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# AN INTRODUCTION TO WATER ECONOMICS AND GOVERNANCE IN SOUTHERN AFRICA

## NOTES FOR THE COURSE WATER ECONOMICS AND GOVERNANCE

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# INTRODUCTION

Over the past decade, demand for competent knowledge and professional skills in the field of water economics and governance to assist with design and implementation of appropriate water management and policy measures has been steadily increasing in the eastern and southern Africa region as well as in other parts of the continent. The need to take into account issues such as efficiency, equity and environmental health when designing and implementing Integrated Water Resources Management requires considerable strengthening of existing regional capacity in this field, hence the importance of relevant degree and non-degree training for improved water policy and management decision-making.

This provided a strong motivation for the establishment in 2009 of the International Center for Water Economics and Governance in Africa (IWEGA) aimed at filling research and capacity building gaps in the region for this crucial domain.

IWEGA, based at the University Eduardo Mondlane in Maputo, is today an acknowledged center of excellence in the continent and overseas, and is a full member of WaterNet and of the NEPAD Centers of Excellence in Water Science and Technology. IWEGA is also one of the key partners of the UNESCO water chair in Water Economics and Transboundary Water Issues, based at the Australian National University.

Degree and non degree training are among the priorities of IWEGA, which is responsible since 2010 for a full course in water economics and governance within the WaterNet regional MSc in IWRM and since 2011 within the MSc in Agricultural Economics at the UEM.

This collection of training notes serves as a basis and support for the above mentioned courses and, limited to specific chapters, for the non-degree training workshops that IWEGA organizes periodically in the region.

The present document is not a manual, but a simple collection of ordered material used during training sessions and specifically tailored for post graduate students of southern Africa. It contains for this reason a large number of case studies and examples derived from recent researches run in the region by the teams of scientists rotating around the IWEGA community.

The notes are organized as follows. After an introductory chapter on the role that water has for the development issues of the region, a discussion on the economic nature of water is provided (chapter 2). Then the reader will find a presentation of the concepts and methods for water economic valuation (chapter 3), with particular reference to Cost-Benefits Analysis (chapter 4). The following two chapters are dedicated to market failures/externalities (chapter 5) and their control through policy instruments (chapter 6). Chapter 7 is an overview of the concepts about water governance and institutional analysis of the water sector, with particular reference to the South African case. Finally, chapters 8 and 9 focus on two peculiar aspects of water management and policies: pricing and tariffs for water service provision and water allocation.

The references listed at the end of each chapter are available in PDF form and will be provided as further readings only to the students that follow IWEGA courses, along with the PPT presentations.

Bibliographic references quoted in the text and not listed at the end of the sessions can be found in the bibliographies of the further readings.

In order to facilitate students' personal learning processes, at the end of each chapter a list of key concepts treated and some questions for revision of topics are provided.

# 1

# WATER AND DEVELOPMENT, SOME CONSIDERATIONS ABOUT SOUTHERN AFRICA

Water is a crucial factor for development. Southern African countries are among the least developed in the world (Tab. 1), and water access remains an objective on top of the local leaders' political agendas. Nevertheless, if we look at regional statistics (Tab. 2), bulk water in Southern Africa is not a scarce resource. The real problem is access to water.

There are in the region huge differences in terms of water access between those groups of populations that also benefit of a higher livelihood standard, and those who live in conditions of poverty, often extreme.

Tab. 1 Trends in SADC state HDIs

| State | HDI rank (of 177 countries) | 1975 | 1985 | 1995 | 2004 |
|---|---|---|---|---|---|
| South Africa | 121 | .653 | .703 | .741 | .653 |
| Namibia | 125 | -- | -- | .694 | .626 |
| Botswana | 131 | .500 | .636 | .660 | .570 |
| Swaziland | 146 | .529 | .583 | .604 | .500 |
| Lesotho | 149 | .463 | .535 | .573 | .494 |
| Zimbabwe | 151 | .548 | .642 | .591 | .491 |
| Angola | 161 | -- | -- | -- | .439 |
| Tanzania | 162 | -- | -- | .423 | .430 |
| Zambia | 165 | .470 | .486 | .425 | .467 |
| Malawi | 166 | .327 | .368 | .414 | .400 |
| DRC | 167 | .414 | .431 | .392 | .391 |
| Mozambique | 168 | -- | .290 | .330 | .390 |

Source: UNDP 2006

Tab. 2 Freshwater resources

| State | Total renewable water $km^3$ (yr of data) | Freshwater withdrawal $km^3/yr$ | Per cap freshwater withdrawal $m^3/yr$ | % domestic | % industry | % agriculture |
|---|---|---|---|---|---|---|
| Angola | 184 ('87) | 0.35 | 22 | 23 | 17 | 60 |
| Botswana | 15 ('01) | 0.19 | 107 | 41 | 18 | 41 |
| DR Congo | 1283 ('01) | 0.36 | 6 | 53 | 17 | 31 |
| Lesotho | 5 ('01) | 0.05 | 28 | 40 | 40 | 20 |
| Malawi | 17 ('01) | 1.01 | 78 | 15 | 5 | 80 |
| Mozambique | 216 ('92) | 0.63 | 32 | 11 | 2 | 87 |
| Namibia | 46 ('91) | 0.30 | 148 | 24 | 5 | 71 |
| South Africa | 50 ('90) | 12.5 | 264 | 31 | 6 | 63 |
| Swaziland | 5 ('87) | 1.04 | 1,010 | 2 | 1 | 97 |
| Tanzania | 91 ('01) | 5.18 | 135 | 10 | 0 | 90 |
| Zambia | 105 ('01) | 1.74 | 149 | 17 | 7 | 76 |
| Zimbabwe | 20 ('87) | 4.21 | 324 | 14 | 7 | 79 |

Source: CIA Factbook (www.cia.gov/search?NS-collection=Factbook)

Southern African countries have GINI index among the highest in the world (Fig. 1), and this means that elites of rich, well water served people, leave along with the majority of poor that struggle for water and for life (last two columns of Tab. 3).

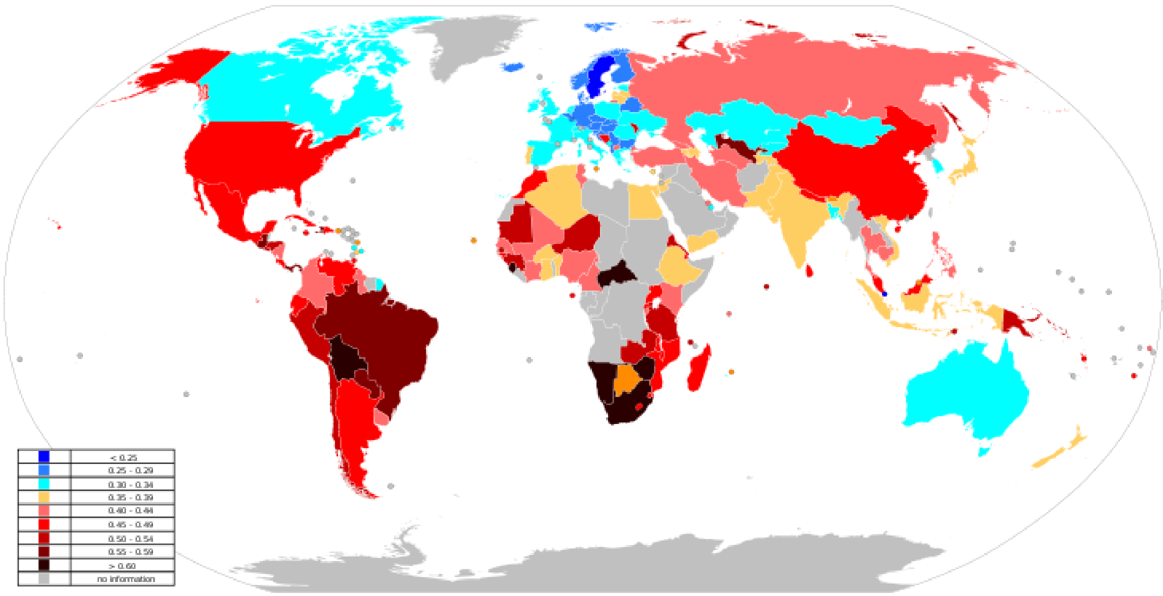



**Fig. 1 Gini_Coefficient_World_CIA_Report_2009**

Tab. 3 . Select Indicators for SADC states

| Country | GDP growth 1975-2004 % | GDP growth 2005-06 % | % HIV+ 15-49 age group | % pop with sustainable access to improved water source (2004) | improved sanitation (2004) |
|---|---|---|---|---|---|
| Angola | -0.7 | 11.1 | 3.7 | 53 | 31 |
| Botswana | 5.7 | 4.0 | 24.1 | 95 | 42 |
| DRC | -4.8 | 1.9 | 3.2 | 46 | 30 |
| Lesotho | 4.7 | 3.1 | 23.2 | 79 | 37 |
| Malawi | -0.4 | 6.2 | 14.1 | 73 | 61 |
| Mozambique | 2.6 | 6.6 | 16.1 | 43 | 32 |
| Namibia | -0.8 | 3.6 | 19.6 | 87 | 25 |
| South Africa | -0.5 | 3.9 | 18.8 | 88 | 65 |
| Swaziland | 2.1 | 2.5 | 33.4 | 62 | 48 |
| Tanzania | 0.8 | 3.3 | 6.5 | 62 | 47 |
| Zambia | -2.0 | 4.3 | 17.0 | 58 | 55 |
| Zimbabwe | -0.3 | -5.4 | 20.1 | 81 | 53 |

Source: UNDP, 2006; World Bank, 2008

Most Southern African Economies are based on export of raw products :oil/minerals or agricultural commodities (Tab. 4).

Tab. 4 Export profile

| State | X % of GDP | Manufacturing as % of X | Primary goods as % total exports |
|---|---|---|---|
| Angola | 73.5+ | 3.6 | -- |
| Botswana | 50.7 | 3.9 | -- |
| DRC | 19 | -- | -- |
| Lesotho | 48 | -- | -- |
| Malawi | 27 | -- | 84 |
| Mozambique | 30 | -- | 96 |
| Namibia | 46.3 | 13.5 | 58 |
| South Africa | 27.1 | 18.6 | 42 |
| Swaziland | 84 | -- | 23 |
| Tanzania | 19 | -- | 80 |
| Zambia | 16.4 | 11.7 | 90 |
| Zimbabwe | 42.8 | 12.8 | 72 |

+ U.S. exports make-up 13% of its GDP; exports from Canada and Western European states are all greater than 20% of GDP.
Source: World Bank (2008) and UNDP (2008)

These systems do not produce accumulation of capital within the countries and therefore do not foster local development. On the other side, they favor the accumulation of rent position for elites (Swatuk, 2008).

Irrigated, large scale agriculture and the mining sector are the major water users in rural areas (last three columns of tab. 2, where mines are combined with the industrial sector), but their benefits do not stay in the region, as they are often in the hands of multinationals who have only operational teams locally, while their headquarters and financial stocks are in developed countries.

As for the agricultural sector in particular, crossing the data on agricultural water and land uses (Tab 5 and Tab 6), it is evident that a huge amount of water used is concentrated in a very small land surface. This allows concluding that irrigated land, today in the hands of few people who produce mostly export crops, could be extended and allocated to food crops in order to improve local food supply and rural livelihood. And this also considering the limited share of fresh water currently used.

Table 5. Land and agriculture

| State | Territory $km^2$ | Arable land % of total | Permanent crops % of total | Other % of total | Irrigated land $km^2$ |
|---|---|---|---|---|---|
| Angola | 1,246,700 | 2.6 | .23 | 97.1 | 800 |
| Botswana | 600,370 | 0.6 | .01 | 99.3 | 10 |
| DR Congo | 2,345,410 | 2.9 | .47 | 96.7 | 110 |
| Lesotho | 30,355 | 10.9 | .13 | 89.0 | 30 |
| Malawi | 118,480 | 20.7 | 1.18 | 78.1 | 560 |
| Mozambique | 801,590 | 5.4 | .29 | 94.3 | 1,180 |
| Namibia | 824,418 | 1.0 | .01 | 99.0 | 80 |
| South Africa | 1,219,912 | 12.1 | .79 | 87.1 | 14,980 |
| Swaziland | 17,363 | 10.3 | .81 | 88.9 | 500 |
| Tanzania | 945,087 | 4.2 | 1.16 | 94.6 | 1,840 |
| Zambia | 752,614 | 6.9 | .04 | 93.0 | 1,560 |
| Zimbabwe | 390,580 | 8.2 | .33 | 91.4 | 1,740 |

Source: CIA Factbook (www.cia.gov/search?NS-collection=Factbook)

**Tab. 6 Land and agriculture in selected SADC countries**

| | Territory | Arable | Irrigated | % irrigated on arable |
|---|---|---|---|---|
| | *Kmq* | *Kmq* | *Kmq* | |
| | | | | |
| Malawi | 118.480 | 24.525 | 560 | 2,3 |
| Mozambique | 800.000 | 43.200 | 1180 | 2,7 |
| Zambia | 752.000 | 51.888 | 1560 | 3,0 |
| Tanzania | 945.000 | 39.690 | 1840 | 4,6 |
| SA | 1.200.000 | 145.200 | 14900 | 10,3 |
| Swaziland | 17.000 | 1.751 | 500 | 28,6 |

In conclusion, in Southern Africa's agricultural sector, is it a problem of water scarcity or of land bad use?

The important differences in terms of access to water by groups of people within the same country, largely linked to the differences of their livelihood conditions, pushed several observers to state that "Water flows where money is" (oral communication by Prof. A. Szollozi-Nagy, Rector of the IHE Unesco Institute for Water Education).

Clear dualities in this sense can be observed in the two main areas of water use in Southern Africa: the agricultural sector, where irrigated agriculture for export while rainfed agriculture is for local food production, and the domestic uses, as explained here below.

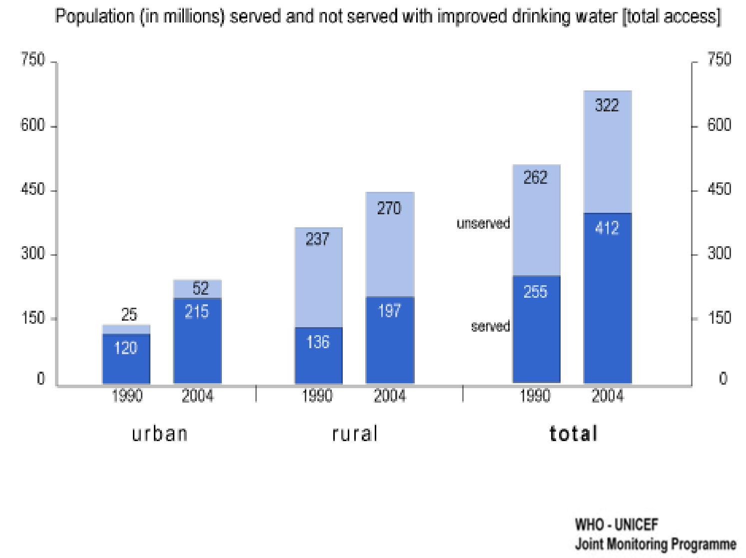
With very few exceptions, actually, urban areas are relatively well supplied in potable water, while rural areas lack dramatically of water provision and sewage systems (fig. 3 and 4).

Fig. 2

WHO - UNICEF
Joint Monitoring Programme

Fig. 3

Sub-saharan Africa




This situation has a direct consequence on the water quantities used by households in the region. In fact, urban households in sub Saharan Africa, particularly in the high standard residential blocks, consume five to ten times more water as an average than rural households.

These dualisms are provoked by a deep social inequity in Africa, and particularly in Southern Africa. And what is worst according to Swatuk (2008) is that there is evidence that the privileged elites have no interest in changing this situation. Instead, public policies and development programs should address these situations as water is a key factor for human and economic development. Access to water is fundamental in order to alleviate poverty and start development virtual cycles.

Several experts observe that three “Ps” are at the origin of the problems of water sector in Africa: Population, Pollution and Poverty. The huge increase of **population** (and urbanization rates) in Africa is a factor of human pressure on the environment and particularly on water resources, both in terms of availability and quality. **Pollution** is a direct consequence of the uncontrolled and fast development of population and of the human activities related to it. 50% of the beds in hospitals of the world are occupied by patients with water-borne diseases. **Poverty** and inequities, as indicated above, are a consequence, but in many cases they are also the cause, of water access problems in Africa.

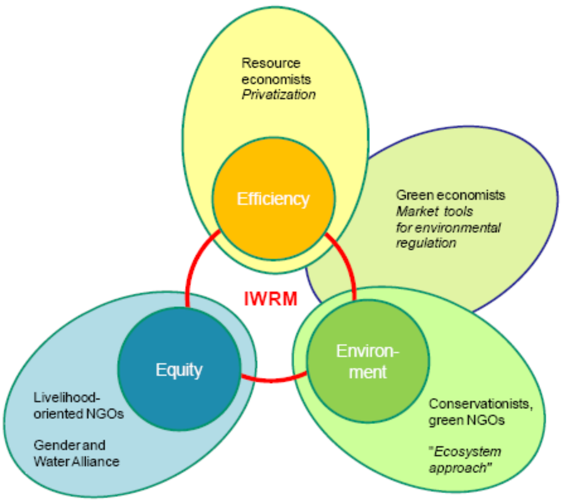
In order to face these problems, two main paradigms of water management were developed (Swatuk, 2008):

- Modernist/hydraulic mission = > water supply through investments for development (dominant in the south, appreciated by local governments).

- Environmentalist/giving voice to society, stakeholder participation =>water demand management (dominant in the north or through civil society/int. organizations)

Starting from the nineties, a new concept was introduced: Integrated Water Resource Management (IWRM). This concept, in line with the second paradigm above presented, highlights the human component of water management, with particular emphasis on water demand management, and consequently the economic value of water, stakeholders' involvement and participation, the role of women, institutional governance, and environmental sustainability. To some extent, the concept of IWRM recalls and applies to water management the idea of sustainable development as defined in the Bruntland report (1986), where the three Es (Efficiency, Equity and Environmental sustainability) were presented (Fig. 4).

**Fig. 4 IWRM and the three Es (Molle, 2008)**




"IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). Molle (2008) considers IWRM as a "Nirvana concept". "Nirvana concepts are concepts that embody an ideal image of what the world should tend to. They represent a vision of a 'horizon' that individuals and societies should strive to reach. Although, just as with nirvana, the likelihood that we may reach them is admittedly low, the mere possibility of achieving them and the sense of 'progress' attached to any shift in their direction suffice to make them an attractive and useful focal point" (Molle, 2008). Inconveniences of Nirvana concepts, according to Molle, consist in the fact that they are generic, vague, and difficult to apply in reality, easy to manipulate and «interpret», and «good for every context».

Beukman (2002) considers the following as key water issues in Southern Africa:

- Inequity in the sectoral allocation of water
- Inefficient allocation of water
- Inadequate capacity for "decentralization"
- Lack of integration and complex local development
- Unsustainable supply side management bias (lack of demand water management)

Looking at these issues, and considering that economic analysis aims at improving the efficiency level of resource allocation and to analyze demand and supply behaviours in economic systems, it results clearly the crucial importance of the economic analysis for water management.

Governance issues as well, including institutional and political aspects of water management, are part of the key issues indicated by Beukman. In this course processes and tools to support water governance and stakeholders' participation are presented and discussed as well.

Water resource availability, or lack of it, is linked to economic and social progress, suggesting that development is likely to be influenced by how water resources are managed. At a national level it can be seen that countries which have higher level of income tend to have a higher level of water use. Water management policies must take into consideration a holistic view of water resources, where off stream and in stream uses are synergetic in order to improve human development and social welfare, by preserving the environment.

To understand water management and water use it can be useful to develop synthetic indexes which are able to link socio-economic variables and water variables such as water availability and water use.

Sullivan (2002) developed the concept of Water Poverty Index (WPI), which comprises various elements, such as: water availability, access to safe water, clean sanitation, and time taken to collect domestic water.

These elements can be combined into a synthetic index or WPI formula as follows:

$$WPI = w_a A + w_s S + w_t (100 - T)$$

Where:

A=adjusted water availability, assessed as %. This is the ground ad surface water availability related to ecological + basic human water requirements plus all domestic and productive uses of water.

S= Population with access to safe water and sanitation (% of total).

T= index between 0 and 100 to represent the time and effort taken in collecting water for the household => the higher T, the lower this component of the WPI.

$w_a$, $w_s$ and $w_t$ are the weights given to each component of the index so that $w_a + w_s + w_t = 1$.

Since A, S and T are defined to be between 1 and 100 and $w_a$, $w_s$ and $w_t$ are between 0 and 1, to produce a WPI value of between 0 and 100, the formula needs to be modified as follows:

$$WPI = \frac{1}{3}[w_a A + w_s S + w_t (100 - T)]$$

According to Sullivan (2002), rich countries such as Finland and Canada have WPI respectively equal to 78 and 77.7. Mozambique has one of the lowest WPI in the world: 44.9. It is worthwhile noticing that countries such as Kuwait or Israel, with the A component of the WPI close to 0, show a WPI close to 55 because of the good performance of the other two components.

The development of the WPI can deliver a comprehensive, though quite macro-level oriented, tool to help in water management at a variety of levels, and, in particular, make a contribution to the process of poverty alleviation in poor countries.

**Key concepts treated**

Water availability and water access

Poverty and water access

In Southern Africa, more land could be irrigated and more arable land could be used to improve food supply

Differences in the livelihoods of groups of people

Dualities in water access

Water management is a problem of investments, water reallocation, institutional building, stakeholder empowerment

The main paradigms to solve water management problems are: the supply oriented one (hydraulic mission) and the demand oriented one (IWRM)

IWRM is a concept that looks at water management considering the human component of it and not only the technical, engineering aspects

Economics of water and governance aspects are crucial for IWRM

Water Poverty Index (WPI) are synthetic indexes able to link socio-economic variables and water variables such as water availability and water use

**References**

Beukman, R. (2002) Access to water: some for all or all for some?, Physics and chemistry of the Earth, 27: 721-722.

Molle, F. (2008) Nirvana Concepts, Narratives and Policy Models: Insights from the Water Sector, Water Alternatives, 1 (1): 131-156.

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**Exercises**

1. Provide a definition of water availability and one of water access

2. What do we mean by dualities in water access?

3. What is a WPI?

# 2

# WATER AS AN ECONOMIC GOOD

## Some definitions of economics

Economics is the study of the use of scarce resources to satisfy unlimited human wants (Richard Lipsey)

Economics is the study of how societies use scarce resources to produce valuable commodities and distribute them among different people (Paul Samuelson)

Economics is the study of how individuals, firms, governments and other organizations within our society make choices and how those choices determine how the resources of society are used (Joseph Stiglitz)

## Microeconomics and macroeconomics

Microeconomics deals with the individual parts of the economy: consumers and producers. Analysis of **producer** and **consumer** behaviour, demand and supply functions, costs, benefits, etc.

Macroeconomics focuses on the economy as a whole (aggregates). Analysis of economic systems, impact of policies on economic sectors, national and regional accounting, inflation, employment, etc.

## Basic concepts of microeconomics

**Wants**: human desires of an increased wellness/wellbeing – they are unlimited.

**Needs**: necessities, basic requirements of things that are essential for life (water, food, shelter, clothes). They are not unlimited. Basic needs can be calculated for human survival, correct daily diet, etc.

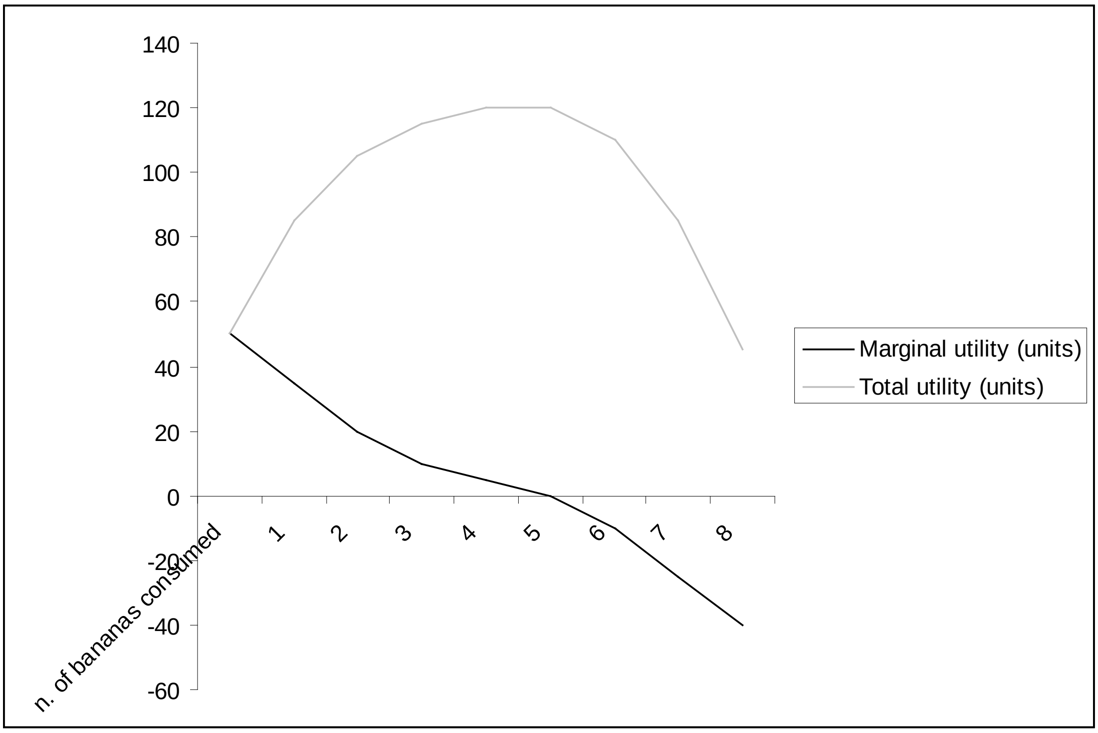
**Goods and services**: are means humans consider capable of satisfying their wants. Goods are material, while services are immaterial. Good and services are limited.

The capacity of goods and services to satisfy human wants is called **Utility**. In other terms, utility is the degree of satisfaction that a consumer derives or expect to derive from consumption of a good or service.

According to microeconomics mainstream theory, the rational human being, as a consumer, aims at maximizing his/her utility. (postulate of **economic rationality**).

The extra utility an individual derives from an extra unit of good is called **marginal utility**. The **law of diminishing marginal utility** (Gossen, 1854) states that the marginal utility of a good or service eventually declines as more of it is consumed during any given period.

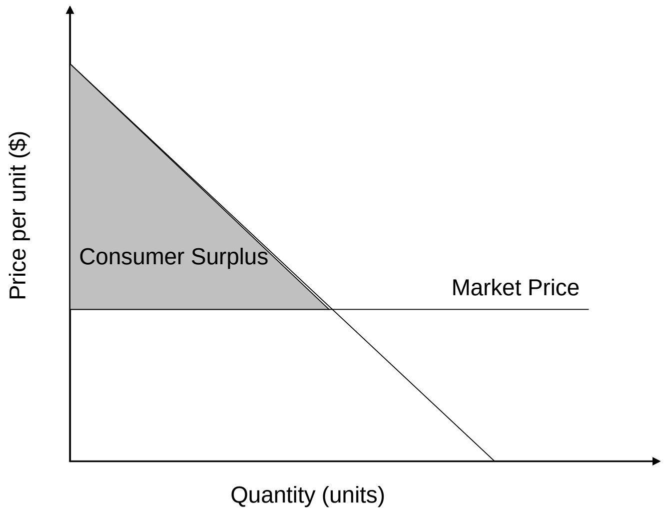
| n. of bananas consumed | Marginal utility (units) | Total utility (units) |
|---|---|---|
| 1 | 50 | 50 |
| 2 | 35 | 85 |
| 3 | 20 | 105 |
| 4 | 10 | 115 |
| 5 | 5 | 120 |
| 6 | 0 | 120 |
| 7 | -10 | 110 |
| 8 | -25 | 85 |
| 9 | -40 | 45 |




The law of diminishing marginal utility, along with the consumer equilibrium concept, stating that a consumer will maximize his/her utility by equaling the weighted marginal utilities of all available goods and services, is at the origin of the **downward-sloping demand curve** shape. In other terms, following the demand curve, the demand of a good or service will increase as the price of this good or service falls.

This implies that consumers actually receive more than their money's worth. The reason is that the market price is usually lower than the prices consumers are **willing to pay** for all but the last (or marginal) unit of the product concerned. The difference between what consumers pay and the value or utility that they receive is called **consumer surplus**.

Demand curve

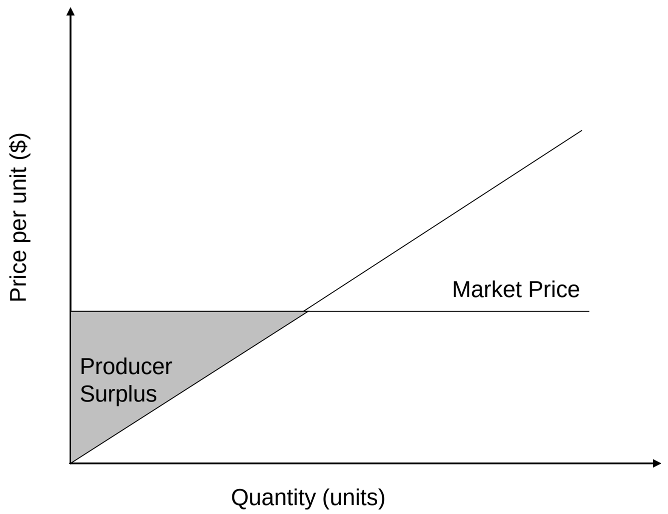



On the other hand, supply can be defined as the quantities of a good or service that producers plan to sell at each possible price during a certain period.

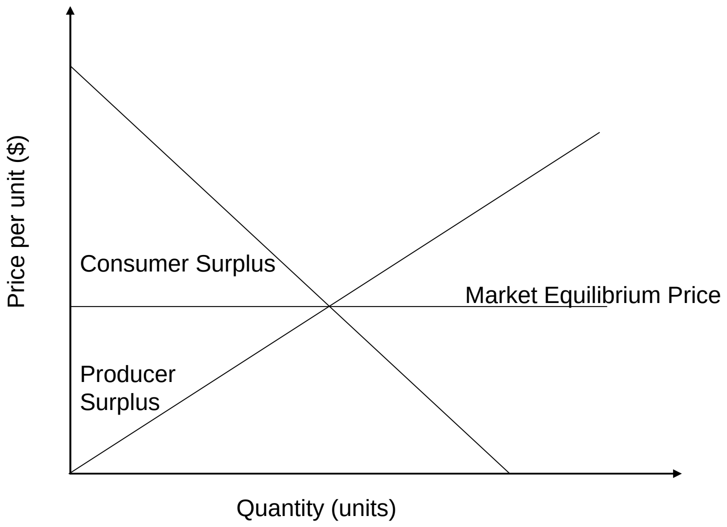
In contrast to the quantity demanded, the quantity supplied increases as the price of the product/service increases. The individual supply curve corresponds usually to the marginal long run (when all is variable as also investments can be replaced and modified) cost of production.

Similarly to the demand curve approach, this implies that, given a certain market price, producers actually receive more than they would expect. The reason is that the market price is usually higher than the prices producers are **willing to accept** for all but the last (or marginal) unit of the product concerned. The difference between what producers pay in terms of marginal cost of production and the total revenue they receive is called **producer surplus**.

Supply curve




Combining demand and supply curves, we can represent a simple market, where a consumer and a producer interact in order to exchange quantities of a certain good or service with the aim of maximizing their level of satisfaction.




The demand curve intersects the supply curve at a point corresponding to the equilibrium price and the equilibrium quantity. At this point, consumer and producer surpluses are the highest possible (maximization of welfare).

The **equilibrium price** can be considered the best proxy for the **economic value** of a good or service that can be produced and exchanged in a market (commodities are the best example because labeled goods and services influence the perfect competition through differentiation of products).

**Cost of production**: Accounting costs are the expenses incurred to produce a product these are explicit monetary costs. Economic costs include explicit and implicit costs and refer to the opportunity cost. **Opportunity cost** is the value of the resource employed in a certain production at its best alternative use. In other terms it is the value of the best alternative sacrificed/forgone by choosing to produce a particular product. **Production opportunity cost** is the sum of Explicit opportunity cost (monetary disbursements for acquiring non owned resources) + Implicit opportunity cost (non monetary payments due to the non-allocation of available resources to alternative -best- use). **Consumption opportunity cost** is the lost welfare deriving from the non allocation of an available resource to an alternative use.

The **total cost** is the cost of producing a certain quantity of product; **average cost** is the total cost divided by the quantity produced; **marginal cost** is the addition to total cost required to produce an additional unit of product.

### Is water an economic good?

Two main characteristics are required for a good to be an economic good: **usefulness** (economic agents consider that its consumption increases their utility); **scarcity** (limited availability, implying economic choices in its allocation).

Water has both characteristics. It could therefore be treated as an economic good. Nevertheless, water, as a natural resource and as a fundamental component of human life, has a number of **attributes that distinguish it from a "standard" economic good**, such as a commodity or a labeled product. These attributes are described below and have crucial consequences on the economic analysis of water.

***Hydrologic and physical attributes:***

Water is *mobile*, implying problems in the identification and definition of specific units of the resource. Because of its mobile nature, water is what economists call a “high-exclusion costs” resource, meaning that exclusive property rights on the resource are difficult and expensive to establish and enforce.

Water *supplies tend to be highly variable and unpredictable*, and this has a huge impact on the management of the resource.

Water is a nearly *universal solvent*, meaning that when available in sufficient amount, it provides an inexpensive capacity for absorbing wastes and pollutants, but when it becomes scarce, quality problems raise due to the concentration of wastes and pollution problems.

*Interdependency among users is pervasive*, as return flows exist and downstream users are often impacted by the water quality released from upstream users. Externalities and third party effects arise then.

*Water problems are often site-specific* and therefore general principles must be adapted to local situations.

