Efficient allocation of water resources among competing users: economic, environmental and organizational considerations [Final report]

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Efficient Allocation of Water Resources Among Competing Users: Economic, Environmental and Organizational Considerations.

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Plan of the report

Abstract

It is now well recognized that an efficient management of scarce water resources is crucial for guaranteeing the sustainability of agriculture. Fresh water is one of the most limiting factors for agricultural production in both Israel and France. As competition with other sectors (urban, industrial and environmental) increases, the Israeli farmers find themselves relying more and more on the utilisation of recycled and saline water. In France, an increase of irrigated areas in the last two decades has led in case of drought to severe degradation of the environment and to inefficient administrative banning on water uses. Thus new policies and approaches need to be designed to improve water management strategies.

Our **principal objective** is to formulate policy recommendations in both countries by evaluating the consequences of new alternatives for the allocation of this scarce resource, in order to guarantee economically efficient water sharing subject to several environmental constraints. Therefore the project is aimed at developing and implementing agro-economics models which describe the economic, environmental and organizational aspects involved in sharing different types of water (i.e. fresh, recycled etc.) among few potential consumers: the agricultural sector (with different types of irrigated cultures and crop mix), the environmental sector and the urban and industrial sector, at the regional or water basin levels. **The models** evaluate and compare several schemes of cost and profit allocation between the economic entities involved: (i) direct negotiation by utilizing a mechanism design model; (ii) allocation via an agreed upon objective/neutral middle-man by using different approaches from game theory and (iii) allocation via an adequate pricing system.

We developed our agro-economic models/approaches based on the relevant state of the art literature, especially the literature that deals with water pricing practices in the world under uncertain conditions. For the Israeli part, a model determined the optimal crop mix and the optimal allocation of the limited (fresh and recycled) water and land resources among all potential water users. The selected region (the Sharon region, in central Israel) includes 4 economic entities: a city (the wastewater producer), two groups of farmers and a river authority. The objective here is to maximize the regional social welfare, which is composed of the sum of the agricultural and environmental net benefits while taking into consideration the impacts of salinity and nitrogen on the commercial yields of the various crop and the environmental damage associated with irrigation with recycled water over an aquifer. The model suggests economic and environmental improvements to the potential wastewater consumers: the farmers might be able to increase their irrigated areas and benefits and that the river authority is expected to increase its stream flow and benefits. **On the practical side**, the work shows that in Israel, cooperation between all the economic entities in the selected region is profitable to each entity and also improves the environmental conditions.

In France, we studied an original pricing scheme aiming at the improvement of the ecological state at the river, by guaranteeing a minimum water level in the river, and an increase in farmer’s profit so that they would accept to adopt such a pricing system, while a constraint was the budget equilibrium of the water user association. Our result is very encouraging, since we see that locally there is a real demand of such analytical results, obtained with a thorough analysis of the properties of such pricing systems, in order to accompany the ad hoc tentative essays of the water user association. Practically too, we show that the economic efficiency of the agricultural water may be considerably enhanced, while

the environmental conditions may be improved, with a pricing system that field studies showed acceptable.

The **cooperation of French and Israeli teams** consists in exchanging on the economic and mathematical tools (we both use mathematical programming, game theory and mechanism design approaches) when developing the models. We discussed the difficulties involved in implementing our models in our respective countries (taking into account the quality of water in Israel and the uncertainties of water supply in France) while taking into consideration the current experiences and possible solutions currently applied in both countries. These two kinds of contributions (on the theoretical part for solving the model difficulties, and on the practical applications) showed the scientific interest of the cooperation. This cooperation was concretised by the writing of a first scientific paper accepted for the 13th World Water Congress, two papers were already been submitted to ranked journals (a French economic review and the Journal of Agricultural Economics) and we expect to submit three more manuscripts to scientific reviews during the next months. Moreover, discussions on the use of waste water in Israel showed there was some interesting work to do on comparable contract design for sludge disposal in France. This cooperation was carried out through meetings with French and Israeli partners in Aix en Provence (2006), Paris (2007), Montpellier (2007), and through e-mail exchanges.

Future works would be very interesting in order to 1/ extend our scientific research in the fields of irrigation and waste water agro-economics, notably in France in order to explore other possibilities of our first results displayed 2/ extend our joint research to other fields of interest such as investigating sludge allocation among competitive users both in France and in Israel, 3/ work on the links between the ‘pricing’ and the ‘planning’ approaches into a unique project such as developing pricing mechanism to wastewater in Israel, and working on the implementation on the European Union Water Framework Directive in France.

