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THE VALUE OF WATER

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1. Introduction

There is a widespread perception among water professionals today of a crisis in water resources management. Water resources are poorly managed in many parts of the world, and many people – especially the poor – lack access to adequate water supply and sanitation. Moreover, this is not a new problem – it has been recognized for a long time, yet the efforts to solve it over the past three or four decades have been disappointing, accomplishing far less than had been expected. In addition, in some circles there is a feeling that economics may be part of the problem. There is a sense that economic concepts are inadequate to the task at hand, a feeling that water has value in ways that economics fails to account for, and a concern that this could impede the formulation of effective approaches for solving the water crisis.

My own personal assessment is that the situation is somewhat more complex than critics suggest. On the one hand, as environmental economics has evolved over the past forty years, it has developed a conceptual toolkit that I think is well suited for dealing with many of the issues of water supply and water resource management. On the other had, economists sometimes slip into older ways of thinking and characterize economic value in terms that are inadequate or misleading. Moreover, even among economists there is an inadequate appreciation of the complexities of water as an economic commodity; these render it distinctive from other commodities and they contribute to the explanation of the current crisis in water.

This paper examines the economic concept of value and some related notions as they apply to water, at least partly in light of these concerns. It consists of two main sections. Section 2 reviews the economic concept of value, explains how it is measured, and discusses how this has been applied to water in various ways. Section 3 takes on the debate regarding whether or not water can or should be treated as an economic commodity, and discusses the ways in which water is the same or different as other commodities. The paper ends with a few concluding observations in Section 4.

2. What is Economic Value? How is it Measured?

Is economic value measured by market price? If an item has a price of $x, is this also the amount of its economic value? Most people assume the answer is yes, and economists sometimes also make this statement. For example, the following passage equates the economic value of water with its market price:

> "Water has economic value only when its supply is scarce relative to demand. Whenever water is available in unlimited supply, it is free in the economic sense. Scarce water takes on economic value because many users compete for its use. In a market system, economic values of water, defined by its price, serve as a guide to allocate water among alternative uses, potentially directing water and its complementary resources into uses in which they yield the greatest total economic return."[1]

If it were true that economic value is measured by market price, this would imply that only marketed commodities can have an economic value. Items that are not sold in a market – including the natural environment, and public goods generally – would have no economic value. If this were so, economic value would indeed be a narrow concept and at variance with many people's intuitive sense of what is valuable.

In fact, however, economic value *is* different than price. Price does not in general measure economic value, and items with no market price can still have a positive economic value.

This was first pointed out by Dupuit (1844) and Marshall (1879). But, as explained below, it took until the 1970s for this to become well accepted within modern economics. It was around this time that operational procedures became available to measure economic value separately from price; and it was around this time that non-market valuation emerged as a field in economics. It so happens that water as a commodity played a role in these developments, both clarifying the economic concept of value and developing operational procedures for measuring it.

2.1 The Meaning of Economic Value

The distinction between market price and economic value was famously noted by Adam Smith in a passage in the *Wealth of Nations* describing the paradox of water and diamonds:

> The word Value, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called 'value in use'; the other, 'value in exchange'. The things which have the greatest value in use have frequently little or no value in exchange; and, on the

[1] Ward and Michelsen (2002)

> contrary, those which have the greatest value in exchange have frequently little or no value in use. Nothing is more useful than water; but it will purchase scarce anything; scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it. (Book I, chapter IV).

Smith was using the comparison between water and diamonds to illustrate a distinction between two different meanings of "value". In fact, neither the distinction between the definitions of value nor the use of water to illustrate it was original with Smith.[2] Two thousand years before Smith, Plato had observed that: "Only what is rare is valuable, and water, which is the best of all things ... is also the cheapest."[3] In fact, Plato and Smith were both expressing a thought that had occurred to many other people over the ages, namely that the market price of an item need not reflect its *true* value. Market price reflects the fluctuating circumstance of daily life, whether the vagaries of supply (sudden scarcity, monopoly, etc) or demand (temporary needs, changes in taste, fads and fashions), while the true value is something more basic, enduring, and stable.

Just what this true value is has been seen differently at different times. For Plato, the true value was intrinsic to the Ideal Form underlying the item. For Aristotle, it was intrinsic to the natural end that the item served. Aristotle also originated the distinction between this value – in effect, value in use – and value in exchange: "Of everything which we possess there are two uses ... one is the proper, and the other the improper or secondary use of it. For example, a shoe is used for wear, and is used for exchange; both are uses of the shoe."[4] For Saint Thomas Aquinas, the true value of an item was determined by its "inner goodness", an intrinsic quality of the item stemming from its relation to the divine purpose. In the 14th century, some Scholastics propounded a view closer to Aristotle's that the intrinsic value of an item arises from its inherent usefulness and ability to please man according to rules of reason. However, starting with Davanzati in 1588, Italian humanists stressed subjective human preference rather than objective human need as the basis of true value. Men seek happiness, Davanzati wrote, by satisfying all their wants and desires, and they value items as these contribute to this end. While value reflects human preference -- not only wants of the body but also what one later writer called "wants of the mind, most of them proceeding from imagination" – price reflects not only demand but also supply, and that is influenced by scarcity. As Barbon wrote in 1690, "things may have great virtues, but be of small value or no price if they are plentiful."

These quotations from the sixteenth and seventeenth centuries demonstrate an awareness of three key principles. First, demand is separate from supply. Demand indicates what things are worth to people; supply indicates what things cost. Second, market price reflects the interaction of both demand and supply and, in principle, is

[2] Moreover, as I shall argue, Smith's analysis of this example is incomplete, and the conclusion he drew from it is largely incorrect.
[3] Plato *Euthydemus*, as cited in Bowley (1973). The discussion that follows draws on Bowley, Schumpeter (1963), Gordon (1975), Pribram (1983) and Niehans (1990).
[4] Aristotle, *Politics*, Book I, 9.

separate from each of them. Third, the value that people place on an item (their demand for the item) inevitably reflects their subjective preferences.[5]

Returning to Adam Smith, given his distinction between value in use and price (value in exchange), which is fundamentally the more useful measure of value? Here I part company from Smith because, following Hume and Locke before him, he associated the true value of an item largely with its cost of production. This English School held that, while the market price of an item at any particular point in time is determined by demand and supply, in the long run this will tend towards what Hume called a "fundamental price," and Smith a "natural price," which is determined by the underlying cost of production. Implicitly, they were assuming a horizontal long-run supply curve, so that consumer demand has no influence on price in the long run. This is now seen as a special case, and the modern economic concept of value focuses essentially on value in use.

The modern concept was first formulated by Dupuit (1844) and Marshall (1879). Dupuit stated that the "maximum sacrifice expressed in money which each consumer would be willing to make in order to acquire an object" provides "the measure of the object's utility." Marshall used a very similar formulation; he defined the "economic measure" of a satisfaction as "that which a person would be just willing to pay for any satisfaction rather than go without it." These definitions highlight the distinction between demand and supply: the measure of value is what the item is worth to the individual, not what it costs. Thus, an item can be cheap to produce, in the sense that its total cost is low, but highly valuable to the owner, in that its total value to him is large, or conversely.

Generalizing from this, the modern economic concept of value is defined in terms of a tradeoff. When an economist states that, for some individual, X has a value of 50 in terms of Y, this means no more, and no less, than that the individual would be willing to exchange X for 50 units of Y. Y is said to be the numeraire in terms of which value is measured, This numeraire can be money but it need not be; it could, for example, be some specific commodity. The tradeoff is in no way limited to market goods; it can be between any two items that the individual values, regardless of whether these have a market price.

Before any further discussion of the relation between value and price, it is necessary to introduce a distinction which was lacking in Smith's analysis but was understood by Dupuit and Marshall, namely the distinction between *marginal*, on the one hand, and *average* or *total*, on the other. Thus, marginal value needs to be distinguished from average or total value, and marginal cost from average or total cost. The marginal quantity measures the change in total value, or total cost, associated with a unit change in quantity while the average measures total value, or total cost, averaged over the total quantity. Admittedly, there is one case where they are the same: if the marginal value (or

[5] This applies to water, too, even though it is obviously an essential want of the body. Without wishing to demean the importance of water, I will present some evidence below that, compared to other items they could buy, people sometimes place a lower value on improving their access to water than what the public health professionals would recommend.

marginal cost) is constant as quantity changes, then marginal cost (or value) coincides with average cost (or value). But, in general, marginal value and marginal cost are *not* likely to be constant. In particular, the general presumption is that marginal value (and marginal utility or marginal benefit) decline with quantity.

The notion of declining marginal utility was the cornerstone of Dupuit's analysis. Dupuit recognized that if the consumer is free to vary the quantity of an item purchased, she will choose this quantity so as to equate her marginal value (utility) for the item to its price. In that case, the market price provides an accurate measure of the *marginal* value associated with the last unit of consumption. But, Dupuit stressed, the *total* payment does not accurately reflect the *total* value of all units consumed. This is because of diminishing marginal utility: if the marginal value of the last unit just equals the market price, it follows that the marginal utility associated with the *infra-marginal* units will be *higher* than this market price. In effect, the consumer earns a "profit" on the infra-marginal units because they are worth more to her than the price she pays, which in fact is why she consumes a larger quantity thereby rendering these units infra-marginal. Marshall, who independently formulated a similar argument thirty years later, called this profit the "consumers' rent" in 1879, and the "consumer's surplus" in 1898.