*Groundwater supplies have distinctive attributes*, as groundwater flows slowly and it is difficult to assess the potential yield and quality of an aquifer.

***Water demand characteristics:***

It is useful to group the values of water into five classes. These are a) commodity benefits; b) waste assimilation benefits; c) aesthetic and recreational values; d) biodiversity and ecosystem preservation, and e) social and cultural values. The first three types of values can be treated here as economic, while the last pair are not part of this discussion as they are noneconomic values.

It is useful to look at water demand keeping in mind the continuum from rival to nonrival goods or services. A good or service is said to be rival in consumption if one person’s use in some sense preclude or prevent use by other individuals or businesses. *Private goods* are rival in consumption. When goods are nonrival in consumption, one person’s use does not preclude enjoyment by others. These are called *public or collective goods*. Nonpayers cannot be easily excluded. Water for agricultural or industrial uses tends towards the rival end, while aesthetic value of a beautiful stream is largely nonrival. Nonrivalry is linked to the *high exclusion costs of wa*ter. And this brings to *free-riding*, i.e. to the enjoyment of water by those who have not helped pay for its cost of production.

a) Commodity benefits: these benefits derive from personal drinking, cooking and sanitation, or uses contributing to productive activities. Water for these uses tends to be rival in use and has the characteristic of a private good. These uses are usually called *consumptive uses* and take place away from the natural hydrologic system. They are therefore called *offstream uses*.

Other types of economic commodity values associated with water may not require it to leave the hydrologic system. These are for instance the waterways transportation and hydroelectric power generation. These are therefore called *instream* uses and because they involve very little consumption of water, they are called *nonconsumptive* uses. These uses have some aspects of rivalry of private goods.

b) Waste disposal benefits: water has a huge assimilative capacity, and this characteristic is closer to being a public rather than a private value as it is difficult to exclude dischargers from utilizing these services.

c) Aesthetic and recreational values are the third type of economic benefits of water. These values are instream and nearer to the public good end spectrum, even if congestion can lessen total enjoyment of the resource.

Another potential economic value of water is provided by so-called *non use* or *passive uses*. People are in fact willing to pay for environmental services that they do not use or experience. People are w-t-p for these services just because they exist (existence value) or because they can be available for future uses (option value) or for the next generations (bequest value).

***Social attitudes towards water:***

Because water is essential for life, more than for other commodities its social and cultural values conflict with economic values. In the Dublin Conference of the UN on Water and Environment (1992) it was asserted that "...it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price". Many people intuitively reject *pricing* of a resource that is necessary for life, and some cultures and religions proscribe water allocation by market forces. However, in many societies, only a small percentage of the total water consumption is actually used for drinking and preserving human life. Most water is used for convenience, comfort, aesthetic pleasure, or to produce commodities. These uses can be subject to economic measures of water demand management.

***Legal and political considerations:***

Water management and governance design falls in the field of political science, or political economy. Some aspects of water governance can be here underlined.

*Transaction costs*, i.e. those costs required to establish, operate and enforce a resource allocation, are very high when water is scarce, as more complex rules become necessary and their enforcement is more difficult.

Water problems are local-specific and local water management is necessary. But without a coordination of local policies and management, the *cumulative impact of many small decisions* can produce very unexpected and undesirable effects at a higher scale.

Water is a *common pool resource* (Ostrom, 1990). These economic goods are characterized by rivalry in use and very high exclusion costs. For these resources, dilemmas arise when rational individual behavior of users bring about a result which is non optimal from the society point of view (tragedy of the commons, Hardin, 1968). The role of institutions and organizations in governing the common pool resources is crucial.

**Key concepts treated**

The ABC of microeconomics: consumer's and producer's behaviour

Markets, equilibrium prices, and costs

Water: a "special" economic good

Benefits and costs of water

## References

Young, RA (2005) Determining the economic value of water, Concepts and methods, Resources for the Future, Washington DC. (Selected parts)

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## Exercises

1. Define an economic good (or service)

2. Why water is a special economic good?

3. Draw a demand curve and make explicit the consumer surplus.

# APPENDIX

## Definition of commodity

A commodity is a good for which there is demand, but which is supplied without qualitative differentiation across a market. It is fungible, i.e. equivalent no matter who produces it. Examples are petroleum, notebook paper, milk or copper. The price of copper is universal, and fluctuates daily based on global supply and demand. Stereo systems, on the other hand, have many aspects of product differentiation, such as the brand, the user interface, the perceived quality etc. And, the more valuable a stereo is perceived to be, the more it will cost. In contrast, one of the characteristics of a commodity good is that its price is determined as a function of its market as a whole. Generally, these are basic resources and agricultural products such as iron ore, crude oil, coal, ethanol, salt, sugar, coffee beans, soybeans, aluminium, copper, rice, wheat, gold, etc. Soft commodities are goods that are grown, while hard commodities are the ones that are extracted through mining. (Wikipedia).

Water as a natural resource could have characteristics of a commodity (like crude oil, coal etc.), but unlike these natural resources it is a basic need for human life, and it has characteristics of a public good (in its natural state it is a common pool resource (CPR) – no exclusivity). Water can also be extracted and labeled by a private company and in this case it becomes a good traded with a brand (oligopolistic/imperfect competition). Therefore, water is an economic good with a very complex identity: from pure public good (the rain) to CPR (a river, a lake), to a club good (agricultural water in an irrigation scheme) up to pure private water (water in a bottle).

But it is never a commodity, as only a very small part of the total water available and used is extracted and bottled to be commercialized on a market and labeled. Water that is extracted, treated and distributed for domestic, industrial and agricultural uses is generally not transportable at a reasonable cost and therefore does not get into global markets. Its value/price is therefore determined locally. Again, this is not a commodity. The determination of its price (tariff) for users is more similar to the one for electric power provision (water supply and electricity services) than to the market price determination for a commodity.

## Consumer equilibrium

An individual is considered aiming at reaching the highest attainable level of total utility in order to maximize his/her satisfaction (homo oeconomicus' rationality).

(S)he proceeds to this target first of all identifying his/her scale of preferences. This assumption implies that economic agents are able to "write down" their scales of preferences among various goods/services and assign to each dose of good/service the corresponding level of satisfaction.

We introduce here the concept of Weighted marginal utility (WMU). This is the marginal utility per unit divided by the price of that unit (MU/P).

Now let's consider that a consumer has the following scale of preferences in respect of the weekly consumption of bread, meat and rice.

| Units | Goods | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Bread (Pb=US$1) | | | Meat (Pm=US$3) | | | Rice (Pr=US$2) | | |
| | MUb | TUb | MUb/Pb | MUm | TUm | MUm/Pm | MUr | TUr | MUr/Pr |
| 1 | 54 | 54 | 54 | 90 | 90 | **30** | 66 | 66 | 33 |
| 2 | 48 | 102 | 48 | 81 | 171 | 27 | 60 | 126 | **30** |
| 3 | 42 | 144 | 42 | 72 | 243 | 24 | 54 | 180 | 27 |
| 4 | 36 | 180 | 36 | 63 | 306 | 21 | 48 | 228 | 24 |
| 5 | 30 | 210 | **30** | 54 | 360 | 18 | 42 | 270 | 21 |
| 6 | 24 | 234 | 24 | 45 | 405 | 15 | 36 | 306 | 18 |
| 7 | 18 | 252 | 18 | 36 | 441 | 12 | 30 | 336 | 15 |
| 8 | 12 | 264 | 12 | 27 | 468 | 9 | 24 | 360 | 12 |
| 9 | 6 | 270 | 6 | 18 | 486 | 6 | 18 | 378 | 9 |
| 10 | 0 | 270 | 0 | 9 | 495 | 3 | 12 | 390 | 6 |

And let’s consider that the consumer has only 12 US$ (Budget constraint) to spend per week on these goods.

The combinations of goods the consumers can afford weekly with 12 US$ are indicated in the following table (considering 10 units as max for each good in the combination):

| | | Units of | | |
|---|---|---|---|---|
| Combination | Bread | Meat | Rice | Total Utility (Utils) |
| 1 | 10 | 0 | 1 | 336 |
| 2 | 9 | 1 | 0 | 360 |
| 3 | 8 | 0 | 2 | 390 |
| 4 | 7 | 1 | 1 | 408 |
| 5 | 6 | 2 | 0 | 405 |
| 6 | 6 | 0 | 3 | 414 |
| **7** | **5** | **1** | **2** | **426** |
| 8 | 4 | 2 | 1 | 417 |
| 9 | 4 | 0 | 4 | 408 |
| 10 | 3 | 3 | 0 | 387 |
| 11 | 3 | 1 | 3 | 414 |
| 12 | 2 | 2 | 2 | 399 |
| 13 | 2 | 0 | 5 | 372 |
| 14 | 1 | 1 | 4 | 372 |
| 15 | 1 | 3 | 1 | 363 |
| 16 | 0 | 4 | 0 | 306 |
| 17 | 0 | 2 | 3 | 351 |
| 18 | 0 | 0 | 6 | 306 |

From this table it is easy to identify the combination that provides the highest utility. It is combination n.7.

If we go back to the previous table, we observe that combination n. 7 corresponds to the units of the three goods that have the same WMU, namely 30.

We can therefore state that **to obtain the consumer’s equilibrium (position of highest satisfaction for a specified budget), we must determine a) which combinations are affordable and b) at which of these combinations the WMU are the same for all goods in question.**

At equilibrium, the consumer derives the same utility from the last $ spent in each product.

The general rule behind this finding is that the equilibrium condition is:

$$\frac{MU_b}{P_b} = \frac{MU_m}{P_m} = \frac{MU_r}{P_r}$$

This is also referred to as the law of equalising the weighted marginal utilities (Gossen's second law).

This law moves the viewpoint of consumer choice from the subjective valuation into the objective valuation of the market (because of the prices).

Note that if:

$$\frac{MU_a}{P_a} = \frac{MU_b}{P_b}$$

Then:

$$\frac{MU_a}{MU_b} = \frac{P_a}{P_b}$$

**Deriving an individual demand curve**

Let's consider that a consumer has 10 US$ budget to buy chocolate (c) and yoghurt (y) and that his/her scale of preferences is as follows:

| Units | | | Goods | | | |
|---|---|---|---|---|---|---|
| | Chocolate (Pc=US$2) | | | Yoghurt (Py=US$3) | | |
| | Muc | Tuc | MUc/Pc | Muy | Tuy | MUy/Py |
| 1 | 30 | 30 | 15 | 39 | 39 | 13 |
| 2 | 20 | 50 | **10** | 30 | 69 | **10** |
| 3 | 14 | 64 | 7 | 24 | 93 | 8 |
| 4 | 10 | 74 | 5 | 18 | 111 | 6 |
| 5 | 6 | 80 | 3 | 15 | 126 | 5 |

From the table, and applying the equilibrium condition, it is clear that, with 10US$ available, the consumer will maximize his/her utility buying 2 units of chocolate and 2 units of yoghurt, getting a WMU of 10 and a total utility of 119.

The ratios of MU and P are the same of course:

$$\frac{MU_c}{MU_y} = \frac{20}{30} = \frac{P_c}{P_y} = \frac{2}{3}$$

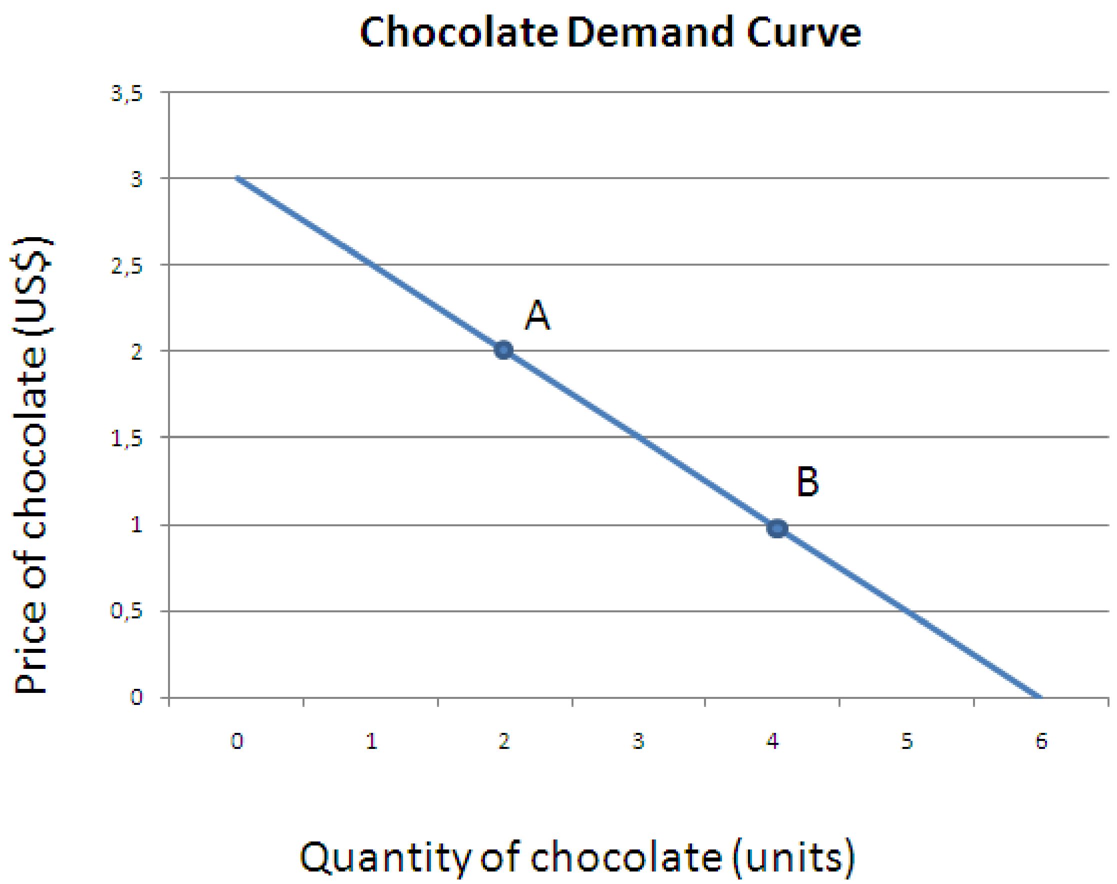
Let's now suppose that *Ceteris Paribus* the price of chocholate shifts from 2US$ to 1 US$. This would change the scale of preferences of our consumer to the one indicated in the following table:

| Units | | | Goods | | | |
|---|---|---|---|---|---|---|
| | Chocolate (Pc=US$1) | | | Yoghurt (Py=US$3) | | |
| | Muc | Tuc | MUc/Pc | Muy | Tuy | MUy/Py |
| 1 | 30 | 30 | 30 | 39 | 39 | 13 |
| 2 | 20 | 50 | 20 | 30 | 69 | **10** |
| 3 | 14 | 64 | 14 | 24 | 93 | 8 |
| 4 | 10 | 74 | **10** | 18 | 111 | 6 |
| 5 | 6 | 80 | 6 | 15 | 126 | 5 |

From this table it is easy to understand that the new equilibrium for the consumer that can spend 10US$, Ceteris Paribus, is 4 units of chocolate and 2 units of yoghurt.

$$\frac{MU_c}{MU_y} = \frac{10}{30} = \frac{P_c}{P_y} = \frac{1}{3}$$

Concentrating our analysis on chocolate, it is clear that a shift of price from 2 to 1 per unit triggers an increase in quantity demanded from 2 to 4, as the figure below indicates:




A utility maximizing consumer (rational) therefore will demand a greater quantity of a product when the price of that product falls, while other things remain unchanged. This determines a **individual demand curve that slopes downward from left to right**.

**Elasticity of Demand**

Elasticity of variable A on variable B is is the percentage change in variable A when variable B changes by 1%. This is calculated by the formula:

$$e = \frac{\%changeA}{\%changeB}$$

In economics it can be useful to calculate the elasticity of the demanded quantity of a product with respect to its price (price elasticity), to the income of consumers (income elasticity) and to the price of other products (cross elasticity).

We analyse here only the price elasticity ($e_p$)

$e_p$=percentage change in the quantity demanded of a product/percentage change in the price of the product

For instance, if the price of the product changes by 5% and this results in a 10% change in the quantity demanded, $e_p$ is 10%/5%=2 This implies that a 1% in change of the price will lead to a 2% change of demanded quantity.

$$e_p = \frac{\frac{\Delta Q}{Q} x100}{\frac{\Delta P}{P} x100}$$

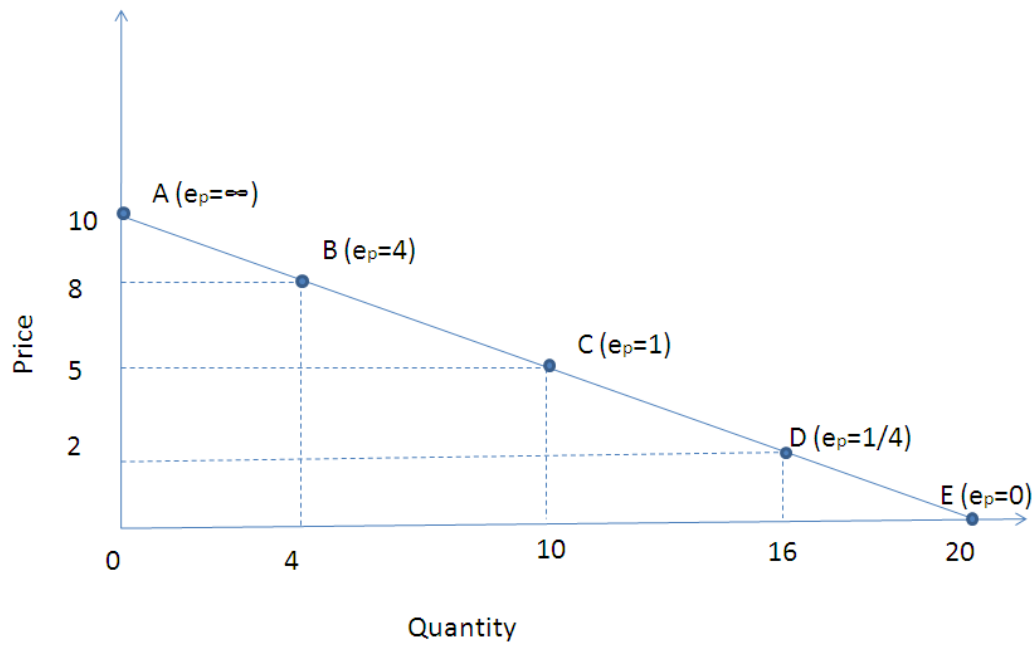
Since the 100s cancel out: $e_p = \frac{\frac{\Delta Q}{Q}}{\frac{\Delta P}{P}}$

$$= \frac{\Delta Q}{Q} x \frac{P}{\Delta P}$$

$$e_p = \frac{\Delta Q}{\Delta P} x \frac{P}{Q}$$

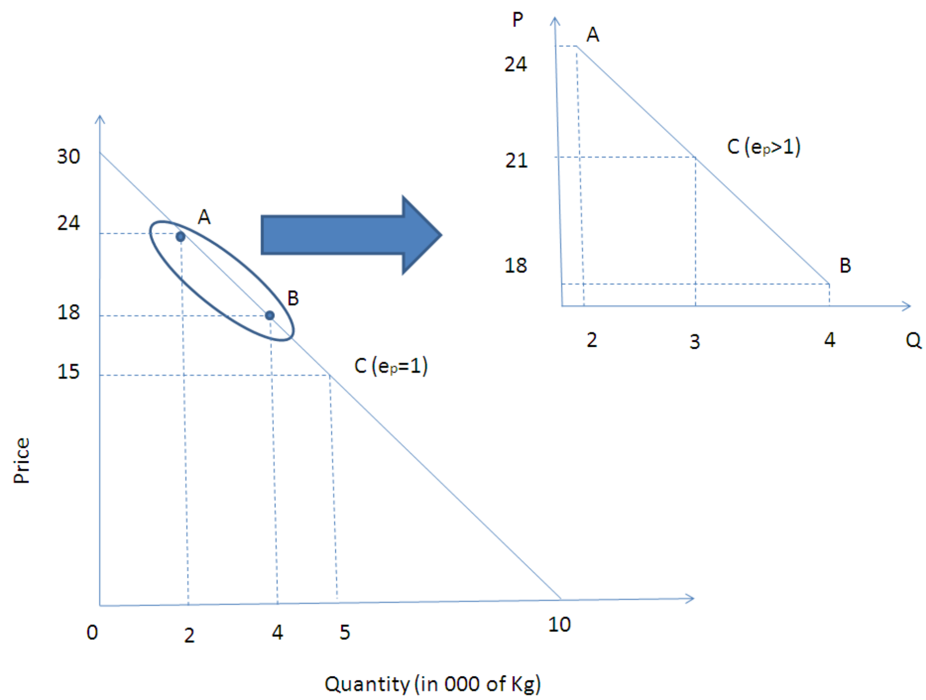
In this equation, $\frac{\Delta Q}{\Delta P}$ is the inverse of the slope of the demand curve, which is a constant. $\frac{P}{Q}$ represents the ratios of prices and quantities in different points of the curve. It therefore changes making change as well $e_P$.

For instance, in the linear demand curve illustrated here below, the slope is ½ (ignoring the minus sign), therefore the inverse of the slope is 2, constant. We can therefore calculate the price elasticity using the presented equation in points A,B,C, D and E. At A the price P is 10 and the quantity Q is 0. The elasticity is therefore infinite. At point B ep=2x8/4=4. At C it is =2x5/10=1x1/2=1. At D it is ¼ and at E=0 as P=0.




This analysis shows that within a linear demand curve, price elasticity ranges from ∞, where the curve meets the price axis, to 0, where the curve meets the quantity axis. $e_p$ is equal to 1 in the midpoint of the demand curve.

Even if the above curve is technically correct, it is unrealistic, as very seldom prices range from 0 to ∞. It is much better to consider a range of prices and quantity that are likely to encounter in real life. The following figure shows that from a "complete" demand curve for quantity of beef (000Kg) demanded at certain prices, only a portion (between A and B) is examined. In this portion, e>1 as it stands above the midpoint of the demand curve.



Also, to calculate the price elasticity of demand for beef, the **arc elasticity** on this specific sector of demand curve is applied. The arc elasticity is the elasticity coefficient calculated by comparing two points on a demand curve.

The average of the two points is used as the basis to calculate the changes. In the example, therefore, the calculations are as follows:

(18+24)/2=21 as the basis for price

(2000+4000)/2=3000 as the basis for quantity

$$\frac{\frac{2000}{3000}}{\frac{6}{21}} = \frac{2}{3} x \frac{21}{6} = \frac{7}{3} = 2.33$$

The general formula to calculate arc elasticity is:

$$e_p = \frac{(Q_2 - Q_1)/\left[(Q_2 + Q_1)/2\right]}{(P_2 - P_1)/\left[(P_2 + P_1)/2\right]}$$

The 2s cancels out and we have:

$$e_p = \frac{(Q_2 - Q_1)/(Q_2 + Q_1)}{(P_2 - P_1)/(P_2 + P_1)}$$

**An example of opportunity cost**

Mr X is an employee earning 45 000 US$/year. He has 50 000 US$ in his savings account. He decides to resign from his employment and start his own business. He uses the 50 000 US$ to purchase the equipment to start the business.

In addition to the explicit money costs that he incurs, he has to consider the 45 000 US$/year which he has sacrificed by resigning from his post as well as the interests he would have earned by keeping the 50 000US$ in the savings account.

These implicit opportunity costs are added to the explicit costs to arrive at his total economic (or opportunity) cost of production.

Economic cost of production = opportunity cost = explicit costs (accounting costs of production, including the 50 000 US$ investment) + implicit costs (including interests lost from the 50 000 US$ in the savings account and the 45 000 US$/year salary lost after resigning).

**Efficiency**

In economics, the term economic efficiency refers to the use of resources so as to maximize the production of goods and services. An economic system is said to be *more efficient* than another (in relative terms) if it can provide more goods and services for society without using more resources. In absolute terms, a situation can be called economically efficient if:

- No one can be made better off without making someone else worse off.

- No additional output can be obtained without increasing the amount of inputs.
- Production proceeds at the lowest possible per-unit cost.

These definitions of efficiency are not exactly equivalent, but they are all encompassed by the idea that a system is efficient if nothing more can be achieved given the resources available.

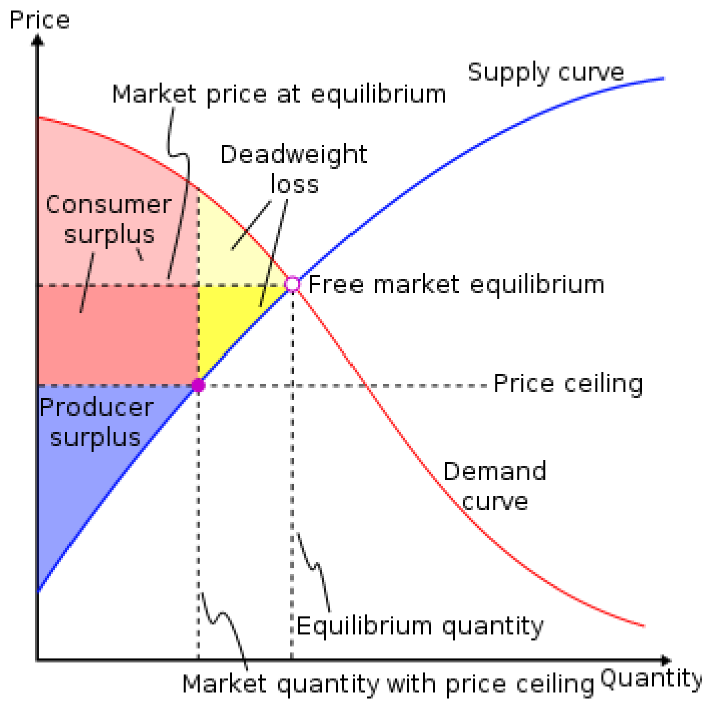
**Pareto efficiency**, or Pareto optimality, is a concept in economics with applications in engineering and social sciences. The term is named after Vilfredo Pareto, an Italian economist who used the concept in his studies of economic efficiency and income distribution.

Given an initial allocation of goods among a set of individuals, a change to a different allocation that makes at least one individual better off without making any other individual worse off is called a Pareto improvement. An allocation is defined as "Pareto efficient" or "Pareto optimal" when no further Pareto improvements can be made.

Pareto efficiency is a minimal notion of efficiency and does not necessarily result in a socially desirable distribution of resources, as it makes no statement about equality or the overall well-being of a society.

**Deadweight loss**

In economics, a deadweight loss (also known as excess burden or allocative inefficiency) is a loss of economic efficiency that can occur when equilibrium for a good or service is not Pareto optimal. In other words, either people who would have more marginal benefit than marginal cost are not buying the product, or people who have more marginal cost than marginal benefit are buying the product. Deadweight loss can be beneficial when there is a negative externality, in which case it can be considered a deadweight *gain*, as it would help those that the negative externality was hurting.



**Shadow pricing**

In a cost-benefit appraisal, "shadow prices', which reflect the social value of goods, replace the market prices that are used in the private calculation. In a perfectly competitive economy market prices and shadow prices will coincide, if we ignore complications introduced by issues of income distribution. Cost-benefit analysis and calculation of private profitability will yield the same result in this case.

Market distortions, however, will cause shadow prices and market prices to differ. This makes cost benefit analysis difficult, since "shadow prices' or "social values' cannot be directly observed.

# 3

# WATER VALUATION

## Welfare Economics

As previously discussed, economic goods and services can be private, public, open access, or club goods following their characteristics of exclusivity and rivalry. Exclusivity particularly is linked to the property right system that is established and that regulates the ownership and use of a good or service.

Remembering the Coase theorem, if a property right system exists and is well defined and accepted by all parties, it is theoretically possible, although in reality very difficult, to reach a condition of Pareto optimality in the use of natural resources without external intervention. The bargaining between the parties will suffice. But if this condition is absent, for instance when efficient allocation of resources characterised by open access is the objective, then government intervention is necessary. In an article dated 1968 G. Hardin introduced the famous “Tragedy of the commons”, illustrating the unsustainable use of common pool resources without an external regulatory framework. More recently, in 1990, Elinor Ostrom in her “Governing the commons” discussed the role of collective action and governance in the management of the commons as a third way between the market and the public intervention.

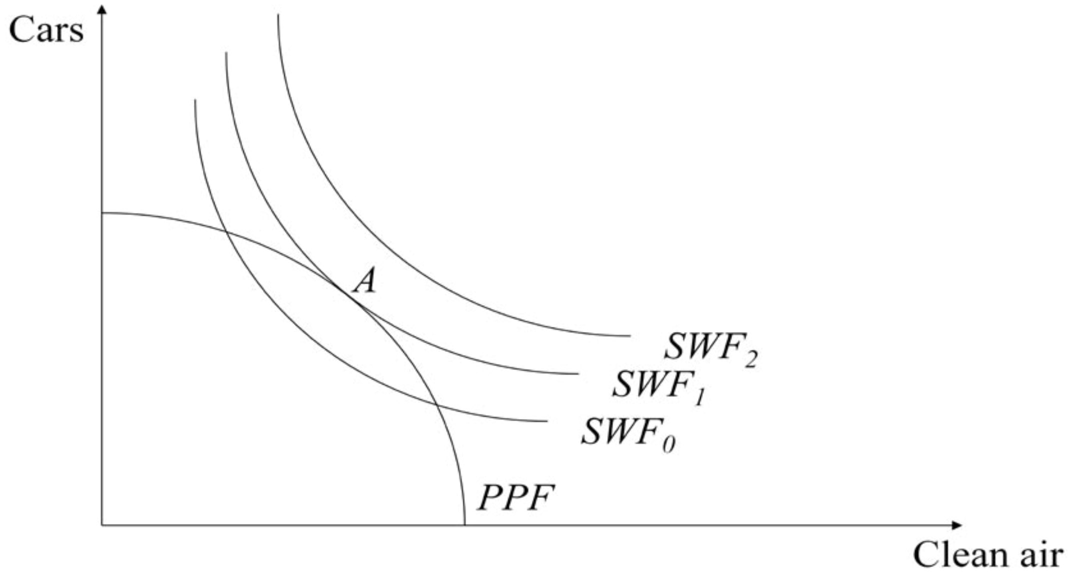
Nevertheless, even in the presence of a full set of private property rights, market failures (externalities) exist. These externalities move the system far from the optimal allocation of resources and therefore create a gap between private optimum and social optimal allocations.

To contrast and evaluate the gap between socially optimal allocations of natural resources and those achieved by private actions; economists draw on a large body of work called *welfare economics*.

According to Harwick and Olewiler (1998), welfare economics is “the study of the level and distribution of individuals’ and groups’ well-being in the economy”. Different allocations of resources are compared to evaluate under which outcome society will be best off.

The technique used is the creation of an aggregate *social welfare function*-SWF (fig. 1), which represents and “adds up” each individual’s well being or utility function in some fashion. This is then used to compare alternative equilibriums. In the following figure, the *production possibility frontier* - PPF of that specific society is compared with several SWF levels, represented by indifference curves. The PPF links the combinations of maximum possible production of cars and clean air for that society. Clearly, to move rightward (far from the origin of the axis) an innovation would be necessary. In the current conditions, A represents the point of optimal allocation of the two resources, as it allows reaching the higher SWF. This is the point of Pareto efficient or optimal allocation of the two resources that maximizes the social well being.

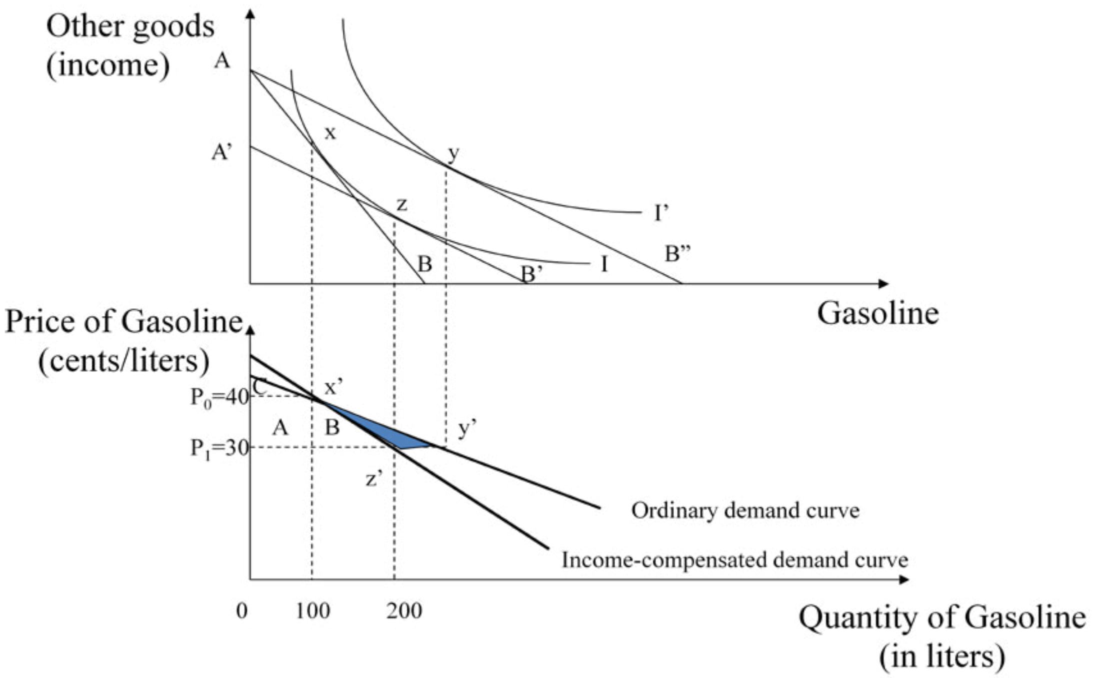
**Fig. 1 – Optimal allocation of clean air and cars**




This is a very simple representation. Following what indicated above, for a full social optimum, consumers and producers should maximize their surplus (utilities and profits), a full set of property rights exists and markets are efficient (no market failures).