1. Some water problems and the place of irrigation in France and in Israel

Chronic scarcity of water is a fact of life in Israel where aggregate demand exceeds the supply of fresh water in a largely semiarid environment. The commonly agreed upon policy of maintaining a long-term balance between potential available water and the utilization of water resources has not been able to keep up with consumer pressure, especially the pressure from the agricultural sector. The Israeli water economy is in the midst of a crisis, the main features of which are a shortage of fresh water and a steadily increasing deficit, poor and declining groundwater quality (gradual salinization), and pollution of most of the streams by untreated urban, industrial and agrochemical effluents (Zaslavski, 2001).

The main quantitative expression of the crisis is a sharp decrease in the ability to pump groundwater without crossing predetermined red lines, where the agricultural sector bears the brunt of the necessary cuts. Since all significant natural water resources in Israel are largely overexploited, attention is being increasingly focused on the development of unconventional water resources, namely, desalination of sea water and recycling of sewage effluents. The supply of reclaimed sewage is growing substantially due to increases in water supply for the growing domestic and industrial sectors, and the expansion of irrigation with recycled effluents. Indeed, a large-scale transition in agricultural water use, from good-quality water to treated wastewater, has already taken place. This shift requires the development of many more environmentally safe water-treatment plans, reservoirs and conveyance systems. Treated wastewater can also be used for river restoration.

In France too, the sustainability of agriculture is directly linked to the better efficiency of water use. Moreover, this resource constitutes a constraint which will be all the more binding that a possible change in the climate might increase the periods of water shortage. Moreover, in this country, a possible increase of plant cultures as a source of energy may arise. In France, the increase in irrigated areas in the last two decades, combined with increasing competition from the domestic and industrial sectors, in the summertime, has led as in Israel to a drastic reduction in agricultural production, in case of drought, to a severe degradation of the environment and to inefficient administrative banning on water uses. Hence, in France it increases the conflicts between the agricultural sector and the rest of the population. In both countries, despite its modest role in the national product (less than 2% of the GDP in Israel and 2.7% in France [source: INSEE]), agriculture consumes about 48% and 68% [source: CI Eau – Centre d'Information sur l'Eau] of the nation's limited freshwater supply, respectively.

In Israel, as de facto in France, there is a consensus among policy makers and water experts that the supply of potable water (i.e., urban consumption) should receive top priority. Nevertheless, some water experts point out that while water used by industry or tourism is many times as productive as that used by the agricultural sector; water, in France is made available to farmers at about 65% of its price at the cities' gates. Treated wastewater can also be used for river restoration. In France, after having built many individual or collective dams in order to increase water–storage capacity — "supply management", efforts are currently being focused on "demand management," i.e. the use of less irrigation water for the same production and the search for more efficient alternatives for sharing water among the different uses, while trying to find more efficient water-pricing schemes (Garcia and Raynaud, 2004).

Sharing a scarce resource

When water rights are ill-defined, it is difficult to use standard economic tools such as, for example, markets, as an efficient allocation method. There is no private ownership of water in Israel as in France. The Israeli Water Law of 1959 states that all water sources are publicly owned and that their utilization is controlled by the Water Commissioner. A single government-owned company, Mekorot, operates the National Water Carrier (NWC)[1] and provides approximately 60% of the total water supply; regional cooperatives and municipalities and private well owners supply the rest.

The allocation is administrative: the Water Authority issues permits for production (extraction) to suppliers as well as allocations (quotas) for agricultural consumers. In the past, these quotas constrained the use of water in agriculture. However, more recently, with higher prices for water and lower prices for agricultural products, the agricultural sector fails to exploit all of its allocation. Households, on the other hand, were never constrained in their consumption and formal quotas for this sector were abolished several years ago. The current water laws do not permit trading in water quotas, and the transfer of water rights between sectors such as agriculture and industry is unlawful.

In France, farmers pay a price to their water user associations (WUA) which does not reflect the scarcity of the resource. Moreover, France tries to impose a tax on water use, but the money collected in this way does not return to the agricultural sector. The farmers' opposition to such taxation is therefore quite understandable, even when its low level does not reduce water consumption for irrigation in the slightest. One of our objectives here is to determine the context and set of hypotheses which may allow calculating an "adaptative" pricing (AP) system, at the level of the WUA, under some constraints, taking into consideration the recent progress in the economic theory. We therefore aim at these following specific goals:

a) An improvement in the ecological state of the river, by inserting a minimum water level in the stream;
b) An increase in farmers' profits, so that they would be willing to adopt such a pricing system;
c) Budget equilibrium at the level of the WUA.

In addition, we intend to implement a few relevant approaches from game theory, especially in the field of transferable utility (TU) games, which consist of desirable allocation elements (i.e. individual rationality, economic efficiency, group rationality). The TU games allow the nomination of an agreed-upon objective middle-man whose task is to suggest an acceptable, desirable allocation among the participants by taking into consideration their relative strengths.

