to its amount



# Marginal use and marginal utility

- Marginal use of a good or service is the specific use to which an agent would put a given increase, or the specific use of the good or service that would be abandoned in response to a given decrease
- Marginal utility of a good or service is the utility of its marginal use.
- The „law of diminishing marginal utility“ (Gossen’s First Law)  
«As additional amounts of a good or service are added to available resources, their marginal utilities are decreasing»

**What are marginal use and marginal utility?**





# Total benefit and marginal benefits

- The total benefit is the cumulative change in benefit that arises for increasing quantity being allocated (or used), i.e. the function

$$B = B(Q)$$

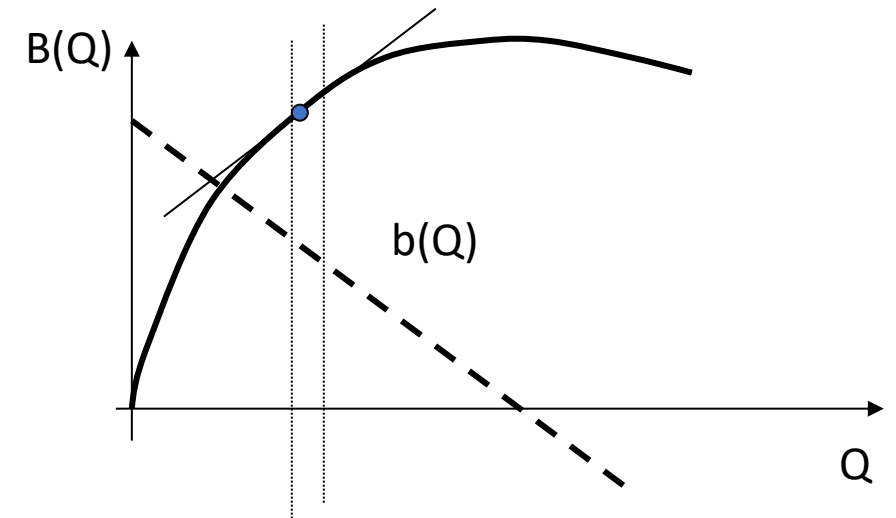
- The marginal benefit is the relative change in benefit for increasing the quantity being allocated of one unit

$$b = \frac{dB(Q)}{dQ},$$

hence

$$B = \int_0^Q b(q) dq$$

**What are the total and the marginal benefits related to quantity allocation?**





# The Principle of Equal Marginal Utility (PEMU)

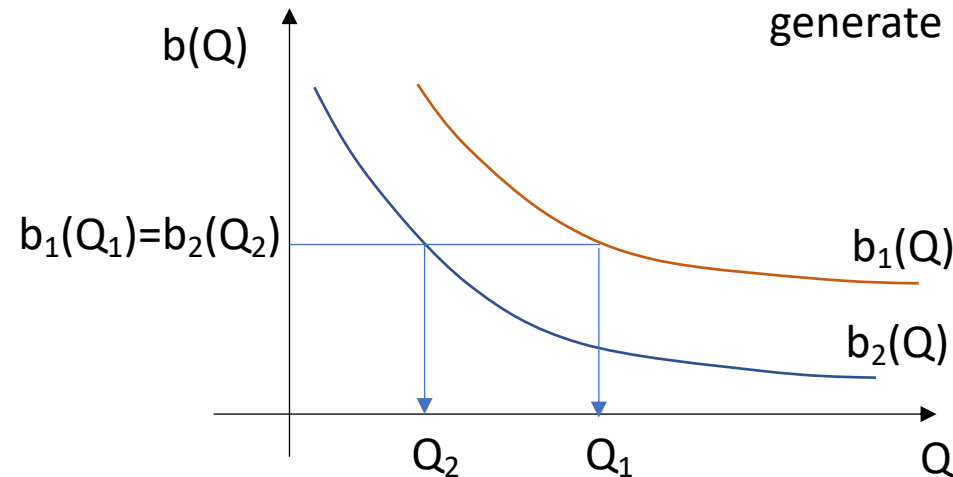
Two users characterized by marginal benefits  $b_1(Q)$  and  $b_2(Q)$ , and sharing at a time a common resource (e.g., water volume), will generate the maximum total benefit when the amount of resource is shared between the two uses such that the two marginal benefits are equal, that is:

The total benefit

$$B_T = \sum_{i=1}^n \int_0^{Q_i} b_i(q) dq$$

for sharing the resource such that  $Q_1 + Q_2 = Q$   
is maximum when

$$b_1(Q_1) = b_2(Q_2)$$



**What does the PEMU means in practice?**

The PEMU states that the optimal allocation of a common good between two uses generates the maximum total benefit when the good is shared in proportions that generate equal marginal benefits



# How can the PEMU be proved? (optional)

The PEMU generally holds for unbounded problems, i.e., in the case there are no active constraints (e.g., physical, economic, political, social) affecting allocation among the activities. If there is no significant storage at the diversion node, and assuming that both mbf are positive monotonically decreasing functions, the objective function TB can be analytically maximized, i.e., by finding

$$\text{Max}_{\mathbf{Q}, T_h} \left[ \sum_{i=1}^2 \int_{T_h} \int_0^{Q_i} f_{\text{act}}(\tau) b_i(q; \mathbf{r}_i(\tau)) dq d\tau \right], \quad I = q_1 + q_2$$

$$\frac{d}{dQ_2} \left( \int_{T_h} \int_0^{I-Q_2} f_{\text{act}}(\tau) b_1(I - q_2; \mathbf{r}_1(\tau)) d(I - q_2) d\tau \right) + \frac{d}{dQ_2} \left( \int_{T_h} \int_0^{Q_2} f_{\text{act}}(\tau) b_2(q_2; \mathbf{r}_2(\tau)) dq_2 d\tau \right) = 0.$$

$$\int_{T_h} \frac{d}{dQ_2} \left( \int_0^{I-Q_2} f_{\text{act}}(\tau) b_1(I - q_2; \mathbf{r}_1(\tau)) d(I - q_2) \right) d\tau + \int_{T_h} \frac{d}{dQ_2} \left( \int_0^{Q_2} f_{\text{act}}(\tau) b_2(q_2; \mathbf{r}_2(\tau)) dq_2 \right) d\tau = 0.$$

By gathering now the two domains of integration and making the derivative one obtains

$$\int_{T_h} f_{\text{act}}(\tau) \left( b_1(I - Q_2; \mathbf{r}_1(\tau)) \frac{d(I - Q_2)}{dQ_2} + b_2(Q_2; \mathbf{r}_2(\tau)) \right) d\tau = 0,$$

which finally reduces to the condition

$$\int_{T_h} f_{\text{act}}(\tau) (-b_1(I - Q_2; \mathbf{r}_1(\tau)) + b_2(Q_2; \mathbf{r}_2(\tau))) d\tau = 0.$$

By making use again of the continuity at the node

$$b_1(Q_1; \mathbf{r}_1(t)) = b_2(Q_2; \mathbf{r}_2(t)).$$



# Type of costs

Both fixed costs  $C_{fix}$  and variable costs  $C_{var}$  affect the total cost  $C$

$$C(Q) = C_{fix} + C_{var}(Q)$$



$$c = \frac{dC}{dQ} = \frac{dC_{var}}{dQ}$$

Fixed costs do not affect marginal costs!

**What are fixed and variable costs for a project?**

Fixed cost occur at once and are independent of the use of the resource (e.g., setting up a contract for energy allocation). Variable costs depend on the amount of the service or good being used



# Economies of scale

Compare now the marginal cost  $c(Q^*)$  for a given demand  $Q^*$  to the average cost

$$\bar{C} = \frac{C_{fix} + C_{var}(Q^*)}{Q^*}$$

$c < \bar{C}$	Economy of scale (additional units are produced for less than the previous unit)
$c > \bar{C}$	Diseconomy of scale (diminishes marginal productivity)

## What is intended with economies of scale?

This is the relationship existing between the increasing production amount followed by a unitary cost decrease. The marginal cost (not affected by fixed costs) is used as a term of comparison with the average total cost (affected by fixed costs)

Cournot dilemma: resistency to monopolium of productive structures



# Externalities

- Negative externalities: marginal social costs of production are greater than that of the private cost function (e.g., a given private production pollutes the environment and this affect social costs)
- Positive externalities: marginal social costs of production are less then that of the private cost function (e.g., education of people)