In order to represent the consumer surplus, a simple system where consumers must choose between gasoline and other goods is considered (fig. 2). In the chart below, the indifference curves representing the consumer welfare for different combinations of gasoline and other goods are compared with budget constraints. In the case of AB (gasoline price=40c/l), I would be the highest indifference curve reachable and x the optimal combination of the consumed goods (gasoline quantity=100l).

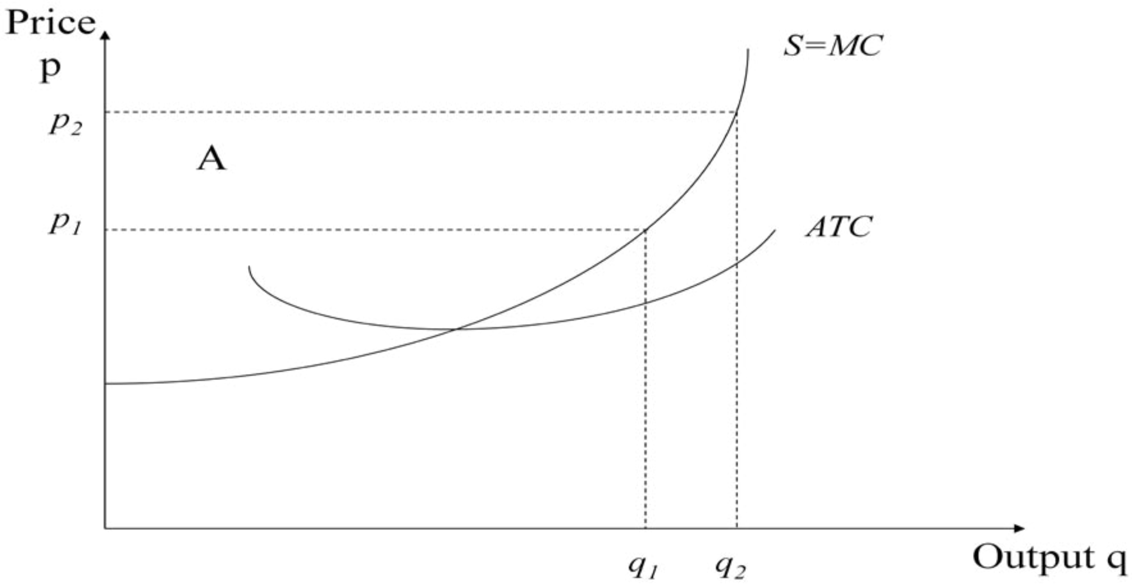
**Fig. 2 – Ordinary and compensated demand and consumer surplus**



X' represents in the chart below the combination of gasoline quantity (100l) and price (40c/l) found through the comparison of indifference curves and budget constraint above. If we consider that the price of gasoline goes down to 30c/l, then the budget constraint becomes AB", and the new equilibrium is y, corresponding to y' in the chart below. A simple reduction of price allows therefore to build up the ordinary demand curve (marshallian) where x' and y' sit. But I'>I and this means that the consumer is in a condition of higher welfare because of the reduction of the gasoline's price. It is like if the consumer income was higher than before. To take into account this fact, we need to calculate what would be the quantity of gasoline bought as a result of exclusively the reduction of price. And this can be calculated coming back to the original I and then comparing it with the parallel budget constraint to AB" that is tangent to I. This is A'B' and the new equilibrium is z, corresponding to z' (30c/l and 200l) in the chart below. x'z' sit on the income-compensated (hicksian) demand curve. The income-compensated (welfare) variation for the change of gasoline price is the area A+B. This is the max willingness to pay –ceteris paribus- of the consumer to purchase gasoline at the lower price. The *consumer surplus* for the same variation is A+B+ the shaded area as it is calculated under the ordinary demand curve.

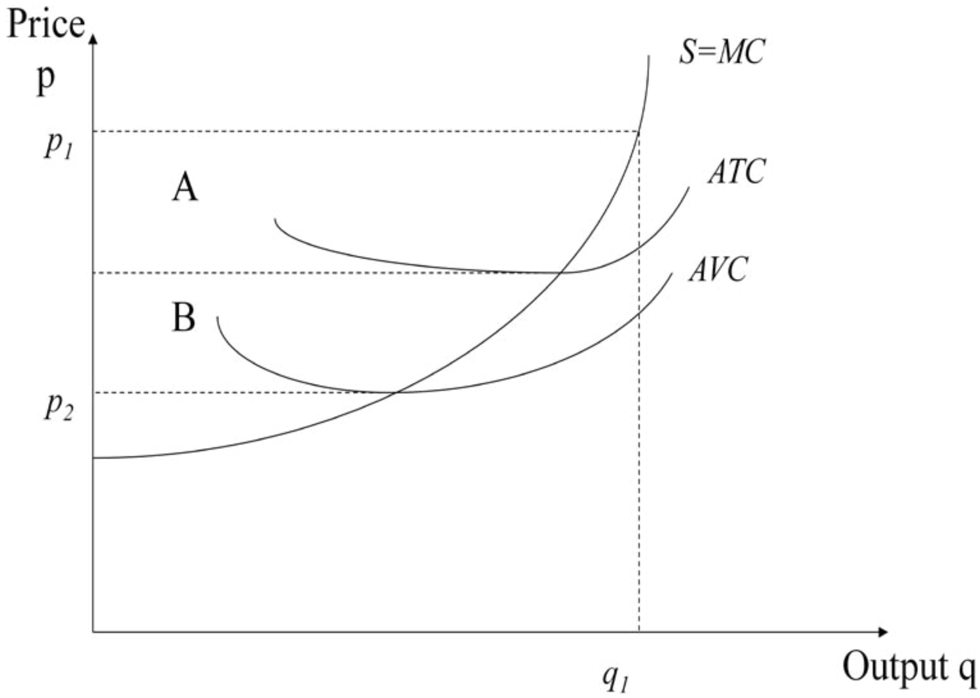
The producer, on the other side will maximize his surplus represented by the difference between the marginal production cost and the market price (Fig. 3). Following the same reasoning as before, the compensating and equivalent variation of welfare for the price increase is represented in the figure below by the area A. MC= marginal cost, representing the supply curve in the short term. ATC=average total cost.

**Fig. 3 – Welfare change associated with an increase of price for the firm's output**



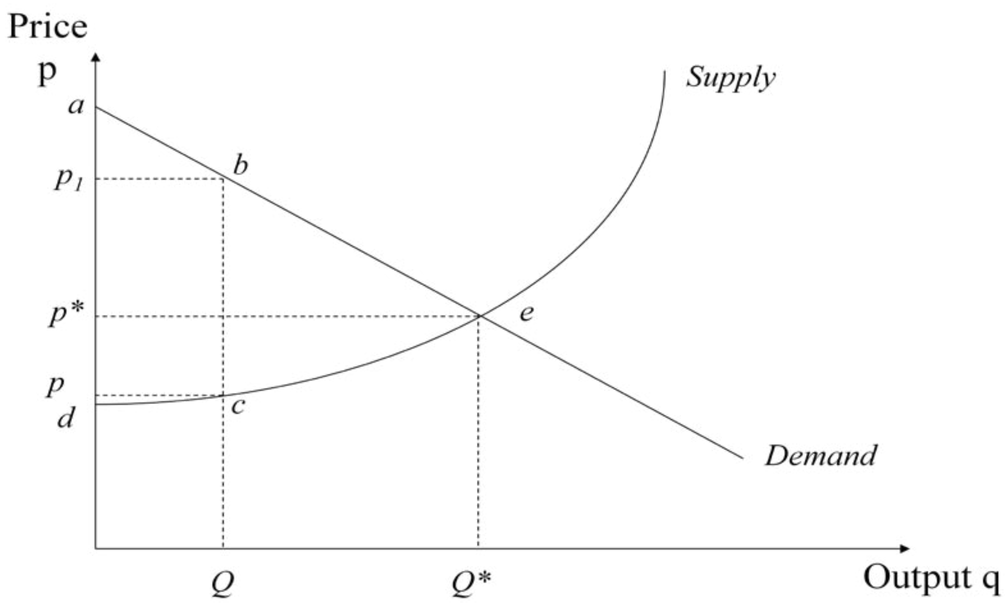

The real producer surplus will be higher and corresponding to the area A+B in figure 4, as on the medium term, the firm would be willing to produce until it is able to cover the fixed costs (difference between the total and the variable costs), and therefore the total *producer surplus* is the area A (profit) + the area B (average fixed costs).

**Fig. 4 – Producer surplus**




The *maximum social welfare* is reached when consumers and producers maximize their surplus. In the figure below this correspond to the point e, where supply clears demand and market prices are equilibrium prices. This is a condition that can be reached through a perfectly competitive market. Figure 5 indicates graphically that no other combination of price and output can yield a larger sum of producer and consumer surpluses than P* and Q*. Q (with the corresponding P and P') is an example of inefficient situation. e is the Pareto optimal combination of prices and quantities for this specific output in this specific society.

**Fig. 5 – Social welfare optimum**



It is worthwhile noticing that when Q is output produced, the welfare loss *bce* correspond to the *deadweight loss*.

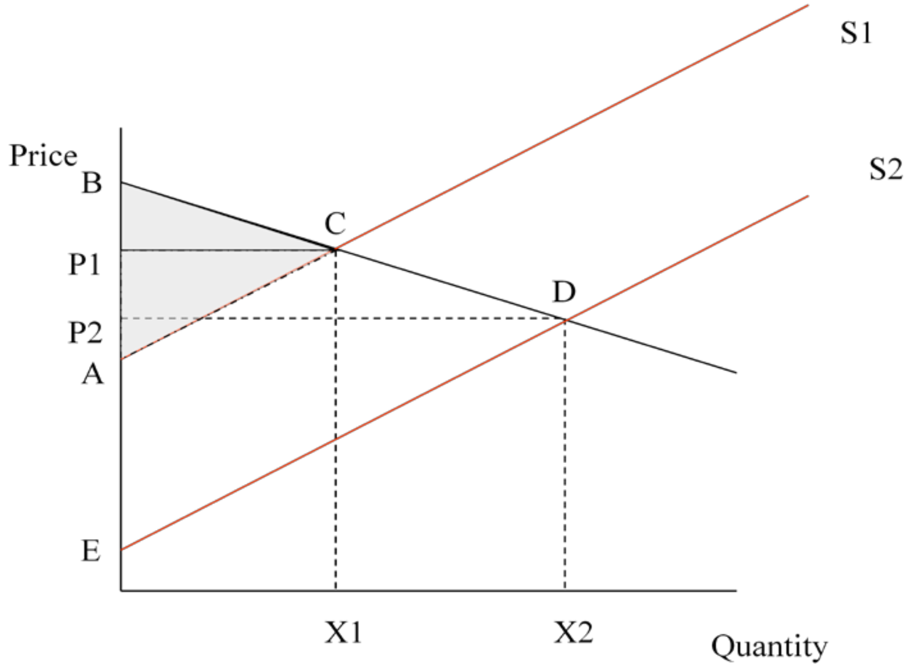
Even in a perfectly competitive market, externalities can exist and therefore, the social optimum is not reached. The role of the government can be aimed at:

a) reaching Q* and P* in the absence of a competitive market;

b) limiting externalities that reduce the social welfare even in presence of competitive markets;

c) identifying new equilibria like in figure 6, where an investment increases the supply of a good or a service. In this situation, the new supply curve (S2) determines Incremental Net Social Benefit = ACDE.

**Figure 6 – Increase of the Net Social Benefit in an economic system**




In all the above described cases, in order to design and select the type and size of the public intervention, it is crucial to quantify economically the costs and benefits of the policy measure to be adopted and the investments to foresee.

In the case of the water sector, numerous investments or decisions (public or private) imply costs and benefits to be carefully calculated before a decision is made on the path to follow in order to improve the social welfare. Examples are, the construction of a new dam, the extension of a water supply network, the repairing of a water treatment plant, or the renovation of a small scale irrigation scheme.

And because water is a very particular economic good, with many characteristics of a non private and marketable good, its valuation requires specific techniques called *non-market valuations*.

The following paragraphs illustrate non-market valuation techniques applied to the water sector.

**Types of water values**

There is no single economic value for water, as it is the case for most environmental and natural resources. When a value for water is being estimated, what is being measured is the welfare change associated with some induced changes in the attributes of the commodity. As the measure differs according to the specific attributes of the situation in question, it is important to keep clear what these attributes are. The list below contains most attributes to consider for water valuation

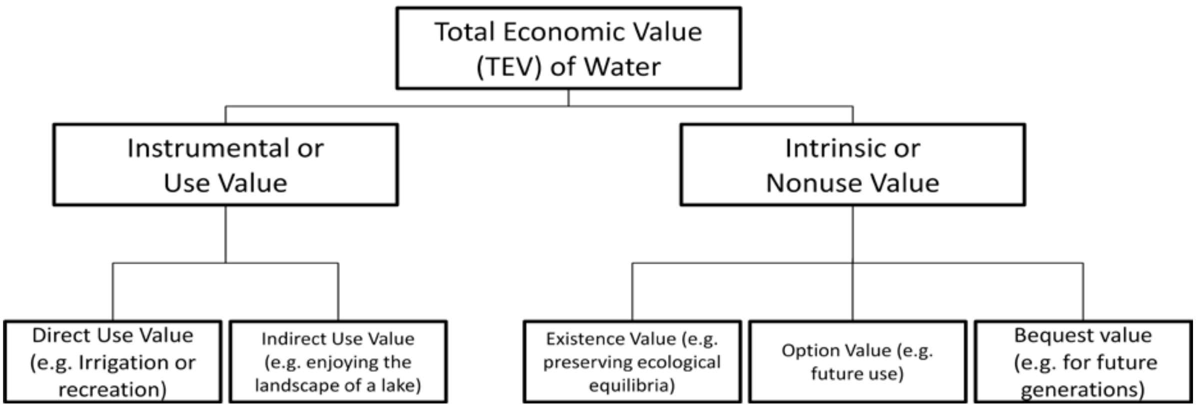
1- *Long run Vs short run values*: demand elasticity and consequently willingness to pay differ substantially following the period we consider for the possible investments related to water provision. This has to do with the degree of fixity of certain inputs, particularly when water is a producer's input. In the short run usually because of the fixity of certain inputs, water demand is more rigid, and therefore WTP is higher.

2- *At-site Vs at-source values*: Spatial, temporal and quality attributes are crucial in the determination of water value. In terms of space, due to the costs of transportation, energy, storage, the value of water with the same quality at the point of use can differ widely from the value at source. Quality issues are also important when water moves from the source to the site of use, as treatments, filtering etc. may increase the quality and the cost of the resource. Finally, water value can change with time as both demand and availability usually change overtime (fluctuations). An important consideration lies behind these values: raw water (bulk, natural resource) can be captured, transported, treated, stored in order to transform it into the commodity that is available at the point of use. This requires costs related to the services and processes necessary to transform the resource into a commodity.

3- *Per period Vs capitalized values*: Because water provision requires investments and long term projects, the value of the resource can consider the present value of the stream of periodic values/cost necessary to make the water available. Usually water is valued per period, and therefore not considering the capital costs. In the case of capitalized values, of course, the water value is 10 to 20 times higher that the annual value.

4- *Use Vs Nonuse values*: this difference was introduced by Krutilla in 1967 and can be summarized as in the scheme here below (fig. 7). Water as an environmental asset has use values, which are the conventional preferences measured by WTP. Nonuse values apply when individuals who do not use water feel nevertheless a deprivation (loss of welfare) if the asset were to vanish or be withdrawn.

**Figure 7 – The total economic value of water**




5- *Appropriate measure of water quantity*: to assign a value to water, one must express it as a monetary value per unit water volume or quantity used. For offstream uses three measures are possible: withdrawn, delivered and depleted. The first two are usually similar, but water losses can make the second much smaller than the first. The third term is important when consumptive uses are at stake.

## Methods for water valuation

Water valuation methods can be classified according to the techniques for quantification. These are in this case divided into *inductive* and *deductive* methods. The first group, more numerous, goes from the particular to the general, i.e. from direct observation to general relationships. In the second group are approaches reasoning from the general to the particular. Deductive techniques require construction of empirical and behavioural models, from which specific parameters or shadow prices are deducted.

Another classification of non-market valuation methods is the one between *revealed preference* approaches and *stated (or expressed) preference* approaches. Revealed preference methods make use of individuals' behaviour in actual or simulated markets in order to infer the value of an environmental good or service. Stated preference methods attempt to elicit environmental values directly from respondents using survey techniques.

The following table (tab. 1) provides a partial taxonomy of methods of nonmarket valuation of water investments and policies, broadly classified according to whether they are based on an inductive or deductive technique.

**Table 1 – A broad taxonomy of nonmarket valuation methods**

| *Valuation Method* | *Description of Method and Data Sources* | *Useful for Valuing Water as:* |
|---|---|---|
| **Inductive Methods** | | |
| Econometric Estimation of Production and Cost Functions | Primary or secondary data on industrial and agricultural inputs and outputs analyzed with statistical (usually regression) techniques | Producers' at-site valuations |
| Travel Cost Method (TCM) | Revealed preference method using econometric analysis to infer the value of recreational site attributes from the varying expenditures incurred by consumers to travel to the site | Valuation of recreational services and derived at-source valuations for changes in water supply |
| Hedonic Property Value Method (HPM) | Revealed preference approach using econometric analysis of data on real property transactions with varying availability of water supply or quality | At-source demands for changes in quantity or quality revealed by transactors in residential or farm properties |
| Contingent Valuation Method (CVM) | Expressed preference method using statistical techniques for analyzing responses to survey | At-source valuations of environmental (e.g. instream) water supplies. Also at-site valuations of |

| | | |
|---|---|---|
| | questions asking for monetary valuation of proposed changes in environmental goods or services | changes in residential water supplies |
| Choice Modelling (CM) | Expressed preference method using statistical techniques to infer WTP for goods and services from survey questions asking a sample of respondents to make choices among alternative proposed policies | At-source valuations of environmental (e.g. instream) water supplies. Also at-site valuations of changes in residential water supplies |
| **Deductive Methods** | | |
| Basic Residual Method | Constructed models for deriving point estimate of net producers' income or rents attributable to water via budget or spreadsheet analysis | At-site or at-source estimates for offstream intermediate goods (agriculture, industry) for single-product case |
| Computable General Equilibrium (CGE) Models | Constructed models for deriving net producers' income or rents attributable to water via price-endogenous optimization models | Recently adapted method used mainly for offstream intermediate goods (agriculture and industry) |

**Contingent Valuation Method**

Contingent valuation (CV) is an important survey-based procedure for eliciting the economic value of the quality and availability of nonmarket commodities. The method is particularly attractive because of its simplicity and flexibility, and it is commonly applied to cost-benefit analyses and environmental impact assessments.

The CV framework is based on maximizing utility from the consumption of market and non-market goods such as environmental quality Q. Q is therefore used as an argument in the individual's utility function,

$$U(X,Q) \qquad (1)$$

Where X is a vector of market goods. The individual's problem is to maximize *U (.)* subject to the budget constraint,

$$PX = M \qquad (2)$$

Where P is a vector of market prices, and M is income. When Q is given, the solution of the utility maximization problem is a set of Marshallian Demand functions,

$$X_i(P,M,Q) \qquad (3)$$

The Contingent Valuation Methodology (CVM) builds on the above framework adopting indirect utility functions,

$$V_i(P, M, Q) \quad \forall i \tag{4}$$

Where $i = 1, \ldots, N$ denote individuals.

Since a market does not exist for the environmental good Q, its value is inferred from survey data reporting households' willingness to pay (WTP), or willingness to accept compensation (WTA) for a change in its quantity or quality.

When a policy change is implemented so that quantity or quality of Q improves, i.e. from $Q_0$ to $Q_1$, the CVM survey measures the compensating surplus an individual is willing to pay to enjoy the improvement, i.e. remain at the same (compensated) utility level.

$$V_i(P, Q_0, M) = V_i(P, Q_1, M - WTP) \tag{5}$$

Where WTP is individual *i*'s stated willingness to pay, P, M and Q as defined above.

The individual's willingness to pay for the change could formally be represented by the change in expenditure resulting from a change in Q while holding the utility level constant at $U_0$.

$$WTP_i = m(P, Q_1, U_0) - m(P, Q_0, U_0) = \left\{ PH(P, Q_0, U_0) - PH(P, Q_1, U_0) \right\} \tag{6}$$

Where *m (.)* is the expenditure function, and *H (.)* is the Hicksian (compensated) demand function.

Until recently, stated preference data analysis focused mainly on WTP measures and their implication for environmental decision-making. The major advantage of the WTP approach is that anything of value to people can be translated into utilities in a framework that operates in financial terms. As illustrated above, underlying the WTP method is the assumption of utility maximization and the related axioms about preferences of consumers.

Questions have been raised in the literature on reliability and appropriateness of WTP measures for resolving social choice problems. Those include the reliability and validity of the survey instrument, the rationality of responses, and the sensitivity of the results to sequence, context and delivery of the questionnaire. WTP values are subjectively held valid to fill gaps caused by non-existent markets in situations in which we can only rely on responses to hypothetical questions. Assigning hypothetical or actual WTP to environmental options requires that the completeness axiom holds, yet the hypothetical nature of the CVM-WTP survey implies that preferences do not exist until the time an individual is invited to make a choice.

**Application**: *A two-step model to estimate the determinants of quality and quantity values of water for domestic uses in South Africa* (Banda et al., 2006).

A regression model based on cumulative logistic function and a Tobit model (two step) was used to calculate the probability of WTP and the actual WTP values of urban and rural residential water users in the Steelpoort sub-basin of South Africa.

A sample of 375 households, divided into 2 strata: urban and rural was surveyed through direct interviews. A questionnaire contained questions about the socioeconomic characteristics of the households and the water uses, and close-ended questions regarding WTP for improved water quality and quantity.

The following table (table 2) summarizes the results in terms of rural and urban households' WTP (US$/household/month) for improved quantity or quality of water.

**Table 2**

**Predicted willingness to pay (US $/household/month) for improved quantity and quality of water**

| Location | Median WTP for Quantity | Mean WTP for Quantity | | Median WTP for Quality | Mean WTP for Quality |
|---|---|---|---|---|---|
| Rural | 2.4 | 2.3 | | 0.5 | 0.7 |
| Urban | 0.1 | 0.3 | | 0.1 | 0.5 |
| | | | | | |
| Steelpoort | 1.9 | 1.8 | | 0.2 | 0.6 |

**Choice Modelling Method**

Choice modelling (CM) (or choice experiments) is a generalization of the CVM in that it gives respondents a menu of alternative scenarios characterised by several attributes, from which they have to choose. Respondents compare the available options and choose the one that maximizes their utility. As compared to CVM where the focus is on willingness to pay, CM allows the researcher to pose to the respondents a number of constructs to understand the influence of variations in the level of attributes on their choice. CM makes it "…*easier to estimate the value of the individual attributes that make up an environmental good…This is important since many management decisions are concerned with changing attribute levels*". CM is also useful for analysis of situational changes and trade-offs between attributes.

Data for CM are generated by systematic and planned procedures where attributes and levels are predefined to create choice alternatives.

The theoretical foundations of CM are in the random utility theory (RUT). The hypothesis of the RUT is that individuals make their choices based on the characteristics of the good along with a random component. The random component may be a result of the uniqueness of preferences of the individual or because the researchers may not have complete information about the individual. The theory therefore states that the utility $U_{ij}$ of an individual *i* derived from a scenario *j* is not known but can be decomposed into a deterministic component $V_{ij}$ and an unobserved random component, $\varepsilon_{ij}$:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \qquad (1)$$

Where $V_{ij}$ can be expressed as a linear function of the explanatory variables as follows:

$$V_{ij} = x'_{ij}\,\beta \qquad (2)$$

Where $\beta$ is a vector of coefficients associated with the vector $x'$ of explanatory variables, which are attributes of scenario *j,* and these include price, and the socioeconomic factors of individual *i* (Snowball *et al.*, 2007; Greene, 2000).

The individual *i* would be assumed to choose alternative *j* over alternative *k* if $U_{ij}>U_{ik}$.

The assumptions placed on the random component of the utility define the statistical model utilized.

The selection of an alternative can be expressed as:

$$\mathrm{U}_{\mathrm{ij}} > \max_k \in_{ci,k \neq j} U_{ik} \tag{3}$$

Applying the CLM, the probability of choosing an alternative *j* among *n* choices for individual *i* is:

$$P_i(j) = P\left[x'_{ij}\,\beta + \varepsilon_{ij} \geq \max_k \in_{ci} \left(x'_{ik}\,\beta + \varepsilon_{ik}\right)\right] \tag{4}$$

$$= \exp(x'_{ij}\,\beta) / \sum_k \in_{ci} \exp(x'_{ik}\,\beta)$$

This means that the probability that the individual *i* chooses *j* is equal to the probability that the utility derived from *j* is greater than the utility derived from any other alternative.

The most common econometric models used to process data in CM are the multinomial logit model (MLM), the nested multinomial logit (NML), and the conditional logit model (CLM). Conditional logit model (CLM) was used in the following example. For the CLM it is assumed that the error disturbances have a type 1 extreme value distribution: $\exp\left(-\exp(-\varepsilon_{ij})\right)$ .

**Application**: *Households' preferences and willingness to pay for multiple use water services in rural areas of South Africa* (Kanyoka et al., 2008).

Choice modeling was the approach used to identify the attributes determining demand for water services and quantify their relative importance in a rural area (Ga Sekororo) of South Africa.

A sample of 169 households was divided in 2 strata: without and with indwelling private taps. A focus group study allowed identifying water services attributes and levels used to design the options to be submitted to interviewed households in the form of choice cards In order to reduce the number of attribute and level combinations for the experiment, an orthogonal design was used to allow an investigation of "main" effects without being able to detect all interactions between attributes. This is quite sufficient, since main effects usually count for 80-90% of the variation in the data of choice experiments.
6 attributes were presented as choice determinants to stratum 1, whilst the attribute "source of water" was not part of the choice sets for stratum 2. The orthogonal design allowed generating 24 water service alternatives (sets of attributes' levels) for stratum 1 and 18 sets for stratum 2. The 24 and 18 combinations for the two strata were then paired into 12 and 9 choice cards respectively, each containing two alternative sets, from which the respondents were asked to select one. At least 3 cards (one at a time) were presented to each surveyed household.
The submission of an average of 4.8 cards to each respondent resulted in a number of available observations of 169 x 4.8 ≈ 811.
Results show that households in rural areas are willing to pay for water services' improvements. Due to the current poor level of water services in the area, users are primarily concerned with basic domestic uses and, consequently, demand for productive uses is low. Only households already relatively well served are interested in engaging in multiple water uses.
The following table (Tab. 3) shows the WTP estimated for various attributes of water provision in the surveyed area.

**Table 3**

WTP in US$/ $m^3$ for various attributes of water provision

| | Households with Private taps | Households without Private taps |
|---|---|---|
| Quantity | 0.2 | 0.3 |
| Quality | 0.3 | 0.5 |
| Frequency | 0.2 | 0.3 |
| Private tap | 0.0 | 0.7 |
| Quant.+ Quality | 0.5 | 0.8 |

**Travel Cost Method**

The essence of TCM stems from the need to travel to a site to enjoy its service. The inference from TCM is based on the assumption that demand for recreation depends on the cost incurred to travel to the tourism site to enjoy the environmental amenities anticipated from recreation at the visited area.

Travel cost models are synonymous with empirical models of demand for environmental services using observations of the cost of accessing an environmental site. TCM as applied to a recreation demand model assumes that the number of trips a person makes for recreation purposes in a season depends on the price of the trip, the quality of the recreation site, their income and other socioeconomic characteristics of that person. Recreation demand models are categorised into two types: (1) single site models and (2) multiple site models. Single site models use aggregate data from zones where visits per capita from each zone are regressed to travel cost from the zone to the site. Other studies use individual observations as a unit of measurement rather than the zonal aggregates. Multiple site models generalise single site models by estimating demand for a set of sites over a period of time.

There are several advantages to using the travel cost approach in valuing natural resources. First, the TCM provides estimates of use value of the natural resources upon which recreation services are derived. Second, the TCM provides a framework for estimating the value of the unique characteristics of a site. For instance, multiple site models capture the differences in use and non-use values of various sites in terms of the differences in environmental quality. When one works with heterogeneous sites, the price of each site can be decomposed into a set of implicit prices for each environmental attribute it possesses. Third, the absence of information, especially prices, does not prevent demand estimation. Usually, information sets can be imputed from data collected during the survey and from secondary sources. For example, when the use of time is measured together with the occupation of the respondents, time can be valued in monetary terms using labour market prices. Various studies assume an opportunity cost of time equal to or below the market wage rate.

Although TCM has traditionally been used in the estimation of recreation demand, the method can also be used in other behavioural models analysing household allocation of time. The versatility of the TCM could be exploited to analyse situations where the opportunity cost of time spent accessing resources is used to estimate welfare measures associated with the resource in question. In an ideal world, welfare measures from a CVM should be comparable to welfare estimates obtained from an indirect method such as the TCM. CVM welfare measures are sensitive to the design of survey and questions, formulation of scenarios and the proportion of the sample who are not willing to pay. In addition the CVM welfare measure assumes that the willingness to pay (WTP) bids are chosen independently of the other exogenous variables. On the other hand, the TCM welfare measure is sensitive to the specification of the travel cost variable as a proxy for price in the demand equation.

Households in rural African areas use river water and communal standpipes for drinking, cooking, bathing, washing and other domestic water uses. While metering is a common pricing mechanism in piped water systems in urban areas, the rural areas setting is different because water demand has no corresponding price data but varies with the time taken for a trip to a standpipe or river, the household income and the family members involved in collecting water.

The time spent fetching water and the environmental hazards from the quality of water sources are assumed to be the main determinants of household water demand.

Water demand is specified for a rural household $i$, choosing the number of trips $t_{ij}$ to take per month to collect water from the preferred source. The number of trips is related directly to the amount of water a household uses in each period and is influenced by a number of factors such as the roundtrip time taken to travel to the source of water, the number of family members involved in collecting water, the income of the household, availability of alternative sources of water and quality of water.

The time spent on collecting water has an *opportunity cost* equal to the wage that an individual (with a particular skill) could get on the local labour market. Since the household has income from other sources including work-related remuneration, the budget constraint for the household is written as follows:

$$Z_i \le M_i + \sum_{j=1}^{H} t_{ij} h_{ij} w_{ij} \qquad (1)$$

where $H$ is household size, $t_{ij}$ is the number of trips taken by member $j$, $h_{ij}$ is the time taken per trip to fetch water, $Z$ is a bundle of market goods, the consumption of which can be supported by household income $M$ and $w_{ij}$ is the wage rate for individual $j$'s time. Equation (1) addresses the issue of variability of wages for individuals depending on the quality of labour. It also says that a household could increase its consumption of market goods by working the extra hours committed to fetching water.

The allocation of time to household tasks and labour market activities is constrained by the maximum available time:

$$\sum_{j} t_{ij} h_{ij} + L_i = T_i \qquad (2)$$

where $L_i$ is household $i$'s participation time in the labour market and the other variables are as defined above.

Recreation demand offers a classic application of trip generating functions, the related travel cost and the opportunity cost of time. Unlike the classic application in which a person seeking recreation selects the sites to visit, most households in rural Steelpoort have one major source of water.

The classic trip generating function is modified to specify demand in terms of number of trips to the water source as influenced by changes in one or more independent variables. It is assumed that demand for water varies directly with the number of trips, but indirectly with factors such as the number of containers, household members involved in fetching water and the use of wheelbarrows, all of which affect the volume of water collected on a trip.

The integer values for the number of trips could be modelled as a latent variable of the form:

$$t_{ij} = f(p_i^*, S_i^*, \vartheta^*, \beta) + \upsilon_i \tag{3}$$

where $p_i^*$ is the average opportunity cost of time for each household per trip as defined below, $S_i^*$ is a vector of household characteristics, $\vartheta^*$ is a vector of perceived quality attributes of the water source, $\beta$ is a vector of unknown parameters and $\upsilon_i$ is an error term:

$$p_i^* = \frac{\sum_{j=1}^{H} t_{ij} h_{ij} w_{ij}}{\sum_{j=1}^{H} t_{ij} h_{ij}} \tag{4}$$

Since the number of trips taken by members of a household to collect water is a random, non-negative integer value with a non-negative mean, the number of trips can be modelled using a *Poisson distribution*. The probability of observing a non-negative number of trips $t_{ij}$ is given by the Poisson probability density function:

$$\mathrm{P}(t_{ij} = n),\ n = 0,1,2,\ldots = \frac{e^{-\lambda_i}\lambda_i^n}{n!} \tag{5}$$

where $\lambda_i$ is the mean and variance of the distribution assumed to be positive for a given vector of explanatory variables $V_i$, and a set of parameters $\beta$.

The sample likelihood function in terms of observed number of trips per household is given by the probability of observing that number of trips:

$$L(\beta | \mathrm{V}, t_i) = \prod_{i=1}^{N} \frac{\exp(-\exp(V_i\beta))\exp((V_i\beta)t_i)}{t_i!} \tag{6}$$

The expected number of trips is an equivalent representation of the demand for water since each household reports the amount of water that it collects on each trip. In other words, observing the number of trips a household takes to fetch water is the same as observing the household's demand for water. From the foregoing, the demand for water is an exponential function of the variables determining the expected number of trips, $\lambda_i$:

$$\lambda_i = e^{(\beta' V)} \tag{7}$$

Alternatively, the demand curve can be expressed as a semi-logarithmic function:

$$\ln \lambda_i = \beta_0 + \beta'_w p_i^* + \beta'_S S_i^* + \beta'_\vartheta \vartheta^* \tag{8}$$

*Linearisation* of the demand function allows estimation of the total consumer surplus by integrating the demand function over the relevant price range. This gives the value of water for collective tap or river water on the assumption that water has a cost in terms of the money value of time spent collecting water. Since demand is an exponential function of the opportunity cost of time, the integral of the function over the relevant price range gives the consumer surplus. Ignoring all variables except the opportunity cost of time from equation (8) and integrating directly gives:

$$CS = \int_{v}^{\infty} \lambda_i \, dw = \frac{\lambda_i}{\beta'_w} \tag{9}$$

The application of the TCM to valuation of rural water resources is appropriate because the model does not suffer from the same theoretical limitations as ecotourism models. In particular, when the proportion of non-participants increases with the distance to the recreation site, the ecotourism model would have the problem of a truncated sample with possible exaggerated consumer surplus estimates. In this particular application, there is only one purpose for a trip to the source of water and therefore the spatial limitation of multiple objectives of a trip does not arise.