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[1] The NWC, which is made up of canals and pipelines, was constructed almost 40 years ago, and is designed to divert the Jordan water from the Sea of Galilee to the center of the country and to Negev desert, thus enabling the settlement of this extremely arid region. The uniqueness of this carrier goes beyond the transference of water from the north to the arid south. It has become an operational tool, connecting all three major water sources into one system (Kislev, 1993). During the wet winter season, when even the southern part of Israel gets some precipitation, water is still being pumped from the Sea of Galilee and injected into the Coastal Plain and the Mountains aquifers, to recharge the declining water tables. During the summer time, irrigation all over the country is a must, because there is no precipitation between May and November and water is pumped from both the Sea of Galilee and the aquifers.

2. Linear programming, game theory and mechanism design: a first approach in Israel

The objective of the project is to develop an analytical framework in order to investigate the impacts of different water-allocation methods among various consumers (i.e. the agricultural and environmental sectors) in a rural region and to apply it to a situation in Israel (the Sharon region in the centre of Israel). The region has several water sources (fresh water and treated wastewater), which differ in quality, quantity and cost.

The first model, a Linear Programming Model (LP), determines the optimal crop mix and optimal allocation of the limited water and land resources among all potential users. The model's objective is to maximize the sum of net benefits (gross benefit minus relevant costs) in the examined area, while taking into consideration the impacts of salinity and nitrogen on the commercial yield of the various crops and the environmental damage associated with recycled water irrigation over an aquifer. The LP model incorporates, in one endogenous system, the economic, physical and biological relationship in the water-soil-plant-environment system. Given the aggregate value of the net benefit obtained from the solution of the LP model, we analyzed and compared a few allocation methods among the examined parties: (i) via an agreed-upon objective middle-man whose recommendations will be based on different approaches from Transferable Utilities games (Also known as a cooperative games with side-payments), and (ii) via direct negotiations between the parties involved, under uncertain conditions, utilizing a Mechanism Design model. The empirical results, despite of their dependence on specific agricultural, environmental and health restrictions, can provide a realistic framework for decision makers to improve the current inefficient use of treated wastewater.

Key questions:

a. What is the organizational structure (level of cooperation) which will optimize the total social welfare in a well defined region composed of a few economic entities?

b. Are there any advantages in regional cooperation among the economic entities?

c. What is the set of solutions which are efficient/fair for the economic entities in the region; what the negotiation boundaries are; and what are the solutions suggested by an objective middle-man?

d. What are the conditions that encourage collaboration in the examined region under asymmetric information?

Results and comments

At first we developed a regional level, short-run planning model which determines the optimal crop mix and the optimal allocation of the limited (fresh and recycled) water and land resources among all potential users, under certain conditions. The model's objective is to maximize the regional social welfare, composed of the sum of urban, agricultural and environmental net benefits under several agri-environmental restrictions. Given the results obtained from the Planning Model, we analyzed and compared a few allocation methods among the examined parties via an agreed-upon objective middleman whose recommendations are based on different approaches from the concept of transferable utility games. The different approaches refer to the allocation of the additional net benefit (gross benefit minus the parties' stand-alone values) obtained in the examined area, among the parties. Then we extended our analysis by implementing models from the literature of mechanism design assuming uncertainty conditions (asymmetric information). The analysis is applied to the Sharon region in central Israel.

The empirical analysis focuses on the monetary incentive for cooperation between the producer of the recycled wastewater, the city, and some or all of the wastewater consumers. It is shown that acting alone is not a desirable solution under both certainty and uncertainty conditions. Under the grand coalition, the highest additional net profit is achieved and therefore will be preferred by a benevolent central planner. Moreover, the optimal cooperative solution enables each group of farmers to reallocate their freshwater quota efficiently, to cultivate new land areas without uprooting orchards and to expand the area planted for crops which can be irrigated only with fresh water or with wastewater purified to a tertiary level. In addition, the use of tertiary wastewater by the farmers reduces the amount of irrigation with fresh water by 1.1 M3, compared to the non-cooperative scheme.

Although the proposed solution (i.e. a grand coalition) is economically efficient, it may be rejected by one or more of the economic entities in the region unless an acceptable allocation scheme is mutually agreed upon. Since the quota of fresh water is not transferable by law in Israel, the only way to affect the distribution of the regional additional net benefit from cooperation is through direct monetary transfer (side payments). We examined and compared different allocation schemes based on commonly used concepts from the game theory literature, i.e. the Core, the Shapley values and the Nucleolus. Being the only wastewater producer in the region, the city has the highest negotiation strength. Therefore, under all examined approaches, the city gains the highest additional net profit allotment (more than 50% of the total). The RA gains the second largest additional net profit allotment (about a third). The RA's double role in the examined region, as the largest tertiary wastewater consumer and as a tertiary wastewater supplier to the farmers, provides it with relatively high negotiation strength. The two groups of farmers gain the lowest allotment, being only wastewater consumers. However, when comparing the solutions obtained to their initial status, we find that the nearby and distant farmers improve their profits by 40 and 35.5%, respectively.