In summary, if there is a market price for the item in question and if the consumer is free to vary the quantity of this item that she purchases, its marginal value to her is reflected in, and can be measured by, the market price; otherwise, not. Even when price reflects marginal value, *total* expenditure does *not* reflect *total* value; instead, total expenditure *understates* total value because of the presumption of diminishing marginal utility. The distinction between marginal and total is the key to the full resolution of the diamond and water paradox: water may have a smaller value than diamonds at the margin, but it undoubtedly has a larger total value.

Although Dupuit and Marshall correctly enunciated the economic concept of value in its modern formulation, it actually dropped out of favor with economists around the turn of the last century. Marshall himself came to be troubled that his use of the demand curve to measure consumer's surplus was inexact and relied on the assumption of a constant marginal utility of income. And, as the ordinal utility revolution took hold in economics, Marshall's analysis based on cardinal utility appeared hopelessly out-dated and irrelevant. It took until the 1970s before these issues were fully resolved and the Dupuit-Marshall concept was recognized as being both fully consistent with modern, ordinal utility theory and susceptible of rigorous empirical measurement. This came about as a result of several important conceptual advances.

First, Hicks rehabilitated the Marshallian concept of consumer's surplus in a series of papers starting with Hicks (1939) which demonstrated that this concept is in fact consistent with ordinal utility theory and that it could be measured exactly if one were given an indifference map. However, this was a pyrrhic victory because the general view was that, while it is a useful theoretical construct, the indifference map is not itself directly observable. Hence, Marshall's measure as re-interpreted by Hicks was not measurable in practice. This view finally changed around 1970 as the result of the development of what is known as duality theory, including the demonstration by Hurwicz and Uzawa (1971) of a theoretically rigorous yet practical numerical procedure for identifying the specific utility function underlying any given system of demand equations that satisfies the formal requirements of modern ordinal utility theory. This now made it possible to start with an econometric estimate of a suitably specified demand equation for a marketed commodity, or a system of demand equations for a set of commodities, and derive a theoretically consistent and rigorous estimate of the Dupuit-Marshall measure of the economic value of these commodities.

Second, building on Hicks (1939), Henderson (1941) discovered an alternative way of characterizing the tradeoff that underlies the economic concept of value. When one says that a person is willing to exchange X for 50 units of Y, this could mean either (i) the person would be willing to give up (pay) 50 units of Y to obtain X or (ii) the person would accept 50 units of Y to forego X. The first uses *maximum willingness to pay* (WTP) as the measure of value, and is the measure mentioned by Dupuit and Marshall and analyzed by Hicks (1939). The second is the new measure that was suggested by Henderson; it uses *minimum willingness to accept* (WTA) as the measure of value. Together, these exhaust the logically possible ways of expressing a tradeoff. Hicks (1942, 1943, 1946) analyzed the relationship between them in the case of a price change and showed that they differ by an income effect.[6]

The third development was the extension of the economic concept of value to a broader class of items than market commodities. In fact, nothing limits "X" in the definition of economic value given on page 5 above to being a market good; it could actually be *anything* from which people derive satisfaction. This suggests that the same definition of economic value can be applied to *non-market* items. For example, one could say that a person values some aspect of his health at 50 units of Y if he would be willing to exchange 50 units of Y to preserve that aspect of his health; that he values a beautiful sunset at 50 units of Y if he would be willing to exchange 50 units of Y to experience it; or that he values an endangered species of animal at 50 units of Y if he would be willing to exchange 50 units of Y to ensure its preservation. In each case, it should be evident that there are two possible ways to formulate the exchange: a WTP formulation and a WTA formulation. This was demonstrated formally by Maler (1971, 1974) who showed that, when Y is money, the Hicksian analysis and its modern formulation in terms of duality theory carry over from the valuation of market goods to non-market items.[7] Maler's analysis thus provides a formal justification for the field of non-market valuation, including the monetary evaluation of the natural environment.

2.2 Non-market Valuation and Water

[6] An important paper by Willig (1976) showed how one could use Hurwicz and Uzawa's result to develop a tight numerical bound on the possible difference between WTP and WTA in the case of a price change for a marketed commodity. The Hurwicz-Uzawa result implies that both WTP and WTA can be derived from an econometric estimate of suitably specified demand equations.

[7] However, there is an important difference. With valuation of non-market items, the difference between the WTP and WTA measures involves not only an income effect but also a substitution effect (Hanemann, 1991).

Economic valuation deals with the valuation in monetary terms of items that people might care for. Non-market valuation applies the same notion to items that are not sold in a market. It is important to emphasize that the Dupuit-Marshall concept of economic value carries over to such items. This is because, even for something that is not sold in a market, it is still meaningful to conceptualize the economic measure of the satisfaction from the item as the monetary amount which the person would be just willing to exchange for the item if it were possible to make such an exchange. In effect, this generates a monetary measure of the change in the person's welfare by using the change in the person's monetary income that she would consider equivalent to the item in question in terms the overall impact on her satisfaction.[8] [9] [10]

The history of non-market valuation in the United States is closely intertwined with water projects, since these were an important motivation for the development of cost-benefit analysis. The idea of cost-benefit analysis originated in the United States, in Hammond's (1960) phrase, as "an administrative device owing nothing to economic theory" in the context of managing the activities of the US Army Corps of Engineers around the beginning of the last century. The 1902 River and Harbor Act had created a Board of Engineers to review navigation projects; in conducting a review, the Board was required to consider the commercial benefits from such projects in relation to their costs. The River and Harbor Act of 1920 further required the separate reporting of special, or local, benefits as opposed to general, or national, benefits for the purpose of ensuring proper local cost-sharing. In 1934, the National Resources Board appointed a Water Resources Committee to consider "the development of an equitable system of distributing the cost of water resource projects, which should include not only private but also social accounting." Finally, the Flood Control Act of 1936 permitted the Army Corps of Engineers to involve itself in flood control provided that, in a famous phrase, "the benefits to whosoever they may accrue are in excess if the estimated costs." In 1946, a Subcommittee on Benefits and Costs of the federal Inter-Agency River Basin Committee was appointed to investigate the practices of the various federal agencies that were engaged in the evaluation of federal water resource projects and to formulate some "mutually acceptable principles and procedures." This led ultimately to the publication

[8] The equivalence can be conceptualized in two possible ways – the maximum amount that the person would be willing to pay to gain the item, or her minimum willingness to accept to forego it.

[9] It should be noted that this definition provides a unified approach to welfare measurement for both firms and households. In the case of households, whose objective function is defined in terms of utility, the monetary measure is the change in income that is considered equivalent to the change in utility. In the case of firms, whose objective function is defined in terms of profit, the monetary measure is the change in profits itself.

[10] Although the modern economic concept of value is defined in terms of a tradeoff, it is possible that some people find themselves unable to make a trade-off because for them the two items being compared are incommensurable. A type of preference that gives rise to such trade-off aversion is where there is a lexical ordering over commodities: certain goods in *any* quantity or quality *always* take precedence over *all* quantities or qualities of other goods, so that no amount of increase in the latter can ever compensate for any reduction in the former. This is known as lexicographic preferences. A modified version of lexicographic preferences is where the lexical ordering applies only below a threshold level of the good (Lockwood, 1996); among other things, this generates a situation where the individual might have an infinite WTA for a reduction in an item.

in 1950 of what became known as the "Green Book" which attempted to codify the principles of cost-benefit analysis for use by federal agencies. The following decade saw the publication of many academic journal articles and six major academic books dealing with the economic analysis of water projects.

The 1950s were when the field of non-market valuation began to come into existence. The approach that emerged first is what became known as the travel cost method or, more generally, the revealed preference method. It arose initially out of an effort by the National Park Service (NFS) to measure the economic value associated with the national parks. At the time there were no entrance fees at national parks, so the NFS could not use park revenues as a measure of their value. The issue was assigned to a staff economist who wrote to ten distinguished economic experts for their advice. All but one replied that it was impossible to measure recreational values in monetary terms, but the tenth, Harold Hotelling disagreed. He saw that, even though there was no entrance fee for a national park, it still cost visitors something to use the parks because of expenses for travel, lodging and equipment. These expenditures were not captured by the NFS but, they still set a price on the park. Moreover, this price would vary among people coming from different points of origin. By measuring the price and graphing it against visitation rates one could construct a demand schedule for visits to the site, and then determine consumer's surplus in the usual manner as the area under this demand curve.