**Application**: *A TCM model to estimate the demand for rural domestic water where there are no nominal prices for water in rural South Africa* (Banda et al., 2007).

The behavioural aspects of water demand in rural Steelpoort are inferred from the statistical realisation of household water use indicators including water consumption per capita, the number and length of trips taken when collecting water, the role of household members in fetching water, the type of containers used and the source of water. The model identified those social aspects that are important in assessing the benefits of investing in infrastructure aimed at improving access to water and also for to categorise the stakeholders by the type of benefits they stand to gain from improving water infrastructure.

TC was applied to the same sample as the study on CVM (375 hhs).

The following table (Tab. 4) provides estimations of the welfare measures corresponding to the water value for collective tap users and river water users in the surveyed area.

**Table 4**

Consumer surplus/$m^3$ in US$

| | Collective tap | River |
|---|---|---|
| US$/$m^3$ | 0.3 | 0.5 |

**Residual Imputation Method (Farm crop budget analysis)**

The RIM determines the incremental contribution of each input in a production process. If appropriate prices can be assigned to all inputs but one, the remainder of total value of product is attributed to the remaining or residual input, which in this specific case is water.
Residual valuation thus assumes that if all markets are competitive, except the one for water, the total value of production (TVP) equals exactly the opportunity costs of all the inputs:

$$TVP = \sum_i VMP_i Q_i + VMP_w Q_w \qquad (1)$$

Where:

TVP= total value of the commodity produced;
$VMP_i$= value of marginal product of input i;
$Q_i$= quantity of input i used in production, w for water.

It is assumed that the opportunity costs of non-water inputs are given by their market prices (or their estimated shadow prices). Therefore the shadow price of water can be calculated as the difference (the residual) between the total value of output (TVP) and the costs of all non water inputs to production. The residual, obtained by subtracting the non-water input costs from total annual crop revenue equals the gross margin and can be interpreted as the maximum amount the farmer could pay for water and still cover costs of production. It represents the at-site value of water:

$$GM = TVP - \sum_i P_i Q_i \qquad (2)$$

Where:

GM= gross margin;
$P_i$= price of input i.

This monetary amount, divided by the total quantity of water used on the crop, determines the marginal value for water ($VMP_w$), corresponding to the irrigator's maximum willingness to pay per unit of water for that crop. Average values were used in this study as a proxy of the marginal ones.

$$VMP_w = \frac{TVP - \sum_i P_i Q_i}{Q_w} \qquad (3)$$

The assumptions of the RIM are not overly restrictive, but care is required to assure that conditions of production under study are reasonable approximations of the conceptual model. The main issues can be divided into two types: 1) those relating to the specification of the production function and 2) those relating to the market and policy environment (i.e. the pricing of outputs and non-residual inputs). If inputs to production are omitted or underestimated (incorrect production function) or if there are inputs that are unpriced or not competitively priced, then the RIM will generate inaccurate estimates. To overcome the first problem, all relevant inputs should be included in the model. The second problem can be solved by determining shadow prices for the inputs that are not correctly priced. Because of this sensitivity to the specification of the production function and the assumptions about market and policy environment, the residual imputation method is only suitable when the residual input contributes a large fraction of the output value. This is however the case for irrigated agriculture in water scarce regions.

**Application:** *Irrigation water value at small scale schemes: evidence from the North-West Province, South Africa* (Speelman et al., 2008).

In this study values are calculated for small scale irrigation schemes in the North West Province of South Africa, using the residual imputation method. A sample of 320 farms was interviewed to get data about water use and crop budgets. An average water value of 0.188 US$/m³ and 0.259 US$/m³ respectively when negative GM are considered =0 or not considered was found, in line with expectations for vegetable crops (Tab. 5).

**Tab. 5**

**Aggregate average value for the vegetable crops in this study**:

**0.259 US$/m³** when cases with negative GM are not counted
**0.188 US$/m³** if a value of zero is attributed to these cases

**Summary of water values estimated through non market valuation methods in South Africa.**

The following table (Tab. 6) provides a summary of the different water values estimated using the above described valuation techniques for different water uses. In addition, an estimate coming from a partial equilibrium model (PEM) is included. This method will be discussed in a following chapter.

**Table 6 - Water value (US$/m$^3$) calculations according to the five presented methods**

| | CVM | TC | CM | RIM | PEM |
|---|---|---|---|---|---|
| Domestic uses | | | | | |
| River users | 0.58 | 0.5 | 0.8 | | |
| Coll. Tap Users | 0.58 | 0.3 | 0.8 | | |
| Private tap users | 0.06 (urb.) | | 0.5 (rur.) | | |
| Irrigation water | | | | 0.25 (0.18) | |
| CS for the catchment | | | | | 0.5 |
| OC of env. protection | | | | | 0.27 |

The comparison of the results obtained with different techniques shows a strong consistency and a good robustness of the methods applied to the studied contexts.

**Key concepts treated**

Consumer & producer surplus maximization

Private and social welfare

Pareto efficiency

Welfare economics and water valuation for policy making

Types of water values

WTP and WTA

Use and nonuse values

Non-market valuation methods

Inductive and deductive valuation methods

Stated and revealed preference methods

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## Exercises

1. What is the objective of welfare economics?

2. What welfare economics has to do with water management?

3. Why do we need to estimate water economic value for policy decision-making?

4. List two stated preference and two revealed preference methods and describe briefly their characteristics.

5. Which non-market valuation method would you use to estimate at-site residential water in rural areas of your country, and why?

# 4

# COST BENEFIT ANALYSIS FOR WATER RESOURCES DEVELOPMENT

## Theoretical foundations of CBA[1]

Cost Benefit Analysis was developed in the middle of the nineteenth century. The idea of measuring the net advantages of a capital investment project in terms of society's net utility gains (welfare economics) originated precisely with a publication by the French J. Dupuit about the management of the utility of public works (1844). CBA can be thought of as providing a protocol to measure allocative efficiency in the economy. As long as *positive net benefits* of a project exist, there is potential for compensation of those who bear costs, so that a system already Pareto efficient is preserved, while a system sub-efficient (much easier to find) can move towards this direction. The compensation criterion to preserve Pareto efficiency is also referred to as the Kaldor-Hicks criterion.

CBA is therefore a method based on the concepts of economic valuation described in the previous chapter and that aims at calculating the net benefits of a project or a policy for a specific society.

## Need for and usefulness of CBA for the public sector

In a situation of constant insufficiency of resources to be allocated to improve social welfare, it is crucial for policy-makers, to dispose of tools and methods that quantify monetarily the positive or negative social outcomes of a new project (e.g. a new dam) or of a policy measure (e.g. the introduction of a water charge).

Unlike a private investment, for which after having verified its technical feasibility the only real interest for the firm is the capacity to produce profit, in the public sector profit is not the main objective.

Profit determination can be implemented through a financial analysis, consisting of the calculation of costs and expected benefits of a project in current or constant (market) prices. When the real allocation problems (scarcity value of allocated resources) and the social impacts of a project have to be considered, then economic and social analyses are required.

Economic analysis is mainly based on the concept of opportunity cost. External costs are also estimated. A social analysis is particularly interested at the distribution of outcomes and costs among society's groups and individuals. Equity issues are particularly important.

The main differences between cost-benefit analysis in the public sector and profit determination in the private sector are summarized in table 1.

[1] This paragraph and the following one are from: Mullins D, Mosaka DD, Green AB, Downing R, and Mapekula PG (2007). A Manual for Cost Benefit Analysis in South Africa with Specific Reference to Water Resources Development, WRC Report No. TT305/07.

**Table 1: The Main Differences between Cost-Benefit Analysis in the Public Sector and Profit Determination in the Private Sector**

| | | *CBA* | *Profit determination* |
|---|---|---|---|
| 1. | From the point of view of | Community | Shareholders |
| 2. | Goal | Apply scarce resources effectively and efficiently | Maximise net value of firm |
| 3. | Discount rate | Social time-preference rate | Market rate or weighted marginal cost of capital plus uncertainty and risk premium |
| 4. | Value unit | Opportunity cost | Market price |
| 5. | Dimensions | All aspects necessary for a rational decision | Limited to aspects of decision-making that may affect profits |
| 6. | "Advantages" | Additional goods, services, products, income and/or cost savings | Money income |
| 7. | "Disadvantages" | Opportunity costs in terms of goods and services foregone. | Money payments and depreciation calculated according to accounting principles (GAAP) |

**Benefits and costs of water**

Water uses increase users' welfare, and therefore provide benefits. These benefits are both commodity benefits (to households, industries and farms) and public environmental values, including recreation, fish and wildlife habitat and a medium for carrying pollution from human production and consumption activities.

At the same time, water provision implies a cost. There are two different types of costs incurred in providing water to users. The first, obvious, is that of constructing and operating the infrastructure necessary for storing, treating and distributing water. This is the use cost, previously indicated as accounting cost, or explicit monetary costs.

The second, less obvious, cost is the opportunity cost incurred when one user uses water and therefore, affects the use of the resource by another user. Also, the choice to allocate water to a specific use has the opportunity cost of not using that resource for its best alternative use.

Calculation of these costs allows implementing economic analyses such as cost-benefit analysis (CBA), which help making decisions about investments or water allocations.

A typical case where economic concepts and tools are applicable to water management is when investments in capturing, storing, delivering and treating water are envisaged.

**Determination of values in CBA**

The main peculiarities in the determination of values in CBA are the concepts of opportunity cost, shadow prices, and externalities.

Opportunity costs as previously discussed, is the value of the resource employed in a certain production at its best alternative use. For instance, OC of production inputs, is the production that is given up elsewhere by withdrawing these inputs from their alternative use.

Shadow prices are the opportunity costs of products and services when the market price, for whatever reason, does not reflect these costs in full. Examples are shadow wages of labour where the fact that minimum wages are fixed, is taken into account.

Externalities or external costs and benefits have also been largely discussed. They enter in public interest valuation, while private profit estimations do not need them.

Methodologically, in economic and social analyses, in the absence of market prices, the non-market valuation techniques presented and discussed in the previous chapter become of crucial importance.

**Criteria for project assessment**

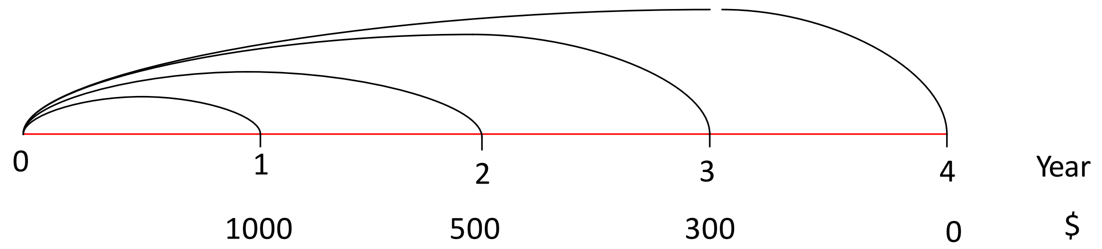
After completion of the economic valuations of costs and benefits, every project should be assessed individually in order to determine whether it will increase community welfare. The projects should then be ranked in priority order in terms of financial and economic criteria.

An important concept to be considered in CBA is the one of *discounting*. Costs that are immediately incurred and benefits that are gained in the present time are judged differently by the community from costs and benefits that materialize over a period of time. The community would rather prefer to receive a benefit today than in the future, while deferred costs are more attractive than immediate payments (time preferences).

Therefore the money value of costs and benefits over time cannot simply be added together; the time preferences of the community have to be taken into account through the use of a weighting process. This process is done with the aid of a rate that reflects the value of a benefit or cost over time. It is known as the social discount rate (*r*).

The following figure shows the process of discounting when r is 8% per year and 1800 dollars are expected to be paid or received over a period of three years, respectively 1000 the first year, 500 the second, and 300 the third.

Figure 1 – Discounting process




$r = 8\%$

$$Ao = 1000/(1+0{,}08)^1 + 500/(1+0{,}08)^2 + 300/(1+0{,}08)^3$$

$$Ao = 1592{,}\ 7$$

It is clear that the discounted amount (Ao)=1592,7 is smaller than the simple arithmetic sum of the expected amounts overtime (1800). And the higher r, the lower Ao.

The choice of r is of crucial importance in the implementation of a CBA, as a small variation of r determines very important changes in the CBA outcomes.

Following the economic theory, r should correspond to the marginal return on capital (OC of capital), or alternatively to the long-term real interest rates (cost of funding to the State). Other consider that social time preference rate should be considered.

An important practical consideration about r is that choosing a higher r, future costs and benefits will be considered less when discounted, so a higher r would favour for instance projects where future pollution costs are important.

The *Net Present Value* Method (NPV) is the discounted sum of all net benefits (B-C) over the project life. The formula can be expressed as:

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

The criterion for the acceptance of a project is that the NPV must be positive. Where a choice has to be made between mutually exclusive projects, the project with the highest NPV will be chosen since it maximizes the net benefit to the community.

The *Internal Rate of Return* (IRR) is the discount rate at which the present values of costs and benefits are equal, or in other terms at which the NPV of the project is =0.

$$IRR = NPV_0 = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+r)^t} = 0$$

Only projects with an IRR higher than the social discount rate, which forms a lower limit, will be considered for funding.

The *Benefit Cost Ratio* (BCR) is the ratio of the present value of the benefits relative to the present value of the costs, i.e.:

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

A project will be considered only if BCR>1.

**Uncertainty and sensitivity analysis**

Although it could be accepted that the decision maker if aware of the fact that the projected outcome of a project cannot be interpreted in absolute terms, it is important that the analyst provides the decision maker with some idea of the degree of certainty/uncertainty to which the project outcome would be subjected to.

To do this, project evaluators usually perform the so-called Selective Sensitivity Analysis in order to establish the sensitivity of a project's outcome to changes in a limited number of key input variables. In essence; the analyst selects a key variable/parameter, one which he feels is both subject to wide variations and capable of significantly affecting the results of the CBA. The analyst then selects likely high and low outcomes for this parameter and repeats the computation of the CBA using these values. The decision maker is then presented with the new values of the criteria for project assessment resulting from the chosen values (high and low) of the parameters selected for the sensitivity analysis and introduced in the computation.

### A pedagogical example[2]

**The problem:** The town of Bintuli, important industrial center, produces every year 59 750 000 $m^3$ of industrial wastewater. The total wastewater production (including domestic) is 99 170 500 $m^3$ /year. Today a municipal treatment plant treats 11 400 000 $m^3$ of industrial wastewater. 87 770 455 $m^3$ /year of wastewater (55% industrial and 45% domestic) are sent to the river.

To solve this problem, the public authority considers three *Options***:**

1) Maintaining the status quo

2) Improvement of the existing station

3) Build a new facility

As for technical reasons option 2 is considered not feasible, it is decided to implement a **CBA** on options 3 and 1.

The following table (Tab. 2) shows the incremental costs of option 3.

Table 2

| **Investment and Operating and Maintenance Costs, Bintuli Wastewater Treatment Projec** | |
|---|---|
| Item | Cost ($ million) |
| *Investment costs:* | |
| Buildings and structures | 3.42 |
| Equipment and supplies | 13.15 |
| **TOTAL INVESTMENT COST** | **16.57** |
| | |
| *Operating and Maintenance Costs:* | |
| Electricity | 0.68 |
| Salaries | 0.09 |
| Chemicals | 0.06 |
| Maintenance | 0.58 |
| Other | 0.21 |
| **Total O&M costs** | **1.62** |

Table 3 shows th incremental benefits of option 3

2 This example is taken from "Asafu-Adjiaye, J (2000) Environmental Economics for Non Economists, World Scientific, Singapore."

Table 3

| Incremental Economic Benefits ($ millions) | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Year* | *Recycled water* | *Afforestation* | *Reed harvesting* | *Reduced mortality* | *Reduced morbidity* | *Water treatment cost savings* | *Incremental economic benefits* |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | 0,66 | | | 0,01 | 0,18 | 0,11 | 0,96 |
| 5 | 0,99 | | | 0,02 | 0,38 | 0,11 | 1,5 |
| 6 | 1,64 | | 0,02 | 0,03 | 0,57 | 0,11 | 2,37 |
| 7 | 2,63 | | 0,02 | 0,05 | 0,76 | 0,11 | 3,57 |
| 8 | 3,29 | 0,01 | 0,02 | 0,06 | 0,95 | 0,11 | 4,44 |
| 9 | 3,29 | 0,02 | 0,02 | 0,06 | 1 | 0,11 | 4,5 |
| 10 | 3,29 | 0,03 | 0,02 | 0,06 | 1,06 | 0,11 | 4,57 |
| 11 | 3,29 | 0,04 | 0,02 | 0,07 | 1,11 | 0,11 | 4,64 |
| 12 | 3,29 | 0,05 | 0,02 | 0,07 | 1,17 | 0,11 | 4,71 |
| 13 | 3,29 | 0,06 | 0,02 | 0,07 | 1,23 | 0,11 | 4,78 |
| 14 | 3,29 | 0,07 | 0,02 | 0,08 | 1,3 | 0,11 | 4,87 |
| 15 | 3,29 | 0,08 | 0,02 | 0,08 | 1,37 | 0,11 | 4,95 |
| 16 | 3,29 | 0,09 | 0,02 | 0,09 | 1,44 | 0,11 | 5,04 |
| 17 | 3,29 | 0,1 | 0,02 | 0,09 | 1,51 | 0,11 | 5,12 |
| 18 | 3,29 | 0,1 | 0,02 | 0,1 | 1,59 | 0,11 | 5,21 |
| 19 | 3,29 | 0,1 | 0,02 | 0,1 | 1,68 | 0,11 | 5,3 |
| 20 | 3,29 | 0,1 | 0,02 | 0,11 | 1,76 | 0,11 | 5,39 |

And finally, table 4 shows the incremental NET benefits of the project over its 20 years of expected life, and the NPV and IRR calculated following the methods illustrated above.

Table 4

| **Net Incremental Economic Benefits ($ million)** | | | | |
|---|---|---|---|---|
| Year | Incremental economic costs | Incremental sales revenue | Incremental economic benefits | **Incremental net benefits** |
| 1 | 2,01 | | | -2,01 |
| 2 | 8,45 | | | -8,45 |
| 3 | 6,11 | | | -6,11 |
| 4 | 1,62 | 1,91 | 0,96 | 1,25 |
| 5 | 1,62 | 1,91 | 1,5 | 1,79 |
| 6 | 1,62 | 3,17 | 2,37 | 3,92 |
| 7 | 1,62 | 3,17 | 3,57 | 5,12 |
| 8 | 1,62 | 3,17 | 4,44 | 5,99 |
| 9 | 1,62 | 3,17 | 4,5 | 6,05 |
| 10 | 1,62 | 3,17 | 4,57 | 6,12 |
| 11 | 1,62 | 3,17 | 4,64 | 6,19 |
| 12 | 1,62 | 3,17 | 4,71 | 6,26 |
| 13 | 1,62 | 3,17 | 4,78 | 6,33 |
| 14 | 1,62 | 3,17 | 4,87 | 6,42 |
| 15 | 1,62 | 3,17 | 4,95 | 6,5 |
| 16 | 1,62 | 3,17 | 5,04 | 6,59 |
| 17 | 1,62 | 3,17 | 5,12 | 6,67 |
| 18 | 1,62 | 3,17 | 5,21 | 6,76 |
| 19 | 1,62 | 3,17 | 5,3 | 6,85 |
| 20 | 1,62 | 3,17 | 5,39 | 6,94 |
| | | | ***11,58 NPV at 12%*** | ***21% IRR*** |

To take into account uncertainty in in the calculation of the NPV of option 3, a sensitivity analysis of the IRR was implemented by changing the capital costs, the O&M costs, and the Net Benefits over a range between -30% and +30%. Table 5 shows this.

Table 5

| ***Sensitivity of the IRR*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | *Change in Net Economic Benefits* | | | |
| | | | | | | | |
| | | **-30** | **-15** | **0** | **15** | **30** | |
| | **-30** | 23 | 25 | 27 | 29 | 31 | |
| *Change* | **-15** | 20 | 22 | 24 | 25 | 27 | |
| *in Capital Costs* | **0** | 17 | 19 | 21 | 23 | 24 | |
| | **15** | 15 | 17 | 19 | 21 | 22 | |
| | **30** | 14 | 16 | 17 | 22 | 20 | |
| | | | | | | | |
| | **-30** | 19 | 21 | 23 | 25 | 26 | |
| *Change* | **-15** | 18 | 20 | 22 | 24 | 25 | |
| *in O&M Costs* | **0** | 17 | 19 | 21 | 23 | 25 | |
| | **15** | 16 | 18 | 20 | 22 | 24 | |
| | **30** | 15 | 17 | 19 | 21 | 23 | |
| | | | | | | | |

Results of the sensitivity analysis suggest an acceptable robustness of the CBA.

**Application**: *Combining multi-agent simulations and cost-benefit analysis to evaluate policy options for the management of livestock effluents in Réunion Island* (Farolfi et al., 2008).

This study uses a multi-agent system to simulate the behaviour of economic players in a context of rapidly evolving environmental policy. The area under study is represented by a sector of a French overseas Department, Réunion Island, with a high concentration of pig farms in the upland region and extensive sugarcane plantations in the coastal zone. Local pig farmers' reactions to several policy options aimed at reducing the pollution coming from pig rearing are simulated first. Multi-agent simulations are then coupled with cost-benefit analysis in order to calculate the net present value of different policy options.

According to Layard and Glaister, in any CBA exercise it is recommended that one proceeds in two stages:

a.) value the costs and benefits in each year of the project (in this case the policy option adopted); and

b.) obtain an aggregate present value of the project by discounting costs and benefits in future years to make them commensurate with present costs and benefits, and then adding them up (Layard and Glaister, 1994).

Aggregated costs and benefits deriving from different simulated policy options were then calculated for each year and a CBA over a ten-year period was implemented to obtain net present values (NPV) at year 0 for different policy options. Due to the nature of the analysis, the NPV standard formula was slightly adapted in order to calculate the present value of the cost for the implementation of a policy option ($PV_c$). The modified formula was:

$$PV_c = \sum_{t=0}^{n} \frac{(C_t - B_t)}{(1+r)^t} \qquad [1]$$

Where:

$C_t$ = costs of the policy option at year t
$B_t$ = benefits of the policy option at year t
r = discount rate
n = years of policy implementation

Annual farmer's costs and benefits calculated through simulations run with Echos were first aggregated to obtain collective values by type of farmers and for the whole study area. Then the choice of a discount rate and the use of equation [1] allowed obtaining the present value of the cost ($PV_c$) for the simulated adoption of two different policy options. Table 3 illustrates the results of this analysis applied to the policy option consisting of a high tax (3 €/KgN) over the whole simulated period combined with a subsidy covering 70% of slurry transportation costs [In the previous section, a tax progression every 2 years was simulated. A constant level of tax in the CBA analysis simplifies calculations and reduces the number of variables changing overtime]. For this policy option, the surface of sugarcane farms in the coastal area was randomly set between 20 and 40 ha in the first scenario and between 40 and 80 ha in the second one. Costs and benefits of this option were then compared with costs and benefits of the policy option consisting of a lower tax (0.7 €/KgN) over the whole period and a subsidy covering 42% of the annual cost of a collective compost plant. No subsidy for transportation costs was contemplated in this second option.

The following incremental costs compared to the status quo were considered: incremental cost for pig farmers [resulting from the pollution taxes plus the cost of transport, or the unsubsidised cost of collective treatment, according to the policy option analysed. The reduction of spreading costs contributes to the reduction of this incremental cost] and annual subsidies to be paid by public institutions in order to cover slurry transportation or collective treatment costs.

On the other side, incremental benefits were represented by the annual cost reduction for sugarcane farmers (resulting from the use of free pig slurry instead of buying mineral fertilisers), and the double dividend for the society produced by the tax payment for the spread of slurry above the legal limit on structural excess areas.

The reduction of accumulated additional nitrogen in the soil at year ten of the simulation was then calculated, as this represents the positive environmental impact of the adopted policy with respect to the status quo. The discounted cost of the adopted policy was then expressed in absolute terms and in terms of cost per unit of reduced pollution.

Analyses were conducted over a period of ten years, using a discount rate of 6%, a higher value than the present inflation rate in Réunion. This discount rate accounts for the risk of the investments (Table 6).

Table 6 Present values in € of the incremental cost ($PV_c$) of two policy options over a ten year simulation (r=6%)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Option 1. Subsidising effluent transport to sugarcane farms ( 20 ha > 40 ha)** | | | | | | | | | | | | |
| | Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | TOTAL |
| Subsidy | | 0 | 166, 931 | 226,565 | 226,565 | 226,565 | 226,565 | 226,565 | 226,565 | 226,565 | 226,565 | 1,979,450 |
| Δ cost PF | | 229,618 | 220,550 | 213,130 | 216,031 | 198,321 | 228,855 | 222,748 | 209,008 | 219,695 | 196,336 | 2,154,290 |
| Double dividend | | 229,618 | 163,969 | 138,473 | 138,931 | 125,191 | 151,145 | 145,038 | 135,878 | 141,985 | 123,206 | 1,493435 |
| Δ cost SF | | 0 | 3,176 | 4,580 | 4,580 | 4,580 | 4,580 | 4,580 | 4,580 | 4,580 | 4,580 | 39,817 |
| Policy option cost | | 0 | 220,336 | 296,641 | 299,084 | 295,115 | 299,695 | 299,695 | 295,115 | 299,695 | 295,115 | 2,600,489 |
| *Residual N (Kg)* | | *483,216* | | | | | | | | | **$PV_c$6%** | **1,840,518** |
| *Reduced N (Kg)* | | *95,047* | | | | | | | | **$PV_c$/KgN reduced** | | **19.36** |
| **Option 1. Subsidising effluent transport to sugarcane farms ( 40 ha > 80 ha)** | | | | | | | | | | | | |
| | Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | TOTAL |
| Subsidy | | 0 | 198,779 | 239, 746 | 242,952 | 309,924 | 360,509 | 423,919 | 304,936 | 337,710 | 297,099 | 2,715,573 |
| Δ cost PF | | 219,847 | 225,038 | 200,763 | 199,5452 | 190,076 | 216,489 | 221,832 | 198,015 | 212,366 | 192,061 | 2,076,031 |
| Double dividend | | 219,847 | 153,282 | 121,374 | 119,389 | 88,244 | 91,145 | 74,198 | 98,321 | 98,626 | 95,725 | 1,160,153 |
| Δ cos SF | | 0 | 12,258 | 14,406 | 18,940 | 19,460 | 22,437 | 26,391 | 19,047 | 21,032 | 18,482 | 172,453 |
| Policy option cost | | 0 | 258,276 | 304,729 | 304,164 | 392,296 | 463,416 | 545,161 | 385,584 | 430,418 | 374,953 | 3,458,997 |
| *Residual N (Kg)* | | *403,216* | | | | | | | | | **$PV_c$6%** | **2,415,103** |
| *Reduced N (Kg)* | | *175,684* | | | | | | | | **$PV_c$/KgN reduced** | | **13.75** |
| **Option 2. Subsidising Compost collective station** | | | | | | | | | | | | |
| | Year | 1 | 2 | 3 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | TOTAL |
| Subsidy (disc.) | | 0 | 175,105 | 181,940 | 202,613 | 194,944 | 215,451 | 217,451 | 208,449 | 221,619 | 202,947 | 1,820,520 |
| Δ PF Collective syst. (disc) | | 0 | 16,183 | 10,687 | 9,924 | 24,122 | 9,924 | 23,053 | 16,489 | 29,466 | 12,519 | 167,939 |
| PF Tax | | 104,885 | 52,214 | 32,519 | 10,909 | 687 | 382 | 198 | 840 | 840 | 794 | 204,268 |
| Double Dividend | | 104,885 | 52,214 | 32,519 | 10,909 | 687 | 382 | 198 | 840 | 840 | 794 | 204,268 |
| Net costs (but subs.) | | 0 | 191,288 | 192,627 | 226,736 | 204,868 | 238,504 | 242,947 | 224,937 | 251,085 | 215,466 | 1,988,458 |
| *Residual N (Kg)* | | *135,834* | | | | | | | | | **$PV_c$ 6%** | **1,988,458** |
| *Reduced N (Kg)* | | *443,066* | | | | | | | | **$PV_c$/KgN reduced** | | **4.49** |

**Notes:**
1) PF = Pig Farmers; SF = Sugarcane Farmers
2) Annual values for collective system subsidies and pig farmers' collective treatment costs are discounted in the simulation

Results indicate that the policy option consisting of a lower tax combined with a subsidy for the collective compost plant is the less expensive. Furthermore, its impact in terms of pollution reduction is higher. Increasing the available surface in the coastal zone improves only marginally the results of the policy option aimed at transferring effluent to the sugarcane plots. In addition, the feasibility of the second policy option is far higher when compared to the previous one. In particular, the high tax imposed on pig farmers in order to push them to adopt a strategy of transfer of effluent to the coastal zone is not acceptable in the specific context, and does not reflect the general orientation of the environmental protection policy in France and in the EU.
Other structural and technical constraints linked to the transfer of effluent to the coastal area, namely the poor quality of the roads and the consequent low capacity load for slurry, were already mentioned. An improvement of the road connections between Grand Ilet and the coastal area would correspond to high additional costs that are not considered in this analysis. In this simulation, an optimistic load capacity for transportation of 20T of slurry was taken into account, corresponding to 80 KgN per trip. In fact, as already mentioned, the current state of the roads in the studied area allows only a load capacity of 10T of slurry.

Summarizing, the results of the presented simulations show clearly that a "stick and carrot" policy based on the combined use of environmental taxes and subsidies would be effective in the studied context either through the adoption of a pollution tax higher than 0.3€/KgN, or by coupling it with a subsidy covering a significant share of the alternative strategy's annual cost. In other terms, a low level of economic instruments does not seem to be sufficient to induce pig farmers toward a strategy of effluent management alternative to the present one, i.e. spreading all organic matter on the Grand Ilet plots.
In particular, at subsidy levels below 70% of the annual transportation cost, the transfer of effluent to the coastal area does not look attractive for the pig farmers (especially for those who do not own spreading and transport facilities).
The CBA was conducted on the two options that MAS simulations indicated to be the most applicable to the studied context showed that a lower tax on effluents coupled with a subsidized collective compost station would be economically more viable, socially more acceptable, and

environmentally more effective than the option aimed at facilitating the transfer of organic matter towards the sugarcane farms of the coastal area.

## Key concepts treated

Financial, economic and social analysis of a project

Shadow prices

Opportunity costs

Time preferences

Discounting

Net Present Value

Internal Rate of Return

Benefit Cost Ratio

Sensitivity analysis

Incremental costs and benefits

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## Exercises

1. What is Cost Benefit Analysis?
2. What is the difference between profit determination and CBA?
3. Can you give two examples of water-related projects where CBA would be necessary?
4. Why sensitivity analysis is necessary when a CBA is implemented?
5. What are the economic concepts behind the idea of discounting?

# 5

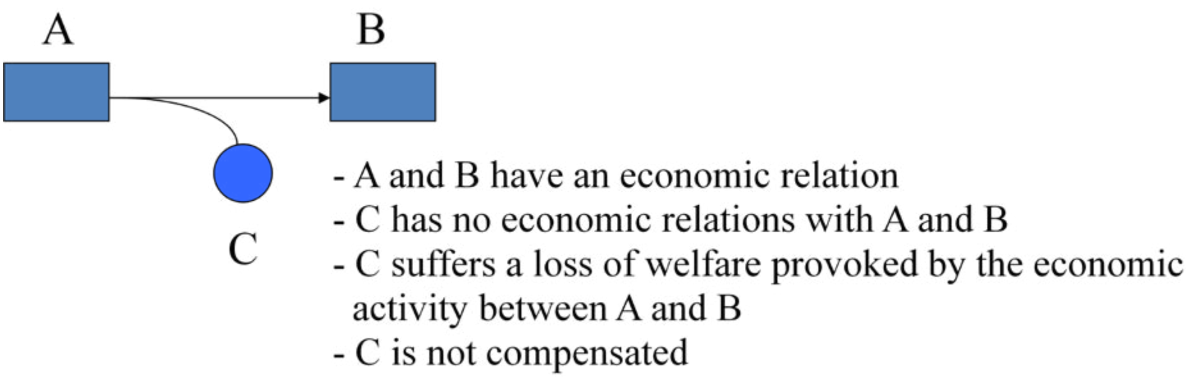
# EXTERNALITIES

## Definition

In economics, an **externality** is a cost or benefit, not transmitted through prices, incurred by a party who did not agree to the action causing the cost or benefit. A benefit in this case is called a positive externality or **external benefit**, while a cost is called a negative externality or **external cost**.

According to Pearce and Turner (1990), a negative externality is the uncompensated loss of welfare provoked by one economic agent to another (Fig. 1).

Figure 1. Graphic representation of a negative externality




In these cases in a competitive market, prices do not reflect the full costs or benefits of producing or consuming a product or service, producers and consumers may either not bear all of the costs or not reap all of the benefits of the economic activity, and too much or too little of the good will be produced or consumed in terms of overall costs and benefits to society. For example, manufacturing that causes air pollution imposes costs on the whole society, while fire-proofing a home improves the fire safety of neighbors. If there exist external costs such as pollution, the good will be overproduced by a competitive market, as the producer does not take into account the external costs when producing the good. If there are external benefits, such as in areas of education or public safety, too little of the good would be produced by private markets as producers and buyers do not take into account the external benefits to others. Here, overall cost and benefit to society is defined as the sum of the economic benefits and costs for all parties involved.

