An Economic Approach to Water Scarcity

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1 Water as an Economic Good

A limitation—but also an advantage, depending on the viewpoint—of economic evaluation is to refrain from any a priori criteria, value judgments and ethical parameters. For an economist, the concept of "value" always refers to an objective dimension, which descends from the fact that a given action determines a variation in the utility of some individuals. Evaluation actually concerns the measurement of how individual or collective utility change, as a consequence of the action that is analysed. Therefore, for an economist, ideas such as the "ecological footprint", "water footprint", "virtual water" and similar carry a neutral meaning, since a high consumption of water (or of anything else) has not, in itself, a negative or positive connotation. What we need to know instead is the extent to which a given use of a resource affects other possible alternative uses of the same resource that are on their own "valuable", that is, generate positive utility: Is anybody's utility negatively affected, and how? Does use x prevent or limit the use y?

Clearly, it is intuitive that using a lot of water where it is available in sufficient quantities to satisfy all uses, including anthropogenic and ecosystemic ones, cannot be considered a negative value.

The case of water is also complicated by the fact that it involves, on the one hand, a good which is cyclically renewed and, on the other hand, is "flowing", with limited possibilities for storage and conservation. In other words, it must be considered that the use does not necessarily negate the possibility of an alternative use (the same water, returned to the cycle, will be once again available).

At the same time, non-use does not necessarily mean a saving, since water that flows without being used will sooner or later end up in the sea.

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Therefore, the important elements for an economic analysis concern not so much the consumption, but the concentration of the consumption over time and the possible occurrence of conflicts among competing users. The resource availability has to be evaluated instant by instant. An important impact, in economic terms, can take place, for example, because in that exact moment use "*x*" prevents or makes use "*y*" more difficult, or because it draws on a stock (e.g. groundwater, a lake) which denies someone else the option of using that same stock in the future.

Claiming that water is an "economic good" has nothing to do with its transformation into a commodity, namely a marketable good traded for a price. However, it also concerns the need to calculate in the costs all the sacrifices that a given use involves. Sacrifices that can be broadly divided into three categories:

– financial costs: these are the economic resources necessary to make the water available (e.g. withdrawal, transportation, treatment) and for its recovery after use, returning it to the environment (sewerage/drainage, purification, sludge treatment, etc.);
– scarcity costs (sometimes defined as "resource costs"): these are the alternative economic values which are sacrificed when a certain use hinders or prevents another. For example, if the water use by farmer *x* prevents its use by farmer *y*, the scarcity cost will be equal to *y*'s economic production value (equal to the market value of his output, after production costs);
– environmental costs (sometimes defined as "negative externalities"): these are the value of the ecosystem, paysage or similar elements where a given use of the resource has an impact. For example, the pollution caused by the release of contaminated water could result in the reduction of a water body's ecological quality, depriving it of certain environmental functions.

As can be seen, we are dealing with *contingent* cost categories, in that they cannot always be verified and cannot be easily associated with a given use or impact. A resource cost arises not only because there is someone who uses water, but also because there is someone else who would like to use it in their place. An environmental cost is quite difficult to correlate to the quantity of water withdrawn, as it depends, instead, on when, where and how it is withdrawn (and after released).

The literature regarding water footprinting and "virtual water" has certainly raised the awareness that not all uses are the same and that before establishing if a certain use results in a footprint or not it is necessary to distinguish how it occurs. For example, by distinguishing between the consumption of "blue" water (surface water or groundwater) and "green" water (rainwater contained in the soil as moisture), or, in the case of the former, depending on the renewability of the resource used, or by distinguishing "dissipative" or "non-dissipative" uses—where dissipation is, basically, reducing or eliminating availability for a given period of time.

However, to be more in line with the economic impact definition, these indicators are still much too general, in that withdrawing the same quantity of water from the same source using the same method does not necessarily impact in the same way (for further information, see in this volume "Not all drops of water are the same" by M. Antonelli and F. Greco). Therefore, these indicators are more useful for a quick overview and to identify the regions where it is more likely that a situation of stress may be identified, but they are not, however, enough in themselves to identify the situation neither to identify critical situations, nor to guide policymakers and recommend actions. Therefore, an in-depth ad hoc study for each context is necessary, both to accurately gather information on what are the stress factors (which sectors and which uses suffer from stress, and what ecosystem elements are damaged) and to identify the most suitable actions to be undertaken.