## What is meant with externalities?

Externalities are costs or benefits that are caused by a given use of the resource and affect other users (e.g., a producer who pollute the environment and other pay the price for that)



# Financial vs economic efficiency

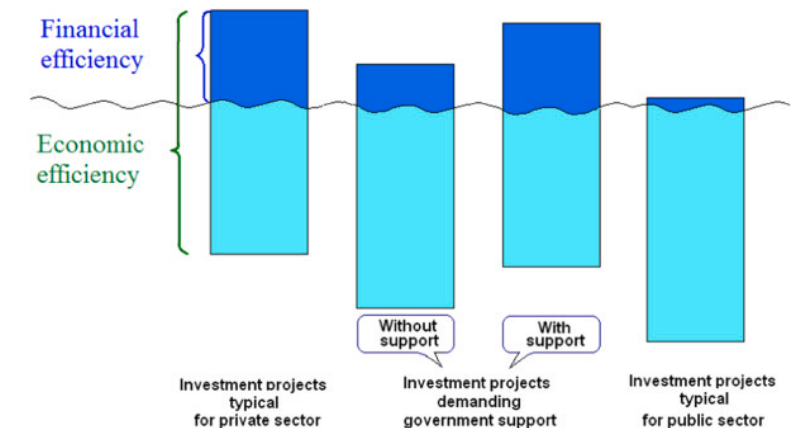
- Financial efficiency

Is concerned only with money flow, a good or a service is of value only if money changes hands when it is exchanged or consumed. **It improves if the net financial return increases**

- Economic efficiency

Is concerned with all goods and services valued by the public regardless of whether consumption is accompanied by monetary exchange (e.g., willingness to pay for something). **It improves if the net wealth of society increases**

**What is the difference between financial and economic efficiency?**

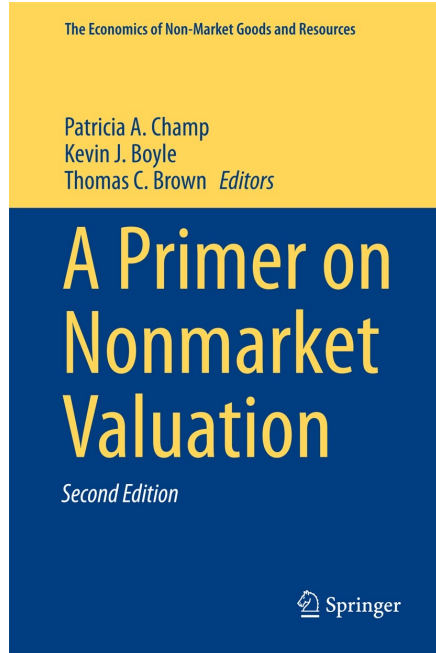


Source: Novikova, 2022

<https://doi.org/10.1016/j.evalprogplan.2021.102018>



# Market vs non-market (or non-valuable) goods



Topic: ecosystem services

**Value:** (ecology meaning) that which is desirable or worthy of esteem for its own sake; thing or quality having intrinsic worth (Webster's New World Dictionary)

**Value:** (economist meaning) a fair or proper equivalent in money, commodities, etc. (Webster's New World Dictionary)

## What are market and non-market goods and resources?

Marked goods have assigned an instrumental value

Non-marked goods have assigned an intrinsic value

Benefits-costs analysis becomes then very problematic in the absence of a common agreement about the value of non-market goods or resources (e.g., ecosystem services)

**Ecology view** → philosophic intrinsic value (valuable in and for itself. Independently of any utility)

**Economist view** → philosophic instrumental value (as a mean to some other end or purpose, e.g. increased human well-being)