## Implications

Standard economic theory states that any voluntary exchange is mutually beneficial to both parties involved in the trade. This is because either the buyer or the seller would refuse the trade, if it won't benefit both. However, an exchange can cause additional effects on third parties. From the perspective of those affected, these effects may be negative (pollution from a factory), or positive (honey bees that pollinate the garden). Welfare economics has shown that the existence of externalities results in outcomes that are not socially optimal. Those who suffer from external costs do so involuntarily, while those who enjoy external benefits do so at no cost.

A voluntary exchange may reduce societal welfare if external costs exist. The person who is affected by the negative externalities in the case of air pollution will see it as lowered utility: either subjective displeasure or potentially explicit costs, such as higher medical expenses. Alternatively, it might be seen as a case of poorly defined property rights, as with, for example, pollution of bodies of water that may belong to no-one (either figuratively, in the case of publicly-owned, or literally, in some countries and/or legal traditions).

On the other hand, a positive externality would increase the utility of third parties at no cost to them. Since collective societal welfare is improved, but the providers have no way of monetizing the benefit, less of the good will be produced than would be optimal for society as a whole. Goods with positive externalities include education (believed to increase societal productivity and well-being; but controversial, as these benefits may be internalized), public health initiatives (which may reduce the health risks and costs for third parties for such things as transmittable diseases) and law enforcement. Positive externalities are often associated with the free rider problem. For example, individuals who are vaccinated reduce the risk of contracting the relevant disease for all others around them, and at high levels of vaccination, society may receive large health and welfare benefits; but any one individual can refuse vaccination, still avoiding the disease by "free riding" on the costs borne by others.

There are a number of potential means of improving overall social utility when externalities are involved. The market-driven approach to correcting externalities is to "*internalize*" third party costs and benefits, for example, by requiring a polluter to repair any damage caused. But, in many cases internalizing costs or benefits is not feasible, especially if the true monetary values cannot be determined.

The monetary values of externalities are difficult to quantify, as they may reflect the ethical views and preferences of the entire population. It may not be clear whose preferences are most important, interests may conflict, the value of externalities may be difficult to determine, and all parties involved may try to influence the policy responses to their own benefit. An example is the externalities of the smoking of tobacco, which can cost or benefit society depending on the situation. Because it may not be feasible to monetize the costs and benefits, another method is needed to either impose solutions or aggregate the choices of society, when externalities are significant. This may be through some form of representative democracy or other means. Political economy is, in broad terms, the study of the means and results of aggregating those choices and benefits that are not limited to purely private transactions.

Private and social costs: Social costs are the spillover costs to society (society pays off the costs), while private costs are the costs given to the individual firms or producer.

**Examples**

A negative externality is an action of a product on consumers that imposes a negative side effect on a third party; its "social cost". Many **negative externalities** (also called "external costs" or "external diseconomies") are related to the environmental consequences of production and use.

- Air pollution from burning fossil fuels causes damages to crops, (historic) buildings and public health. The most extensive and integrated effort to quantify and monetise these impacts was in the European ExternE project series.

- Anthropogenic climate change is attributed to greenhouse gas emissions from burning oil, gas, and coal.

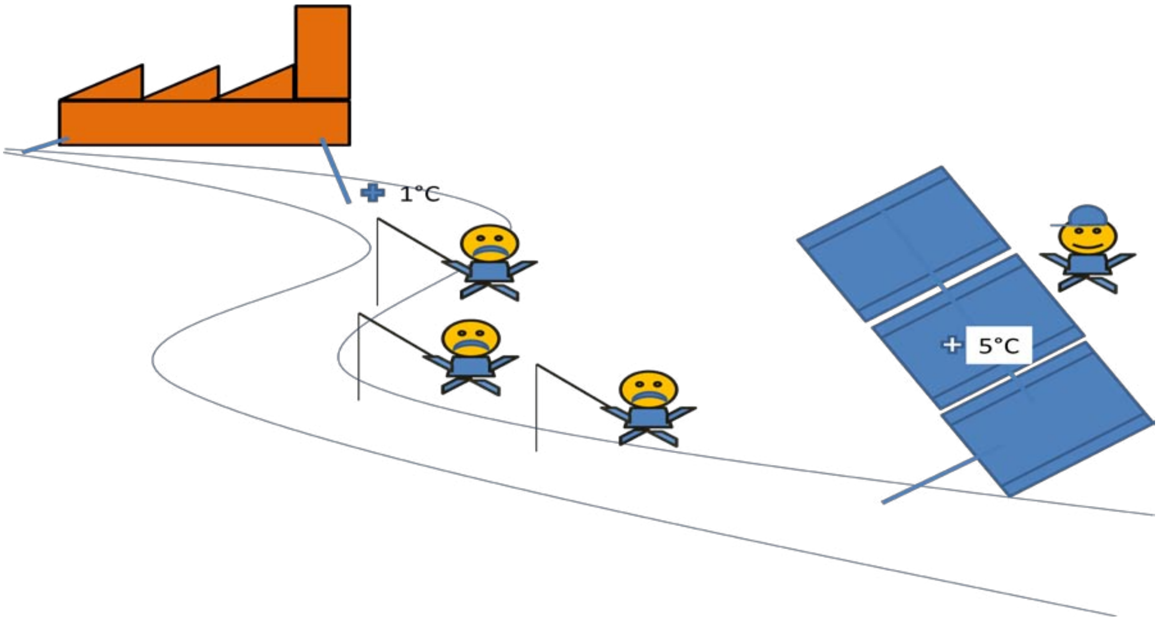
- Water pollution by industries that adds poisons to the water, which harm plants, animals, and humans.

Examples of **positive externalities** (beneficial externality, external benefit, external economy, or Merit goods) include:

- A beekeeper keeps the bees for their honey. A side effect or externality associated with his activity is the pollination of surrounding crops by the bees. The value generated by the pollination may be more important than the value of the harvested honey.

An example of an externality perceived as negative by some agents and positive by some others (Fig. 2). A power station situated upstream a river increases the water temperature of the water flow by 1°C. This reduces drastically the fish population of the river, reducing the welfare of local fishermen. At the same time, the higher river temperature is a benefit for the aquaculture farm situated downstream the river, which requires higher temperature (by 6°C) for its fish breeding. Now that the power station upstream warms the river, the farm requires an increase of temperature of only 5°C, with lower heating requirement and therefore lower costs for the farmer, who is now happier.

Figure 2. An externality perceived as positive or negative by different agents




## Formalization

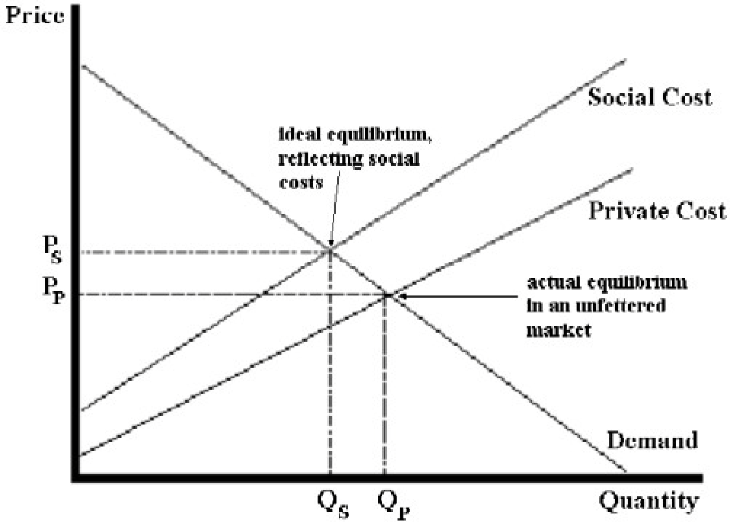
The usual economic analysis of externalities can be illustrated using a standard supply and demand diagram if the externality can be monetized and valued in terms of money. An extra supply or demand curve is added, as in the diagrams below. One of the curves is the *private cost* that consumers pay as individuals for additional quantities of the good, which in competitive markets, is the marginal private cost. The other curve is the *true* cost that society as a whole pays for production and consumption of increased production the good, or the marginal social cost (Fig. 3).

Similarly there might be two curves for the demand or benefit of the good. The social demand curve would reflect the benefit to society as a whole, while the normal demand curve reflects the benefit to consumers as individuals and is reflected as effective demand in the market.

The graph below shows the effects of a negative externality. For example, the steel industry is assumed to be selling in a competitive market – before pollution-control laws were imposed and enforced (e.g. under laissez-faire). The marginal private cost is less than the marginal social or public cost by the amount of the external cost, i.e., the cost of air pollution and water pollution. This is represented by the vertical distance between the two supply curves. It is assumed that there are no external benefits, so that social benefit *equals* individual benefit.

When environmental laws are applied and the industry must pay for the externalities produced, the new supply curve, represented by the social cost, appears. This determines new equilibrium price and quantity (Ps and Qs). A new "pareto optimum" is found.

Figure 3. Private and social costs. Market equilibriums when externalities exist




In other terms, in an economic system where all the goods and services are privately traded, and markets are in perfect competition, prices ($P_P$) define the long term equilibrium between supply and demand.

Therefore, resources are optimally allocated ($Q_P$) and the system is efficient.

But:

- Market failures exist (i.e. externalities)

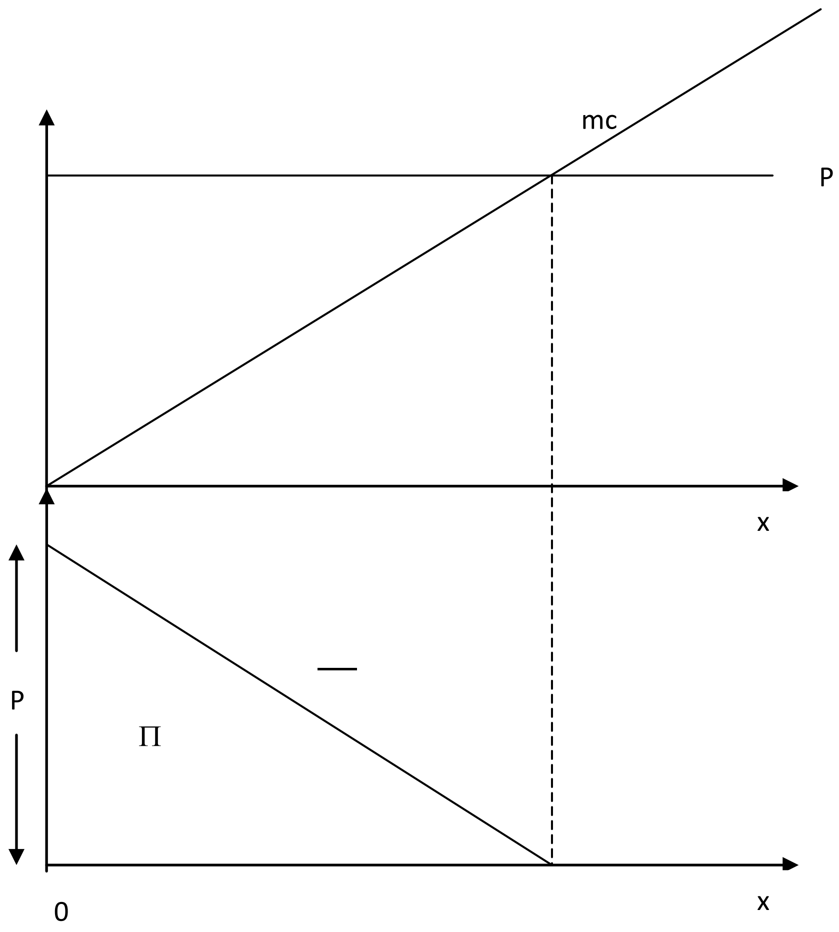
- Some goods are not privately traded (ex. common

  pool resources/ public good)

The new market equilibrium, in presence of an externality, can be calculated as follows.

Formally, the marginal cost of production is at the origin of the microeconomic theory about the behaviour of the producer. From its analysis, considering a market in perfect competition, where price P is given, the marginal net private benefit MNPB function can be derived, as follows.

First order condition (maximizing $\Pi$)




The optimal level of externality is indicated in the figure below (fig. 5), and correspond to A+B, which in the graph is the level of externality when producing Q*. In the absence of externality (or if an environmental policy is not implemented), $Q_{\Pi}$ would be the optimal level of production, leading to the maximization of producer's profit, and causing an externality A+B+C+D.

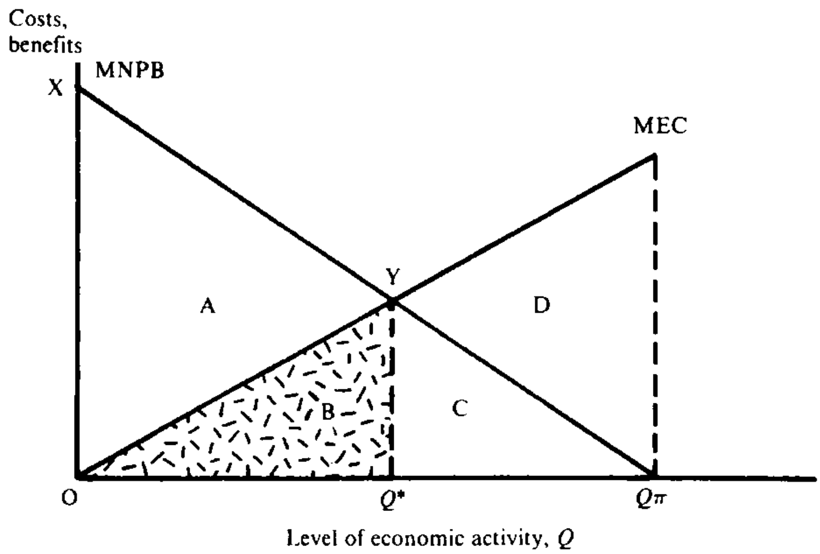



Fig. 5. **Economic definition of optimal pollution.**

The new price (PS) of figure 3 can be obtained by adding the external cost to the cost of production and identifying the social cost. The new first order condition in the production function equalizing the price to the marginal social cost will give $P_S$ as indicated below.

MNPB = MEC

MNPB = $P_P$-MC

Imposing => P -MC = MEC

=> $P_S$ = MC+MEC

MC+MEC = MSC

=> MNPB = MEC => $P_S$ = MSC

*This is the condition for Pareto-optimality* in presence of an externality.

**Possible solutions**

There are at least two general types of solutions to the problem of externalities:

- Command and control approach, based on interdictions, obligations, standards and related penalties;
- Pigovian taxes or subsidies intended to redress economic injustices or imbalances.

A Pigovian tax is a tax imposed that is equal in value to the negative externality. The result is that the market outcome would be reduced to the efficient amount. A side effect is that revenue is raised for the government, reducing the amount of distortionary taxes that the government must impose elsewhere. Economists prefer Pigovian taxes and subsidies as being the least intrusive and most efficient method to resolve externalities.

Ronald Coase argued that if all parties involved can easily organize payments so as to pay each other for their actions, then an efficient outcome can be reached without government intervention. Some take this argument further, and make the political claim that government should restrict its role to facilitating bargaining among the affected groups or individuals and to enforcing any contracts that result. This result, often known as the Coase Theorem, requires that

- Property rights be well defined
- People act rationally
- Transaction costs be minimal

### Key concepts treated

Externalities and external costs as market failures

New economic equilibriums in presence of externalities

Ways of correcting market failures and to redress the systems

Pareto optimal conditions

Pollution and externalities

### References

Pearce D., Turner R.K., 1990. Economics of Natural Resources and the Environment, Harvester Heatsleaf, NY, 378p. Chapter n. 4.

### Exercises

Provide a definition of a negative externality

Why externalities can be positive or negative?

Formalize graphically and mathematically the optimal level of externality

How can we reduce externalities?

# 6

# POLICIES FOR POLLUTION CONTROL AND WATER QUALITY IMPROVEMENT

Pollution and more specifically water pollution was presented earlier in this course as a source of negative externalities, bringing the system far from efficiency. Negative externalities can be controlled and possibly kept at their optimal levels through policies for pollution control deriving from environmental economic theory.

This chapter will illustrate the main policy tools for pollution control and their functioning in a system where externalities must be reduced.

The first step consists in defining the economic system.

## A basic economic system

We will deal here with the simplest possible economic system, composed by a producer that we consider also the source of pollution, and a pollutee, bearing the externality.

The **producer/polluter** will be a rational economic agent, trying to maximize his/her profit function:

$$\pi = py - x$$

$$y = \sqrt{x} \Leftrightarrow x = y^2$$

$$\pi = py - y^2$$

Where:

$\Pi$=profit

p=price

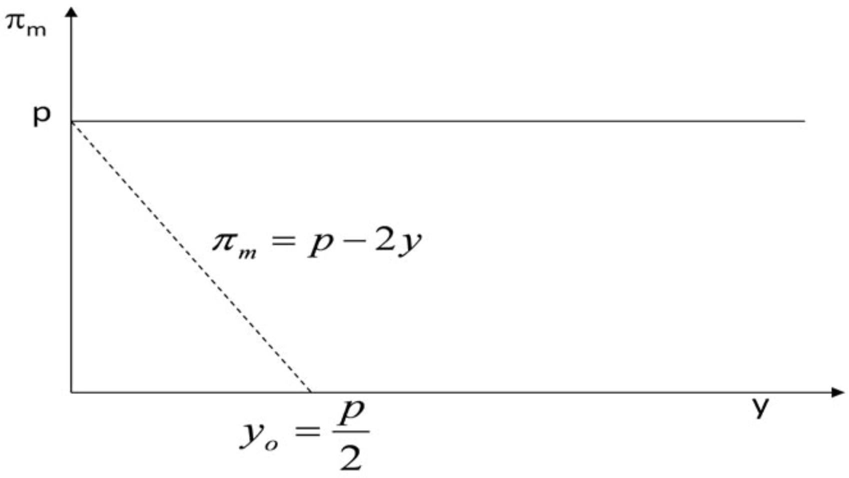
y=quantity sold

x=costs of production

Given the chosen profit function shape, the producer will maximize his profit at:

$$\frac{d\pi}{dy} = \pi_m = p - 2y = 0 \Rightarrow y_o = \frac{p}{2}$$

This condition can be represented graphically as follows:




The **pollutee** will suffer a welfare reduction (the externality) equal to:

$q = ay^2 \qquad a > 0$

$EC = \beta q \qquad \beta > 0$

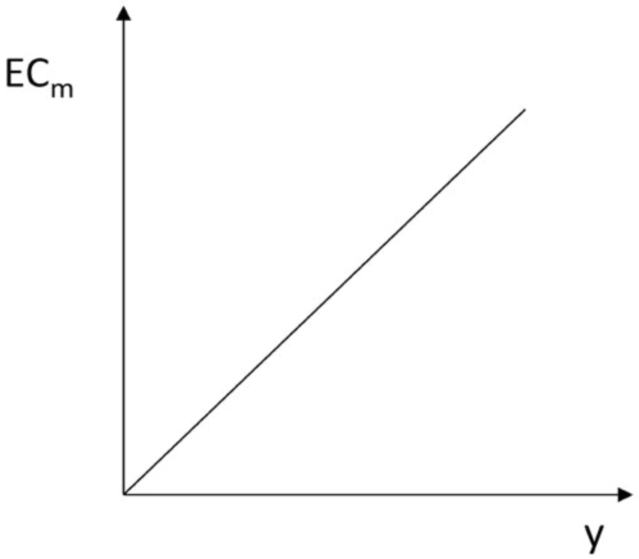
Where:

q is the pollution produced

EC is the external cost or the externality suffered

With the chosen function for EC, its marginal value is given by:

$$\Rightarrow EC = \beta a y^2 \Rightarrow \frac{\partial EC}{\partial y} = EC_m = 2\beta a y$$




If we consider the level of pollution $q_0$ where the producer maximizes his/her profit, the total level of externality at this point is:

$$EC = \beta q_0 = \beta a y_0^2 \ = \beta a p^2 / 4$$

By introducing the social cost represented by the externality into the private profit equation, we can obtain a social welfare function. The objective for the society is to maximize this new function as follows:

$$\max_y \pi - EC \Rightarrow \max_y py - y^2 - \beta a y^2$$

The first order condition for this will therefore correspond to:

$$\frac{\partial(\pi - EC)}{\partial y} = p - 2y - 2\beta a y = p - 2y(1+\beta a) = 0$$

$$\Rightarrow \ p = 2y(1+\beta a) \Rightarrow y^* = \frac{p}{2(1+\beta a)}$$

This is the optimal level of production for the maximum social welfare.

It can be noted that, as a>0 and β>0, then:

$$\Rightarrow y^* < y_0$$

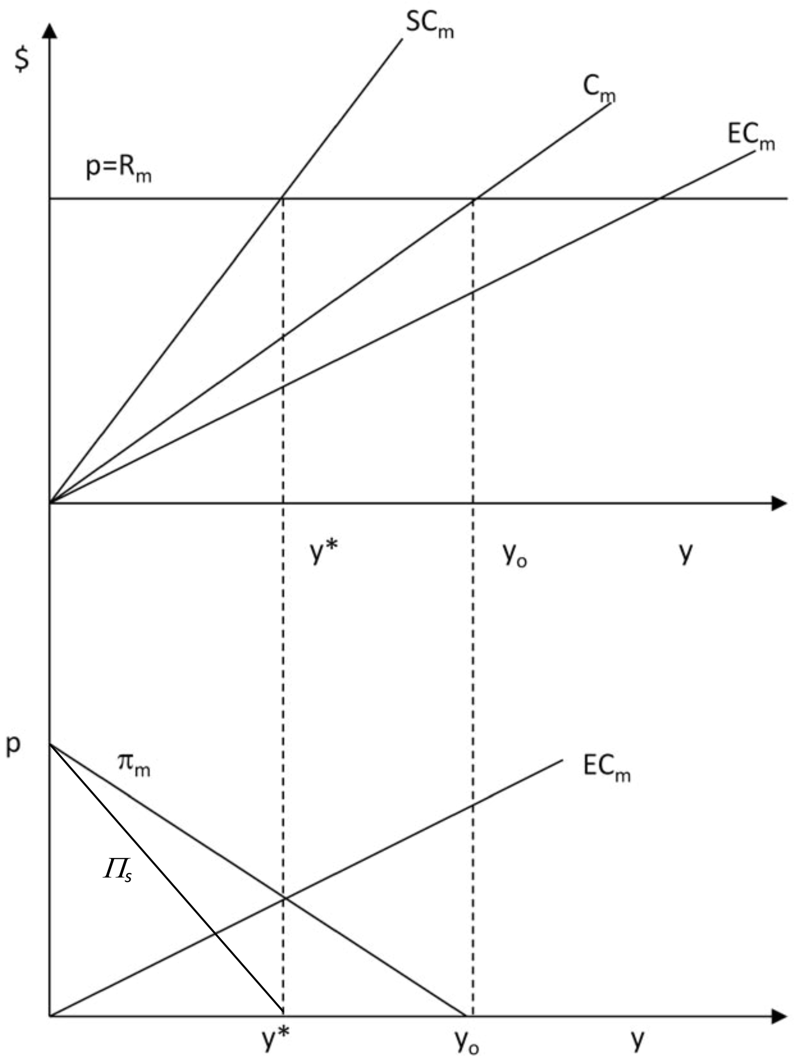
$$\Rightarrow q^* = a y^{*2} < q_0 = a y_0^2$$

This simple system of producer/polluter and pollutee can be represented graphically as follows, where the terms correspond to:

$$\pi_m = R_m - C_m = 0 \Rightarrow R_m = C_m$$

$$\pi_s = R_m - C_m - EC_m = 0 \Rightarrow$$

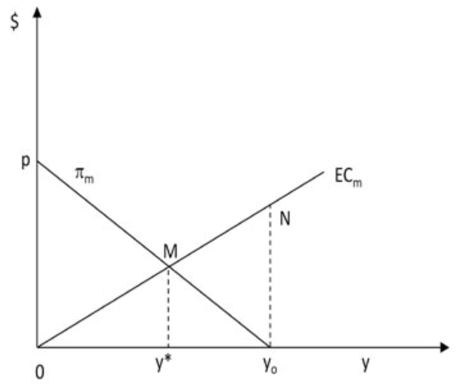
$$R_m = C_m + EC_m = SC_m$$




The **economic interpretation** of this can be analyzed in the figure below, where At y* the loss of private profit is ($y^*y_0M$), compensated by the reduction of external costs ($y^*y_0NM$). This brings the system to a net gain of ($My_0N$).

Similarly we can explain why it is not socially justified to reduce y<y*. The conclusion is that, according to the efficiency criterion, it is convenient to reduce ($y^*y_0NM$), but not (0y*M). The latter

is a "**Pareto irrelevant**" externality.



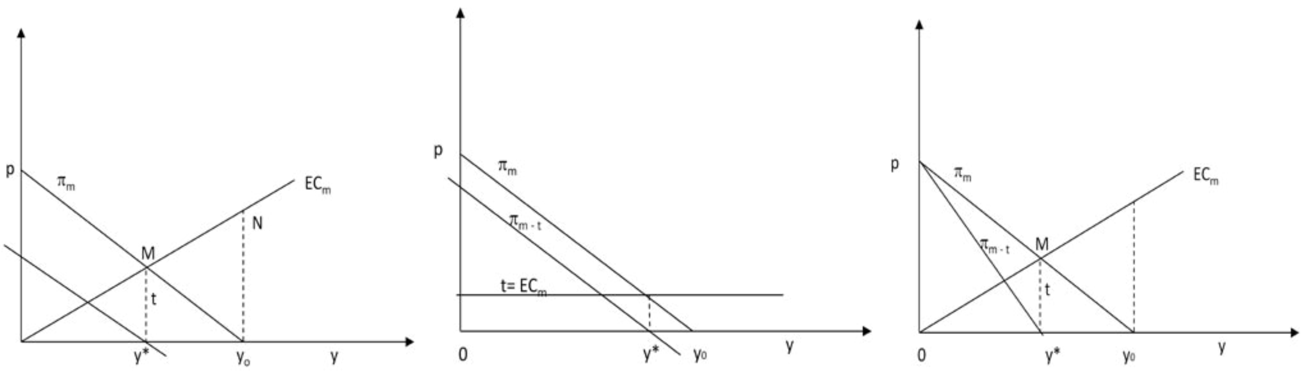
**How to reach the social optimum**

The most evident solution to reduce the external costs and reach the social optimum would be to reduce p of an amount My*. In this case, the producer/polluter would face a price = p-My* and the criterion of profit maximization would conduct him to a production =y*, as indicated in the following figure.

It is interesting to note that the first diagram (A), presented in most environmental economics manuals, is wrong. In fact, since t=ECm, either EC has a linear relation with y, and in this case the correct figure is B (ECm constant), or it has a quadratic relation with y (ECm linearly growing), and in this case the correct figure is C (with the resulting modified marginal profit function originating from p).

The formulation presented below is valid only for the case B. Conversely, the conclusion (only at y*) is valid for both B and C.

A B C




A tax based on the ECm, t, is the so-called **pigouvian tax**, from Cecil Pigou, who theorized first the application of this type of instruments to control pollution. When t=EC*m => corresponding to y*, then it is called optimal pigouvian tax.

The application of the pigouvian tax (My*) will push the producer with the profit function indicated above to produce the following level of production:

$$\pi = (p - My^*)y - y^2 \Rightarrow \pi_m = (p - My^*) - 2y = 0 \Rightarrow y = \frac{p - My^*}{2}$$

Or, calling the tax simply t:

$$\pi = (p - t)y - y^2 \Rightarrow \pi_m = (p - t) - 2y = 0$$

$$\Rightarrow y^* = \frac{p - t}{2}$$

**Numerical calculation of taxes and subsidies**

Now let's consider to have our system of pollutee and our polluting firm as defined above. Remember that the production function is:

$$y = \sqrt{x}$$

This is a Cobb-Douglas production function ($y=aX^bZ^c$), in this case: $y=X^{1/2}$

And let's calculate taxes and subsidies to reach the social optimum through a numerical example:

$p=12$

$\pi=12y-y^2$

$\pi_m=12-2y$

$\pi$ max when: $12-2y=0 \Rightarrow y_0=6$

$\pi$ max $=36$

Pollution: $q=0.01y^2 \Rightarrow q_0 = 0.36$

$EC=50q \Rightarrow EC_0=18$

Social optimum: $y^*=p/2(1+\beta a)=12/2(1+50*0.01)=4$

$q^*=0.16$

$\pi^*=32$

$EC^*=8$

In the numerical case presented above, the pigouvian tax would be t=4 for a y*=4, as described in the appendix.

We can proceed now to the **calculation of the tax or the subsidy necessaries to reach the social optimum**

We put two conditions:

1) There is no pollution abatement technique

2) As the objective is to reduce pollution, total & marginal $\pi$ of the polluter are a function of q

Because $\pi=12y-y^2$ and $q=0.01y^2$. Therefore $y=10\sqrt{q}$

$$\Pi(q) = 120\sqrt{q} - 100q$$

$$\frac{\partial \Pi}{\partial q} = 120\frac{1}{2}q^{-\frac{1}{2}} - 100 = 60q^{-\frac{1}{2}} - 100 = \frac{60}{\sqrt{q}} - 100$$

The necessary and sufficient condition for social optimum is that:

$\Pi$m(q)=ECm(q)

And therefore:

$$\frac{60}{\sqrt{q}} - 100 = 50 \Rightarrow \frac{60}{\sqrt{q}} = 150 \Rightarrow q^* = (\frac{60}{150})^2 = 0.16$$

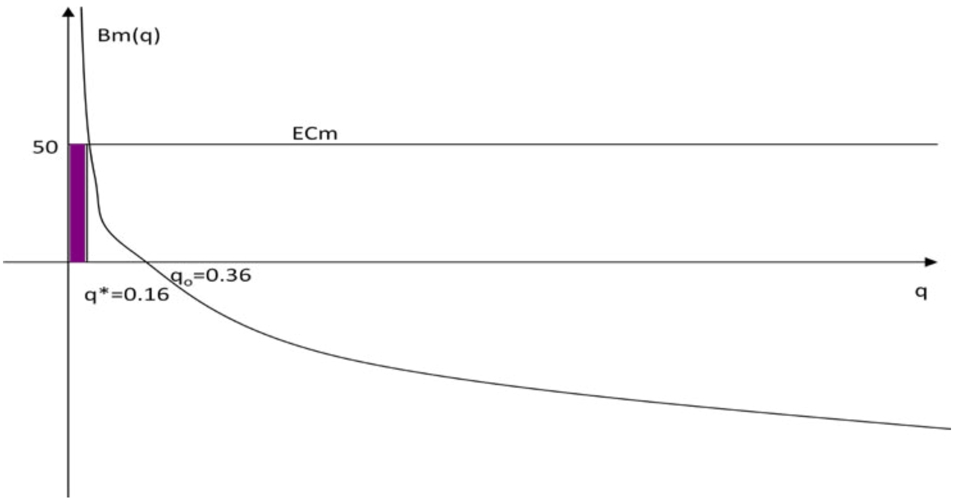
That confirms the result in the calculation of q* when $\Pi$ was in function of y.

**Definition of the optimal tax (t*), the one allowing to reach social optimum**

t = the tax rate is uniform and is applied to q => T=tq => T=tay$^2$ =>T=0.01ty$^2$

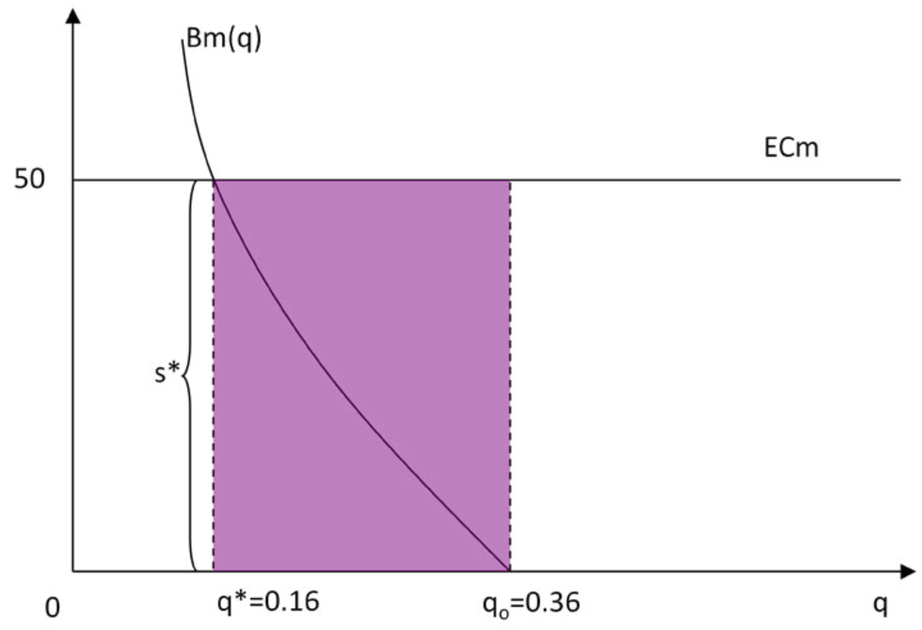
t*=$\Pi$m(q*)=$\delta$T/$\delta$q=50

T*=8=(50)(0.16)




T* is the product of the tax and takes the form of a revenue for the env. Agency.

**Definition of the optimal subsidy (s*), the one allowing to reach social optimum**




The social optimum can be reached applying a subsidy to the system. In this case the producer polluter is pushed to reduce pollution up to q=0.16 by accepting a compensation for the loss of benefit.

s=uniform rate of subsidy

$S=s(q_0-q^*)$, $q_0=0.36$

$\Pi m(q^*)=\delta S/\delta q=s^*=t^*=50$

$S^*=50(0.36-0.16)=10$

**Standard and associated penalty**

A third way of regulating pollution would be the **application of a standard at q=0,16 and the imposition of a penalty** equal to t* or s*, but applicable only in the case of transgression.

**Interpretation of the economic transfers following the different regulating tools**

In the case of the application of a **standard and penalty**, the producer/polluter, considered as respectful of the standard, gets $\pi^*$, the pollutee looses the “pareto irrelevant externality” = 8, while the agency does not pay or receive anything, as the producer is considered to respect the standard. The problem here is in fact the loyalty of the producers and the difficulty and cost of enforcement of this tool.