The NFS report followed the majority view and asserted that it was not possible to set a monetary value on outdoor recreation. However, in 1956 the State of California hired an economic consulting company to estimate recreational benefits associated with the planned State Water Project. This company learned of Hotelling's idea and decided to apply it. A survey of visitors was conducted at several lakes in the Sierras and data were collected on how far they had traveled and how much they had spent. Using these data, a rough demand curve was traced out, and an estimate of consumer's surplus was constructed. This analysis appeared in Trice and Wood (1958), the first published application of the travel cost method. At the same time, Marion Clawson (1959) at Resources for the Future had begun collecting data on visits to Yosemite and other major national parks in order to apply Hotelling's method to them, which was the second published application. By 1964, there were at least five more applications in various parts of the US, and the travel cost method was an established procedure.

The insight behind the travel cost method, and revealed preference generally, is that, while people cannot buy nonmarket goods such as clean water or an unspoiled environment directly, there sometimes exist market goods that serve as a partial surrogate for the nonmarket good because the enjoyment of these goods is enhanced by, or depends on, the nonmarket good. In that case, the demand for the market goods is used as a surrogate for the demand for the non-market good.

The limitation of this approach is that there may not exist a market good that can serve as surrogate for the nonmarket good of interest. Moreover, even if such a good exists, it may not capture *all* of people's preferences for the complementary non-market good. The conceptual identification of what might be omitted by the revealed preference approach came about as a result of papers by Weisbrod (1964) and Krutilla (1967). Both authors started from the premise that some of people's motives for valuing the natural environment may differ from those for valuing a market good. People may value the natural environment out of considerations *unrelated* to their own immediate and direct use of it. Weisbrod focused on uncertainty and what became known as "option value": some people who do not now visit a national park, say, may still be willing to pay money to protect it from destruction or irreversible damage because they want to preserve their option of visiting it in the future. Krutilla focused on what became known as "bequest value" and "existence value."[11] With bequest value, the notion is that some people would be willing to pay because they want to preserve the park for future generations. With nonuse value, the notion is that some people would be willing to pay even if they knew that neither they nor their children would ever visit it; in Krutilla's example, people may "obtain satisfaction from mere knowledge that part of the wilderness in North America remains." These are legitimate sources of value, Krutilla and Weisbrod felt, but they would not be respected by private managers of the environmental resource. Nor would they be adequately measured by a conventional revealed preference analysis such as the travel cost method. Consequently, some other method of measurement is needed.

The alternative approach, first suggested by Ciriacy-Wantrup (1947), is to interview people and elicit their monetary value; this became known in economics as the contingent valuation (CV) method.[12] Ciriacy-Wantrup was discussing soil conservation and he noted that several of the benefits were non-market goods, such as reduced siltation of rivers or reduced impairment of scenic resources. He characterized the problem as being how to obtain a demand curve for such goods, and suggested the following solution: "[Individuals] may be asked how much money they are willing to pay for successive additional quantities of a collective extra-market good. The choices offered relate to quantities consumed by all members of a social group... If every individual of the whole social group is interrogated, all individual values (not quantities) are aggregated. The results correspond to a market-demand schedule. While noting the possible objection that "expectations of the incidence of costs in the form of taxes will bias the responses to interrogation," he felt that "through proper education and proper design of questionnaires or interviews it would seem possible to keep this potential bias small."

Having identified a solution conceptually, Ciriacy-Wantrup never pursued it further. The first significant application was by Davis (1963) which dealt with the economic value of outdoor recreation in the Maine woods; to measure this Davis interviewed a sample of hunters and recreationists and asked how much more they would be willing to pay to visit the area.[13] The next application was by Ridker (1967); to measure the damages from air pollution, Ridker included some questions in a survey

[11] The latter is now also called "non-use value" and "passive use value."
[12] More recently, the term "stated preference" has been used to cover CV and related approaches. They are also known as direct valuation whereas revealed preference approaches are referred to indirect valuation because they do not measure preferences directly but instead infer them from externally observed behavior.
[13] Probably the first CV study was actually conducted in 1958 for the NFS, which hired a market research company to survey residents of the Delaware River basin about their willingness to pay (WTP) entrance fees for national parks

about people's WTP to avoid soiling from air pollution. In 1969, a steady stream of CV studies began to appear in the economics literature. Official recognition was given to CV in 1979, when the US Water Resources Council included it along with travel cost as recommended methods of non-market valuation.

The first application of nonmarket valuation in the US, the 1957 valuation of recreation benefits from the California State Water Project, was a harbinger of things to come: since then many non-market valuation studies have been conducted in the US in connection with water resources management issues, and the environmental consequences of water projects have come to play a significant role in the design and approval of water projects. These trends emerged slowly in the 1970s and 1980s, driven by developments in the implementation of the 1969 National Environmental Policy Act (NEPA).[14] NEPA required federal agencies to prepare a "detailed statement" of environmental impacts for proposed major actions which significantly affect the quality of the human environment, including the identification of the environmental impacts of the proposed action, alternatives to the proposed action, and any adverse environmental impacts which cannot be avoided should the proposal be implemented.

In consequence, since the mid-1980s it has not been acceptable in the US to perform an economic assessment of a major water project without including some non-market valuation of the project's environmental impacts. For example, non-market valuations of environmental impacts were included in the Department of Interior's re-assessment of the operation of Glen Canyon Dam on the Colorado River in 1984-1992, and in the Bureau of Reclamation's assessment of the Central Valley Project Improvement Act in 1993-1996. In California, they were included in the State Water Resources Control Board's review of the diversions of water from the San Francisco Bay/Delta to the Central Valley and Southern California, conducted in 1987-1994, and in the Board's 1993 Mono Lake Decision requiring Los Angeles to reduce its diversion of water from streams feeding Mono Lake on the eastern side of the Sierra Nevada.[15] In the case of Mono Lake, the Board decided that it was in the public interest to reduce Los Angeles' diversion from Mono Lake by about two thirds, despite the resulting loss of hydropower and water supply (which amounted to over 8% of Los Angeles' total water supply) primarily in order to protect habitat for birds and other wildlife; non-use values associated with habitat protection constituted the main component of environmental benefits (Wegge, Hanemann and Loomis, 1996).

It should be emphasized that the use of non-market valuation applies to positive as well as negative environmental impacts of water projects. The experience in the United States has been that these can generate significant economic benefits associated with water-based recreation, eco-tourism, and the non-use value of ecosystem protection. These environmental benefits sometimes greatly outweigh the benefits from agricultural or even urban water use. In short, in the U.S. we have now moved from the traditional situation where there was essentially a single objective for large water projects, namely

[14] Subsequently, a number of states passed laws imposing similar reporting requirements on agencies of the state government; for example, the California Environmental Quality Act was enacted in 1970.
[15] I served as the Board's economic staff for both of these issues.

the provision of water for off-stream uses, to a situation where any new water project must have environmental restoration as an explicit objective along with the provision of any off-stream uses.

3. Is Water Different?

Now that the economic concept of value has been explained, the question arises whether it is appropriate to apply this concept to water. Is water an economic commodity, and can it be analyzed using the conceptual framework of economics in the same way as any other commodity?

The answer is contested ground between economists and their critics. One of the four Dublin Principles, adopted at the 1992 International Conference on Water and the Environment in Dublin, holds that "Water has an economic value in all its competing uses and should be recognized as an economic good." Similarly, Baumann and Boland (1998) write: "water is no different from any other economic good. It is no more a necessity than food, clothing, or housing, all of which obey the normal laws of economics." Per contra, Barlow and Clarke (2002) proclaim it as a "universal and indivisible" truth that "the Earth's fresh water belongs to the Earth and all species, and therefore must not be treated as a private commodity to be bought, sold, and traded for profit…the global fresh water supply is a shared legacy, a public trust, and a fundamental human right, and therefore, a collective responsibility." Vandana Shiva (2002) writes in a similar vein about a clash between two cultures: "a culture that sees water as sacred and treats its provision as a duty for the preservation of life and another that sees water as a commodity, and its ownership and trade as fundamental corporate rights. The culture of commodification is at war with diverse cultures of sharing, or receiving, and giving water as a free gift."

My own view lies somewhere between these two positions. Baumann and Boland are undoubtedly correct when they point out that food, clothing and shelter, like water, are necessities of life, and they are typically provided through the market, but this provokes little complaint from non-economists. Why, they ask, should water be different? I believe there are two reasons why this is so. First, water is clearly viewed by many people as being different. The fact that water, unlike other household commodities, arouses such passion speaks for itself: for better or worse, water is perceived as a having a special significance that most other commodities do not possess. [16] This itself has economic consequences. Second, I believe that water has some other *economic* features that make it distinctive. These features make water different from, say, bread or land, *as an economic commodity* yet they are often overlooked by economists. They matter greatly because they affect the demand for water, its value, and the social and

[16] This is true in rich as well as poor countries – in the US, for example, it is notoriously difficult for publicly owned urban water utilities to obtain political approval for even trivial rate increases while other household utilities such as cable television raise their rates with impunity; Glennon (2004) has a similar observation.

institutional arrangements by which it is supplied. To explain them, I will need to introduce several more items from the economists' conceptual toolkit.