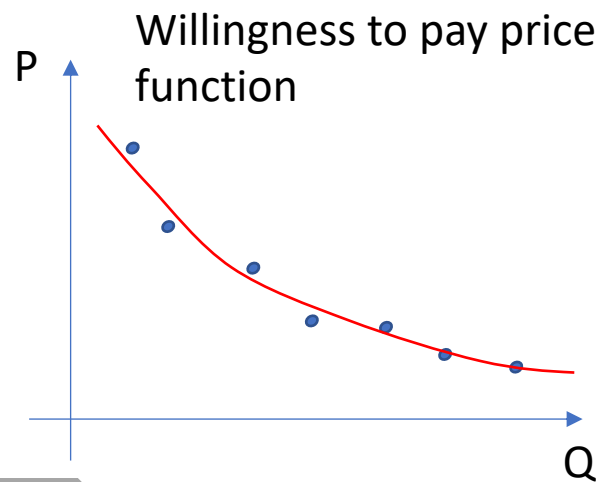
# Contingent (i.e. survey-based) valuation methods

There are several methods available, we focus here at the “People willingness to pay”, as an example

The “Willingness to pay” is based on conducting operational surveys on a sample population interested by the specific ecosystem services to be assessed

People are asked to assess how much they would pay for increasing units of environmental “goods” that sustain related ecosystem services (e.g., amount of flow, or water depth in a river, etc.)

Problem: the method is subjective and results strongly dependent on personal uses or the “vicinity” to the service to be assessed



## Can the economic value of financially non/valuable goods be assessed?

### The value of the world's ecosystem services and natural capital

Robert Costanza<sup>1</sup>, Ralph d'Arge<sup>2</sup>, Rudolf de Groot<sup>3</sup>, Stephen Farber<sup>4</sup>, Monica Grasse<sup>5</sup>, Bruce Hannott<sup>6</sup>, Karin Limburg<sup>7</sup>, Shabir Nazem<sup>8</sup>, Robert V. O'Neill<sup>9</sup>, Jose Paruelo<sup>10</sup>, Robert G. Radtke<sup>11</sup>, Paul Sutton<sup>12</sup> & Marjan van den Belt<sup>13</sup>

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<sup>11</sup> Population Laboratory, Pasadena, California 91106, USA  
<sup>12</sup> National Center for Geographic Information and Analysis, Department of Geography, University of California at Santa Barbara, CA  
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The services of ecological systems and the natural capital stocks that produce them are critical to human well-being. They contribute to human welfare, both directly and indirectly, and are the basis of the total economic value of the planet. We have estimated the current economic value of 16 biomes, based on published studies and a few original calculations. For the entire biomes, the value is estimated to be in the range of US\$16–54 trillion (10<sup>12</sup>) per year. Because of the nature of the uncertainties, this must be considered a gross national product total is around US\$18 trillion per year.

Because ecosystem services are not fully captured in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere. The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite. However, it can be instructive to estimate the “incremental” or “marginal” value of ecosystem services (the estimated rate of change of value compared with changes in ecosystem services from their current levels). There have been many studies in the past few decades aimed at estimating the value of a wide variety of ecosystem services. We have gathered together this large (but scattered) amount of information and estimate the product of two or more ecosystem services together as ecosystem functions. For simple functions and services together as ecosystem functions. For simple functions and services together as ecosystem functions. For simple functions and services together as ecosystem functions.

Although we acknowledge that there are many conceptual and empirical problems inherent in producing such an estimate, we think this exercise is essential in order to (1) make the range of potential values of the services of ecosystem more apparent; (2) establish at least a first approximation of the relative magnitude of global ecosystem services; (3) set up a framework for their further analysis; (4) point out those areas most in need of additional research; and (5) stimulate additional research and debate on the problems and uncertainties we encountered indicate that our estimate represents a minimum increase: (1) with additional effort broader range of ecosystem services more realistic representations of dependence; and (3) as ecosystem and “nature” in the future.

<sup>1</sup>Source: Address: Department of System Ecology, University of Stockholm, S-106 91 Stockholm, Sweden.

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### Pricing Biodiversity and Ecosystem Services: The Never-Ending Story