All of the suggested solutions are reasonable and fair and are expected to be accepted by all the players without distorting the efficiency. Moreover, all of the suggested solutions fulfil the core equations and therefore possess the desirable characteristics of the core (individual rationality, group rationality and efficiency).

Under conditions of asymmetric information the city increase its share to more than 60% of the total allocation on the expense of the other economic entities. However, still the RA gains the second largest additional net profit allotment under both alternatives. The RA's double role under the optimal alternative provides it with relatively high negotiation strength compared to the other wastewater consumers (nearby and distant farmers). The city strength increases under uncertainty conditions.

Under both conditions, it is also expected that the suggested solutions will receive the approval of the "green" lobbies, due to the significant contribution to the environment (i.e. river rehabilitation) and to better utilization of the scarce freshwater resource. The models presented in this research can serve as a building block for such extended analyses.

3. Water pricing: analysis of the international literature

3.1. Water pricing: a general introduction

In economic text books (Mankiw, 1998), economic goods are classified in four categories depending on two criteria which are the degree of rivalry (the degree to which consumption by one user reduces the possibility for consumption by others) and the degree of excludability (the degree to which users can be excluded).

		Rivalry	
		HIGH	LOW
Excludability	HIGH	**Private goods** Bottled water Piped irrigation network with limited global water allocation	**Club goods** Domestic water network with no provision problem
	LOW	**Common pool resources** Ground water	**Public goods** Uncontrolled river with abundant good quality water

Table 1: Goods differentiation according their rivalry and excludability characteristics

As shown in Table 1, we can easily find examples of water uses in each category. But trickier is the fact that the same water can be transferred from one kind to another by intervention or regulation.

Multiple values and costs

To understand pricing procedures, it is moreover necessary to define cost and value. Generally speaking, costs represent the supply side whereas values lie on the demand side. These two symmetrical notions are central to price determination. In the case of water, Rogers and al. (1997) and Rogers (1998) propose the following decomposition:

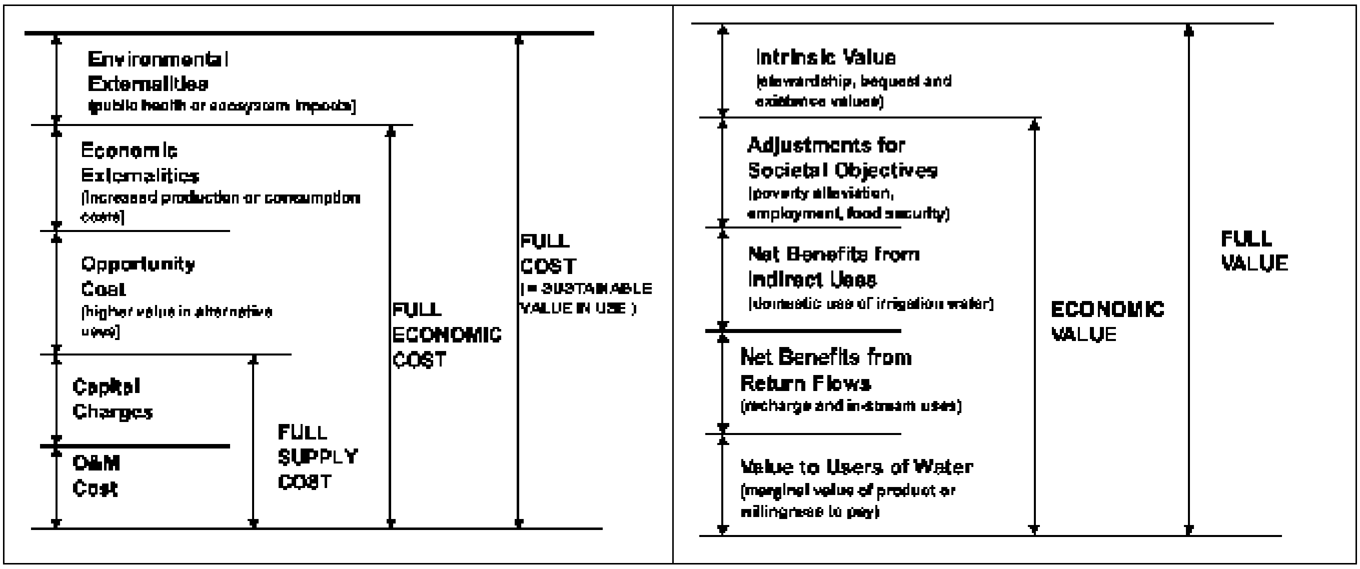

Fig. 1: General water cost and value definitions (Rogers, 1998)

In the build-up of the costs, are distinguished:

A/ the **supply cost**, being the financial costs related to the production of the water, which consists of the operational and maintenance costs (transport, distribution, collection, treatment of supplied water/waste water), the costs of invested capital (that result from the need to raise loans for investment in infrastructure) and capital depreciation .