3.1 Water as a Private Good, Water as a Public Good

Since Samuelson (1954), economists have drawn a distinction between conventional market goods – also known as private goods – and what are known as *public goods,* "which all enjoy in common." The two key properties of a public good are *non-rivalry in consumption* and *non-excludability*. With conventional goods, one person's consumption necessarily competes with that of another, in that more consumption by one person renders a smaller quantity of that good available for consumption by anybody else. With public goods, by contrast, more consumption by one person in no way reduces the amount available for others. Conventional consumption goods are excludable in that, if this is so desired, it is physically possible to exclude any person from consuming the commodity. With public goods, by contrast, if the good is available for consumption by anybody, it is available for consumption by all. Examples of a public good suggested by Samuelson were "an outdoor circus or national defense which is provided for each person to enjoy or not, according to his tastes." The abatement of pollution in a lake is another example of a public good, as are other types of environmental improvement: my enjoyment of the clean water in the lake in no way reduces the amount of clean water available for your enjoyment (non-rivalry) and, if the water in the lake is clean for me to enjoy, it is clean for everyone's enjoyment (non-excludability).[17]

In this framework, water is both a private good and a public good. When water is being used in the home, in a factory or on a farm, it is a private good. When water is left in situ, whether for navigation, for people to enjoy for the view or for recreation, or as aquatic habitat, it is functioning as a public good.[18] Moreover, while the water in a reservoir is a private good, the storage capacity of the reservoir per se may be a public good. By contrast, most of the other commodities associated with food, clothing or shelter are purely private goods and have no public goods aspect; this is one of the respects in which water is different than these other commodities in economic terms.

Samuelson identified two important consequences of the public good properties. First, while public goods are likely to be supplied collectively, for example through a voting process, rather than through a decentralized market, it is likely that they will be *undersupplied* because people have a selfish incentive to free ride on the collective decision process by understating their true interest in the public good. Second, the valuation of public goods is fundamentally different than that for private goods because a public good can be enjoyed simultaneously by many while a private good can be

[17] In addition to private and public goods, there can also be an intermediate case, sometimes called a quasi-private good, where there is non-rivalry but excludability. An example is television frequencies, public libraries, or bridges. Furthermore, there may be non-rivalry at low levels of aggregate consumption of a commodity but rivalry at high levels of consumption, once the item becomes congested – this could happen, for example, with a park or a bridge.
[18] To the extent that water-based outdoor recreation is excludable, this would be a quasi-private good.

consumed by only one party at a time. Thus, the value placed on a given unit of a private good is that of a single user – in an efficient market, this will be the user with the highest and best use for the item. By contrast, the value placed on a public good is that of many people, namely all those for whom the item has some value.[19] This is why the non-market benefits of environmental preservation can sometimes outweigh the use benefits associated with the diversion of water for off-stream agricultural or urban use.

The public good nature of water in situ, historically associated with navigation, has had a decisive influence on the legal status of water. In Roman law and, subsequently, in English and American common law, and to an extent in Civil Law systems, flowing waters are treated as common to everyone (*res communis omnium*), and are not capable of being owned. These waters can only be the object of rights of use (usufructuary rights), but not of rights of ownership.[20] Thus, even though water and law are often complementary inputs, there is a crucial distinction in that land can be owned, while water cannot.

3.2 The Mobility of Water[21]

A distinctive physical feature of water is its mobility. Water tends to move around. It flows, it seeps, it evaporates. When water is applied to plants in the field (or to an urban landscape), a substantial portion either seeps into the ground or runs off the ground as tailwater. In addition, in residential indoor uses and most industrial uses there is usually an outflow of wastewater after the use is completed. The consequence is that there can be several sequential uses of the same molecule of water since water is rarely consumed fully by a given user and what is left is physically available, in principle, for use by others.[22]

The mobility of water and the opportunity for sequential use and re-use make water relatively distinctive as a commodity – especially compared to land, for which such multiple, sequential uses are impossible (except in nomadic societies). These properties of water have important economic, legal and social implications. Keeping track of water flows is often costly and difficult without sophisticated technology. Consequently, it is often hard to enforce excludability or to establish property rights to return flows. In this respect, water is very different as an asset than land, which is relatively easy to divide and fence. The common solution is to resort to some form of *collective* right of access; in

[19] This follows from Samuelson's demonstration that the aggregate demand curve for a public good is constructed in a radically different manner than the aggregate demand curve for a private good. With a private good, the aggregate demand curve is the horizontal sum of every individual's demand curve for the good; with a public good, the aggregate demand is the vertical sum; this observation had in fact already been made by Ciriacy-Wantrup (1947). In terms of the distinction between use and non-use values, if there is a non-use value for an item this is a public good.

[20] By contrast, groundwater beneath private land and springs or rainwater found on private land is typically treated as being privately owned.

[21] The analysis in this and the following two sections was influenced by reading Young and Haveman (1985).

[22] In the process, however, there can often be some reduction in the quality of the water relative to that in the first use. Because of the solvent properties of water, the return flows are apt to dissolve and absorb chemicals in the media through which they pass.

effect, this internalizes the externality associated with the mobility of return flows. A classic example of this is the riparian water right in English and American common law. This permits any landholder whose property is adjacent to a stream or body of water to divert a reasonable amount of water, provided this does not cause harm to other riparian landholders or interfere with their co-equal right to divert a reasonable amount of water. The riparian right to the use of water is not a right to a fixed quantity, and it is a co-relative right shared with all other riparians along the same stream.[23]

3.3 The Variability of Water

In addition to the mobility of water in streams, another crucial feature is the variability of supply in terms of space, time, and often quality. Spatially, water is distributed very unevenly across much of the globe; just six countries – Brazil, Russia, Canada, Indonesia, China and Colombia – account for half of the world's total renewable supply of freshwater (Worldwatch Institute, 2004). Even within countries and regions, there is unequal spatial distribution. In California, for example, two thirds of the state's population live in Southern California, but this region receives less than 10% of the state's total precipitation. For any given region, there is substantial variation in precipitation both within the year and between years. In California, for example, approximately 80% of the annual precipitation falls between October and March, while three quarters of the water use occurs between April and September.[24] Beyond this, cycles of wet and dry years occur in California as a function of wider climactic phenomena such as the interannual El Nino- Southern Oscillation and the Pacific Decadal Oscillation. While the annual runoff in California has averaged about 71 million acre feet (MAF) over the past 90 years, it has been as low as 15 MAF (in 1977) and as high as 135 MAF (in 1983).

Because of this variability, the major challenge for most large water systems is the spatial and temporal matching of supply with demand. Storage is typically the key to controlling the temporal variability in supply, while inter-basin transfers are used to overcome the spatial mismatch between supply and demand. But, the variability of supply has affected not just the engineering of water resource systems but also the legal, and institutional arrangements for the use of water. The variability of supply is yet one

[23] In American law, there is a further requirement that riparians put the water to a reasonable use. With surface water, the major alternative in American law to the riparian right is the appropriative right, which was developed in the arid West. This permits the diversion of water, regardless of whether the diverter owns the riparian land, in a fixed quantity, subject to the principle of "first in time is first in right." The theory is that, if the streamflow is inadequate to meet all the diversion requirements, those with a more recent ("junior") date of initial diversion cede to those with an older ("more senior") date. On the ground in at least some states, such as California, the practice seems to be rather different, since the precedence of seniority is not self-enforcing without resort to litigation; much of the time, what actually happens with appropriative rights may be closer to a version of the riparian system.

[24] The seasonal variability of precipitation in California is exacerbated by the fact that it is an arid region with a Mediterranean climate. But precipitation is distributed unevenly throughout the year in almost all parts of the world, albeit not as severely as in California. In Europe, the major part (46%) of the runoff occurs during April to July, and similarly in South America; in Asia, 54% occurs in June to September; in Africa, 44% occurs in September to December; in Australia and Oceania, 40% occurs in January and April (UNESCO, 2000).

more point of divergence between water and land, and it explains why the property rights regimes are different: it would surely be difficult to apply the ownership rights in land to so variable a resource as water.

Besides the variability in supply, there is the following parallel feature on the demand side for water. In typical agricultural uses of water, which account for the greatest volume of water use in many areas, the demand is intermittent in nature, in that crops need to be irrigated only at periodic intervals rather than every day. Until the advent of affordable storage, which was mainly a phenomenon of the 20th century and large-scale (and perhaps subsidized) diversion of water, the intermittent nature of agricultural demand was an important factor supporting the sharing of access whereby, if there is water in the stream and one member of the group is not currently diverting water from the stream, other members of the group are allowed to divert the water rather than let it flow to "waste" in the ocean.[25] This is another difference with land: while the demand for water is intermittent, the demand for land to grow crops or to locate a building is continuous, and there can be no such sharing of the same resource among multiple users. The intermittent nature of the agricultural demand for water is conducive to the collective sharing of a right of access as opposed to individual ownership of a property right.

3.4 The Cost of Water

Compared to other commodities, and other utility services, the cost of water has several distinctive features which complicate its supply.