In the case of the **tax**, the producer gets $\pi^*$-T*. The polluter still looses 8, while the agency gets the income coming from T*.

Finally, in the case of the **subsidy**, the producer is the winner, as he gets $\pi$*+S*, while the polluter still looses 8 and the agency must pay S* to the producer.

| | **Standard** | **Tax** | **Subsidy** |
|---|---|---|---|
| **Polluter** | **32** | **24** | **42** |
| **Pollutee** | **-8** | **-8** | **-8** |
| **Agency** | **0** | **8** | **-10** |
| **Total** | **24** | **24** | **24** |

For a total social surplus at q* of 24 in the three cases, it is clear that the **taxes** are those tools imposing the payment of EC to the polluters, and produce an income to the agency, that can use it for either compensate the pollutee or for other purposes (second dividend). Taxes are also easier to collect than penalties and they require much less control and police enforcement. In the case of a **standard**, the agency does not get any payment, while the polluter is relatively happy as he gets all $\pi$* without the need to compensate the pollutee for EC*. But the costs of enforcements and the risk of non compliance of the standards are not calculated here, while they are usually very high. This is why standards, unlike taxes, are often considered non efficient (and non effective by the way) tools for pollution control. **Subsidies** are finally very appreciated by producers/polluters as they earn more than what they would producing without environmental regulation ($\pi$max=36), but they are very costly for the agency and in the absence of pollution abatement, they can stimulate more producers to get into the industry, then increasing the pollution.

**Co-operation between parties, the Coase approach**

**Ronald Coase** in an article published in 1960 and titled “The problem of social cost”, showed that under certain conditions, very difficult to observe in real life, the social optimum could be obtained simply by leaving the parties bargaining. This is known as the Coase theorem. There is no doubt that co-operation among agents (here polluter and pollutee) would be of benefit for the whole society. Here below, the non co-operation is presented as a competitive game, where the two players, the polluter and the pollutee, have two possible strategies each: abate pollution or not for the polluter: protect himself from pollution or not for the pollutee. In the case of pollution control, the polluter will pay the cost of it, and his profit $\Pi 1$ will reduce by three units. In the case of protection from pollution, the pollutee, even spending for it, will anyway increase his welfare with respect to the situation where he does not protect himself. We have therefore here two dominant strategies: No pollution control for the polluter and Protection for the pollutee. They will choose these strategies regardless the choice of the other party. This will bring the system to the situation No Control-Protection (which is here a Nash Equilibrium), where the social profit is 33, lower than the 34 of the situation Control-Protection. The equilibrium is therefore not efficient. Policy interventions (taxes, standards/penalties, subsidies, etc.) could push the parties to co-operate and therefore reach the Pareto optimal condition instead of the Nash equilibrium.

**Interest in co-operation:**

pollutee

| polluter | No protection | | | Protection | | |
|---|---|---|---|---|---|---|
| | $\pi 1$ | $\pi 2$ | $\pi$ | $\pi 1$ | $\pi 2$ | $\pi$ |
| No pollution control | 20 | 10 | 30 | 20 | 13 | 33 |
| Pollution control | 17 | 15 | 32 | 17 | 17 | 34 |

Solution = non-co-operative equilibrium =Nash

To reach a Pareto optimum => External intervention

More precisely, the Coase theorem states that:

- If a clear and definite property rights system is established, polluters and pollutees are pushed spontaneously to bargain and to reach an efficient allocation of resources => co-operative equilibrium =>Pareto optimum.
- This equilibrium is reached regardless of who has the rights.

The Coase theorem can be illustrated with the example below, where one polluter and one pollutee bargain.

$z=q_0-q$ = pollution-control effort

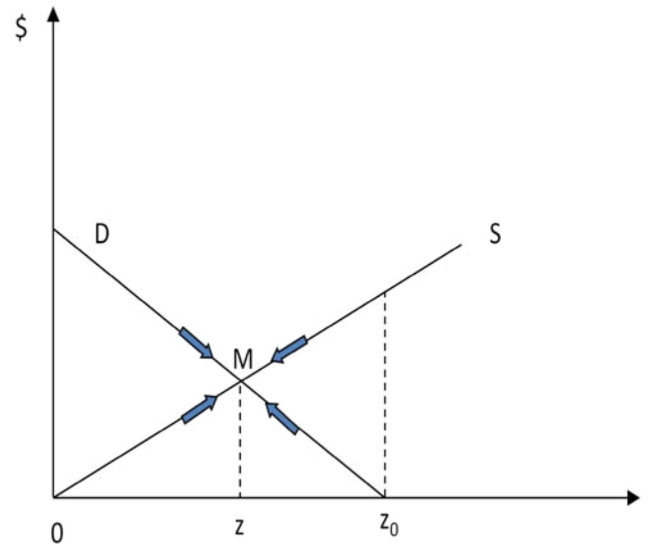
ECm = marginal external cost = pollution-control demand by pollutee (D(z))

$\pi_m$=marginal benefit of pollution= pollution-control supply by polluter (S(z))

ECm is an increasing function of q; $\pi_m$ is a decreasing function of q (NB it was constant in the previous examples). Therefore they are respectively increasing and decreasing functions of z.

$D(z)=ECm(q_0-q)$. This is the marginal willingness to pay for pollution control; $S(z)= \pi_m(q_0-q)$. This is the marginal willingness to pay to pollute.

If the law defines that there should not be any pollution in the environment, bargaining starts at $z_0$ (polluter-pays principle); if the law gives the polluter a right of exclusive use of the environment, then the bargaining starts at 0.




The Coase theorem is very difficult to apply in the real world. Coase himself identified a number of constraints making of it a nice theoretical framework, but almost impossible to implement.

Transaction costs, income effects and free-riding are some of the major hurdles. Furthermore moral hazard, i.e. the polluter does not know the actions of the pollutee (asymmetry of information), is often present.

**Income effects**

These effects change the equilibrium point as a result of the bargaining, and therefore hamper to reach the social optimum. In this case The equilibrium changes according to the legal framework.

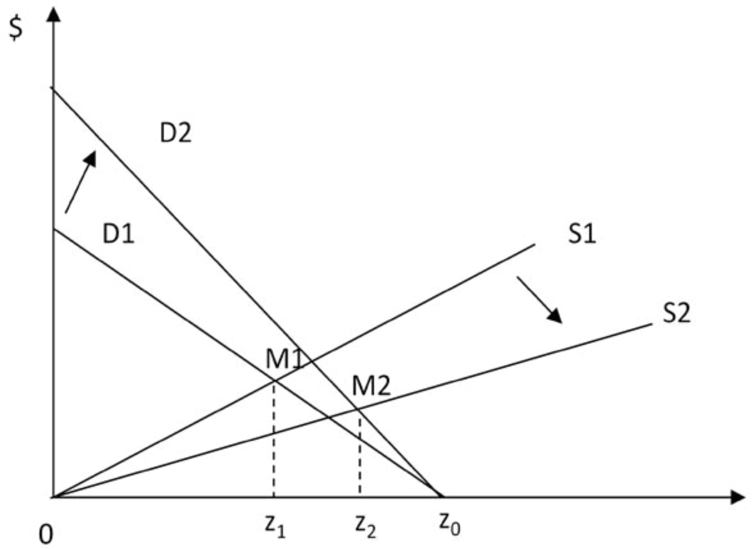
Case 1 polluter not responsible

Case 2 polluter responsible.

In case 2 the polluter must compensate the pollutee. The latter increases his revenue whereas the polluter decreases his one =>effect on the demand/supply curves.

NB: M and the corresponding z change and $z1<z2$.

The final equilibrium that follows a bargaining and the consequent pollution-control effort will be different following different initial distribution of rights on the use of the resources.




**Transaction costs**

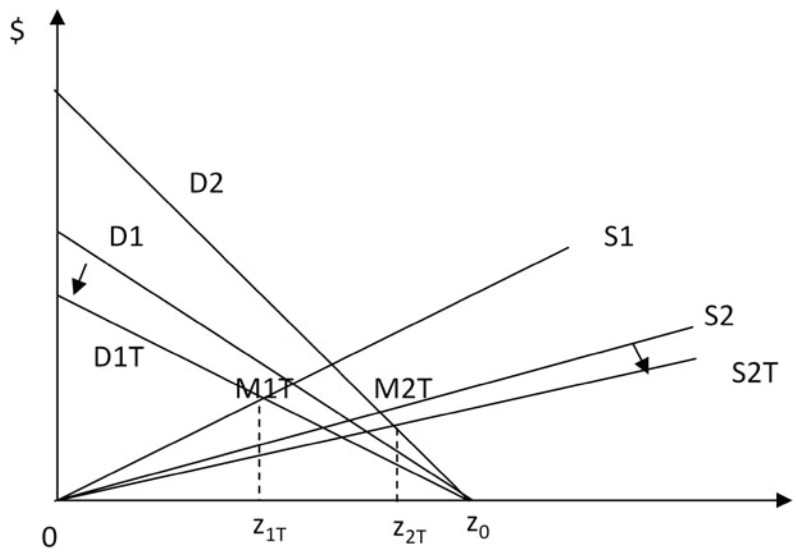
Case 1 polluter not responsible

Case 2 polluter responsible.

In case 1 the pollutee must engage the negotiation, and bears the transaction costs (TC). His demand therefore decreases to D1T. In case 2 the polluter has to engage negotiation and pays TC => his supply functions becomes S2T

at M1T the corresponding z1T< z1

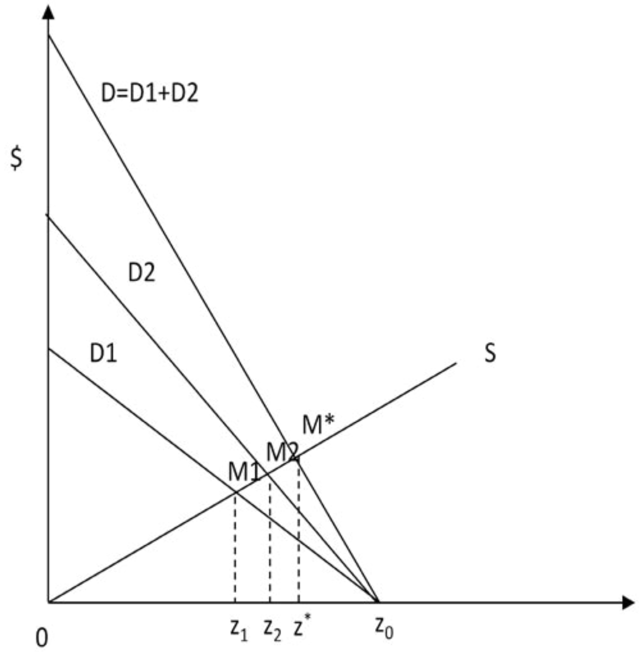
at M2T the corresponding z2T>z2




In conclusion, Income effects and TC do not refute the first part of the Coase theorem, because an equilibrium is reached, but the second part, because the equilibrium depends on the property rights distribution.

**Free riding**

If we have two pollutes, the demand for pollution control is the verical agregation of D1 and D2




Let's suppose we are in situation 1=polluter not responsible. This means that pollutee 1 is not interested in taking part to the negotiation, because leaving pollutee 2 to bargain, he will benefit of the negotiation at 0 cost of a level of pollution-control (z2) higher than the one he would achieve bargaining individually with the polluter (free riding). This implies that the pollutee 1 knows the demand function of pollutee 2.

In other terms M* and the corresponding z* would imply a cooperation between pollutees. But this , in presence of free riding, doesn't take place and M2 is not a social optimum.

**Using taxes to reach a standard at the lowest possible cost**

This framework was introduced by Baumol and Oates in 1977 and goes under the definition of "efficiency without optimality".

We consider now that the agency does not know the pollution abatement technologies and costs. The objective is therefore to reach standards defined to protect population's health at the lowest possible cost.

A didactic example is shown below, with **two polluting firms, and an agency**. This allows nonetheless observing some interesting general findings.

The two firms have the same profit function as the one shown at page 5. But they have a different function of pollution (different technologies):

$q_1=0.1y_1$ $\qquad$ $q_2=0.2y_2$

$q^o_1=0.6$ $\qquad$ $q^o_2=1.2$ $\qquad$ => $\qquad$ $Q^o=1.8$

If a standard is going to be imposed $Q^*<Q^o$ => it allows reaching $Q^*$ by applying to each firm a reduction of pollution equal to the ratio $Q^*/Q^o$. For instance: if a standard 0.9 is the objective, both firms have to reduce by ½ their pollution, and therefore of their production (no pollution abatement technique is considered here). But this is not the solution at the lowest cost, resulting in a total cost of 18 (9 for each firm as the profit passes from 36 to 27) consequent to the reduction by 2 of their production.

Expressing the two profit functions with respect to q:

$\pi_1(q_1)=120q_1-100q^2_1$

$\pi_2(q_2)=60q_2-25q^2_2$

Starting from $q^o_k$ with k=1,2 any reduction of the pollution determines a reduction of profit (due to the fact that there is no pollution abatement, and therefore the only way of reducing pollution is reducing production). The latter can be written as:

$AC_k(q_k)= \pi_k(q^o_k)- \pi_k(q_k)$ [1]

And deriving:

$AC_{m1}(q_1)=120-200q_1$

$AC_{m2}(q_2)=60-50q_2$

The respect of Q* at the lowest cost brings to the solution of the following program:

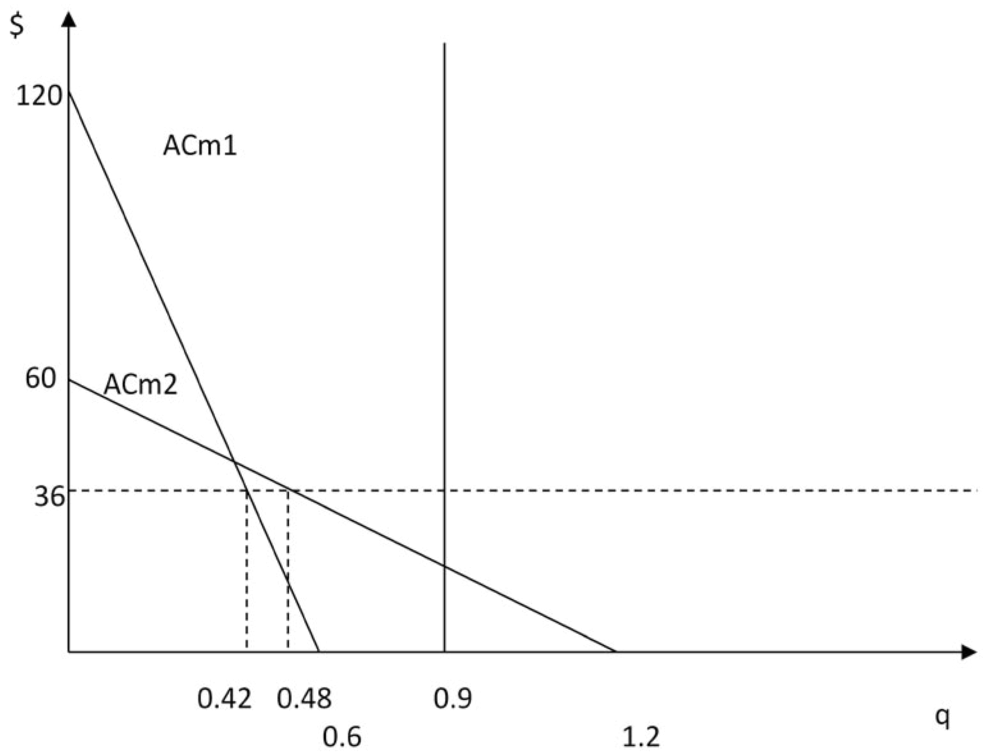
- $AC_{m1}(q_1)=120-200q_1-\lambda=0$
- $AC_{m2}(q_2)=60-50q_2-\lambda=0$
- $q1+q2=Q^* = 0.9$

The unique solution of this simple lagrangean verifies: $AC_{m1} = AC_{m2}=\lambda$

$q^*1=0.42$; $q^*2=0.48$; $\lambda^*=36$

Substituting q*1 and q*2 in [1], AC1(0.42)=3.24, AC2(0.48)=12.96

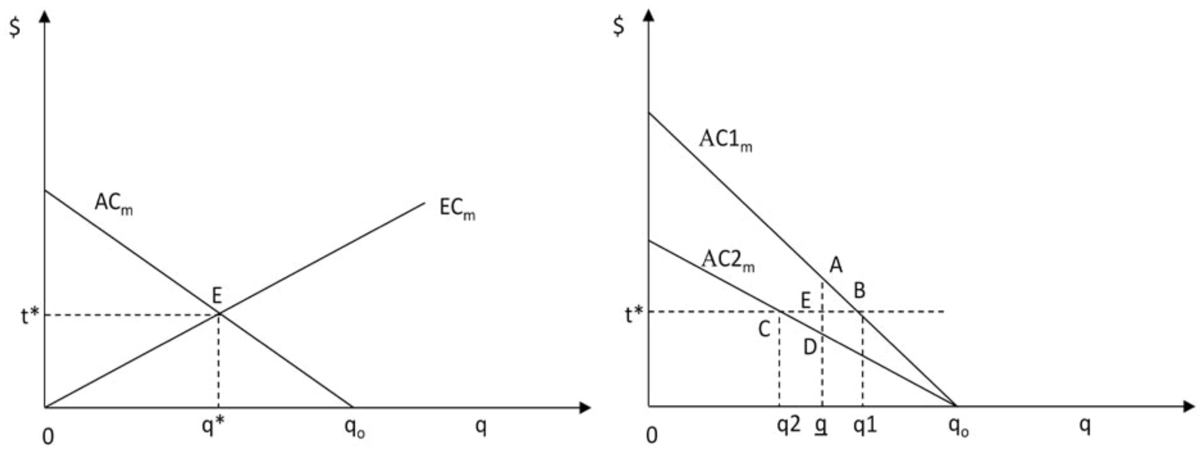
This determines a total cost AC1+AC2= 16.20<18 which would be the cost if the simple division by 2 of the pollution from the two firms was required.




In conclusion, the tax allows the firms to adapt their level of pollution control in function of their technologies and costs; and this makes the taxes more efficient than the standards. Of course, this is valid assuming that both polluters pay t* for the pollution produced until the standards, being these standards individualized or not.

This example can be generalized as follows:

Let's suppose that the environmental agency has calculated t* that would bring the system to the social optimum. Adopting t* would push the firm 1 to q1 and the firm 2 to q2. The same result could be reached by q=1/2(q1+q2), but at a higher cost. In fact q would impose an effort of pollution control too high for 1 and too small for 2, with an additional pollution-abatement cost corresponding to the sum of the areas EAB (real cost)+ECD (unutilized resources) (assuming that a tax is paid for the pollution produced until the standard, being it individualized or not).



Analysis of the economic transfers following the different regulating tools:

Application of the tax to reach Q*

The first polluter pays (36)(0.42)=15.12 and the second pays (36)(0.48)=17.28 for a total of 32.4. This amount goes to the agency.

If a subsidy of the same unitary amount is applied, polluter 1 receives (36)(0.6-0.42)=6.48 and the second receives (36)(1.2-0.48)=25.92 for a total of 32.4 that goes from the agency to the polluters.

The agency can also just define an individualised standard to 0.42 for the first and 0.48 for the second polluter. This will not imply any economic transfer.

All these solutions are equivalent under the social point of view, but not in terms of economic consequences of the policy adopted. Financial transfers can improve or worsen the economic position of polluters or agency.

**Key concepts treated**

How to formalize the simplest economic system with an external cost (one polluter and one pollutee)

How to reach the optimal level of externality (social optimum)

How to calculate environmental policy instruments: tax, standard, subsidy

Taxes to reach standards

Bargaining among economic agents and Coase theorem

**References**

Pearce D., Turner R.K., 1990. Economics of Natural Resources and the Environment, Harvester Heatsleaf, NY, 378p. Chapter n. 5-7.

**Exercises**

Provide a definition of pigouvian tax

Why taxes are more efficient that standards and penalties for pollution control?

What is the second dividend

Why the Coase theorem is difficult to apply in reality?

Provide a definition of free riding and moral hazard

# APPENDIX

## Relation between production, pollution and externality in the presented economic system

**Basic functions:**

$q = ay^2$ Quadratic relation between q and y

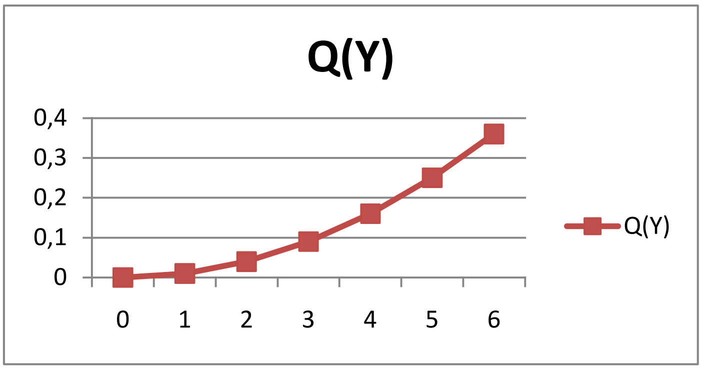
$EC = \beta q$ Linear relation between EC and q => quadratic between EC and Y

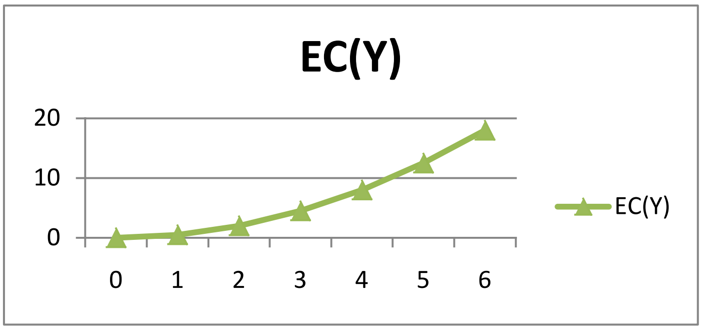
**Numerically:**

*q=0.01y²*

*EC=50q = 50*0.01 y²*

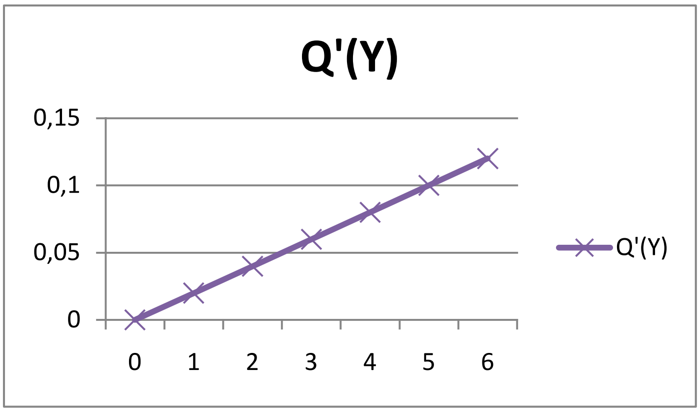
**Graphically :**

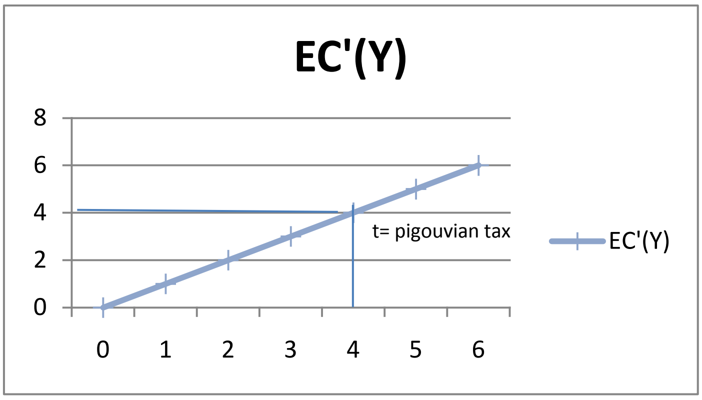



**The derivatives of these functions:**

**Graphically:**




**The numeric relation between EC and Q:**

*EC=50q*

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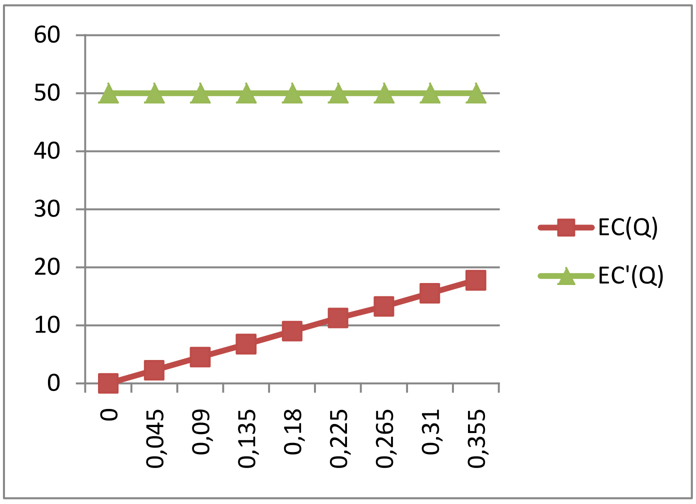
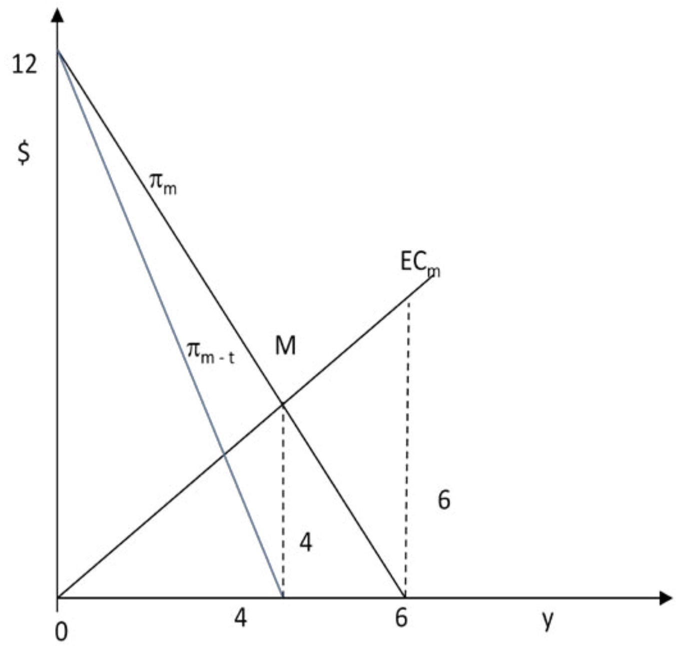
**Graphically:**



It can be observed in this last figure that EC is a linear and growing function of q, while its derivative (marginal EC(q)) is a constant on 50. And 50 would be the value of EC(q) when q=1. Also note that when q=0,16, then EC(q)=8, as in the example at p. 7.

**Optimal pigouvian tax for the economic system presented in the text**

Let's remember that the simple economic system was as follows:




$\pi=12y-y^2$

$\pi_m=12-2y$

$\pi$ max =36

Pollution: $q=0.01y^2 \Rightarrow q_0 = 0.36$

$EC=50q \Rightarrow EC_0=18$

Social optimum: $y^*=p/2(1+\beta a)=12/2(1+50*0.01)=4$

$\pi^*=12.4-4^2 = 32$

$EC^*=8$

$T=t.q= EC^*=8$

$\pi^*-t = 24$

The producer-polluter is forced to pollute up to y* (4) and compensate the pollute (or the agency) for the pareto-irrelevant externality = 8. His/her profit is socially optimal = area 0-M-12 = 24.

# 7

# WATER INSTITUTIONS AND GOVERNANCE

## An institutional perspective of water management[3]

The neoclassic mainstream approach is dominant in the economic analysis regarding water resource management and allocation. This approach is based on the research of the efficiency and looking at Pareto optimality as the criterion to be followed in order to allocate natural resources (Cf. chapter on valuation and welfare economics).

This "orthodox" approach (since alternative economic paradigms such as the ecological economics, the institutional economics etc. are considered "heterodox") presents a number of simplifications and shortcomings that are addressed below and that suggest an alternative and complementary economic approach for the management of water resources.

The main shortcomings of the mainstream approach have to do with: the lack of consideration for distributional aspects among society members; the lack of consideration for the institutional and legal framework arrangements among economic agents; the lack of dynamic and temporal perspective.

These shortcomings are presented by Bromley (1982) through four examples:

- The faultiness of Pareto optimality
- The ambiguity of Pareto-irrelevant externalities
- The presumed providence of private property and the lack of consideration of future effects of bargaining (the arbitrary use of the discount rate)
- The false assumption that the existing institutional arrangements are "optimal".

In essence, according to Bromley, Pareto optimality and economic efficiency are not an adequate basis for guiding collective action. An institutional perspective, in the sense of the neo-institutional economics (NEI)[4] is then proposed as a framework to understand water and land management policies and their consequences.

Following NEI, **institutions** are "collective conventions and rules that establish acceptable standards of individual and group behaviour". **Organizations** are then the "operationalization of the institutions", and being an organization, the firm is the physical manifestation of a constellation of institutions.

(Negative) **externalities**, previously defined as external costs, market failures that create a gap between Pareto-optimality and the real system even when all the welfare economics conditions are respected (perfect competition markets bringing to optimal allocation of inputs for production and optimal distribution of utility among consumers), are now seen as divergences between the nominal and the real boundaries of a concern at stake (e.g. water pollution). As a consequence,

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[3] The first two paragraphs of this chapter are extracted from Bromley, DW (1982).

[4] Williamson, O (1981) « The modern corporation : origins, evolution, attributes », Journal of economic literature, 19 (1981) : 1537-68.

where the mainstream economist proposes a tax to internalize the externality, the NEI looks at the dynamic nature of the firms and the analysis would focus on the implication of changes in the choice domain of the firm (the boundaries).

The reason for creating a firm, in NEI, is to reduce **transaction costs**, considered as those costs appearing before the occurrence of a transaction and to allow it. Outside the firm, the market is an organization itself, and price movements guide resource flows. Inside the firm, these market transactions are replaced by entrepreneurial direction. The firm is a constellation of contracts among owners of production factors. There are items for which the firm acquires full and permanent control (employees) and other for which partial and temporary control is chosen (consultants).

**Externalities** exist when decisions made by a firm hold important implications for other firms or consumers and these implications are beyond the recognized (institutional and/or physical) boundaries of the firm, and there are no contracts regulating those impacts. There is therefore an **incongruity between the real and the nominal domain of the firm**.

These gaps between real and nominal boundaries must be filled in order to control and possibly eliminate externalities. It is a matter of identifying and implementing those rules (contracts, institutions) that would regulate the problems at stake and provoking externalities. When the gaps are filled, private and public institutions come together at certain points of their boundaries. At those points, there is interference on each other's choices and the (dynamic) process of determination of the legitimate range of choice is a difficult phase of negotiation and social dialogue among public and private institutions. It is a necessary aspect of the modern economy.

**Institutions and water management**

Mainstream economists operate in complete isolation from the role of the **courts** and the **legislatures**. But it is there and to a lesser extent in administrative agencies that rights, duties privilegies over the use of natural resources and therefore water are debated and determined. The value of natural resources is therefore to a large extent determined there and not in the market (which usually for these goods do not exist).

An institutional perspective of water management is therefore essential to understand the functioning and the role of those actors in determining the rules and therefore the value of the resource.

Also, **distributional issues** cannot be ignored and looking only at economic efficiency, without considering aspects like equity and environmental sustainability is a too limiting vision of the reality

A NEI perspective of water management would proceed from a recognition that the boundary of the firm (and therefore the domain of choice open to the entrepreneur and its relations with the other economic and institutional agents) is a policy variable along with tax policy, public expenditure and the like.

Some economists think that water access problem ought to be solved by determining the most efficient allocation scheme based on willingness to pay on the part of would-be user groups. But not all things that are scarce and valuable are bought and sold. And water is often among them. More relevant, what determines the conditions of relative scarcity or abundance and therefore the

WTP of water users is the institutional and technical framework where they deal with the resource. Market are after all creations of the societies and not conversely.

Therefore, matters of who controls scarce and variable natural resources such as water should be decided on the basis of a deep social and institutional analysis instead of a narrowly constructed (and often unrealistic) Pareto optimality criterion. It is important to know **who gains and who loses** by the policy alternatives regarding water management.

Summarizing, questions on who controls water, who benefits from that control, and who pays for current use patterns are for Bromley the very questions representing the essence of water economics today. As a consequence, a reformulated water economics should start with a careful social and institutional analysis of the situation regarding the rules regulating the access to and the choices for the use of water. Water management is a **public policy problem** precisely because markets either produce socially unacceptable results, or are not implementable.

A work "**on the ground**", at the local or intermediate scale, as water problems are usually local problems, that cannot be generalized, should be accompanied with new models and approaches (such as multi-agent models, dynamic systems, role-playing games, etc.) in order to take into account the institutional and social aspects presented above. Orthodox analysis and tools should not be abandoned, but their importance should be referred to the scale and scope of a larger approach encompassing the social and ecological dimensions.

**Water governance and institutions: some definitions**

In order to approach the issue of water governance, some generally accepted definitions are provided.

***Institutions*** are norms and rules according to North (1991). As previously indicated, institutions should not be confused with organizations. They can be either formal (e.g. formal constitutional rules like a political system, laws, property rights etc) or informal (behavioural norms, actors' taboos, traditional values, sanctions etc). Institutions structure individual's behavior in their political, social, economic interactions. They make possible collective action and stabilize cooperation modes between actors and organizations. Thus institutions are also defined as the "rules of the game".

***Water governance*** can be defined as 'the range of political, social, economic, and administrative systems that are in place to regulate the development and management of water resources and provision of water services at different levels of society'. (GWP). Therefore, governance refers to the whole range of institutions, networks, directives, legislations, norms, social and political usages, as well as public and private actors who contribute to the stability of a society and of a political regime, to its orientation, to its steering capacity, and to its ability to deliver services and to assure its own legitimacy.

***Institutional arrangements*** are the sets of working rules that are used to determine who is eligible to make decisions in some arenas, and what actions are allowed or constrained. Further, the rules describe what procedures must be followed, what information must or must not be provided and what payoffs will be assigned to affected individuals (Ostrom, 1990), according to neo-institutional economy.