B/ the **economic cost**, which in addition includes the opportunity cost and the economic externalities. The opportunity cost is linked to the fact that water should be allocated to its highest value uses in order to maximize social welfare and thus represent the cost of depriving the next best user of consuming the water. The economic externalities (to which we add social externalities) are the costs incurred by other parties because of certain uses and that are not taken into account.

C/ the **full cost**, which in addition includes the environmental externalities (costs from damage of the environment and aquatic ecosystems) that certain water users impose on other users, including future users, or on the society as a whole (Socratus, 2005 ; Junguo et al., 2003).

Do not appear on Rogers's classification the resource cost. This cost is based on the estimation of water price before and after the reduction of the available water resources.

The value of the resource for a user may be quantified by his/her willingness to pay for its use. But there are additional benefits, such as the benefits from return flows, the multiple effects from indirect uses, and in a broader sense the benefits to meeting societal objectives. All these contribute to the economical value of a specific water use. The full value of water includes in addition the intrinsic value consisting of cultural, aesthetic etc. of the mere water existence. In practice, quantifying in monetary terms environmental externalities, the impacts on long-term sustainability, the intrinsic value and the adjustments to societal objectives of water is very difficult, and rarely taken into account at the time of choosing a water management scheme or a pricing structure.

Water uses characteristics require considering additional issues to thoroughly evaluate costs and values: the reliability of water supply and the quality concerns. Reliability characteristics and levels are different depending on uses and induce different costs. In irrigation, timeliness is most critical in irrigated agriculture where water shortages during critical stages of plant growth result in reduced crop yields. Reliable water supplies for industry and thermal power plants are critical for maintaining desired production levels. Reliable and adequate water supplies are also critical for households. High investment costs are incurred and high prices are paid by households as part of the coping strategies adopted in the face of uncertain water supplies .

3.2. Water pricing objectives

The objectives of water management are multiple and may sometimes be understood as contradictory:

1/ to allocate water to users who valorizes it at the best (efficiency),

Efficiency is defined by Mankiw (1998) as "the property of society to get the most it can from its scarce resources". This means that efficiency is linked to the capacity of society to allocate limited resources between competing sectors in order to maximize the general welfare. Indeed, for neoclassical economists, pricing will facilitate the reallocation of water from sectors with low added value to sectors with a higher added value. And users will buy water as long as price is lower or equal to its marginal value. The demand reduction objective can have two levels: encourage avoidance of waste or achieve balance between demand and supply.

This objective has to be handled carefully because shifts towards alternative water sources are sometimes possible and rather often harmful to the global water management program. For example, in rural areas, if tap water price becomes very high (with the purpose of reducing consumption), people can easily decide to drill a well and use uncontrolled ground water for uses like flush toilets, cleaning or even bathing… The local alternative supply sources are determinant to the efficiency of pricing structures.

2/ to guarantee an access to this essential good to everybody and to be acceptable in order to be applied (equity),

Where economic efficiency has to do with how much wealth a given resource can generate, equity is the "property of distributing economic prosperity fairly among the members of the society" (Mankiw, 1998). A system will be equitable if it allows the distribution of welfare between users following social objectives.

In the agricultural sector, Perry (2001) gives an interesting argument for pricing as a means to redistribute investment benefits. "Investment in irrigation infrastructure is generally publicly funded. The benefits of this investment accrue directly to the farmers whose lands are made more productive, and indirectly to society at large through lower food prices and more assured availability. There is therefore a case that some proportion of the benefits should be recovered to support further investments for others farmers."

3/ to recover costs induced by water extraction/distribution/use, The obvious and inescapable costs attached to water supply are financial cost linked to the necessary investments, operation activities and maintenance, and the capital depreciation. These three costs are of different natures. Investment costs are usually rare, very heavy and often financed entirely or partially with public funds. Exploitation costs are stable, and maintenance costs are due to increase regularly with time. Note that the European Union Water Framework Directive (WFD) in the field of water policy of October 2000 (European Union, 2000), has an entire article dedicated to cost recovery for water services.

4/ to be transparent and simple enough to be understandable,

A special emphasis will be put on this objective in our work. Water pricing, as complicated as it may be in its principle and in the reasoning leading to a price function, will be translated in a simple table indicating the price to pay as a function of the farmer's or user's decisions.

5/ to guarantee environmental efficiency,

Environmental efficiency will be guaranteed by construction, as some water volumes will be let aside for environmental needs.

6/ to guarantee public health, etc.