Water is bulky, and expensive to transport relative to its value per unit of weight. Consequently, the transportation infrastructure for water is far less extensive than that for more valuable liquids such as petroleum. Also, compared to electricity, water is relatively expensive to transport, but relatively cheap to store. Therefore, the strategy for averting shortage takes a different form with water than electricity. If there is a sudden shortfall in supply, with electricity this can be made up almost instantaneously by importing power over the grid from a source that could be 1,000 miles away or more. With water, there is no comparably interconnected transportation grid and, even if there were, it takes longer to move a comparably large quantity of water. Thus, to deal with unexpected outages, one has to either resort to rationing or stockpile sufficient stored water prior to the period of peak use.

Another distinctive economic feature is that water supply is exceptionally capital-intensive compared not only to manufacturing industry generally but also to other public utilities. In the US, for example, the ratio of capital investment to revenues in the water industry is double that in natural gas, and 70% higher than in electricity or

[25] Storage changes this, because streamflow can be stored when it is not currently being used. The discussion here focuses on agricultural rather than urban use of water. Urban use is different because it is more continuous in nature, and when there is a piped water supply this is typically pressurized, unlike with agriculture which relies mainly on gravity flow. Gravity distribution fosters sharing of intermittent access, while pressurized distribution fosters simultaneous individual access.

telecommunications. Moreover, the capital assets used in water supply cannot be removed to another location and are generally unusable for any other purpose; they represent an extreme type of fixed, non-malleable capital. Furthermore the physical capital in the water industry is very long-lived. The infrastructure associated with surface water storage and conveyance and the pipe network in the streets can have an economic life of 50-100 or more years, far longer than that of capital employed in most manufacturing industry or in other public utility sectors.[26]

In addition, there are significant economies of scale in many components of water supply and sanitation. These are especially pronounced for surface water storage: given a specific dam site, within some range, by increasing the capacity of the dam one can significantly reduce the unit cost of stored water. With a groundwater source, by contrast, the economies of scale in production are much less pronounced. There are also important economies of scale in the treatment and conveyance of drinking water and wastewater.[27]

The capital intensity, longevity, and economies of scale mean that water supply and sanitation costs are heavily dominated by fixed costs. In a simple surface-water supply system with minimal treatment of drinking water, minimal treatment of sewage prior to discharge, and a heavy reliance on gravity flow, the short-run marginal cost of water supply and sanitation may be almost zero except for small costs associated with pumping to move water through the system. Even in a modern system with full treatment of drinking water and sewage discharges, the short-run marginal costs are relatively low. In the US, the ratio of operating costs to total costs for efficient water firms is about 10%; by contrast, it is 32% for gas utilities and over 57% for electric utilities.[28, 29]

The capital intensity and economies of scale associated with surface water supply have profound economic and social implications. For one thing, because these are classic pre-conditions for a natural monopoly, they make it more likely that there will be a single

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[26] The Roman aqueduct that still stands in Segovia, Spain is ample testimony to the physical longevity of certain types of conveyance structure. The effective life of a dam is governed by the rate of siltation but can be well over a century. For piping, the American Waterworks Association recommends a replacement cycle of 67 years. A conventional drinking water treatment plant may have a useful life of 40 years, although high technology processes such as reverse osmosis facilities have a shorter life. Compared to surface water, the capital infrastructure associated with groundwater typically has a shorter life; a groundwater pump might typically have a life of about 25 years in the case of an electric pump, or about 15 years for a diesel pump.

[27] With the conveyance of drinking water from the point of production to the point of use, and of treated wastewater to the point of discharge, there are economies of scale with respect to volumetric capacity but not length.

[28] Spiller and Savedoff(1999); Armstrong et al. (1994) report that, in the UK water industry, operating costs represent less than 20%, and fixed costs more than 80%, of total costs.

[29] When piped water supply was introduced into cities in the nineteenth century, water agencies chose not to meter individual homes or small non-residential users partly because of an ethos in favor of promoting universal service but also because water was so cheap at the margin that they felt it was not worth the cost of metering it. By contrast, electricity and gas were metered in residential connections. Water service was financed by charges based on the type or value of the property being served. In the US, metering of residential users did not become common until well into the twentieth century, and there were some notable handouts (Denver and New York City did not meter until about 15 years ago). In the UK, nearly all residential water users were unmetered prior to privatization in 1990.

provider in any given area. More generally, they foster public provision of a surface water supply rather than individual, self-provision, whether the public provision is by a collective of the users or a monopoly seller.[30] Furthermore, the construction and operation of large-scale surface water storage and distribution systems require a high degree of co-ordination and social control. This was the central thesis of Wittfogel's (1957) study of ancient "hydraulic societies" – civilizations that were dependent on large-scale surface water diversion and distribution systems, such as Mesopotamia, Egypt and China. Wittfogel argued that, in such societies, the effective provision of water required the centralization of power and an "oriental despotism" mode of governance in which a state bureaucracy, headed by an absolute ruler, ruled on the basis of its control of the hydraulic system. Wittfogel's work was subsequently criticized by other scholars.[31] Nevertheless, his notion still resonates; it was applied to the American West by Worster (1992), who characterized this as a hydraulic society based on the development and control of water infrastructure by a political elite. This characterization is contested by Kupel (2003), who argues that the history of water projects in Arizona is one of response by civic leaders to requests for service by urban and suburban residents, closely resembling other aspects of the history of modern urban infrastructure. This is not necessarily a contradiction: the commonality in urban infrastructure is capital intensity and economies of scale, with the consequent need for public sector leadership and social co-ordination and, also, the consequent prospect of a handsome increase in land value in the area being served.[32]

Another problematic consequence of the capital intensity, longevity of capital, and economies of scale in surface water infrastructure is the propensity to what might be called lumpiness or, less politely, gigantism in these systems. Because of the economics, there is a strong incentive to make a substantial expansion of capacity at a single point in time rather than to plan for a series of incremental changes spread out over time.[33] The drawback is that it may take many years, or decades, before the demand materializes to utilize this capacity (and the willingness to pay to finance it). When fully utilized, the project provides water at a low cost; but there is uncertainty whether and when it will be

[30] For urban water, the main alternatives to a public supply of surface water are water vendors or household self-provision through pumped wells or rainwater catchments. Where there are water vendors, the unit cost of vended water is always much higher than that of water from piped supply, typically by a factor of 10 or more. The primary reason for the cost differential is economies of scale: it is far more expensive to deliver water in relatively small quantities through multiple trucks rather than in large quantities through a single pipe network. However, the up-front capital investment required for vended water is far lower than for a piped water supply, and this can make vended water a viable alternative.

[31] It was pointed out that large-scale irrigation works in Mesopotamia were developed *after* the rise of a centralized state, so that hydraulic society could be the result rather than the cause of state formation. The Maya civilization, where irrigation was of marginal importance, was cited as evidence that centralized states might not always be associated with hydraulic systems. It was also noted that there are several modern communities in Mesopotamia where small-scale cooperative irrigation works without centralized external control.

[32] As noted above, the increase in land value made it possible to finance urban water infrastructure with property taxes rather than through user charges. This may have been economically rational not only because of the very low marginal cost of urban water, but also because of the public good benefits of urban water supply associated with improved fire protection and also what, in the nineteenth century, were believed to be the public health benefits of washing down streets (Anderson, 1980).

[33] By contrast, systems supplied from groundwater are considerably less lumpy and more scaleable.

fully utilized, and meanwhile it ties up scarce capital. Large surface water projects are risky, and difficult, inter-temporal balancing acts.[34]

3.5 The Price of Water

It is important to emphasize that the prices which most users pay for water reflect, at best, its physical supply cost and *not its scarcity value*. Users pay for the capital and operating costs of the water supply infrastructure but, in the US and many other countries, there is no charge for the water per se. Water is owned by the state, and the right to use it is given away for free. Water is thus different from oil, coal, or other minerals for which the US government requires payment of a royalty to extract the resource. While some European countries, including England, France, Germany and Holland, do levy an abstraction charge for water, these charges tend to be in the nature of administrative fees and are not generally based on an assessment of the economic value of the water being withdrawn. Thus, in places where water is cheap, this is almost always because the infrastructure is inexpensive, or the water is being subsidized, rather than because water is especially abundant.

In the US, it has long been noted that the prices charged to farmers are far lower than those charged to urban residents, often by a factor of 20 or more. It is widely assumed that this is because irrigation water is subsidized by the federal government, but this is not in fact the main reason. It certainly is true that the federal government has subsidized irrigation in the West by waiving interest charges and other means. Between 1902 and 1994, the federal government spent $21.8 billion to construct 133 water supply projects in the West. Although most of the water from these projects is used for irrigation, the cost allocated for repayment by irrigation users was set at $7.1 billion (33%). Of this, $3.7 billion was subsequently waived. Of the remaining $3.4 billion payable by irrigators, only $0.95 billion had actually been repaid as of 1995 (General Accounting Office, 1996). The remaining balance will not be paid off until well into this century, if at all. The combined effect is that recipients of irrigation water from these projects will have repaid, on average, about 10 cents on each dollar of construction cost.