BY MARINO GATTO AND GIULIO A. DE LEO

In 1844, the French engineer Jules Juvenel Dupuit introduced cost-benefit analysis to evaluate investment projects. This methodology relies on the concept of consumer surplus (which is the difference between willingness-to-pay and actual payment; see Nijkamp 1977), which was also defined by Dupuit (1844). The application of cost-benefit analysis to ecological issues fell out of favor three decades ago, and it was gradually replaced by multicriteria analysis in the decision-making process for projects that have an impact on the environment. Although multicriteria analysis is currently used for environmental impact assessments in many nations, in the last 5 years the concept of cost-benefit analysis has again become fashionable, along with the various pricing techniques associated with it, such as contingent valuation methods, hedonic prices, and costs of replacement of ecological services. For example, during the First World Congress of Environmental and Resource Economists held in Venice, Italy, in June 1998, 12 of the 88 sessions were focused on theoretical and empirical problems related to contingent valuation methods. Overall, almost 100 of 500 contributions were related to issues of pricing environmental goods and services. By contrast, only a small number of papers used multicriteria analysis. Economists have generated a wealth of virtuous variations on the theme of assessing the social value of biodiversity, but most of these techniques are inevitably based on price—that is, on a single scale of values, that of goods currently traded on world markets.

Perhaps the most famous recent study on the issue of pricing biodiversity and ecological services is that by Costanza et al. (1997), who argued that if the importance of nature's free benefits could be adequately quantified in economic terms, then policy decisions would better reflect the value of ecosystem services and natural capital. Drawing on earlier studies aimed at estimating the value of a wide variety of ecosystem goods and services, Costanza et al. (1997) estimated the current economic value of the entire biosphere at \$16–\$54 trillion per year, with an average value of approximately \$3.3 trillion per year. By contrast, the gross national product of the United States totals approximately \$18 trillion per year (Costanza et al. 1997).

The paper, as its authors intended, stimulated much discussion, media attention, and debate. A special issue of *Ecological Economics* (April 1998) was devoted to commentaries on the paper, which, with few exceptions, were laudatory. Some economists (Pearce 1998) have questioned the actual numbers, but many scientists have praised the attempt to value biodiversity and ecosystem functions.

Although Costanza et al. acknowledged that their estimates were crude and imperfect, they also pointed the way to improved assessments. In particular, they noted the need to develop comprehensive ecological economic models that could adequately incorporate the complex interdependencies between ecosystems and economic systems, as well as the complex individual dynamics of both types of systems. Despite the authors' caveats and the fact that many economists have been circumspect in applying their own tools to decisions regarding natural systems, the monetary approach is greeted by scientists, policymakers, and the general public as extremely appealing: a number of biologists are also of the opinion that attaching economic values to ecological services is of paramount importance for preserving the biosphere and for effective decision-making in all cases where the environment is concerned (Daily 1997; Finnvedt et al. 1997).

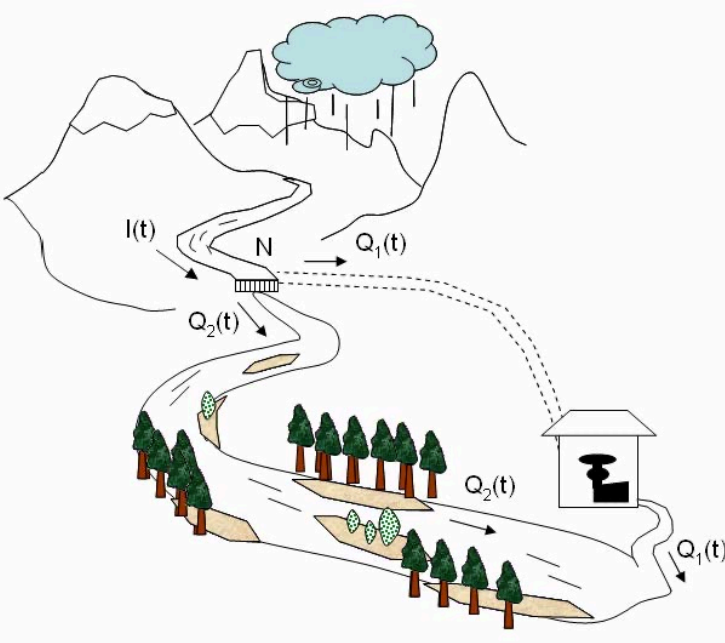
In this article, we espouse a contrary view, stressing that, for most of the values that humans attach to biodiversity and ecosystem services, the pricing approach is inadequate—if not misleading and obsolete—because it implies erroneously that complex decisions with important environmental impacts can be based on a single scale of values. We contend that the use of cost-benefit analysis as the exclusive tool for decision-making about environmental policy represents a setback relative to the existing legislation of the United States, Canada, the European Union, and Australia on environmental impact assessment, which explicitly incorporates multiple criteria (technical, economic, environmental, and social) in the process of evaluating different alternatives. We show that there are sound methodologies, mainly developed in business and administration schools by regional economists and by urban planners, that can assist decision-makers in evaluating projects and drafting policies while accounting for the nonmarket values of environmental services.