2 When Water Is Not Enough

In a certain sense, speaking of water "scarcity" is incorrect. The water available on our Earth enormously exceeds every reasonable future demand we could make on it. Of course, on a smaller territorial scale and for more limited periods of time this is less true. Yet technology literally allows us to have available any quantity of water that we may want to use. The cost of desalinating sea water is about 50 euro cents per cubic metre—a high cost, but not impossible to meet, as far as the value of the water—which descends from the market price of goods that can be produced from that cubic metre, whether they be agricultural, tourism or energy products, is higher than that cost.

And yet, the international agencies of the United Nations or the OECD have signalled the increasing risks of water stress for anthropic communities or for water ecosystems. To understand this apparent paradox, we must specify better what we mean when we maintain that water is scarce.

Scarcity cannot be measured as an absolute, but always in relation to the alternative actions that can be carried out to remedy its (temporary and local) unavailability. In other words, if here and now I do not have the water at my disposal that I wish to use, then the alternatives available to me are many.

One, of course, is to give up using it (this could be a sacrifice for me, no access means no use: but in the end I might survive anyway, if the use destination is not actually vital). Another is to move to where there is water available (this would also be a sacrifice, with all the associated costs, material and immaterial, that this move involves, whether it be temporary or permanent, and so on). Still another is to invest in technology to access the alternative resources (e.g. build an aqueduct to carry water from a place where it is available). In this case, the sacrifice will be the costs associated with the building and maintenance of the infrastructure. Yet again, I could ask someone who is using the resource denied to me to give up using it in exchange for a payment (the sacrifice would be the amount I would have to pay).

Obviously, I will choose the best alternative *for me* (in relation to the sacrifice I must make). In other words, I will always have to compare the "demand"—namely the calculation of how worthwhile it is to use the water, what are the benefits I can expect from its use—with the "supply", that is, the costs (financial, environmental, scarcity) that must be met to access it. When the cost is more than the benefit, using the water—or that water—would become economically irrational.

It is also evident that the abstract desirability to use the water must always take into account the costs. If the cost of the water is zero—that is, if it were available every time it is requested, in the quantity and quality desired—then the demand could be basically quite unlimited. In fact, there will always be an irrigable surface to be added—a new town, a new tourist village or new fountain to be built.

To define scarcity, in economic terms, the cost must be higher than zero. When the cost exceeds zero, only an economic calculation can evaluate if or what sacrifices should be made where its use is involved and allocate the available resources amongst the eventual competing uses.

Therefore, the economic idea of scarcity does not rely on the fact that the resource is more or less plentiful, but if there are mutually exclusive solutions present and levels of sacrifice which must be chosen from.

The issue becomes a little more complicated if we consider that not all those who make sacrifices are able to reason in this way. For a poor community in Sub-Saharan Africa, for example, many of the alternatives are excluded, as they have no purchasing power to allow them any technological solutions, while "relocation" may carry enormous human and social costs when this involves a mass migration. If we consider that access to water is a fundamental right, every "sacrifice" that involves giving up satisfying that right is an unacceptable cost. Furthermore, often the sacrifice is not borne by those economic players able to carry out a rational calculation of the opportunities, but falls, instead, on those subjects which, by definition, cannot bear the cost (the ecosystem, other species, future generations).

However, even these can be adequately taken into account in an economic reasoning, for example, by attributing an infinite value to the non-negotiable aspects of the sacrifice.