***Decentralisation*** is the process of bringing decision-making processes closer to people and/or citizens. Decentralisation can be done through a government agency or within a government department.

***Agentisation*** is the delegation or assignment of government functions to a public entity or agency such as a Catchment Management Agency or Water Board. An agency can take on either a centralised or a decentralised function.

**An example[5]:** *Water supply and sanitation in South Africa, the institutional and governance system.*

The National Water Act of South Africa (NWA, 1998) promotes integrated and decentralized water resource management under a new institutional environment. The act proposed a radically different framework with respect to previous national water laws, particularly with regards to rights to water. Under the new NWA, water is considered a public resource and only the rights to use but not own water are granted to users through a licensing system for which users are required to pay. Another major feature of the NWA is decentralization of water management through establishment of catchment level water management institutions such as Catchment Management Agencies (CMAs) and Water Users' Associations (WUAs). Finally, protective measures are meant to secure water allocation for basic human needs, ecological and development purposes (the concept of Reserve) (Farolfi & Perret, 2002).

Social development, economic growth, ecological integrity and equal access to water remain key objectives of the new water resource management regulation. The mentioned institutions have been put in place over the last thirteen years at various geographical and institutional levels, emphasizing a largely decentralized and participatory approach to water resource management.

The National Water Resource Strategy (NWRS) is the implementation strategy for the NWA and provides the legally binding framework within which water resources in South Africa should be managed (DWAF, 2002). The main objective of the NWRS is to match and balance water demand with water supply (the concept of reconciliation), following the sustainability, equity and efficiency objectives of the NWA.

In terms of water services provision, in 1994 the government published its first White Paper on Water and Sanitation Policy, which led to the Water Services Act of 1997.

The Act calls for higher cost recovery, which proved a challenge due to widespread poverty and a culture of non-payment for water in many Townships, as a remnant of protests against Apartheid. Higher water tariffs and rigorous cut-offs for non-payment, or flow reductions through the installation of "tricklers" that allow only a very limited flow of water, imposed hardships on the poorest.

The Act also modified the role of Water Boards (see below), providing a clear legal definition of the functions of Water Boards and municipalities. Water Boards have historically been the only bulk water providers. Municipalities were obliged to buy water through them. The Act allowed municipalities to develop their own bulk water supply infrastructure or to buy bulk water from providers other than Water Boards. Conversely it also allowed Water Boards to provide retail

[5] This paragraph is based on Farolfi S (2004) "Action research for the development of a decision support tool towards decentralized water governance in SA"; working paper University of Pretoria, n. 18076, and on the Wikipedia site "Water supply and sanitation in SA".

water services at the request of municipalities. Since the Act has been passed the capacity of both Water Boards and many water service providers has increased significantly.

After Thabo Mbeki became President of South Africa in 1999 and a cholera outbreak occurred in 2000, the African National Congress promised **free basic water** during a municipal election campaign in December 2000. In July 2001 a revised tariff structure was suggested that included 6 "kilolitres"" (cubic meters) of free water per month (40 litre/capita/day for a family of five or 25 litre/capita/day for a family of eight). Putting the policy of free basic water in practice proved a challenge. The policy is only being implemented gradually.

In response to the fact that access to sanitation lags significantly behind access to water, the government published its White Paper on Basic Household Sanitation in 2001. It called for universal access to basic sanitation by March 2010, with priority accorded to communities with the greatest needs. The policy outlines the roles of the various stakeholders - households, municipalities, provincial governments, various branches of national government - and establishes coordination and monitoring mechanisms. It also calls for Infrastructure Grants to municipalities to finance investments in sanitation.

The Department of Water Affairs is responsible for the management and protection of bulk water, and for its allocation among competing uses and users.

The provision of water supply and sanitation services is also regulated by the national government, represented by the Department of Water Affairs (DWA), as a policy setter.

DWA coordinates the activity on the field of two main groups of stakeholders:

- Water Boards, which provide primarily bulk water, but also some retail services and operate some wastewater treatment plants, in addition to playing a role in water resources management;
- Municipalities, which provide most retail services and also own some of the bulk supply infrastructure.

Banks, the professional association WISA (Water Institute of Southern Africa), the Water Research Commission and civil society also are important stakeholders in the sector.

Here below the main stakeholders in the South African water services provision are listed and briefly described:

**Water Boards**. Government-owned Water Boards play a key role in the South African water sector. They operate dams, bulk water supply infrastructure, some retail infrastructure and some wastewater systems. Some also provide technical assistance to municipalities. Through their role in the operation of dams they also play an important role in water resources management. The Water Boards report to the Department of Water Affairs. There are 13 Water Boards in South Africa, together indirectly serving more than 24 million people in 90 municipalities in 2005, or about half the population of South Africa.

**Municipalities**. According to the Constitution, the Municipal Structures Act and the Water Services Act of 1997 responsibility for the provision of water and sanitation services lies with the municipalities, which in practice means the country's 52 district municipalities. The national government can also assign responsibility for service provision to local municipalities, of which there are 231. Overall, there are 169 water service authorities in South Africa, including water boards, district municipalities, local municipalities and municipal companies. The responsibility for rural water supply and sanitation has been transferred from the national government, represented by DWAF, to municipalities.

**Private sector participation**. Since 1994 some municipalities have involved the private sector in service provision in various forms, including contracts for specific services such as wastewater treatment, short-term management contracts and long-term concessions.

**Research, training and knowledge**. South Africa has a fairly strong research and training infrastructure in the water sector. The Water Research Commission (WRC) supports water research and development as well as the building of a sustainable water research capacity in South Africa. It serves as the country's water-centred knowledge 'hub' leading the creation, dissemination and application of water-centred knowledge, focusing on water resource management, water-linked ecosystems, water use and waste management and water utilisation in agriculture. The Water Institute of Southern Africa (WISA), a professional association, keeps its members abreast of the latest developments in water technology and research through its national and international liaison, links and affiliations.

**Financiers and promoters**. The Development Bank of Southern Africa (DBSA) is an important player in the water and sanitation sector, both as a financier and as an advisor and project promoter. In 2005-2006 about 29% of its approved projects were for water supply (1,881 million Rand) and sanitation (165 million Rand). Other financing institutions in the sector include the Infrastructure Finance Corporation Limited, which claims to be the only 100% privately owned infrastructure debt fund in the world.

**Civil society**. South Africa has a vibrant civil society, comprising a large number of non-governmental organisations (NGOs) with very diverse goals, membership and methods. On the one hand, civil society includes militant so-called "new social movements" that sprang up after the end of Apartheid.

### An important aspect of water governance: decentralization

Most Southern African countries put in place or amended their water laws and policies during the last 15 years or so, and restructured their institutional and governance frameworks accordingly.

For instance, South Africa voted its National Water Act (NWA) in 1998 and then its National Water Resources Strategy in 2002. Zambia amended in 1994 its Water Act of 1970, whilst Mozambique and Tanzania approved their National Water Policies respectively in 1995 and in 2002, and Namibia voted its Water Resources Management Act in 2004.

Integrated water resource management (IWRM) inspired new Southern African water policies. Among the four so-called Dublin principles (ICWE, 1992) representing the pillars of IWRM, stakeholders participation is the one calling for river basin management at the lowest appropriated level. This refers to the idea of decentralization of water policies implementation. Several authors indicate that effective decentralization requires devolution of authority and responsibility from the center, and acceptance of that authority and responsibility by local entities in the basin. In other terms, following the subsidiary principle, the design and implementation of water management and allocation policies are transferred from the State to local institutions, which are supposed to have a better knowledge of the catchment functioning and where representatives of local water stakeholders are allowed to negotiate and decide jointly water management strategies and measures to be put in place.

While much effort and goodwill was put into decentralization reforms in many basins in the region, results are not uniformly realized. For instance, in South Africa twelve years after the launch of the new NWA, only two catchment management agencies (CMAs) out of the 19 originally foreseen are operational, while many water user associations (WUAs) still struggle to find their place and role in the complex and somehow confused context of water management. In other Southern African countries, the process of decentralization in the water management institutions is even less advanced. It is the case of Mozambique, where in the early 1990s the water sector was highly centralized with all planning, implementation and operational responsibilities and functions in the hands of the National Directorate for Water. Since then, the sector has implemented comprehensive decentralization reforms by progressively setting up regional water administration entities (ARAs). But the only ARA currently fully operational is ARA-Sul, which is responsible for the southern part of the country.

The relatively slow development of the Southern African river basins agencies witnesses the difficulty of implementing decentralization in practice.

Among the main difficulties scholars and practitioners identify in Southern Africa water decentralization processes, the lack of knowledge and information among the relevant stakeholders, including water institutions' staff members, and the lack of negotiation and decision-making tools seem to be particularly relevant and calling for urgent attention.

In South Africa, DWA and local observers recognize the lack of capacity within the department and the necessity to implement decentralization actions through other actors:

- There is currently a serious lack of capacity to ensure compliance monitoring and enforcement given existing capacity within DWA at National and the Regions.

- There are without question, some local government and other role players that have technical, legal and fiscal capability to act decisively but lack the mandate or legal tools.

- The current policy and legal frameworks make provision for delegation of such responsibility, under DWA oversight and regulation, or where the CMA process has commenced, under delegated sub-CMA responsibilities.

**Tools and processes for participatory decision-making** at the local and intermediate levels are seen as important factors for successful water governance decentralization.

In order to address the need of innovative methods for local stakeholders' participation in water management, within a project supported by the Water Research Commission of South Africa, a participatory process called Companion Modelling (ComMod) was implemented in the Kat River valley (Eastern Cape province), where the local WUA was busy drafting its catchment plan. A catchment plan is a document that, once approved by the National Department of Water Affairs, allows the WUA implementing autonomously water allocation strategies on its catchment.

ComMod is a scientific posture based on the use of simulation models and role-playing games (RPG) to assist participatory management of natural resources. Two main features characterize this approach. The first is to take into consideration, from the beginning of the modelling process, the stakeholders' view of the studied problem. The second is to validate model hypotheses through the experience of the stakeholders. ComMod consists of an iterative process of comprehension, confrontation and analysis that involves local users, institutions and researchers. This iteration is also aimed at validating or refuting the tools, such as models and role-playing games, which will be then adopted by stakeholders for local negotiation.

Based on ComMod, the construction of a model called KatAware took place. Several versions of the model and a related RPG were developed with the local WUA.

The ComMod process in the Kat valley lasted three years and was instrumental for the successful negotiations within the local WUA conducting to the production of the catchment plan.

A number of shortcomings, however, were identified by an ex-post external evaluation of the exercise. The ComMod process was considered too long by most of the local stakeholders, and the KatAware model was perceived as a prescriptive and normative tool rather than an interface to facilitate discussions. The related RPG only partially redressed this perception.

In order to address these shortcomings, another project was launched in two different South African catchments (Sabie and Sand in the Mpumalanga province) with the objective to develop a generic platform for negotiation, called Wat-A-Game (WAG), which is aimed at facilitating and speeding-up the construction of new applications adapted to specific realities. WAG, yet still at a prototype stage, was successfully tested in real negotiation contexts and in educational arenas, proving its versatility and potential as an interface for information exchange and negotiation support around water issues at various institutional and geographical scales.

Applied research is currently underway in Southern Africa in the field of new methods and tools that facilitate dialogue and improve decision-making skills of local stakeholders for effective, equitable and sustainable water management. This research is designed and implemented in very close collaboration with all parties involved in water policy decentralization, in order to prevent the risk of failure due to the lack of commitment by some actors in the participatory process and, consequently, the reduced social legitimacy of the developed methods.

**Key concepts treated**

Institutions and organizations

Transaction costs

Firms

Contracts

Externalities in neo-institutional economics

Firms and institutions boundaries

Decentralization

Agentisation

Participation

Tools and processes for water participatory management

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## Exercises

Why mainstream economics is an insufficient framework to study water issues?

What is the difference between an institution and an organization?

What does it mean that institutions can reduce transaction costs?

What do we mean by governance in the water sector?

What is decentralization?

Can you describe a negotiation platform to facilitate water governance?

What is a role-playing game, and why it can be useful to improve water governance?

# 8

# WATER PRICING

Water pricing[6] is a term that covers various processes to assign a price to water. These processes differ greatly under different circumstances.

*Bottled water* is a pure private good. Private or public companies obtain the right to exploit water sources and put water in bottles that are then sold in market at market prices. Retail prices vary widely between countries, brands, bottle sizes (0.33 liter to 20 liters) and place of sale (supermarket, restaurant etc.). They range from US$ 0.20 to US$6 per liter, equivalent to US$ 200 to US$ 6,000 per cubic meter.

In countries where households do not have access to piped water supply, water sellers distribute bulk water by *tanker trucks*. Prices for trucked water are set in the market and vary between about US$1 and US$6 per cubic meter.

Prices for *piped water* supply provided by utilities, be they publicly or privately managed, are determined administratively. They vary from US$ 0.01 to almost US$ 8 per cubic meter (including sewer tariffs).

Prices for *irrigation water* that is being provided by a public agency are also typically determined administratively, usually using a flat rate, since metering is not common in agriculture in most countries of the world. The following pricing systems exist for irrigation:

- Area-based tariffs
- Volumetric pricing, which requires measurement

Tariffs can vary between crops grown and seasons, with higher tariffs charged during the dry season. Agricultural water tariffs vary widely in different countries. In Australia, in the Murray Darling basin, agricultural water prices are in 2010 around 0.6 US$/m3. In France, according to an OECD study, they can combine a volumetric part that goes from 0.001 to 0.01 Euro/m3 to with an area based tariff of about 80 Euro/Ha and per year. Flat rates of 200 Euro/Ha also exist. In Mexico, volumetric charges ranging from 0.02 to 0.4 US$/m3 or flat rates ranging from 20 to 85 US$/Ha have been observed.

In most countries there is no charge for *abstracting water directly from rivers, lakes and aquifers*. However, some countries do levy volumetric charges or fees for water abstraction rights. These charges are typically levied on industries, utilities and farmers. Fees for water abstraction and discharge exist for example in France (redevances), where revenues are significant and are re-invested in the water sector by water agencies established in major basins. In Germany abstraction fees exist only for groundwater and only in some states, and their proceeds go into the general state budget. Mexico also charges for water abstraction and returns proceeds to utilities, but not to industries. Outside the OECD countries few countries charge water abstraction fees. South Africa is one of the rare examples. In almost all countries that have introduced abstraction fees agriculture, the major water user worldwide, is exempted from abstraction fees. Some countries allow water rights to be traded, so that the price for water itself is formed in the market. Such water markets exist in parts of Australia, Chile and the Southwestern United States.

Table 1 summarizes the range of water prices observed around the world for water in its different ways of provision and for different uses.

[6] This paragraph and the following one are modified texts from Wikipedia's definitions for "Water Pricing" and "Water Tariff", to which the authors have added data and information from various sources.

**Tab. 1 Water prices around the world and in various forms (in US$)**

| | Bottled water | Tanker trucks | Piped water | Irrigation water |
|---|---|---|---|---|
| Price/m$^3$ | 200 to 6,000 | 1 to 6 | 0,01 to 8 | 0,001 to 0,6 |
| Flat Rates/Ha | | | | 20 to 80 |

**Water tariffs**

Investment costs for an improved water provision consist of pipelines, pumps, excavation costs, etc. They are usually paid by the local municipality, or the public or private company (e.g. in South Africa the Water Boards) in charge of potable water provision and sanitation services. These companies or local authorities can then recover their investment (and in some case the O&M) costs through the introduction of water tariffs that consumers pay.

A water tariff is a price assigned to water supplied by a public utility (publicly or privately owned) through a piped network to its customers. The term is also often applied to wastewater tariffs. Water and wastewater tariffs are not charged for water itself, but to recover the costs of water treatment, water storage, transporting it to customers, collecting and treating wastewater, as well as billing and collection. Prices paid for water itself are different from water tariffs. They exist in a few countries and are called water abstraction charges or fees.

Water and wastewater tariffs include at least one of the following components:

- a volumetric tariff, where metering is applied, and
- a flat rate, where no metering is applied.

Many utilities apply two-part tariffs where a volumetric tariff is combined with a fixed charge. The latter may include a minimum consumption or not.

Volumetric tariffs can:
- decrease with consumption (decreasing-block tariffs)
- increase with consumption (increasing-block tariffs)
- be proportional to consumption (uniform tariffs)

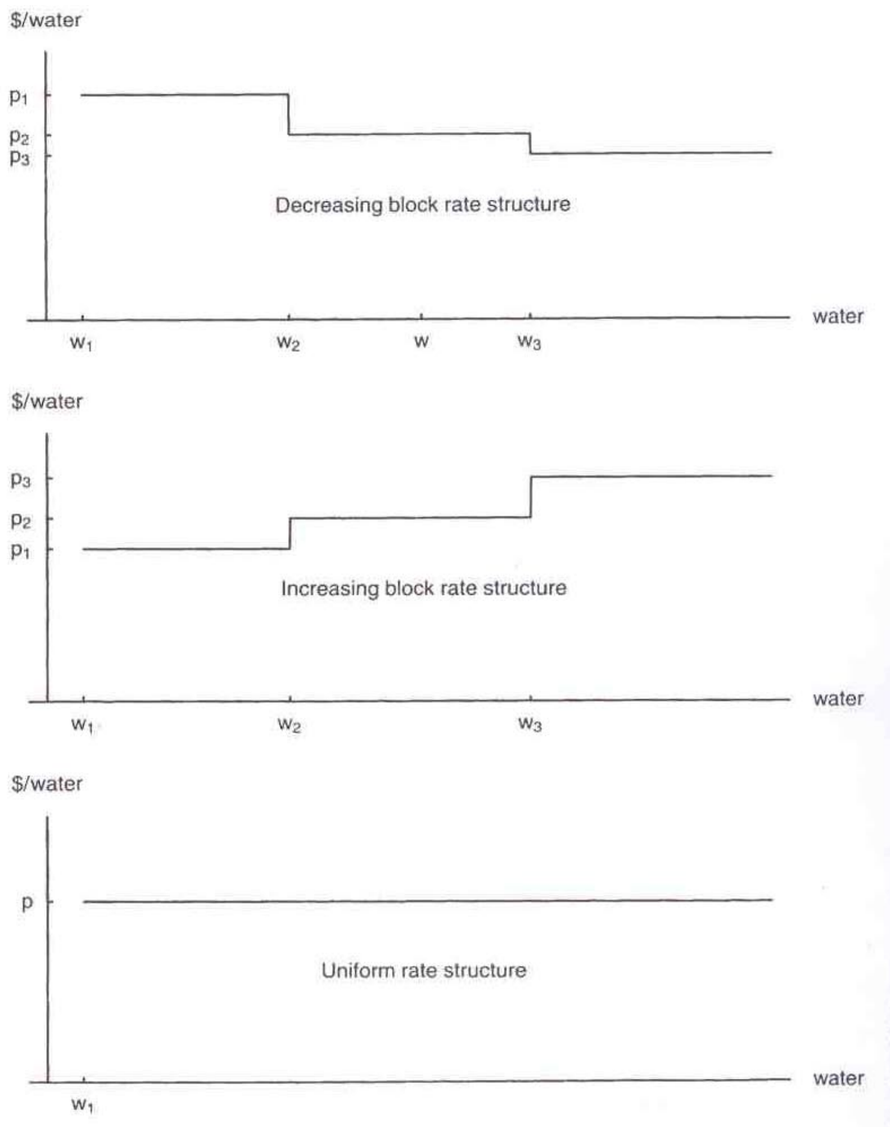
The following figure (Fig. 1) shows the three tariff structures.

The tariff for a first block on an IBT is usually set at a very low level with the objective to protect poor households that are assumed to consume less water than non-poor households. The size of the first block can vary from 5 cubic meters to 50 cubic meters per household and month. In South Africa, the first block of consumption of 6 cubic meters per household and month is even provided for free (free basic water).

Wastewater tariffs typically follow the same structure as water tariffs.

Linear volumetric and Increasing-block tariff systems tariffs are the most common form of water tariffs in OECD countries. Decreasing-block tariffs are apparently only still found in some cities of the United States.

**Fig. 1 Volumetric tariff structure**




## Tariff levels

According to one of the most used methods to compare water tariffs, the highest water and wastewater tariff in the world is found in Scotland, equivalent to US$9.45 per m$^3$ in 2007. The lowest water tariff in the world is found in Ireland, where residential water is provided for free, followed by Cuba with a water tariff equivalent to US$ 0.01 per m$^3$ and no wastewater tariff.

The Global Water Intelligence ran a survey in 2008 on water and wastewater combined prices. The results shown in tables 2 and 3 emerged.

**Tab. 2**

| Top 10 combined water and wastewater tariffs | |
|---|---|
| 1. Copenhagen | $8.69/m³ |
| 2. Aarhus | $8.20/m³ |
| 3. Berlin | $7.00/m³ |
| 4. Glasgow | $6.71/m³ |
| 5. Gent | $6.15/m³ |
| 6. Frankfurt | $5.86/m³ |
| 7. Cardiff | $5.84/m³ |
| 8. Luxembourg | $5.67/m³ |
| 9. Düsseldorf | $5.60/m³ |
| 10. Hamburg | $5.58/m³ |

**Tab. 3**

| Top 10 combined water and wastewater tariff increases | |
|---|---|
| 1. Minsk (Belarus) | 93% |
| 2. Lviv (Ukraine) | 50% |
| 3. Istanbul (Turkey) | 45% |
| 4. Calcutta (India) | 40% |
| 5. Chisinau (Moldova) | 38% |
| 6. Lima (Peru) | 38% |
| 7. Debrecen (Hungary) | 38% |
| 8. Antananarivo (Madagascar) | 37% |
| 9. Warsaw (Poland) | 33% |
| 10. Almaty (Kazakhstan) | 32.6% |

| Bottom 10 combined water and wastewater tariffs | |
|---|---|
| 1=Ashgabat (Turkmenistan) | Free |
| 1=Dublin (Ireland) | Free |
| 1=Cork (Ireland) | Free |
| 1=Belfast (UK) | Free |
| 1=Tripoli (Libya) | Free |
| 6. Baghdad (Iraq) | $0.002/m³ |
| 7. Havana (Cuba) | $0.009/m³ |
| 8. Tashkent (Uzbekistan) | $0.011/m³ |
| 9. Colombo | $0.015/m³ |
| 10. Riyadh | $0.027/m³ |

## Adjusting tariffs

The process of adjusting water tariffs differs greatly from one location to another. In many large countries the process of price adjustment takes place at the municipal level. Rules for price adjustments vary greatly. In the case of public service provision, tariffs are typically adjusted through a decision by the municipal council after a request by the municipal utility. Some countries, such as Germany, stipulate by law that all the financial costs of service provision must be recovered through tariff revenues. Other countries define cost recovery as a long-term objective, such as in Mexico. In the case of private service providers tariff adjustment rules are often laid out in concession or lease contracts, often providing for indexation to inflation.

In some developing countries, water tariffs are set at the national level. Tariff increases are often considered a politically sensitive issue and have to be decided by the Cabinet of Ministers or a National Pricing Commission.

Some countries have created regulatory agencies at the national level, like the CRA in Mozambique, that review requests for tariff adjustments submitted by service providers.

**Water consumers' reactions to changes in water prices**

The responsiveness of demand to a change in price is measured by the **price elasticity of demand**, which is defined as the percentage change in demand divided by the percentage change in price. The price elasticity of drinking water demand by urban households is typically low. In European countries it ranges between -0.1 and -0.25, i.e. the demand for water decreases by 0.1% to 0.25% for every 1% increase in tariffs. In Australia and the United States price elasticity is somewhat higher in the range of -0.1 and -0.4.

**Affordability and social aspects of water pricing**

In about half the OECD member countries, affordability of water charges for low-income households is or could become a significant issue. In developing countries, the poor are often not connected to the network and often pay a higher share of their meager incomes for lower quantities of water supplied by water vendors through trucks. On the other hand, utility bills paid by those fortunate enough to be connected to the network are very low in some developing countries. Different countries have introduced a variety of approaches to protect the poor from high water tariffs.

The affordability of water charges can be measured by macro- and micro-affordability. **Macro-affordability** indicators relate national *average* household water and wastewater bills to *average* net disposable household income. In OECD countries it varies from 0.2% (Italy and Mexico) to 1.4% (Slovak Republic, Poland and Hungary). In the largest OECD countries the share is 0.3% in the United States and Japan, 0.7% in France and 0.9% in Germany. However, **micro-affordability** is quite different. It measures the share of bills in the income of the poor, defined in an OECD affordability study as the lowest decile of the population. This share varies between 1.1% (Sweden, Netherlands, Italy) and 5.3% in the Slovak Republic, 9.0% in Poland and 10.3% in Turkey.

In developing countries the situation is more serious, not only because of lower incomes, but also because the poor are often not connected to the network.

Countries and utilities can therefore put in place social protection measures, such as **income support measures** and **tariff-related measures** in order to insure that piped water remains affordable for the poorest. Income support measures address the consumer's ability to pay and can take the shape of income assistance, water services vouchers, tariff rebates and discounts, bill re-phasing and easier payment plans, arrears forgiveness. On the other side, tariff-related measures keep the size of water bills low for certain groups (e.g. refinement of increasing-block tariffs, tariff choice, tariff capping). The cases of South Africa (free basic water) and the Flanders are good examples of tariff-related measures. Cross-subsidization using different tariffs for different neighborhoods is also possible.

**The French case of pollution charges and their impact on wineries wastewater treatment**

In France, the system of water management and governance based on the Catchment Management Agencies (*Agences de l'eau*) allows for positive (subsidies) and negative (charges called *redevances*) incentives for water users and polluters. This system is based on the economic **polluter (or user) pays principle.**

The charges paid to the catchment agency for pollution represented in 1996 about 13% of the total water tariff that an average consumer had to pay for piped water, and its increase over the previous 6 years was the main responsible for the total water tariff increase. Therefore, a study was run in the south of France in order to understand the reaction by an important industry in the region, the water industry, as a result of the wastewater charge increase.

In effect, since ruling no. 93-1412 of 29 December 1993, the pollution charge on wineries has increased fifteen fold in seven years (from FF 0.35/hl in 1990 to FF 5.10/hl in 1997).

On observing the reaction on the part of wine producers in Languedoc to anti-pollution legislation, we saw that it is primarily the *polluter pays* principle, represented by a pollution charge, combined with subsidies for investment in depollution offered by the local catchment agency, which, in terms of efficiency without optimality approach (Baumol and Oates, 1975), has given the most significant results.

**Regulatory framework: the carrot and stick policy**

The charge (*redevance*) (*Rb)* is the product of the pollution *(Qb)* times the specific coefficient of pollution *(Kp). Qb* is expressed as the volume of effluent discharged on an average day of peak company operations month. This is the yearly pollution charge that wineries have to pay to the local Water Board if they do not treat their effluents. The formula also includes a zonal coefficient *(Kz)*, becoming:

$Rb = QbKpKz$

If the company decides to reduce pollution levels, primarily by introducing an effluent treatment system, a bonus *(P)* is deducted from the gross charge, leaving a net charge *(Rn)* of:

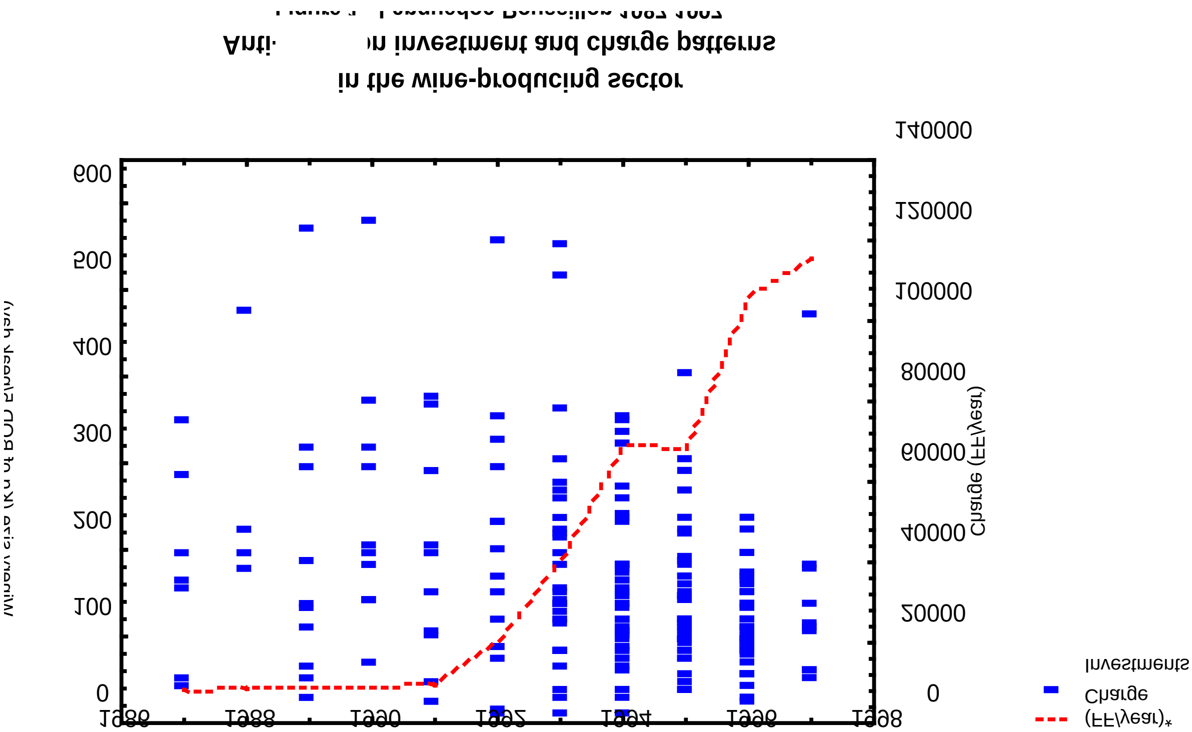
$Rn = Rb-P$

This bonus is directly linked to the evaluation, by the Water Board, of the efficacy of the chosen treatment system for each pollutant.

In opposition to the «negative» principle of a pollution charge, there is the «positive» principle of helping producers wanting to treat their effluents by introducing pollution control technologies. This aid is primarily granted by the Water Board, and is mostly funded by the income from the pollution charge.

Figure 2 shows the «race to invest in depollution» among wineries in the region, in response to the increase in the pollution charge applied to the sector. In particular, we observed the rate at which small and medium-sized wineries chose to invest in an effluent treatment system, as the pollution charge increased.

**Fig. 2**




We set out to show that polluters responded rationally to financial incentives, minimizing the cost of polluting by investing in effluent treatment technology.

The economic calculation made by winery managers can be expressed as follows:

*K1 = annual cost of depollution*
*K2 = annual charge*

Thus: $K1 = ki(1-a)\Delta Q + kg\,\Delta Q + R\,Qn$
$K2 = R\,Qb$

Where:

*ki = unit annual cost of depollution investment*
*a = proportion of investment subsidized*
*ΔQ = annual quantity of pollution treated*
*kg = unit annual cost of operating the depollution system*
*R = unit pollution charge*
*Qn = annual quantity of residual pollution (if any)*
*Qb = annual quantity of pollution produced*

**With the following constraints:**

$\Delta Q = Qb - Qn$
$0 < \Delta Q < Qb$
$0 < a < 1$

These data can be linked to the unit volume of wine produced by dividing the figures by the total volume produced by the winery *(y)*.

Following an increase in charge *R*, producers may decide to treat their effluent once *K2* exceeds *K1*. Until then, they will continue to pay the charge corresponding to their gross pollution output.

We shall now look at the two extreme cases corresponding to real choices: where producers decide not to treat at all, and where they decide to treat all their effluent.

***Case 1*:** No treatment.

In this case $\Delta Q=0$, $Qn=Qb$, hence: $K1 = K2$

The annual cost will thus be equivalent to paying the charge, ie *R Qb.*

***Case 2*:** Total effluent treatment.

In this case: $\Delta Q=Qb$, $Qn=0$, hence:

$$
\begin{aligned}
K1=K2 \;&\Leftrightarrow ki(1-a)\,\Delta Q+kg\,\Delta Q=R\,Qb \\
&\Leftrightarrow \Delta Q[ki(1-a)+kg]=R\,Qb \\
&\Leftrightarrow [ki(1-a)+kg]=R \\
&\Leftrightarrow R/[ki(1-a)+kg]=1
\end{aligned}
$$

It is clear in this case that if the unit cost of depollution is equivalent to or less than the charge, it will be in the producers' interests to treat their effluent.

This is how the cost-effectiveness threshold for total effluent treatment is determined. It is worth treating when:

$$K2>K1 \;\Leftrightarrow R\,Qb>\Delta Q[ki(1-a)+kg] \;\Leftrightarrow\; \boldsymbol{\alpha = R/[ki(1-a)+kg] > 1}$$

**Table 4 - Unitary values for *K1* (1997) and *K2* (1988-92-97) for the 15 wineries in Languedoc-Roussillon surveyed. Values per hl of wine produced, in 1990 francs**

***In bold, the years in which investment was made when $\alpha$ >1 and corresponding values for R(Qb)/y***

| 1997 Prod. (hl) | R Qb/y 1988 | R Qb/y 1992 | R Qb/y 1997 | R Qn/y 1997 (Qn>200 p.e.) | ΔQ[ki(1-a)+kg]/y 1997 | Investment year |
|---|---|---|---|---|---|---|
| 20 000 | 0.59 | 0.95 | ***3.80*** | 0.00 | 3.74 | ***1997*** |
| 115 000 | 0.23 | 0.65 | 1.67 | 0.00 | 0.41 | 1988 |
| 12 000 | 0.43 | 0.60 | 2.25 | 2.17 | 2.75 | 1990 |
| 55 000 | 0.22 | 0.61 | ***2.33*** | 0.00 | 0.66 | ***1994*** |
| 125 000 | 0.25 | 1.12 | ***1.54*** | 0.00 | 1.34 | ***1994*** |
| 79 000 | 0.22 | 0.63 | ***1.52*** | 0.00 | 0.76 | ***1996*** |
| 39 900 | 0.29 | 0.82 | 3.16 | 0.00 | 2.16 | 1983 |
| 93 600 | 0.33 | 0.56 | 2.28 | 0.00 | 1.11 | 1983 |
| 42 000 | 0.23 | 0.40 | ***1.64*** | 0.00 | 0.43 | ***1993*** |
| 19 000 | 0.45 | 0.71 | ***2.79*** | 0.00 | 1.46 | ***1996*** |
| 25 000 | 0.25 | 0.53 | ***2.24*** | 0.00 | 0.99 | ***1995*** |
| 34 000 | 0.31 | ***0.77*** | 2.32 | 0.00 | 0.49 | ***1990*** |
| 20 500 | 0.45 | ***0.81*** | 2.34 | 0.00 | 0.54 | ***1993*** |
| 28 000 | 0.43 | 0.59 | ***1.96*** | 0.00 | 1.43 | ***1995*** |
| 14 000 | 0.28 | 0.50 | ***1.57*** | 0.00 | 0.61 | ***1996*** |

Applying coefficient $\alpha$ to the sample of 15 wineries in our survey seemed to confirm the relation (table 4). All the wineries that invested in depollution systems that fully treated wastewater (14 out of 15) had a coefficient $\alpha$ of over one, and for ten of them, the investment was made at a time when, in constant franc terms, $\alpha$ became >1.