However, these projects account for only about 19% of total irrigation supply in the West. The remainder comes from groundwater or non-federal surface supply projects, none of which is subsidized to a significant degree.[35] While the non-federal irrigation supply is more expensive than the federal supply, typically by a factor of about two or

[34] This is well illustrated by the experience of the Central Arizona Project, the most recent large water project in the US, which actually went bankrupt (Hanemann, 2002). The two key parameters for the economic viability of a water project are the discount rated use to assess the present value of net benefits, and the rate of growth in the public's ability and, more importantly, willingness to pay for the water. Public agencies can generally borrow at a lower interest cost than private firms, and also are more apt to take a long-term perspective in evaluating investment. The public sector's ability and willingness to apply a low discount rate is a major reason for its predominant role in the provision of water supply infrastructure. For all the rhetoric on privatization of water, the private sector seems more interested in taking over the operation of existing infrastructure rather than financing new infrastructure, except for water treatment facilities which, as noted above, have a shorter life than other water supply infrastructure.
[35] If there is a subsidy, it is likely to be for the electricity component.

three, it still is much cheaper than urban water supply. The reason is the difference in costs. Irrigation water is not treated. Irrigation water is not available on demand via a pressurized distribution system. And, the physical capital used for irrigation supply is often old and long-lived, and it may have been paid off long ago. The longevity is a crucial factor because most water in the US – both urban and agricultural – is priced on the basis of its historic cost, which is generally far below its current replacement cost.

3.6 The Essentialness of Water

Water is essential for all life – human, animal, or plant. In economics, there is a concept, also called essentialness, that formalizes this notion. The concept can be applied either to something that is an input to production or to something that is directly enjoyed by people as a consumption commodity. In the case of an input, if an item has the property that *no* production is possible when this input is lacking, the item is said to be an essential input. In the case of a final good, if it has the property that *no* amount of any *other* final good can compensate for having a zero level of consumption of this commodity, then it is said to be an essential commodity. Water obviously fits the definition of an essential final good: human life is not possible without access to 5 or 10 liters of water per person per day. Water fits the definition of an essential input in agriculture, and also in several manufacturing industries (e.g., food and beverages, petroleum refining, lumber and wood products, paper, chemicals, and electronic equipment).[36]

However, essentialness conveys no information about the productivity or value of water *outside the vicinity of the threshold*. It implies nothing about the marginal value associated with, say, applying 30 versus 35 inches of water to irrigate cotton in the Central Valley of California. It says nothing about the marginal value of residential water use at the levels currently experienced in Western Europe or the United States – the latter averages about 120-140 gallons per person per day, more than two orders of magnitude larger than the minimum quantity that is needed for human survival.[37]

The latter statement is not meant to belittle the uses of water by households in Western Europe or the United States. My point is that, in addition to being essential for human life, water contributes in important ways to the enjoyment of the satisfactions of life. Consequently, there are many other residential end uses of water besides its use for drinking. Indeed, if one examines the history of residential water use in the US from the early nineteenth century to the present, it is striking how water consumption has grown over time through the steady accretion of end-uses, each representing the discovery of a new way to employ water for people's use and enjoyment. When a piped water supply first became available in the nineteenth century, the initial household uses were the same ones that had existed when family members had to fetch water from an external source –

[36] These are the largest water-using industries in the US in terms of freshwater intake.
[37] Total urban water use in the US averages about 180-220 gallons per capita per day, depending on the location. Throughout, I am using US units of measure.

drinking, cooking, hand washing, and limited bathing.[38] As time passed, many other uses were found – tubs for bathing, water borne sanitary waste disposal, outdoor landscape and garden watering, automatic clothes washers, swimming pools, automatic dish washers, car washing, garbage disposal, indoor evaporative cooling, hot-tubs, lawn sprinklers, etc. The result has been a constantly rising trajectory of per capita household water use.

Two conclusions can be drawn from this historical experience. First, in developed countries, the fact that water is essential for human life is almost certainly irrelevant when assessing the value of residential water supply because the ways in which water is used are nowhere near the threshold level at which essentialness applies. Second, there is a possibility that some of the developing countries may also move along a rising trajectory of residential water consumption because the things that have made abundant water use an element of a comfortable modern life style in developed countries could also become attractive to people in these countries as their income rises.

For reasons that are entirely understandable, there is a tremendous emphasis in the water literature on the need to secure at least a minimal water supply for the nearly 1.1 billion people around the globe who currently live without access to an improved water source. In developing this estimate, the United Nations and the WHO used a figure of 20 liters per person per day as the minimum human requirement for water for drinking and basic sanitation. Gleick (1999) has argued that this is too low, and has advocated the adoption of a basic human right to 50 liters per person per day as the minimum required for bathing and cooking as well as the other basic needs. As noted above, these low levels of consumption are not very different from the initial levels of water use in developed countries when piped water was first introduced in the nineteenth century. It is important to recognize that, if the efforts to provide improved water supply and sanitation in the developing countries are successful, the future levels of water use that might ultimately emerge in these countries could diverge from these minimum levels, as happened in the developed countries.

In short, while it is obviously appropriate to think in terms of human *needs* for water, it is also appropriate to recognize that people also have *demands* for water as a commodity that generates pleasure by utilizing it in various ways. As they become more affluent, poor people are likely to choose to allocate more of their resources to satisfying not just their needs of the body but also their "wants of the mind, most of them proceeding from imagination," perhaps including some domestic end uses of water that might seem outlandish today.

If and when this broadening of domestic water use beyond the basic minimal level occurs, an important implication is that planners will need to adopt a *behavioral* approach

[38] For example, Blake (1956) notes that out of 15,000 houses with running water in Philadelphia in 1849, only about 3,500 were equipped with private baths. In 1871, by contrast, 112,457 Philadelphia houses had running water, and 80,000 of these had bathtubs and fixtures for hot and cold water (Anderson, 1988). The use of water closets to remove human wastes did not become widespread until almost two decades after the introduction of piped water into homes (Tarr, 1979).

to the analysis and projection of urban demand, as opposed to the engineering/public health approach that dominates the literature on water and poverty today. The behavioral approach focuses not on how much water people need but rather on how much water they are willing to pay for.

The difference between the engineering and behavioral perspectives is well illustrated by the experience of the World Bank over the past fifteen years. Water planners in the Bank originally thought that water and sanitation projects in developing countries were not viable if they required households to pay more than 3-5% of their income for the project services because this would be more than they would be willing or could afford to pay, rendering the projects infeasible (World Bank, 1975). It became evident from detailed household-level studies sponsored by the Bank in the 1980s and 1990s that, in many developing countries, some households spend considerably more than this on access to traditional, unimproved water and sanitation. Some households purchase water from vendors at prices which can be much higher than the cost of piped water. Where there is piped water supply, many households incur expenses on installing storage capacity in the home to ensure that they have water when the pipes run dry; others undertake a wide variety of practices to treat contaminated water in their home to make it safe to drink. Moreover, some carefully designed contingent valuation surveys by Dale Whittington and his colleagues showed that some households have a willingness to pay for improved water supply that can exceed 3-5% of household income.[39]

The issue is not how much a household values access to water versus no access to water at all but, rather, how much it values a piped, public water supply relative to the existing alternatives. In this context, it is interesting to review what is known about how the adoption of water relative to other utility services varies with household income in developing countries. Komives, Whittington and Wu (2003) have analyzed data on the percentage of households at different income levels with four utility services: piped water, sewer, electricity, and telephone.[40] As monthly household income increases from very low levels to US$300 per month, coverage of all of these infrastructure services increases rapidly; above US$300 coverage increases at a slower rate. However, what is most striking is that, for households in this sample, at all income levels, more people have electricity than piped water or sewer. Very few of the poorest households have piped water or sewer, but almost a third of these households have electricity service. In Kathmandu, Nepal, for example, all of the households surveyed had the option to connect to electricity, water, and sewer; the majority of the very poor households chose electricity but not water or sewer. As income increases, the percentage of households choosing water and sewer increases, but the percentage with electricity is always higher. Almost no one, at any income level, has only a piped water service; but many households have electricity and not water. Thus, although most households would certainly like improved

[39] The subsequent experience when the Bank went ahead and implemented the projects has borne out the predictions of the contingent valuation surveys quite well (Griffin et al, 1996). It would be wrong to infer too much from the data on vended water purchases because the vast majority of households in developing countries do *not* buy from vendors. This implies that their willingness to pay for vended water is *less* than the cost.

[40] The data come from the World Bank's Living Standards Measurement Surveys covering over 55,000 households in 15 developing countries.

water and sanitation services, it is not their most important development priority; given their limited resources, many of them want electricity before an in-house piped water or sewer connection. [41]

In short, the fact that water itself is a necessity does not necessarily mean that people prefer piped water over electricity service. Indeed, because water is a necessity, households must already have some access to water supply. The question is thus how much they value an *improved* supply. This will depend on how bad the existing water service is, and how much better the improved service is expected to be.[42]

3.7 The Heterogeneity of Water

It is common to talk of the value of water as though it were a single, homogenous commodity. This is obviously false: water has many dimensions besides just quantity. These include: (a) location, (b) timing, (c) quality, and (d) variability/uncertainty. To a user, one liter of water is not necessarily the same as another liter of water if it is available at a different location, at a different point in time, with a different quality, or with a different probability of occurrence.