Figure 1 illustrates the question. In every context, water availability is limited, but could be increased with a certain cost involved (high, but in general, finite). Yet, bearing this cost would not be desirable if the value linked to use—and represented by the social demand—is not high enough. A water stress situation is usually

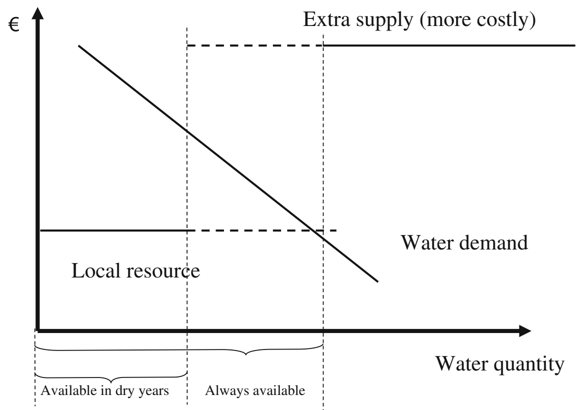

Fig. 1 The scarcity dilemma. *Source* The author

identified when the pressure on the local resources is high (the demand exceeds the quantity which the local system is able to generate at a “normal” cost, but there are not enough resources available to “make the leap” to a more costly solution).

To complicate matters further, we can see that as availability varies according to the season, stress can be verified, or not (and with more or less frequency). In the situation represented in the figure, for example, there is no stress present in normal years (the demand is met by the resources normally available), while, instead, during dry years, the supply becomes insufficient. In similar situations, some subjects, thus, remain unsatisfied. The management system could draw up rationing measures (prices, regulations), or leave it to be dealt with case by case, with the strongest prevailing, or first in first served.

3 Irrigation in Italy: A General Overview

The reasoning carried out above can also be found in an analysis of the irrigation system in Italy—a rather fitting example.

It is well known that, in Italy, the main use of water is in agriculture. Irrigation alone involves more than a half of the anthropogenic withdrawal of water. However, we should remember that these data are only an estimate and that reliable statistics are still not available, especially concerning direct water withdrawals from wells.

For an overall picture, we must turn to the dated but still valuable study conducted by the IRSA-CNR (Water Research Institute—National Research Council) in 1999, which estimated in a little less than 20 km^3 the annual withdrawal of water for agriculture compared to about 40 km^3 of total use. Besides the enormous uncertainty that surrounds these figures, the predominant weight of agricultural use is clearly evident. The irrigated surface area involves 2 million hectares, 80 % in the northern regions (*ibidem*). Most of the demand for irrigation is met by collective systems (reclamation consortia), but a substantial number of farmers use, either as an alternative or additional to collective systems, their own catchment systems (wells, lakes, etc.). On the other hand, Italy is a country blessed with water—the annual resources available are estimated at 52 km^3 (*ibidem*). If this figure is true for the whole country, then it is even more so for the northern regions. The Alpine chain, from this point of view, plays an important role as a “tank”—the snow cover, glaciers, permafrost (i.e. the ice found in the deeper soil strata), the large sub-Alpine lakes and the lowland groundwater represent a water system that not only has a plentiful annual availability, but also benefits from a natural runoff regulation during the different seasons.

Therefore, the huge quantity of water used in the north for irrigation purposes reflects the relatively high availability. A further breakdown of the figures reveals that a substantial percentage of the already high use of irrigation water in the north is for rice cultivation, where irrigation occurs at a moment in the season when competition with other users is limited (spring). The fact remains that the remaining quantities for the more traditional irrigated crops (cereals, especially maize, orchards, market gardening) would already be enough in themselves to determine a high percentage of water use.

Irrigation is of fundamental importance for all those crops where the water requirement—defined by the evapotranspiration coefficient—is not adequately offset by the natural soil moisture. Northern Italy, from this point of view, has a unique feature—its climate is markedly Mediterranean (low rainfall in the summer), but the runoffs are fed by the snowmelt and by the buffers represented by the lakes and underground water. Therefore, a relatively high water requirement can be satisfied, at quite reasonable costs, making use of this runoff. Moreover, since medieval times, the possibility of controlling the runoff using inexpensive systems (gravity water canals, spring water, etc.) has allowed for widespread agricultural development.

Irrigation has played a crucial role in agriculture in the global market networks, guaranteeing a regular production being less governed by seasonal trends. The lower risk linked to seasonality allows for the selection of more specialized crops and a higher productive yield. The *Made in Italy* food production chain, such as that for *Parmigiano Reggiano* to give just one example, relies heavily on the regular supply of animal feed, originating from irrigated crops, since production guidelines require that animals are fed with forage produced *in loco*. The recent spread of irrigation in the area of the vineyards sector is another example—the large investments made by companies in creating a wine production chain aimed at quality excellence makes the companies much more vulnerable to seasonal production fluctuations. Irrigation, with its controlled water supply, results in reducing the climatic risks and, therefore, ensuring a lower risk rate.