3.3. Water pricing structures

If pricing is to be effective in one or the other objectives ascribed to it, then, legal, regulatory, operational and economic conditions must be met. Perry (2001), in the case of irrigation, gives several requirements to be satisfied before pricing can be introduced as a means to improve water distribution. A legal/regulatory framework including procedures for delivered quantities measurement, for accounting deliveries failures (partial, missed, late deliveries…) must exist and be enforced as well as clear recognition of mutual obligations of users and the agency. An operational prerequisite covers the need for the capacity to measure delivered quantities and bill farmers in consequence. The economic requirements lead to, if the objective is to reduce demand, a charged price significant in relation to the benefits derived from using water. The political requirement is very difficult to achieve. Since required prices to induce significant reduction in demand are very often much higher than observed ones, it is very challenging for a government to implement such policies. According to the author, the irrigation sector being sensitive in many countries, such reforms are difficult politically.

Generally speaking, water pricing practices can be classified in two families: volumetric and non-volumetric methods. Volumetric methods rely on the volume and require metered water facility. Non-volumetric methods are based on output/input other than water, e.g. in the agricultural sector the per area pricing. Market-based mechanisms have recently been presented as a tool to address water-pricing inefficiencies inherent in existing irrigation institutions. This relies on market pressures and well-defined water rights to determine the irrigation water price (Johansson, 2000).

To evaluate pricing structures, it is necessary to look at theoretical performances in terms of chosen objectives (efficiency and others, as presented above), but it is also important to take into account the implementation phase and the linked costs (Tsur, 1998). These costs will depend on the local context and elements like information asymmetries or price elasticity that do affect the performances of methods.

1/ Flat rate or non-volumetric pricing

A flat rate is a price that includes only fixed elements. Water charges are independent from the volume consumed. The rate is not always uniform for all uses or users. It is very often indexed on a variety of characteristics: in the domestic sector on the number of inhabitants, the size of the house, the number of taps, different measures of capital value (improved capital value, unimproved capital value, annual rental value) ; in the irrigation sector on output, input, surface…

In all cases the marginal price of water equals zero (Perry, 2001). This means that users are not encourage to save water, since the price of the next unit to be consumed is null.

The great advantage of a flat price is its simplicity. It does not require a metering device. It is easy to implement and transparent. In terms of cost recovery, it makes it easy to secure receipt. But it allows no control on water consumption. And in terms of equity, the effect depends on the indexation chosen. In the context of water scarcity, this type of pricing can be applied with, at the same time, a volume limitation tool as a quota.

2/ Volumetric rate and two-part tariff

Contrary to flat rate, the volumetric rate pricing depends only on the quantity of consumed (or withdrawn, rejected…) water.

This type of pricing does not guarantee cost recovery since the receipt depends directly on the consumed volume. The low water price elasticity though allows good estimation of water response to price changes. Concerning the question of the best unit price the supplier may apply, the economic theory gives an unsettled answer between marginal and average cost pricing.

In order to prevent the risk of not covering costs (and especially fixed costs linked to infrastructures) a two part tariff may be chosen: besides the volumetric pricing, a fixed price is applied to water users. This fixed price will guarantee a minimum regular income assuring the water provider for a part of its cost recovery.

The volumetric part can be priced in three main ways. It can be either constant whatever the level of consumed water or priced “per block”: the cost per additional consumed unit varies when the level of consumption reaches certain thresholds. The block pricing can then increase with the level of consumption (increasing block tariff) or decrease (declining block rate). In the classical increasing block tariff, the bill is the integration of the consumed volume along the different blocks.

Increasing block tariffs (IBT) can be used to impose conservation incentives on some target group of large users. Customers facing the higher prices at the margin will, in theory, use less water than they would under the uniform design; customers facing lower prices at the margin will use more. The increasing block design will conserve water if the sum of decreases in use exceeds the sum of increases. The expectation is that demand in the high blocks will be more elastic than demand in the low blocks, resulting in a net decrease in water use.

Although there is widespread consensus that IBT have many advantages, this type of tariff still deserves more careful examination since an incorrect structure of the IBTs leads to several shortcomings as argued by Boland and Whittington (2000), such as difficulties to set the initial block, mismatch between prices and marginal costs, conflict between revenue sufficiency and economic efficiency, absence of simplicity, transparency and implementation, incapacity of solving shared connections, etc. (Liu and al., 2003).

In order to avoid these problems, several tariffs may be derivated from the IBT. The first one is the IRTs: increasing rate tariffs. In this kind of tariffs, a user pays the same price for all water used in the billing period, but the price increases with increasing use. The water price is then determined by the maximum water consumption of a water user. The water bill for a household is equal to this price multiplied by the water consumption. IRTs are therefore very simple to be implemented.