There are two ways to incorporate the multi-faceted nature of water in an economic analysis. The first approach is simply to define different types of water as different commodities. For example, the consumption of water in January is represented by x_1, that in February is represented by x_2, that in March by x_3, etc. The consumer is then assumed to have a utility function defined over monthly consumption throughout the year and also over other commodities whose consumption is denoted by z (which can be a vector or a scalar), leading to the formulation

$$(1) \qquad u = u(x_1, x_2, .. x_{12}, z).$$

The significance of this formulation is that it leads to *separate* demand functions for consumption in each month. The demand for water in the i^{th} month will be a function of the price of water in that month, the prices of water in the other months (which may or may not be different), and the price of z, as well as the consumer's income, $x_i = h^i(p_1, p_2, .., p_N, p_z, y)$. The differences between one month's demand function and that of another will reflect the different ways in which the two monthly consumptions enter the underlying utility function (1). Given this approach, the annual demand for water is the aggregate of the 12 separate demand functions for the individual months. There is no demand function for annual consumption of water *per se*, except in the special case where the underlying utility function takes the particular form

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[41] This does not mean that water and electricity are not complements – they often are. It simply suggests that people with limited budgets who cannot afford both generally prefer to have electricity first and piped water later.

[42] It may also depend on the quantity of water involved – because of diminishing marginal utility, what a household would be willing to pay per unit for the first 20 lcd is not necessarily the same as it would pay to go from 40 to 60 lcd.

(2) $$u = u(x_1, x_2, .. x_{12}, z) = u(\sum x_i,\ z).$$

This is the only formulation that generates a well-defined demand function for aggregate annual consumption, $X \equiv \sum x_i$. Note, however, that the formulation in (2) implies that water consumption in any month is a *perfect substitute* for consumption in any other month.[43] More generally, if one discounts the difference between facets of water use and treats water as a single, homogeneous commodity, this is equivalent to assuming that the different types are all perfect substitutes for one another. It is an empirical question whether this is a plausible assumption.

The alternative framework for analyzing differentiated commodities was provided in a somewhat simple form by Lancaster (1966) and then broadened by Maler (1974), and is known as the *characteristics* approach to consumer demand.[44] The Lancaster-Maler model extends the utility model (1) by offering an explicit account of *why* the x's are viewed as separate commodities, based on their specific characteristics. The notion is that there is a set of characteristics or attributes associated with each commodity. Suppose there are K relevant characteristics (attributes), and let q_{ik} denote the amount or level of the k^{th} characteristic associated with one unit of consumption of commodity i. The characteristics of each commodity are taken as given by the consumer who is free to vary only the quantity of the commodity, x_i. Thus, if the consumer wishes for more of the k^{th} characteristic, she accomplishes this not by changing the characteristics of any good, since these are fixed to her, but rather by switching her consumption towards commodities with a high level of this characteristic (i.e. a high value of q_{ik}); quality variation is accomplished through quantity variation. If there are N separate differentiated commodities together with undifferentiated consumption, z, the utility function takes the form

(3) $$u = u(x_1, x_2, .. x_N, q_1, q_2, .. q_N,\ z)$$

where $q_i \equiv (q_{i1}, .. , q_{iK})$.The demand functions for commodities now depend on the attributes as well as the prices, and take the form $x_i = h^i(p_1, p_2, .., p_N, q_1, q_2, .. q_N,\ p_z, y)$, $i = 1, .. , N$. Thus, this formulation provides a framework for analyzing the effect of characteristics/attributes on demand – it provides a model of the demand for attributes (i.e., for q).

I have focused so far on the multi-faceted nature of water with respect to consumer choice, but this obviously applies to producer choice also. Both of the

[43] Two commodities are said to be a perfect substitutes in consumption if the consumer is willing to trade off one for the other at the same, fixed rate of exchange regardless of how much or how little is consumed; in his eyes they can always be used in exactly the same way, with exactly the same outcome. When two commodities are perfect substitutes, they have essentially the same value. The polar opposite of perfect substitute is *perfect complement.* Two commodities are perfect complements if they are valued in fixed proportions to one another; consequently, they will always be purchased together in fixed proportions. In this case, no value is placed on increasing one of the items unless there is a corresponding increase in the other; an old-fashioned example (in England) was tea and milk.

[44] The application of Maler's work to the modeling of differentiated commodities was exposited in Hanemann (1980).

approaches described above can be incorporated in a production function just as in a utility function. For example, the production analog of (3) is a production function of the form

$$y = f(x_1, x_2, .. x_N, q_1, q_2, .. q_N, z) \tag{4}$$

where y is output, the x's are forms of water input, and z is a vector of non-water inputs. Suppose, for example, that y is crop production, $N = 2$, x_1 is the quantity of groundwater pumped by a farmer, and x_2 is the quantity of surface water delivered to the farmer by the irrigation district in which he is located. Even if the price were the same, the experience in California has been that most farmers do not consider groundwater and surface water to be equally attractive. They find groundwater more convenient because they totally control its supply and can obtain it at the flick of a switch while, with surface water, they have to wait until the irrigation district is able to route the water to them through the canal system. On the other hand, in some parts of California there are differences in water quality, with groundwater being more saline than surface water. Thus, immediacy of access and salinity are two of the attributes that enter the crop production function (4) in this case.

In addition to providing a framework for conceptualizing the demand for q, whatever this may be, the Lancaster-Maler model also provides a framework for the economic valuation of q. It can thus be used to measure water users' willingness to pay for better availability of water, or less saline water, or a more reliable water supply, or more generally water of one type versus another (e.g., the premium on groundwater versus surface water, or on water at one location versus another).

It should be emphasized that the attributes that differentiate one type of water from another are by no means limited to the type of physical characteristics mentioned so far, such as location, timing, quality, and reliability. Other aspects, such as how the water is provided, can be the object of people's concern and the focus of their preference. With water, users often care greatly about *fairness* in allocation or payment -- what is known as procedural justice -- and this may differentiate one source of water from another in their eyes. The Lancaster-Maler formulation permits one to incorporate such psychological or sociological attitudes within an economic model of the demand for water, so that one can analyze how these attitudes might generate a different value for water when provided in a particular way or obtained from a particular source.[45]

3.8 The 'Average instead of Marginal' Fallacy

In most policy-related applications of economic valuation involving water, the relevant quantity that needs to be known is the marginal value rather than the average or total value of water. Precisely because water is a necessity of life, most people have *some* access to *some* water, and most policy interventions therefore involve changing the quantity and/or quality of access rather than transforming the situation from no access to

[45] What Frey and Stutzer. (2005) refer to as procedural utility can be represented by this model.

some access.[46] The point is that, ceteris paribus, there is likely to be some degree of diminishing marginal utility for consumers, and diminishing returns for producers, which imply that there can be a substantial difference between the marginal value of an increase in water supply and its average value. This needs to be emphasized because researchers have often chosen to use an estimate of the average value of water to measure the benefits of a policy intervention.

An example comes from the recent Spanish National Hydrological Plan (NHP), which proposed a major water transfer from the Ebro River to the Mediterranean coast from Barcelona in the north to Murcia in the South. Of the 1050 cubic hectameters (hm^3) to be transferred, 560 $hm^3$was targeted for delivery to agricultural areas along the coast that have been relying on depleting supplies of groundwater. The correct way to measure the benefit from an increment in water supply for farming in the receiving areas is to estimate the marginal value of water (marginal net profit) in the agricultural uses that would go out of production without the importation of project water. Instead, the economic assessment performed by the Spanish government (NHP 2002) valued the imported water using an estimate of the average value of water in current uses, calculated as the simple ratio of aggregate farming profit in the area divided by aggregate water use. There are two flaws in this approach: (1) It interprets all profit from farming in the area as exclusively a return to water, and (2) it treats the return to water as constant regardless of the amount of water used.

Rather than just being a return to water, the profit from agriculture is likely to be a return to the farmer's investment in land and other fixed assets, and also a return to the farmer's own labor and his family's labor. And, rather than the average value of water being constant in the receiving areas, there are several reasons to believe that the average value declines as more water is supplied, causing the marginal value of water to be less the average value. With varying land quality and the opportunity to grow different crops, farmers in the region are likely to respond to any reduction in water supply by idling their *least productive* land and discontinuing their *least profitable* crops. Furthermore, some users of groundwater also have access to some surface water supply -- in varying ways and to varying degrees, the supplies of water for farmers in the receiving area are interconnected so that, within the area, water is a somewhat fungible commodity. Since the imported water is one among several sources of water for irrigation, the relevant demand function is the farmers' demand for project water, *not* their demand for water overall. Because of the availability of substitutes, the agricultural demand for project water is likely to be more elastic than the demand function for water overall. Therefore, the marginal value of the imported water in the region is likely to be substantially less than the existing average value.[47]

[46] By this, I am not implying that interventions are unimportant or trivial in their consequences.