On the other hand, the fact that the water is plentiful and inexpensive has encouraged the development of an irrigation model that is quite lacking in terms of technology, which discourages the introduction of water-saving technique favours an efficient water use or water saving (so-called water saving technologies).

Most of the networks (more than 2/3 are in the National Irrigation Atlas published by INEA) are "free surface flow" or, however, non-pumped. This means that the water can be channelled making use of gravity, but the allocation methods for the different crops are inflexible, based on preset rotations, with no possibility for a real-time supply for the more vulnerable crops.

The paradoxical effect of this model is that enormous amounts of water are used to irrigate low value-added crops, risking, in the meantime, not having enough water available for the high value-added crops. The latter, end up "queuing", both from a geographical and seasonal point of view, to access the resource.

Thus, it should not be surprising to find in the south—generally less plentiful in water, though in relative terms suffering less damage compared to other situations clearly less favoured by nature—more modern and efficient water systems. These include water saving technology and allocation and supply methods.

4 An Economic Evaluation of Drought Costs and Possible Answers: The Po River Basin

The Po river basin, for the above-mentioned reasons, is a textbook case regarding the economic and environmental problems linked to water use in agriculture. It is a high-risk water area but, at the same time, marked by an extremely intensive use of the resources available. If the availability per capita is more than 3000 m^3/in. (the usual threshold to identify stressed regions is 1700 m^3/in.),[1] the exploitation rate is, conversely, extremely high, reaching almost 40 % of the average resources theoretically available. There is an extremely intense water use for hydroelectric energy production, also supported by an important artificial water body system. Reaching the plains, the large sub-Alpine lakes collect and control the runoff. From here, the main Lombardy and Piedmont irrigation networks spread out, intercepting the water before it percolates into the permeable subsoil of the high plains. The low plains are fed by the resurfacing of the water which then flows into the main course of the Po. The other north-eastern basins, from South Tyrol to Isonzo, display similar features. Instead, in the Apennine range, the lack of large glaciers and lakes results in a more irregular runoff. It is clear from this rapid picture that while the different water uses are in competition, they also complement each other.

80 % of the non-energy water use is concentrated in agriculture. The plentiful availability in normal years encourages an agricultural model particularly dependent on irrigation and the prevailing choice of irrigated crops of a medium–high added value, such as maize, rather than more resistant crops with a lower added value. What makes the system particularly susceptible is the inflexibility of the organizational model. In difficult seasons, this means that for many subjects, the alternative is, quite simply, to give up using water. In fact, if the crop choice is made at the beginning of the season, based on an average availability, then at the moment this availability drops below normal, or the demand is above normal (e.g. due to the effects of a very hot season or if the rainfall is below normal), many subjects find themselves unable to remedy the problem. Just as serious, obviously, is the situation of those farms which have made investments in multi-annual cycles (orchards, vineyards).

Let us take as an example what happened in 2003, a year that can be considered as paradigmatic for a stress situation. A winter with low snowfall, followed by a spring of quite low rainfall, resulted in a water level in the large lake basins very much lower than normal. This singularly dry season encouraged many agricultural companies, especially in the lower basin areas, to heavily tap into the groundwater. The result was a runoff into the main Po water course very much below the norm.

[1]This threshold is based on the Falkenmark and Lindth index, proposed in 1976 and adopted by the United Nations and the main multilateral institutions such as the OECD and the World Bank. (see, e.g. the OECD (2008)).

The large power plant of Porto Tolle, near Rovigo, which uses water from the river for its cooling system, was forced to shut down repeatedly during the month of June, resulting in a major energy shortage in the grid and the need to forecast blackout periods for many users. In order to avoid even worse consequences, the Po Basin Authority drew up an extraordinary plan that requested, amongst others, the release of the maximum quantity available from mountain hydroelectric water bodies and a constant reduction in the water use permitted (−10 %). Thus, a sufficient quantity of water was maintained in the river so as to avoid closing down the Porto Tolle plant, a cornerstone in the national energy network. On the other hand, the cost was a steep decline in agricultural production and a potential reduction in energy generated by the upstream hydroelectric stations.