3/ Decreasing rate tariff or decreasing block tariff (DBT)

First of all, this type of tariff is, unlike the preceding one, in accordance with the “idea” that high value goods “should” be bought at higher price than low value goods. Water will be first purchased for uses with high values, and then only for uses which will lead to less welfare increases. Concerning equity, this type of tariff is "not advisable". "The consumers who acquire smaller amounts of the good and/or service because of their low incomes would be bearing a higher price than those who can afford to consume greater amounts" (Gracia and al., 2001). But it can be justified for the following reasons:

- When users have very different levels of consumption. A consumer hundred times bigger than the average consumer does not create costs hundred times higher, because there is only one pipe line, one billing process… And, since cost per volume is lower with large consumers, it is justifiable to propose DBT in case of heterogeneous users.
- In order to incitate users to stay in the system: as we have explained above, IBT might encourage users who have access to alternative water sources to quit (partly at least) the network, stopping to contribute to the recovery of the costs. This can lead to cost recovery problems for the supplier and besides might lead to negative environmental consequences. DBT does not have this negative incentive.

4/ Two-part tariff

A two-part tariff combines a fixed and a volumetric rate (or a mix of fixed and variable elements). It is generally one of the best simple ways to price water in a multi-objective context. It can reach the three main objectives according to the weight of each part. "Under this system, consumers must pay an entry charge that entitles them to consume the good. Subsequently they will pay an additional smaller amount for each extra unit consumed [in the case of a DBT for the volumetric part]." "Two part tariff are easy to explain and easy to understand." (Gracia and al., 2001).

4. Efficient allocation of water resources in France and in Israel with pricing

4.1. An application in Israel

Prices of water delivered by the national company Mekorot are set by the parliamentary finance committee, and are based on recommendations of the Ministry of Finance, the Ministry of Infrastructure and the Ministry of Agriculture. The prices are determined in consultation with the Water Council in a procedure which is open to political pressure (skilfully applied by the agricultural lobby). Viewing water prices not as an allocation instrument, but as a means of improving income distribution, water charges depend on the type of use: farmers pay the lowest charges, industry pays higher charges and households pay the highest ones. Within each sector, charges do not depend on location: users in all parts of the country face the same charges, regardless of the supply price of water (Kislev, 2002). Private water producers set prices independently.

Tiered pricing (as in preceding section defined "IBT") exists for agricultural users who pay a reduced price of \$0.19 for the first 50% of their quota, a higher price of \$0.23 for the additional 30%, and the full price of \$0.31 for the rest of their quota (which in most cases is not fully utilized). Industries pay an average of \$0.33 per m^3 and cities and towns pay \$0.45 at the "city gate." Neither industries nor municipalities pay tiered charges. Households in cities face tiered charges, paying about \$0.68 for the first block (typically 8 m^3 per household per month), \$1.0 for the second block (typically 7 m^3 per household per month) and \$1.47 per m^3 for any additional consumption. In other words, in addition to the prices that they pay to Mekorot for water, the municipalities impose two layers of surcharges on their households: one for the water-distribution system and for sewage removal, and the other in the form of taxes to help finance general municipal operations. This policy may be beneficial for the city in the short run but it might be very harmful in the long run, when funds will be required for reinvestment and renewal of the old water-delivery and treatment systems (Kislev, 1993). Water prices vary with quality. Water with over 400 mg of chlorides per liter is charged at a lower rate than fresh water according to its salinity level, with the average price being \$0.16 per m^3. The charges for recycled waste water are according to a two-tiered pricing system: the first 50% of the quota is provided at the higher rate of about \$0.15 per m^3 and the rest at the lower rate of \$0.11 per m^3.

The prices charged by Mekorot are subsidized by the government which covers approximately 20% of the cost of supplying the water. In the past, part of the subsidy was implicit. While Mekorot operated the government-financed NWC, its capital cost was not reflected in the water prices. However, since 1993, Mekorot has been working according to a "cost agreement" under which it purchases the capital assets of the water economy, and their depreciation becomes a recognized component of its costs. Governmental support has therefore become explicit.

The current research is divided into two linked parts. First, we develop a regional-level planning model which determines the optimal crop mix and the optimal allocation of the limited (fresh and recycled) water and land resources among all potential water users. The "region" includes 4 economic entities: a city (the producer of waste water), two groups of farmers and a river (the potential users of waste water). The model's objective is to maximize regional social welfare, which is composed of the sum of the agricultural and environmental net benefits (gross benefits minus relevant costs) in the examined region, while taking into consideration the impacts of salinity and nitrogen on the commercial yields of the various crops and the environmental damage associated with irrigation with recycled water over an aquifer. The model incorporates, in one endogenous system, the economic, physical and biological relationships in the water-soil-plant-environment system while taking into consideration the possibility of using recycled wastewater for river restoration. In this part, we expand the relevant optimization models currently available in the literature by adding more realistic agri-environmental restrictions

The result obtained from the used planning model determines the total net benefits in the region that should be allocated among the various players. Obviously, each player would like to have the largest possible share. Here we assume the following allocation procedure: the players reach a cooperative agreement about the basic principles (such as anonymous, symmetrical, efficient and rational) of allocation, and then they nominate an objective middleman who determines the actual allocation, subject to the agreed-upon principles. Specifically, we assume that these principles can be satisfied if the decisions of the middleman are based on an allocation scheme from the concept of transferable utility (TU) games. The different approaches are referred to the allocation of the additional net benefit (gross benefit minus the parties' stand-alone values) obtained in the examined area, among the parties.