Marino Gatto (e-mail: gatto@telepolis.it) is a professor of Applied Ecology in the Dipartimento di Elettronica e Informazione, Politecnico di Milano, Milano, Italy. Giulio A. De Leo (e-mail: deleo@unipr.it) is an associate professor of Applied Ecology and Environmental Impact Assessment in the Dipartimento di Scienze Ambientali, Università degli Studi di Parma, Parma, Italy. © 2000 American Institute of Biological Sciences.



# The case of environmental flows

Perona et al., JEMA (2013)



We think in terms of marginal benefits, e.g.

$$\tilde{b}_1 = \tilde{a}_{11} - \tilde{a}_{12}\tilde{Q}_1$$

$$\tilde{b}_2 = \tilde{a}_{21} - \tilde{a}_{22}\tilde{Q}_2$$

$\tilde{b}_1$

$\tilde{b}_2$

Competition + Constraints

Optimal allocation rule

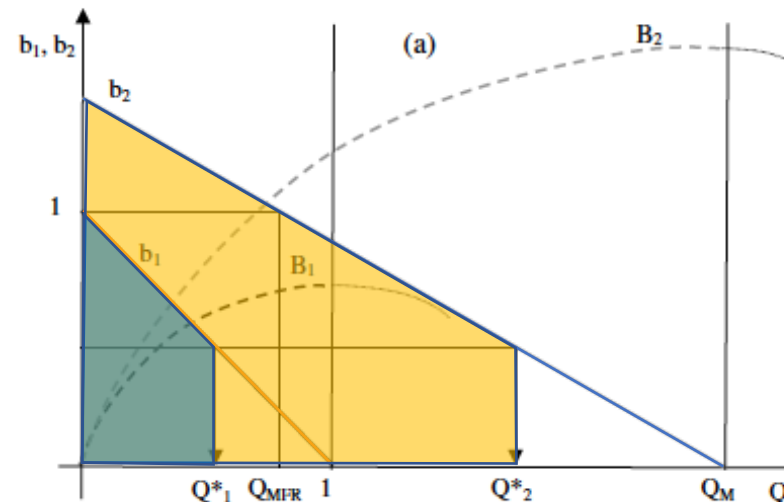
Can we use PEMU to value environmental water uses?

The idea is to show that assigning allocation rules implicitly means to define benefit functions even for non-valuable goods, e.g. like the environmental use of water

$$\text{Max}_{Q, T_h} \left[ \sum_{i=1}^N \int_{T_h} \int_0^{Q_i} f_{act}(\tau) b_i(q; r_i(\tau)) dq d\tau \right]$$



$$b_1(Q_1; r_1(t)) = b_2(Q_2; r_2(t)). \quad \text{PEMU}$$





# Allocation rules and price elasticity of env water use

## Minimal Flow POLICY

$$\begin{cases} I = Q_{\text{hyd}} + Q_{\text{MFR}} \\ b(Q_{\text{hyd}}) = b(Q_{\text{env}}) \end{cases} \quad (\text{PEMU})$$