Therefore, essentially, a situation such as that in 2003 exemplifies the emergence of a potential conflict between alternative water uses, where in normal conditions this does not exist as supply is sufficient for all (including the ecosystem).

In order to quantify the key economic variables, a simulation model was created (see Massarutto and de Carli 2009). Different strategies were examined involving different degrees of intervention in reducing the allowable withdrawals and different hypotheses for the reallocation of the supply amongst the users, favouring those where the water use generated a higher benefit. The model takes into account the fact that the subject that bears the main cost burden resulting from water scarcity, for example, the farmer who finds himself without water, can, in turn, transfer these effects to other subjects. For example, if because of the lack of water the agricultural production declines and the price rises, it will be the consumers who suffer the consequences. For the farmer, the effect is unclear, from the moment that the two variables (quantity and price) shift in opposite directions. However, the model considers the costs and benefits from both an individual and social viewpoint. In fact, for society as a whole, the damage suffered by a subject could be offset by the benefit gained by another subject. For example, if the hydroelectric production is reduced, the plant owner suffers, but, in compensation, the energy could be produced by another plant that would have otherwise remained inactive.

Therefore, for society as a whole, the cost is not equal to the first subject's loss, but, instead, the difference between how much the first loses and how much the second gains. Reasoning thus, we can see in Table 1 how the effects of the dry climatic event, following the management strategy adopted, can be quantified in a total cost of 888 million euros. Yet, with a further breakdown, we can realize that, as a whole, agriculture comes out in front. Faced with a harvest loss of 749 million euros, the price increase verified results in other companies actually obtaining a benefit of 1.37 billion euros.

For the hydroelectric energy producers, there were no appreciable repercussions, as the possible reduction in productive capacity resulting from the earlier outflow was, fortunately, offset by a plentiful rainfall inflow in the following months. This restored the water body levels and, thus, the productive potential.

Instead, the consumers suffered from the impact of the higher prices resulting from a lower production, for a total loss of 1.5 billion euros.

Table 1 Net costs in managing the water stress on players involved

Players involved	€ Mill.
Farmers	**−628**
Production loss	749
Price increase	−1377
Electric energy producers	
Consumers	**1.516**
Loss in well-being—agricultural production	91
Price increase in agricultural products	1377
Loss in well-being—industrial energy use	22
Widespread loss in well-being	26
Total drought cost	**888**

Source Massarutto and de Carli (2009)

It is interesting at this point to analyse what could have occurred if different management scenarios had been adopted. The scenarios explored in the study forecasted:

- for agriculture, that it would not suffer withdrawal reductions, or that it could benefit from the extra quantities released from upstream. Alternatively, there could be a reallocation of the water for the different crops, favouring the high value-added ones, and changing the crop choices to crops requiring less water;
- for energy, where there is a deficit offset by a higher use of the thermal power station, or, alternatively, by a cut-off to users.

The result clearly shows that the first package of measures—neither reducing nor increasing the water supply—has a low impact. Only a limited number of companies could avoid the reduction in produced quantity, and, therefore, the reduction in damages would be negligible. Instead, a reallocation favouring high value-added crops and/or a change in production choices could significantly reduce the costs (up to 75 % less in the most ambitious of the scenarios). However, it should be noted that these scenarios are based on the effective possibility of water reallocation amongst the irrigated crops, which requires huge investments in the networks, thus resulting in a supply "on demand" (the networks would have to be converted into pump systems, and the fee structure changed to be able to use the immediate pricing as a means of reducing the consumption of the less productive uses).

The social costs of a power blackout would be potentially extremely high (0.67 billion euros only for cutting off industrial users with interruptible contracts), while the costs for substituting the usable sources are more limited, increasing in the short term the supply from the thermal power station or from abroad.