The models are applied to the Sharon region in central Israel, which includes two cities [operating one wastewater-treatment plant (WWTP)], the Yarqon River Authority (RA) and two groups of farmers. The motivation for regional cooperation among these economic entities is concealed in the economic and environmental advantages related to the reuse of recycled wastewater for irrigation and river rehabilitation. The farmers might be able to increase their irrigated areas and benefits and the RA is expected to increase its stream flow and benefits.

4.2. An application in France

We will not develop here further the different pricing schemes used in France, since they are generally a direct application of the preceding section (on water pricing). Here we limit ourselves to pricing schemes based on subscriptions and consumptions, which by the introduction of a new freedom degree by including in the pricing formula a second variable, allow to satisfy more constraints or properties. In order to be able to collect and econometrically analyse corresponding data, we use the only pricing scheme based on such a structure which is in use in a Poitou Charente area in France. The pricing formula is there:

$$Fi = 0.5D\left(\frac{V_{Si}}{S} + \frac{V'_{Pi}}{P} x \frac{V'_{Pi}}{V_{Si}}\right)$$

$$\text{with } V'_{Pi} = Max(V_{Pi}, 0.7V_{Si})$$

in which, D is the sum of the water user association expenses
V_{Si} is the volume reserved by agent i
V_{Pi} is the volume consumed by agent i
V'_{Pi} is the volume billed to agent i
Fi is the sum agent i must pay
N is the total number of agents

$$S = \sum_{i=1}^{N} V_{Si}$$

$$P = \sum_{i=1}^{N} V_{Pi}$$

We demonstrated that this scheme has the following properties:

- First it implies that the optimal water subscription is directly linked to the anticipation of water consumption. It allows then to forecast a potential crisis when forecasted consumption are higher than the available water, far before the summer, when there is always some possibility to change the choice of the cultures.

- Second, once a volume is subscribed, the formula incites to diminish the water consumption (till 0.7 multiplied by the subscribed value), since the price increases more than proportionally to the volume of consumed water.

- Third this pricing allows the different farmers to attain a Nash equilibrium, the properties of which, especially concerning the stability, we studied both in a deterministic case (when there is no uncertainty on the rain level in summer, as in Israel) and in the stochastic case. The analytical model is in this last case rather complicated, and we had to make some simplifications in order to be able to compute numerically the equilibriums.

- Fourth, the data gathered showed that the economic agents (the farmers) understand very well this type of pricing (in other words, it was not at all too much complicated), which is very encouraging for the diffusion of such schemes.

- Fifth, the farmers responded with rationality to it, and reserved all the more water that they were risk averse (we classified farmers in two categories: those for which irrigation was an absolute necessity (vegetable producers…), and those for whom it was only a supplement to rain water (wheat growers…), the first being supposed to be more risk averse). An econometric analysis shows that there was less than 1% risk (in fact 0.00936) that the observed difference was due only to chance.

- Sixth, we demonstrated that the budget equilibrium of the Water User Association may be jeopardized, which was anticipated by the farmers. They changed the pricing rule and we began studying the new pricing scheme and the water subscription and reservation, and the culture change during the last years.

Moreover the persons in charge of the Water User Association were very interested to see that it was possible to analyse ex-ante, with mathematical models and simulation tools, a pricing system they were trying to implement with a trial and error method.

Last the study (especially through the Nash equilibrium properties) of such a pricing scheme opens a lot of possibility to adapt it to different conditions, objectives and constraints, a work we hope we will carry on in forthcoming researches.

5. Forthcoming research

We would like to extend our work in order to:

1/ extend our scientific research in the field of irrigation and waste water with an agro-economics approach, notably in France in order to explore other possibilities our first results displayed:

- change of the pricing system the water user association made in order to correct some shortcomings of their initial trial
- explore the application of this French pricing approach for the management of water in Israel (see annex 3) or in different situations.

2/ extend our joint research to other fields of interest such as investigating sludge allocation among competitive users both in France and in Israel,

3/ work, on a more general perspective, on the links between the 'pricing' and the 'planning' approaches into a unique project such as, and working both on the implementation on the European Union Water Framework Directive in France and on the developing pricing mechanism to wastewater in Israel. This would be all the more important than the pressure on the water resource is increase and that the policy makers are all the more eager to use the most efficient tools in the interest of their country.

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