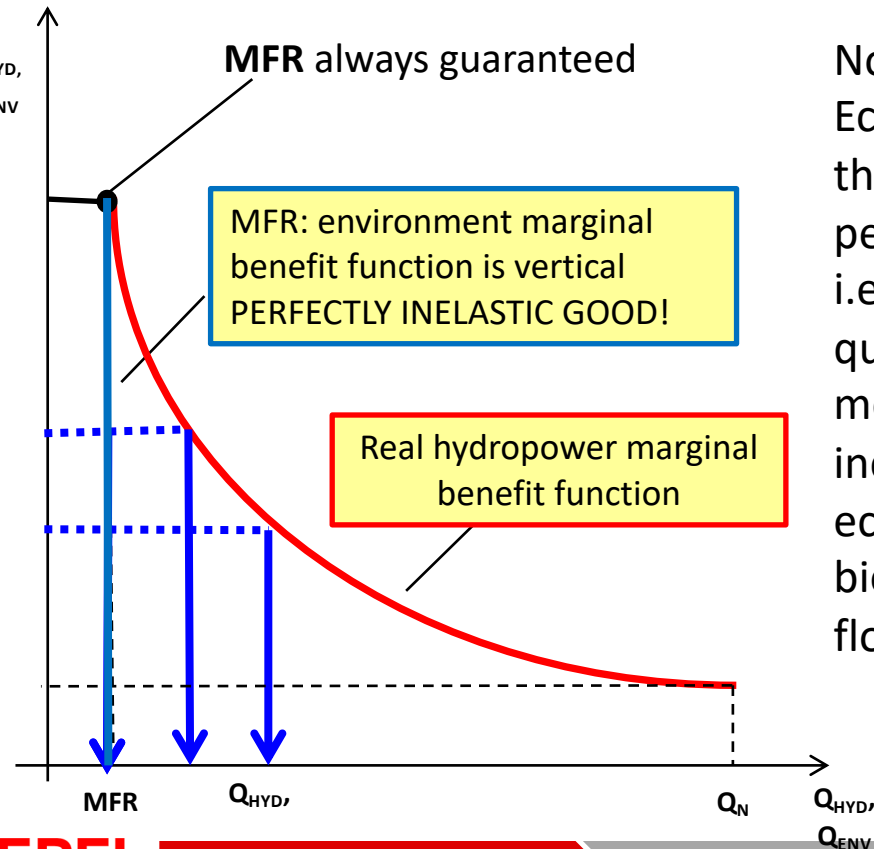
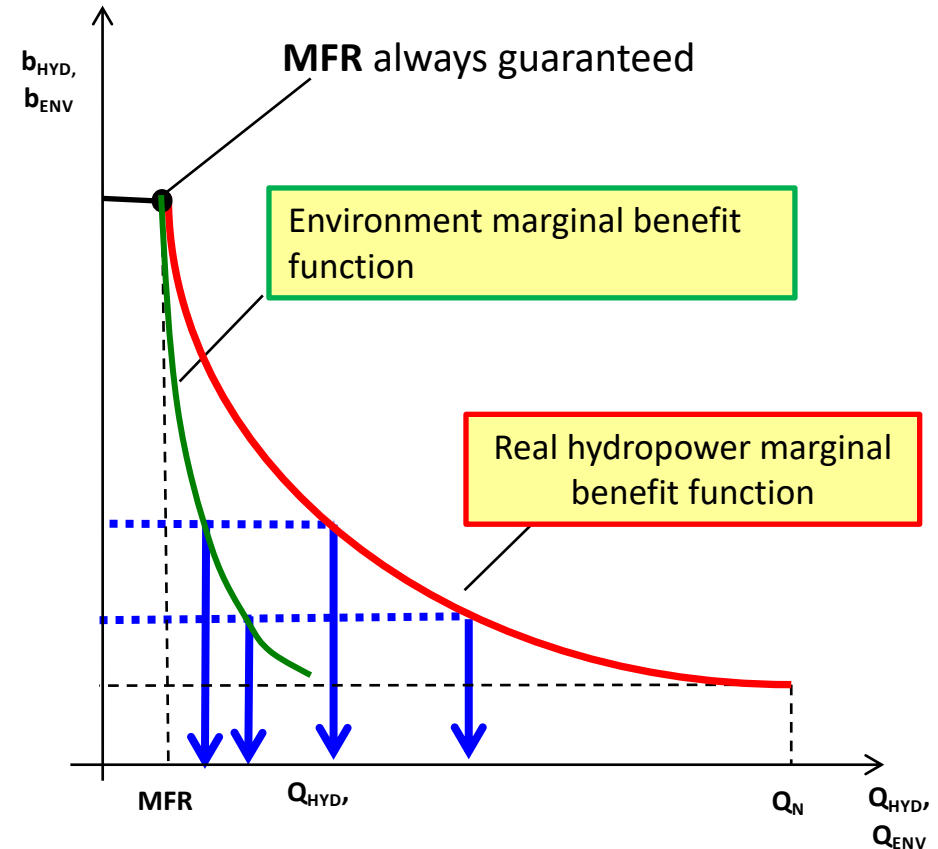
**Is minimal flow  
a good policy?**