Very similar results to those obtained from the Po river basin study described above can be seen in the study on the effects of drought in another irrigated area, the Fruilian plains (Massarutto and Graffi 2012). Here, the model was created so as to specifically consider the possibility of redistributing the water supplied by the present management model (mainly a gravity-induced supply, and therefore, based on rigid rotation and limited possibility of transferring water from one company to another) and the costs of alternative options (investments to put pressure on the networks and so establish an on demand supply).

In the case of Friuli, the estimated critical frequency was 5 years. This means that if the time between the dry events was longer, then it would be better for the community to “run the risk” of choosing more profitable, but also more vulnerable, crops. If the events were more frequent, other strategies would be preferable (risk diversification through more balanced crop choices, investment in new irrigation methods, etc.).

Therefore, the 2003 event has been a lesson and left some quite clear policy implications.

The first is that, contrary to what could be feared, the impact on the agricultural activities as a whole is quite moderate and could be managed using mutual insurance tools (e.g. an eventual compensation for the farmers who lose their harvest borne by those who, instead, obtained a benefit).

The second is that, in the short term, the inflexibility of the system plays in favour of strategies aimed at minimizing the potential damage; however, once the emergency is overcome, it would be advisable to consider adopting medium to long-term projects aimed at reducing overall vulnerability. For example, this could be obtained through a more balanced crop selection. However, this is valid only if the frequency of water stress events exceeds a certain critical threshold.

The third is that the potentially serious effect in terms of social costs, namely a power blackout, could be averted if the system equipped itself with a reserve capacity, able to replace the hydroelectric supply, making use of other energy sources.

5 The Ecological Footprint of Water Consumption in Italy

Apart from the implications concerning the best strategies to face the future phenomena of water scarcity, the case analysed provides some useful recommendations, also from this book’s analytical viewpoint.

As far as a water footprint approach is concerned, Italy is undoubtedly a country with a high internal[2] water footprint—water withdrawals are amongst the highest in the world but efficiency in use amongst the lowest. Italian agriculture, in particular, consumes an enormous quantity of water, and the more it uses, the less efficient its

[2]The internal water footprint is an indicator of the consumption of internal water resources in a delineated geographical area over a given period of time. It is different to the external water footprint which refers, instead, to the consumption of water resources originating from other countries (Hoekstra et al. 2011).

management model appears. With the right measures, water withdrawal could be considerably reduced as, for example, a great deal of water is presently used to irrigate very low value crops.

A misleading interpretation of these indicators is, however, to associate the use of water with “consumption” and, therefore, with environmental “dissipation”. This approach is quite intuitively easy, but is not always correct.

The reduction in the water volume used can be or not be a desirable objective, but, in general, this is not so much due to the fact that we use a lot (in absolute values) but that we use it badly (i.e. using it for a limited social benefit). What should be considered is the degree of conflict amongst the competing uses—obviously also including the “environmental use”, namely water for the production of ecosystem services—as well as the type of water to be used. In fact, the distinction between “green” and “blue” water allows for a much more precise evaluation of the impact of water resource use, as it takes into account the different cost-opportunities of the different virtual water “sources”.

In short, the true “footprint” to be reduced is not so much the quantitative one (how much water we use), but rather the one that occurs due to a chaotic, uncoordinated and disorganized model of accessing a common good. If this was managed more effectively and efficiently, all the social demands, including those of the ecosystems, could be easily satisfied.

Italy, a water-rich country, especially in the north, has been, for some time, experiencing situations of water stress. These are due to the accompanying effects of a demand which, even though lower than in the past in absolute terms, is more inflexible because of the increased vulnerability of water-intensive economic activities, and of a supply which, due to climate changes and a stronger focus on ecological considerations compared to the past, has witnessed an overall reduction in usable resources and more frequent critical seasons.

The 2003 event resulted in social costs estimated at 1.5 billion euros only for the Po river basin. Costs that could have been much lower if the system had been better equipped and organized to tackle the situation, and if it had not had to, for the umpteenth time, face it as an emergency.

It is clear that Italy must rethink its water management model. I believe that the path to change lies mainly in searching for a way to reduce the present vulnerability, with more flexibility and ability to adapt, rather than in merely reducing the volume of water used.

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