[47] If one were considering the total elimination of farming across a large portion of the irrigated acreage in the receiving areas, the difference between the average and marginal value could be of little significance, but in this particular case the change involves about 10% of the irrigated farmland and 9% of the water supply in the receiving area. An important piece of evidence suggesting that the NHP was substantially overstating the value of the project water is the fact that the cost of irrigation water in the receiving areas, including the cost of groundwater pumping, is mainly in the range of 10 - 45 pts/m^3, while the NHP valued the imported water at 125 pts/m^3.

The key difference between the two concepts is that the marginal value involves the derivative of a relationship, and to estimate this one needs a (formal or informal) model of how water generates value. The average value, by contrast, can be estimated crudely by dividing two quantities without any understanding of how they are related in reality, and without any assurance that this ratio will remain constant. Consequently, the use of an estimate of average value, and the assumption of its constancy, although common, are almost certainly a mistake.

3.9 The Benefits of Water

There are numerous ways in which an increment in water might produce benefits, whether to those who use the water directly or to others. Examples include: the use of water for agricultural or industrial production, its use for hydropower or for navigation, residential use, flood control, water based recreation, or aquatic habitat. A key tool used by economists in formalizing many of these benefits is the concept of a production function. A production function is conceived as a technical, but empirical, causal relationship between the levels of inputs required to produce an output, or an outcome, and the level of output or the outcome that results. One example is the production function for an industrial or agricultural output as a function of water and other inputs to the production process. Another example would be a "health production function" relating inputs (including behavior patterns and levels of resource availability) to the production (attainment) of health status outcomes. A third example would be an "ecological production function" relating inputs and resource endowments to the production (attainment) of ecosystem outcomes.

However, while the notion of a production function is undoubtedly useful at the conceptual level for organizing one's thought about these matters, it may work best empirically at a micro-scale (i.e., at a factory level rather than at the level of an entire regional economy) and it implies a notion of causation that may be oversimplified. In practice, it can often turn out to be surprisingly difficult to empirically identify a production function and pin down the specific increment in benefits associated with an increment in water availability. I will illustrate this with the question of water and economic development.

The notion that water supply contributes to economic growth and development is highly intuitive. After all, it is known that many of the world's major cities owe their origin to their location along coasts or rivers where water-borne transportation was facilitated. But, the relevant question is whether an increment in water availability would generate an increment in economic activity today, and how much. In the US, federal water projects have long been advocated for their claimed contribution to regional economic development. However, the actual empirical evidence is less obvious and more negative. As Howe (1968) noted, in industrial processes, water costs are a relatively small fraction of total production costs even in water-intensive industries, and there are many examples of firms in such industries choosing to locate plants in water deficient areas because of market or non-water input considerations.

In the US in the late 1960s, there was a flurry of efforts to conduct formal, ex post statistical analyses of the impact of water availability on economic development; the findings were generally quite negative.[48] The studies were motivated in part by Bower's (1964) hypothesis that the availability of water at the intake end and/or the *effluent* end is not a major factor in *macro-location* decisions of industry relating to location in major geographical areas or regions, such as river basins, but it can be a major determinant of *micro-location* decisions relating to location within the region or basin. Ben-David (1966) found that employment in the major water-intensive industries was not significantly related to a measure of water availability in a cross-section regression of US states, but there was a significant positive impact at the county level in a regression of counties within Pennsylvania. Howe (1968) extended this analysis to include all the counties in the US, and found the evidence for such an effect to be extremely limited. Cox et al. (1971) examined counties in the northeastern US in which large water projects had been constructed between 1948 and 1958, and found no relationship between project size and economic growth over the period 1950-1960. They found that the location of projects was biased towards urban areas, where there is a greater a priori likelihood of economic growth but, once this is controlled for, it seemed unlikely that water resource projects would provide a stimulus to economic growth for strictly rural counties in the northeastern US. By contrast, Garrison and Paulson (1972) examined counties in the Tennessee Valley region and found a significant micro-location relation between water-oriented manufacturing employment and a measure of water availability. At the macro-location level, Carson et al. (nd) sampled counties in geographic sub-regions from all parts of the country, both rural and urban, and found no significant relationship between federal water resource projects and population growth. Cicchetti et al (1973) extended this study using economic sub-regions as the unit of analysis and found that variables representing federal investment in irrigation facilities had no significant impact on regional income and growth, and only a small and not convincingly significant impact on the value of farm output. There was some relationship between economic growth and federal investments in flood control, hydropower and recreation, but the coefficients were often unstable.[49] A similar study by Fullerton et al. of counties in seven western states found no relationship between water investment and economic growth.

It seems clear that investment in water supply does not automatically guarantee economic growth. But, what conclusion can be drawn? Does this mean that there is never an economic case for investing in water supply?

Part of the dilemma arises from the inadequate concept of causation that is being utilized. In the philosophical literature on causation, there is a distinction between necessity and sufficiency: X could be a necessary but not sufficient condition for Y to

[48] The focus of these studies was long-run employment and economic growth *after* the completion of project construction: it was recognized that there would be a short-term increase in employment during the period of construction.

[49] Some of these results and those of Cox et al. (1971) raise the question of the *direction* of causation: do federal investments in flood control, say, cause economic growth, or do growing areas use their political clout to attract federal water investments? Walker and Williams (1982) suggest that the latter is the causal connection.

occur, or it could be a sufficient but not a necessary condition. However, this distinction is generally ignored in both theoretical and empirical analyses of the relationship between water and growth. The production function as conventionally formulated in economics, along the lines of $Y= f(X,Z,..)$, imply that X , Z and the other factors on the right-hand side of the equation are each *sufficient* conditions for producing Y: changing any individual element of X or Z is sufficient to induce a change in the value of Y. Similarly, the conventional forms of regression equation used in the statistical analyses imply that the regressors are each sufficient conditions for a change in the dependent variable. However, the true relationship may be different, and perhaps more complicated.

For one thing, it is not implausible to suggest that having an adequate supply of water could be a *necessary but not sufficient* condition for economic growth. While water does not automatically generate growth, it may be the case that areas which persist in lacking an adequate water supply (regardless of whether or not they started out with adequate water) will not flourish economically. For example, one can expect that people will eventually leave those areas and migrate to other areas that do have an adequate water supply. Thus, lack of water could be a sufficient condition for economic decline or, to put it another way, water may be a necessary but not sufficient for economic growth. But, this is not a relationship that is captured in the existing formulations of production functions and regression equations.[50]

Alternatively, the relationship could be even more complicated. It may be that there are multiple possible causal pathways, such that while there is some causal linkage between water and growth, the linkage is sufficiently imprecise and variable that water is neither a necessary nor a sufficient condition for growth. In effect, there is sometimes a causal linkage, but not always. If this is so, it would require a new formalism to express this type of relationship. One candidate is the discrete mixture approach, which allows for multiple possible functional relationships determining Y, with a mechanism that is at least partly stochastic determining the specific relationship that applies at any particular instance. Within this framework, one of the possible relationships can involve Z as a causal determinant of Y (e.g., as a sufficient condition), while in others Z is not a determinant of Y. I believe that this type of approach might be fruitful for both conceptual modeling and empirical estimation of the consequences triggered by improved access to water at both the household level and also the broader regional level.

[50] One way to operationalize the concept of necessity through what is known as a switching regression. The general structure of a switching regression, framed around a variable Z, is:

$$Y = \begin{cases} f_1(Z, X_{1;}\, \beta_1) + \varepsilon_1 \text{ if } Z \leq 0 \\ F_2(z, X_2, \beta_2) + \varepsilon_2 \text{ if } Z > 0 \end{cases}$$

Here Y is the dependent variable, $f_i()$ represents a possibly non-linear functional relation, X_1 and X_2 are vectors of explanatory variables (which may or may not be different), and β_1 and β_2 are the corresponding coefficient vectors which are to be estimated. In the present context, Z measures the level of water supply and to represent it as essential one would set $f_1(Z, X_{1;}\, \beta_1) + \varepsilon_1 \equiv 0$ when $Z \leq 0$.

4. The Problem of Water

It is commonly said that the problem of water is not one of physical shortage but, rather, one of governance. This is partly but not entirely correct. To be sure, the physical lack of surface of ground water is not an issue in many areas, in that there is an abundance of raw water. The problem is one of matching demand with supply, of ensuring that there is water at the right location, and the right time of year, and at a cost that people can afford and are willing to pay for. The difficulty in accomplishing this is partly institutional and certainly includes issues of governance. However, the problems of governance have to some extent an economic explanation, because the capital intensity and longevity of water and the significant economies of scale create a need for collective action in the provision and financing of water supply, and the looming presence of fixed costs make cost allocation among individual beneficiaries highly problematic. In short, while there clearly are some distinctive emotive and symbolic features of water that make the demand for water different from most other commodities, there are also some distinctive physical and economic features that make the supply of water different and more complex than that of other goods.

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