No, it is not.  
Economically this means that env use would be a perfectly inelastic good, i.e. asking for a precise quantity of water and no more, which is inconsistent with the ecological principle that biodiversity arises from flow variability

Perona et al.,  
JEMA (2013)

## Proportional redistribution POLICY

$$\begin{cases} I = Q_{\text{hyd}} + Q_{\text{env}} \\ b(Q_{\text{hyd}}) = b(Q_{\text{env}}) \end{cases} \quad \text{AND} \quad \frac{Q_{\text{env}} - Q_{\text{MFR}}}{Q_{\text{hyd}}} = p$$

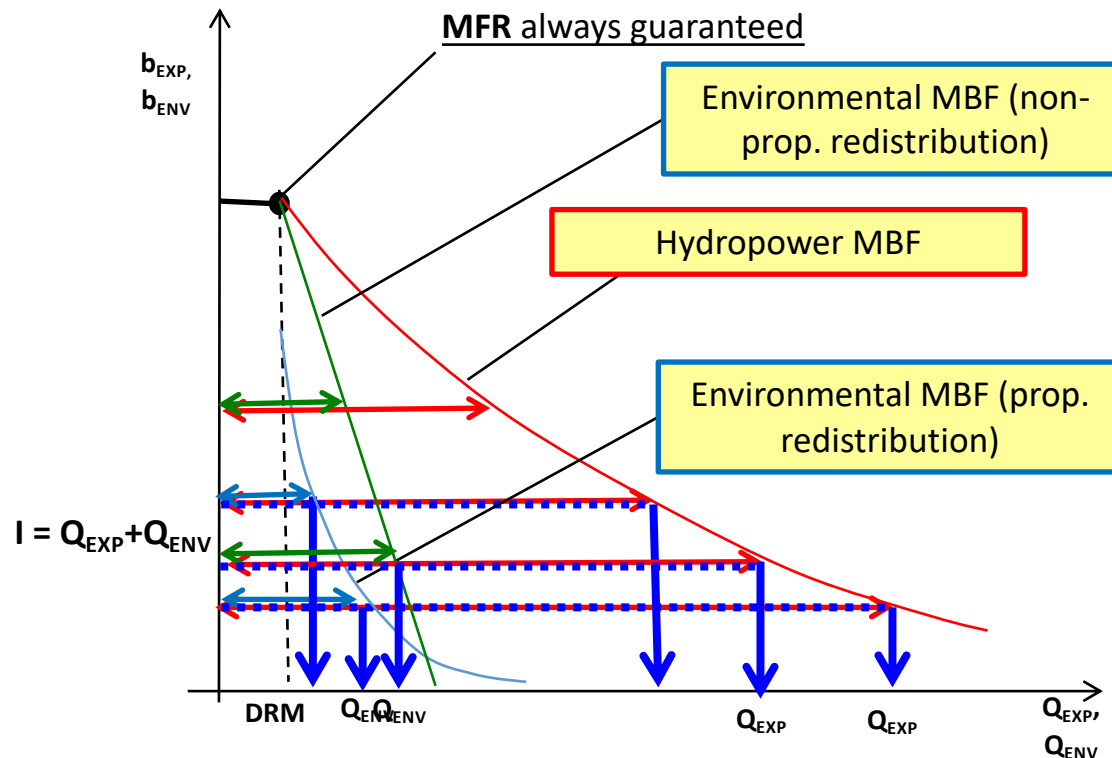




# Meaning for non-proportional allocation

$$\left\{ \begin{array}{l} I = Q_{hyd} + Q_{env} \\ \text{AND} \\ b(Q_{hyd}) = b(Q_{env}) \end{array} \right. \quad \frac{Q_{env} - Q_{MFR}}{Q_{hyd}} = p$$

**Are dynamics policies  
(prop./non-prop.) better?**



Yes, they are because they allow to maintain part of the natural flow regime variability by simply changing allocation percentages as the inflow naturally changes.

This allows to reconcile economy and ecology, that is with the principle that flow variability is important for ecological functions and richness of biodiversity