The wine producers studied demonstrated that not only were they economically rational, they also had access to the necessary information, since their decision to invest was made precisely when the incentive policy made it worthwhile.

**Conclusion of the French study**

The results obtained in under ten years in the wine-producing sector in Languedoc-Roussillon have proved the Water Boards right in terms of their policy based on financial inducements to invest in depollution.

The effectiveness of a policy is evaluated based on its ability to meet its targets, and the Water Boards' declared aim was indeed to make producers invest in pollution control systems. The installation of such systems in around 80% of the region's cooperatives and an increasing number of individual wineries is proof of the success of State intervention.

Moreover, according to the mainstream environmental economics approach, the sole aim in adopting a systems of charges and subsidies is to promote pollution control strategies that minimize the costs (Kneese, 1964, quoted by Shabman, 1984) incurred by producer/polluters.

Policies of this type rely on the rationality of stakeholders in the sector and the availability of information enabling them to choose the least costly depollution system while judging the point at which the rate of charge exceeds the cost of depollution minus the investment subsidy. The reaction on the part of the wine-producing sector in Languedoc-Roussillon seems to confirm both the rationality of producer behaviour and the availability of additional information.

However, there are certain reservations concerning the effectiveness of such policies in terms of sustainable development and the implementation of an overall strategy aimed at improving water resource management in the wine-producing sector.

Producer behaviour in relation to the new environmental constraints, which is apparently rational and informed, is in fact the result of inter-institutional consultation between the Water Board and wine producers' federations. This gives greater importance to the role of institutions in the process of choosing depollution techniques, and broadens the analysis to go beyond the simple notion of a rational and informed «free choice» on the part of producers, as the application of a policy based on a standard economic approach, as in the case of State control of wastewater in France, would have it.

Applying a package of increasing inducements in a very short time failed to create a «selection environment» propitious to the introduction of new technologies, either upstream of the production process or downstream, with the introduction of innovative depollution technologies. Those who have decided to invest in depollution have almost all opted for well-known and fairly «rustic» techniques (evaporation or spreading). Instead, the public sector should have facilitated the emergence of new, more effective and efficient pollution abatement techniques.

## Key concepts treated

Water prices, water tariff, water charges

Two-part tariffs

Price elasticity of demand

Affordability (macro and micro)

Polluter pays principle

## References

Griffin RC, (2006) Water resource economics, the analysis of scarcity, policies and projects. The MIT Press, Chapter 8.

CapNet (2008) Economics in sustainable water management. Training Manual. GWP,EUWI,CE, Chapter 4.

Farolfi S, Montaigne E (2001) *"Environmental policy and eco-innovation in the wine industry",* Proceedings of: « Environmental Innovation Systems », Garmisch-Partenkirchen, 27-29 September.

## Exercises

What is the difference between a water tariff and a water charge?

What types of volumetric tariff structure do you know? Can you describe them?

What types of social protection measures can be put in place by governments/utilities in order to increase the affordability of water to disadvantaged categories of users?

# 9

# WATER ALLOCATION[7]

## Introduction

Protection of basic human and ecological needs, economic efficiency and social equity are the most important pillars guiding water resource allocation and use in most of the countries in the world. In South Africa (SA), the National Water Act (NWA, 1998) promotes integrated and decentralised water resource management under a new institutional environment. New management entities (Catchment Management Agencies – CMAs and Water Users' Associations - WUAs) are currently established at regional and local levels, emphasizing a largely decentralized and participatory approach to water resource management (Hamann and O'Riordan, 2000; Perret, 2002). The decision-making process for water management in SA therefore involves dealing with a complex system of interactions between multiple biophysical and socio-economic needs co-existing in a watershed. This process must also comply with and serve the economic efficiency, social equity, and environmental sustainability objectives of the NWA. Management and control of water demand has been identified as a major task of the newly established CMAs. The approach adopted for water allocation to economic uses relies on a licensing process through which water use authorisations are granted to various applicants. This process involves addressing a number of key questions such as establishing priorities and appropriate regimes for allocation of water between competing uses (Farolfi and Perret, 2002).

However, water allocation decisions are currently made on the basis of very limited information on the behavioural structure underlying the decentralised decisions of the many water users involved. Proper modelling and adequate understanding of the motivations and rules that govern the choices of individual decision makers will provide better guidance for more informed water allocation regimes and policies centrally made by water management agencies. Decision support tools that can integrate in one framework the ecological and socio-economic dimensions of water resource use are accordingly needed to facilitate the design and implementation of water management strategies.

## Water allocation and intersectoral competition for water

When the objective is to increase efficiency in the use of water, it is sometimes necessary to reallocate water from a less productive sector to a more productive one. The first question facing the analyst in this case is: can a reallocation from sector i to sector j yield incremental gains to sector j in excess of the forgone benefits in sector i?

In other terms:

Is $DB_i + IB_k > FDB_j + FIB_k + TPC + CC$ ?

Where:

[7] Large parts of this chapter are based on : Hassan R and Farolfi S (2005) "Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa" , Water SA, 31 (1): 9-16.

$DB_i$ = direct economic benefit (value) to receiving sector
$IB_k$ = indirect economic benefit to affected sector(s), if any
$FDB_j$ = forgone direct benefit in source sector (also called *Opportunity Cost* for the sector j)
$FIB_k$ = forgone indirect benefit in affected sector(s)
*TPC* = transaction and planning costs
*CC* = physical conveyance costs

This is the first condition for efficiency in reallocation of water between two sectors, the second being: the foregone direct and indirect benefits should be the least-cost source of water for the purchasing sector:

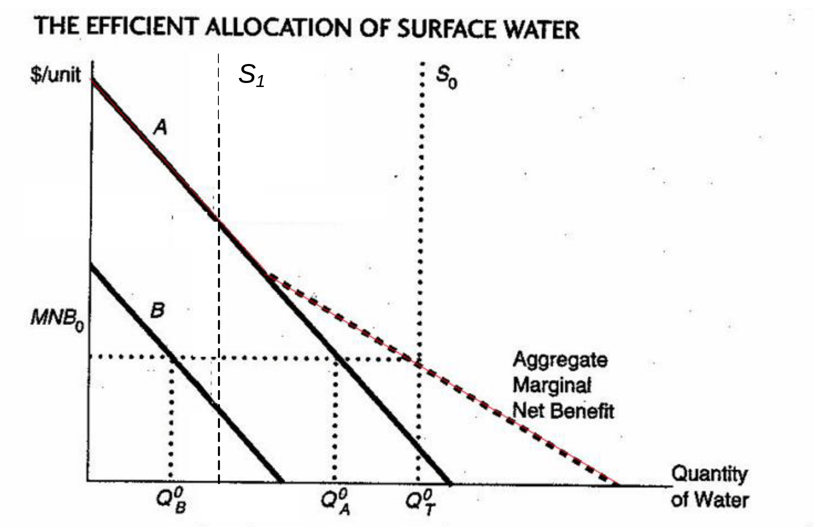
$FDB_j+FIB_k+TPC+CC < AC$

where *AC* is the cost of the next best alternative water source.

It is worthwhile noticing that in cases of economic analyses of investments for water supply and intersectoral reallocation of water, it is required an estimation of marginal (incremental) benefits and costs (or foregone benefits) of changes in water supply or use. Methods to calculate these marginal values will be described in the next chapters.

Following the principles of economic efficiency, surface water (renewable and not stocked) should be allocated so that the marginal net benefit is equalized for all uses. In other terms, every extra liter of water allocated should have the same opportunity cost for any alternative use.

Figure 1




In figure 1, the marginal net benefits (vertical distance between demand curve and marginal extraction and distribution) for water for two individuals (water users) are shown. Considering a fixed supply of $S_o$, the efficient allocation of water will be given by the point of intersection between the aggregate MNB curve and $S_o$.

At this point, $Q_T^0$ will be the total water allocation, with $Q_A^0$ for user A and $Q_E^0$ for user B. Note that the marginal net benefits are equal for the two users and A receives more water as his/her MNB curve is higher than B's one. Note also that in a condition of water scarcity ($S_1$), no water would be allocated to B.

In the real world, this approach based only on economic efficiency should be applied with precaution as: a) other goals are as important as economic efficiency (social equity, environmental sustainability); b) the MNB curves are not known (lack or asymmetry of information); c) water is mostly not a private good, but a common pool resource, with different access rules and not regulated by supply/demand relations.

**A partial equilibrium model for water allocation in a South African catchment**

A partial equilibrium water sector model was developed (Hassan and Farolfi, 2005) to assist water managers and policy makers in SA design and evaluate alternative water allocation strategies. The Steelpoort area, a sub-basin of the Olifants River catchment in the north-east of SA, where a water stress situation exists as total annual water requirements exceed available yield and the deficit is currently supplied at the expense of the ecological Reserve, was chosen as the case study area. The sub-basin is accordingly under pressure for preparation of a water management plan that would alleviate the current stress on the Reserve component, improve the economic efficiency of water use and meet the objective of social equity in water allocation.

The partial equilibrium model is also used to derive and compare values of water and subsidies enjoyed by various uses, assess the rate of recovery of water resource rents and measure the economic welfare cost of protecting the ecological Reserve under different water pricing and allocation regimes.

The water sector model was constructed to represent water supply and demand systems reflecting current water supply and use patterns shown in Table 1, which consist of eight water demand sectors. Compared to earlier efforts employing simpler structures (Farolfi and Hassan, 2003), the main feature of the present water sector model is its improved specification of the demand system. Also, market-clearing conditions were imposed to solve the model for equilibrium price and quantity levels. The model was then used to evaluate alternative water allocation regimes and determine efficiency prices. The components of the SPSB water sector model are described below.

***The water supply component***

In the present model total water supply (*WS*) was set exogenously to remain at current yield levels of 61 $x10^6$ $m^3$ (after providing for the IFR of 94 $x10^6 m^3$).

$$WS = QS \qquad [1]$$

where:

$QS$ a constant corresponding to the water yield in the sub-basin.

Table 1

| Steelpoort sub-basin water resources: Supply, use and balance (2000) | | | |
|---|---|---|---|
| **Supply sources** | | **Demand requirements** | |
| | $10^6$ m³ | | $10^6$ m³ |
| MAR | 396 | Irrigation - large scale | 65 |
| S1. Surface water yield (10.6% of MAR) | 42 | Irrigation - small scale | 3 |
| | | Mining | 12 |
| S2. Groundwater | 14 | Industry | 5 |
| | | Livestock | 1 |
| S3. Usable return flows (A+B+C) | 5 | Forestry | 1 |
| A. Irrigation | 3 | Domestic - urban | 3 |
| B. Urban water | 1 | Domestic - rural | 5 |
| C. Mining and bulk | 1 | | |
| **WS. Total available water (S1+S2+S3)** | **61** | **WD. Total demand (requirements)** | **95** |
| *Balance/deficit (TWS-TWD)* | *-34* | | |
| Reserve (R1+R2+R3) | 96.61 | | |
| R1. Ecological Reserve (in-stream flow requirements - IFR) | 94 | | |
| R2. Basic human needs | 2.61 | | |
| R3. Other needs (strategic, international, contingency) | ND* | | |
| * ND means currently undetermined. Source: DWAF (2002) | | | |

***The water demand system***

Water demand functions were specified for the eight economic use sectors of Table 1, which compete for water in the sub-basin. All users in the same sector were considered homogenous in terms of their demand for water behaviour and hence have the same water demand structure:

$$WD_i = D_i(PW_i, \beta_i) \qquad [2]$$

where:

$WD_i$ defines the representative water demand function for members of sector i (i=1,2, .., n) to depend on the price of water (or water charge) they face ($PW_i$) and their respective water demand behaviour parameters in vector $\beta_i$.

Total demand for water ($WD$) in the sub-basin was then derived by aggregating water demand over the n sectors:

$$WD = \sum_{i=1}^{n} WD_i \qquad [3]$$

Results of model simulations aggregating sectoral demands at different water prices ($PW_i$) were used to construct an aggregate water demand function for all uses in the sub-basin. The aggregate water demand curve $WD$ ($PW$) was then used to determine equilibrium water price and quantity at the sub-basin and perform the intended efficiency pricing analyses using the market clearing condition specified below.

***Equilibrium in the water sector at the sub-basin***

Market clearing conditions were imposed to solve the model for equilibrium water price and quantity and to enable comparative analyses of the existing and alternative water allocation regimes against economic efficiency (equilibrium price) solutions.

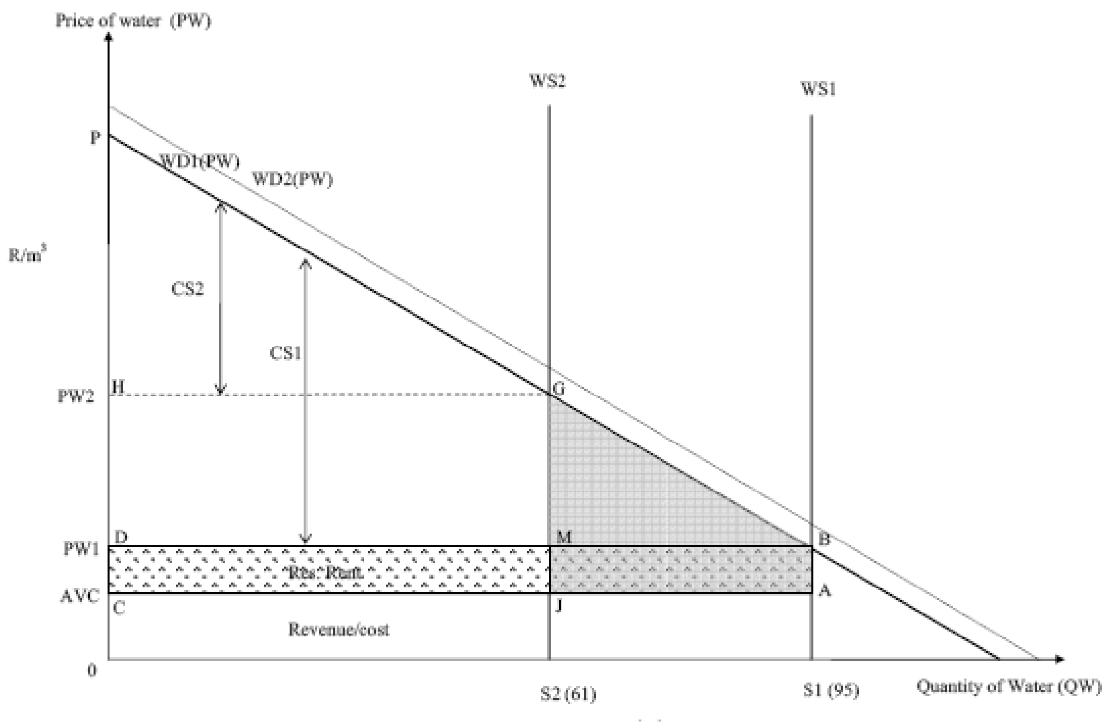
$$WS = QS = WD\ (PW,\ \beta) \qquad [4]$$

Under this condition, an equilibrium price of water (*PW*) can be determined endogenously forcing demand to adjust accordingly to clear the market. This allows comparing economic efficiency regimes of water allocation with alternative options. Various scenarios of water supply and allocation strategies can also be evaluated under this analytical framework in terms of net economic welfare gains and losses. The following section presents the framework adopted for conducting the intended analyses.

***The analytical approach and scenarios of the water sector model***

As presented above, the SPSB water sector model was constructed to satisfy partial equilibrium conditions in the water sector at the sub-basin. Figure 1 depicts the analytical foundations of the water sector model and its potential to address specific research questions of relevance to water allocation strategies following economic efficiency rules. As shown in Table 1 the current water supply and demand situation is represented by the *WS1* and *WD1* curves showing the total supply and demand for water at the sub-basin, respectively.

Figure 1 The analytical framework




Point *A* on Fig. 1 represents the current water allocation system in the SPSB where total water requirements of all economic uses (95 $x10^6m^3$) were supplied at an average supply cost (*AVC*) charged to users. At this point, even if one assumes that *AVC* fully recovers all supply costs (including normal profits, i.e. normal returns to capital investment), which is rarely the case, consumers are paying rates lower than the market price of water (*PW1*) and hence enjoy an indirect subsidy (area *DBAC*) on top of the consumer surplus-*CS1* (*PBD*). This subsidy value represents the water resource rent (*RR*) dissipating to water users. To provide current total requirements of all users at economic efficiency prices the water charge needs to be set at the market clearing equilibrium price *PW1*. In which case the water service provider would recover all its costs (area *C-A-S1-0*) plus the *RR* (area *DBAC*), which may be recovered by an appropriate public agency (government) on behalf of the public through some tax or royalty regime. and water users remain with their *CS* (area *PBD*). This indicates that economic uses of water in the SPSB enjoy a subsidy equivalent to the total *RR* under the current water allocation system. Because different economic use sectors are charged different tariff rates, our framework allows calculation of sector specific subsidy levels employing the respective sector water demand functions specified in Eq.(2).

Moreover, the current water allocation system not only deviates from economic efficiency principles, but also introduces another social cost as total water requirements currently exceed available water supply (yield) with a deficit supplied at the expense of the ecological Reserve. The value of this social loss is not yet known and this research project did not attempt to establish values of ecological services lost as a result of the reduction in the instream flow requirements (IFR). Nevertheless, the analytical framework presented above allows for calculation of the opportunity cost of maintaining the ecological Reserve to fully meet IFR. In this case scenario of protecting the ecological Reserve, only water yield will be available for economic uses, which will shift the water supply curve leftward from *WS1* to *WS2* to supply 61 $x10^6$ $m^3$. If the available yield is to be allocated on economic efficiency basis, users will have to be charged the equilibrium price of water *PW2* at point *G* of Fig. 1. At this equilibrium point *CS* will shrink to *CS2*, water *RR* recovered will equal the area *HGJC* and the resulting net social welfare loss measured by the area *GBAJ* represents the opportunity cost of maintaining the ecological Reserve to fully meet IFR.

The net social welfare loss or opportunity cost of protecting the Reserve should ideally be compared to welfare gains from the economic benefits of the preserved ecological services of the reserve. As said earlier, the present study unfortunately could not establish a value for these ecological services. Nevertheless, the total loss of economic welfare resulting from water allocation regimes that give priority to protecting the reserve and its instream ecosystem services provides a bench mark or baseline estimate of the potential economic benefits to be realised from increasing available water at the sub-basin, against which the cost of investment outlays to increase current water yield levels can be compared and justified.

In addition to providing information on the value of investing in additional water supplies (offstream economic benefits lost as less water is made available in order to protect instream ecosystem services), this also indicates potential economic welfare benefits from investing in technological means to improve water use efficiency as an alternative water management strategy. While increasing water yield will shift the supply curve to the right in the direction of *WS1*, technological improvements will cause the demand curve to shift outwards (*WD2*) leading to higher economic value of water (larger economic surplus and *RR*).

This study will employ the above analytical framework characterizing the current decision environment of water allocation and use in the SPSB to develop an empirical water sector model and use it to analyse various water policy questions under the following scenarios and water allocation regimes:

**Scenario I**. In this scenario economic efficiency rules are followed as the strategy to allocate water to meet total current requirements of 95 $x10^6$ $m^3$ (*WS1*). This scenario allows performing the following analyses:

- Determine the market clearing equilibrium price *PW1*
- Use *PW1* to calculate subsidy levels enjoyed by economic uses under the current water allocation strategy and charges, i.e. how far are current tariff rates from the equilibrium price?
- Derive a measure of the water *RR*, its distribution and rate of recovery
- Calculate the total value of water to economic uses in the SPSB (the sum of *CS* and *RR*)

It is important to note that this policy does not lead to loss in economic welfare apart from the social welfare loss due to reduced ecosystem health caused by lower Reserve, which this study could not evaluate. Accordingly, it was not possible under this scenario to evaluate the trade-off between offstream and instream benefits of water. The more interesting consequence of this policy, however, is its distributional effects as it allows reallocation of economic benefits through the capture and spending of the *RR* by the appropriate public agency or government.

**Scenario II**. The strategy of this scenario gives priority to protecting the ecological Reserve and hence allocates only water yield (*WS2*) among competing economic uses, again guided by the principles of economic efficiency. While preserving instream ecological values, this strategy leads to lower economic welfare as explained earlier. This welfare loss represents the opportunity cost of protecting freshwater ecosystems in the SPSB. Under this strategy the following analyses will be performed:

- Determination of the equilibrium price *PW2* that establishes economic efficiency in water allocation
- Evaluation of how far current water tariffs are from economic efficiency (subsidy levels) under ecologically sustainable water allocation regimes
- Calculation of the welfare loss caused by environmental protection as the opportunity cost of maintaining the ecological Reserve
- Evaluation of the change in water *RR*, its recovery and distribution under this strategy

Results from the first two scenario analyses were be used to evaluate the costs and benefits and hence social desirability and attractiveness of these two alternative water management regimes in the sub-basin.

### *The empirical water sector model of the SPSB*

This section specifies sectoral water demand functions then calibrates the specified empirical model to available data to determine the water demand system parameters for the various use sectors. An aggregate water demand function for the SPSB is then derived by aggregating sectoral water demands.

The SPSB model includes eight water use sectors, as indicated in Table 1. The demand for water by these sectors is modelled as a function of the water price assuming the following linear demand function:

$$WD_i = a_i - b_i PW_i \qquad [5]$$

where:

$WD_i$ determines the quantity of water demanded by sector *i* as a linear function of the water price faced by the sector ($PW_i$).

$a_i$ and $b_i$, respectively, measure the intercept and slope of the demand curves.

### *Calibration of the demand system to available data*

The following data sources were used to conduct the empirical analyses and simulations:

- Levels of water use and charges (cf. Appendix of Hassan and Farolfi, 2005). Information on current levels of water use and charges by sector was compiled from surveys of primary and secondary sources, i.e. water users and water management agencies at the sub-basin;
- The surveys also generated information on domestic water use by urban and rural households, which allowed estimation of water demand parameters for domestic users;
- Estimates of water demand parameters generated by a number of recent water demand studies in the country and elsewhere (see ranges reported in Appendix) were used in the sense of "benefit transfer" to complement this study's efforts to specify the demand behaviour of water users at the SPSB (Dockel, 1973; Hassan et al., 1996; Amir and Fisher, 1999; Veck and Bill, 2000; King, 2004; Tewari, 2003; Mirrilees et al., 2003; Veck and Williams, 2004; Van Vuuren et al., 2004).

Data on current costs of water to various users were compiled for the SPSB. There is a wide range among use sectors in terms of the cost of water. Some users are provided with water from a public network or from a dam (government schemes). On the other hand, other users are self-providers. Government water tariffs/charges levied by DWAF on bulk water supplies to different use sectors were used as water prices (*PW*). Details of the structure of water charges in the SPSB for sectors abstracting water for commercial use are found in the Appendix of Hassan and Farolfi, 2005, and consist of the following components (DWAF, 2003):

- The consumptive (use) charge, which applies only to users receiving water from government water schemes. This charge recovers costs associated with maintenance and operation of the water supply schemes
- The water resource management charge (WRMC), which applies to all users except Schedule 1 users Footnote part of the text please. Schedule 1 users as defined in the NWA are those abstracting water directly from a natural source (including storage and use of rainwater) for non-commercial purposes such as household consumption, gardening and subsistence stock watering, (DWAF, 2003). This charge is introduced to recover actual costs of water resource management activities (e.g. planning and control of water allocations and use, monitoring and control of pollution and invasive alien plants, water conservation and demand management, etc.). Note that this charge also applies to stream flow reduction activities such as cultivated forests (plantations) and commercial dry land agriculture
- The water research levy, which is collected from users, supplied with water from government schemes and water services providers (i.e. municipalities and WUAs including irrigation boards)

While the first two represent recovery of actual water supply costs, the water research levy is treated as a royalty recovering part of the resource rent.

The SPSB water demand system model was calibrated to data on estimates of price elasticity of water demand obtained from a number of sources at observed current levels of water use and price charges to generate the demand system parameters (slope, *b* and intercept, *a*). Details of the calibration process are presented in the Appendix of Hassan and Farolfi (2005).

Using the specified sectoral water demands, a total water demand function for the SPSB was then derived by aggregating over all sectors:

$$WD = a - b\,PW = \Sigma_i\, WD_i = \Sigma_i\,(a_i - b_i\, PW_i) \qquad [6]$$

Simulation of quantities of water demanded by the various sectors $WD_i$ at different price levels $PW_g$, aggregated over all sectors gives total demand by all sectors $WD_g$. Simulated values of $WD_g$ and $PW_g$ were then used to fit an aggregate water demand curve and derive its parameters $a$ and $b$. Since specification of the aggregate water demand curve is sensitive to the chosen sectoral elasticity parameters, this method resulted in the total water demand functions given in the Appendix of Hassan and Farolfi (2005) for the SPSB.

The area under this demand curve is equal to the sum of the areas of all sector demand curves:

$$\int_0^{QW} PW(QW)\,dQW = \sum_{i=1}^{n} \int_0^{QW_i} PW_i(QW_i)\,dQW_i \qquad [7]$$

where:

*QW* refers to quantity of water demanded.

***Results of the empirical model under alternative water allocation regimes***

The two above discussed scenarios (efficiency pricing at current levels of water use of 95 x$10^6$ $m^3$ and at the maximum yield of 61x$10^6$ $m^3$) were evaluated using the estimated water sector model. The model was used to determine equilibrium prices at the two levels of total water allocation and in turn calculate the various values depicted in Fig. 1 under each scenario (e.g. *RR*, *CS* and water subsidies).

For simplicity of notation we will use *Q* in place of *QW*, *P* for *PW* and *C* in place of *AVC*. According to the analytical framework depicted in Fig. 1, we derive consumer surplus (*CS*) measures as follows:

$$CS\,(Q) = \int_0^{Q} (P(Q) - C)\,dQ \quad = \Big|_0^Q \frac{1}{2b} Q^2 \qquad [8]$$

For Scenario I, where *Q* = 95 the integral in Eq.(8) will be evaluated between 0 and 95 to calculate the *CS* (similarly between 0 and 61 for Scenario II, where *Q* = 61). On the other hand, the resource rent (*RR*) is derived as the difference between the equilibrium price at *Q* level of 95 (61 for Scenario II) and costs paid by each user per $m^3$ of water used, which when multiplied by the quantity of water used by each sector gives the total subsidy enjoyed by that sector and when summed over all sectors gives an estimate of the total subsidy at the sub-basin. Results of the above calculations for the two scenarios are summarised in Tables 2 and 3 under the two scenarios described above. Tables 2 and 3 also report results under two elasticity assumptions: a high elasticity (HES) using the upper bound and low elasticity (LES) based on the lower bound of elasticity ranges given in the Appendix of Hassan and Farolfi (2005).

Table 2

| Water sector model solution values for the two water allocation scenarios in the SPSB (2003 values) | | | | |
|---|---|---|---|---|
| | High elasticity | | Low elasticity | |
| | Scenario I | Scenario II | Scenario I | Scenario II |
| Equilibrium price (R/m³) | 0.843 | 4.266 | 0.512 | 5.322 |
| Subsidy (R m.) | 70.85 | 253.56 | 39.48 | 317.25 |
| R/m³ | 0.74 | 4.16 | 0.42 | 5.20 |
| Resource rent-RR (R m.) | 71.49 | 254.07 | 40.12 | 317.82 |
| R/m³ | 0.75 | 4.16 | 0.42 | 5.21 |
| % of RR recovered | 0.90% | 0.20% | 1.61% | 0.18% |
| Consumer surplus (R m.) | 454.42 | 187.36 | 638.38 | 263.20 |
| R/m³ | 4.78 | 3.07 | 6.72 | 4.31 |
| Welfare cost (R m.) | - | 83.82 | - | 96.13 |
| R/m³ | - | 2.46 | - | 2.83 |
| Price elasticity of demand | -0.09 | -0.69 | -0.04 | -0.62 |

The simulation results reported in Table 2 indicate that at current water allocation levels (95 x$10^6$ $m^3$) the market value of bulk water in the SPSB is about R0.84 under the HES assumption, generating more than R 70m of resource rents (*RRs*), almost all dissipating to various water users. At this market-clearing price an economic surplus (*CS*) of more than R 450m is generated giving an average of R 4.78/ $m^3$ welfare water value. It is important here to note the differences between the market clearing (equilibrium) price, which measures the trading value of water, the resource rent (*RR*) that measures the economic (scarcity) value of the resource in-situ and the economic surplus (*CS*) measure, which reflect the maximum social value of the exchanged commodity (maximum willingness to pay for it).

When water supply was limited to the available yield of 61 $m^3$ in order to protect the ecological Reserve, a much higher market price of R 4.16/$m^3$ was achieved, leading to a much higher subsidy of R 2.67/ $m^3$. This, however, reduced the economic surplus to R 3.07/ $m^3$, causing a deadweight loss in the economic welfare value of water of more than R 58 m. This amounts to an opportunity cost of R 1.71 for every $m^3$ of water withdrawn from economic activity for environmental protection. As discussed earlier, this measure of loss in CS from offstream values is not the appropriate measure of net social loss or gain as it does not account for the welfare gains from improved ecosystem functioning (instream values of water), which the present study could not establish. Nevertheless, these results suggest that the average economic value from increasing water supply (yield) to offstream uses in the SPSB amounts to R 1.7/$m^3$. Adding the *RR* realized at the full water supply scenario to this gives a total economic value of R 2.46/ $m^3$ that can be used as a benchmark against which per unit costs of alternative water supply options may be compared. Note that the social benefit from increased water supply to offstream uses (opportunity cost) increases to R 2.83/ $m^3$ under the LES assumption.

It is clear from Table 2 that the only part of the *RR* collected through the water research levy captures a very small portion of the total *RR* under all scenarios and elasticity assumptions of less than 2% at best. The rest of the *RR* dissipates to various water users at the SPSB in different shares as shown in Table 3. Clearly, large-scale commercial irrigation agriculture reaps the lion share of the *RR* as it is the major user of water at the sub-basin followed by mining activities. Rural households and small irrigation farmers are currently subsidized as Schedule 1 users. The per unit subsidy is highest for irrigation farmers while mining, industry and urban households are charged for bulk water at relatively lower subsidy rates.

Table 3

**Distribution of the resource rent subsidy among water use sectors in the SPSB (per cent of total)**

| | High elasticity | | Low elasticity | |
|---|---|---|---|---|
| | Scenario I | Scenario II | Scenario I | Scenario II |
| Rural households | 5.95 | 8.41 | 6.49 | 8.39 |
| Urban households | 2.16 | 3.69 | 1.37 | 3.46 |
| Irrigation-small | 3.57 | 4.69 | 3.89 | 4.59 |
| Irrigation-commercial | 73.77 | 59.22 | 78.02 | 55.31 |
| Livestock | 1.13 | 1.60 | 1.20 | 1.58 |
| Mines | 8.64 | 14.80 | 5.47 | 17.88 |
| Forestry | 1.18 | 1.41 | 1.28 | 1.34 |
| Industry | 3.60 | 6.17 | 2.28 | 7.45 |
| Total (R m.) | 70.85<br>100% | 253.56<br>100% | 39.48<br>100% | 317.25<br>100% |

***Conclusions and limitations of the study***

The preceding analyses showed that bulk water is currently oversupplied to offstream uses in the SPSB at the expense of the ecological Reserve (instream benefits). The study also indicated that bulk water is currently underpriced and the only rent capture instrument used, the water research levy, recovers a negligible proportion of the *RR*. The consequence is dissipation of almost all the *RR* to various offstream users of water in the form of indirect subsidies of about R 0.75 or R 0.42/m$^3$ with the HES and LES assumptions, respectively. Commercial irrigation enjoys the highest subsidy being the major consumer followed by mining. Results of the simulation analysis also indicate that the opportunity cost in terms of economic surplus lost to offstream uses as a result of limiting water supply to protect the ecological Reserve is R 2.83/m$^3$. Together with *RRs* realized at current allocations, the total maximum economic value offstream users are willing to pay for increasing water yields to supply the full requirements' levels currently enjoyed at the SPSB is estimated at about R 2.5/m$^3$. This value, while it does not properly reflect the net social gain or loss of environmental protection, serves as a benchmark value against which per unit costs of potential alternative water supply options can be compared.

**Key concepts treated**

Economic efficiency and water allocation

Intra and inter-sectoral water allocation

Partial equilibrium model

Welfare measures

Resource rent

Scenario based analysis

Aggregated water demand

## References

Tietemberg, T. (2000) Environmental and natural resource economics, Addison Wesley Longman, NY (Chapter 10).

Hassan R., Farolfi S. (2005) “Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa” , Water SA, 31 (1): 9-16.

## Exercises

Provide a graphic framework of efficient surface water allocation between two users

Explain what is a water sector partial equilibrium model

From the presented example, explain why water is heavily subsidized

From the previous example, explain what is the welfare loss of environmental protection