3 Why Is Agricultural Water Demand Unresponsive at Low Price Ranges?

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Introduction

With growing populations, increasing standards of living and growing concern for environmental issues, claims on water resources are intensifying. Competition between sectors is increasing and water allocation mechanisms currently in place, such as fixed allocations or rationing, may no longer be adequate. At the World Water Forum 2000, a large international conference, the majority of the international water community called for reforms in water allocation mechanisms (Cosgrove and Rijsberman, 2000). Proposed reforms relate especially urgently to agriculture. Worldwide, 70–80% of all developed water resources is used for agricultural production. In arid countries where rainfall is insufficient for rain-fed agriculture, this percentage may be as high as 90% (Gleick, 1998). Water use in agriculture is often heavily subsidized and trade in water is limited. Several studies report problems related to water scarcity and resources overexploitation in the USA, India, Pakistan, China, the Middle East and the Soviet Republics (Postel, 1999; Seckler *et al.,* 2000; Rosegrant *et al.*, 2002). They foresee that these problems will only intensify and spread to more regions in the near future, unless adequate action is undertaken to reform prevailing water management practices.

Economic incentives and mechanisms, such as water pricing and introduction of water markets, are often proposed as efficient and effective measures in demand management. According to Perry (2001), the three most common reasons for recommending water charges are:

- To recover the cost of providing water delivery service;
- To provide an incentive for efficient use of scarce water resources;
- As a benefit tax on those receiving water services, to provide potential resources for further investment to the benefit of others in society.

Cost recovery and tax purposes can be achieved through area- or crop-based pricing. These charging mechanisms are generally preferred to volumetric pricing because they are easier and cheaper to implement. To provide an incentive for more efficient use, charges must be a direct function of consumption.

Underpricing may lead to inefficient use of scarce water resources, and the introduction of volumetric water pricing may reduce water wastage and generate revenue to continue essential services in the future (Briscoe, 1996; Rosegrant, 1997; Huffaker *et al.*, 1998; Kumar and Singh, 2001). 'Getting the prices right', i.e. reflecting the economic and social value of the resource, is a desirable way to allocate water efficiently (Dinar and Subramanian, 1997; Johansson, 2000).

But it is debatable if volumetric pricing is an *effective* measure in water demand management. The development of the required institutional and physical infrastructure, lacking in many places, is a costly process. Externalities in water use, caused by recycling of drainage water, may render pricing less effective in reducing water use than foreseen by planners (Seckler, 1996). Perry (1997, 2001) shows that, in Egypt and Iran, costs of pricing to farmers and society outweigh projected benefits. Ray (2002) examines the implicit assumptions under which market forces can induce more efficient water use. She concludes that for India these assumptions are violated and that enforceable and transparent allocation rules may be more effective to curtail water demand. Molle (2001) reaches similar conclusions for Thailand. For the Middle East, Ahmad (2000) predicts that in the absence of well-defined water rights, economic measures may lead to higher water use rather than conservation of water.

Others argue that, especially in developing countries, there are millions of indirect beneficiaries such as the consumers who benefit as much as, or even more than, the direct beneficiaries of irrigation (i.e. farmers). It is therefore unjust to expect the farmers to bear the full burden. They argue that the cost of irrigation development should be legitimately shared by both consumers and producers (Sampath, 1983, 1992; Rhodes and Sampath, 1988).

Finally, several researchers claim that irrigation water demand is inelastic below a threshold price, and elastic beyond it (Varela-Ortega *et al.*, 1998; OECD, 1999). To induce a reduction in demand, considerable price increases are required (either in the general level of charging or through more complex multilevel charges). Political considerations may prevent such price increases (Perry, 2001; Ray, 2002).

For their analysis of policy impacts, economists rely on observed prices and market transactions to infer the value of a particular good. Commonly, the demand curve – as the basis of quantitative economic analyses – is determined through econometric curve fitting techniques using field data. This 'direct' approach is difficult in the analysis of water demand in agriculture. The price of water is only rarely determined in the market. Consequently, the value of water needs to be derived from modelling, starting from production functions and setting up the farmer's optimization problem. Examples of this analytical approach are found in Dinar and Letey, 1996; Rosegrant *et al.*, 2001.

Many analytical studies implicitly assume an ideal situation, free of price distortions and externalities. But the introduction of volumetric water charges as a demand management tool does not happen in a void. Water management practices already in place prior to the introduction of pricing have an important bearing on its effectiveness as a demand management tool. In this chapter two factors are explored: (i) the impact of technology; and (ii) the impact of prevailing rationing regimes.

The remainder of this chapter is organized as follows: the second section explores the impact of technology choice, application efficiency and scale; the third section examines the consequences of rationing; and the last section provides the conclusions and discussion.

Impact of Technology

Gardner (1983, cited in Ray, 2002) states that if water prices rise to reflect its opportunity cost, a rational farmer will have any or all of the four following responses: the farmer demands less water and leaves land fallow; applies less water to the crop accepting some yield loss; switches to less water-demanding crops; and/or invests in more efficient irrigation techniques. Literature provides evidence that farmers respond in all these ways. Examples are found in Ray and Williams (1999) for India; Bernardo and Whittlesey (1989) for Washington State; Hoyt (1984) for Texas; Berbel and Gomez-Limon (2000) for Spain; and Ogg and Gollegon (1989) and Weinberg *et al.* (1993) for the western USA.

The reduction in water use intended by more efficient irrigation depends to a large extent on the water application technology and its potential to substitute water for other inputs. Varela-Ortega *et al.* (1998) compare the price elasticity of water demand in three regions in Spain. They conclude that in the 'old' irrigation schemes where water application techniques are relatively inefficient, the response to increasing water charges is much higher than in the modern systems with drip systems. The authors conclude that the technical endowment in an agricultural district has a major effect on its response to water pricing.

Broadly speaking, three categories of application technology can be distinguished: surface, sprinkler and drip. The most capital-extensive but water- and labour-intensive technique is surface irrigation. Generally, sprinkler irrigation uses less water but requires more capital. Lastly, drip irrigation typically uses the least amount of water and labour but is the most capital-intensive technique.

Where water price is low, a rational farmer will substitute relatively expensive inputs – such as capital and labour – for cheap water.[1] For example, instead of manually weeding paddy fields, labour input is reduced by maintaining a water layer on the field to suppress weed growth, at the expense of additional water to cover evaporation and percolation losses. Conversely, where water charges are high, it may be cost-effective to invest in field canal lining to reduce seepage losses.[2] For each technology, the substitution potential, i.e. the scope of water savings through increased labour and capital input, differs. It is typically highest in surface irrigation. In drip irrigation systems, where water application efficiency is already high compared to surface systems, the scope of water savings is limited and comes at a relatively high incremental cost.

Theoretically, water pricing may impact both technology choice and the level of substitution. With increasing water charges, a farmer will operate the existing technique in a more water-efficient manner, until it becomes cost-effective to switch to a more advanced application technique using less water.

Technology choice

Empirical evidence, however, shows that technology choice is hardly driven by water price. It is mainly determined by structural factors, agronomic conditions and financial constraints (see Molle and Berkoff, Chapter 2, this volume). For example, on sloping fields the use of sprinklers may be more appropriate than flood irrigation which requires levelling. For reasons of erosion control and better fertilizer application, a farmer may opt for furrows or drip. Favourable subsidy schemes may induce a switch to drip because it gives higher yields per hectare, reduces labour input and is less prone to salinity problems. Lack of spare parts, knowledge and credit may prohibit the use of advanced technologies as sprinkler and drip. Crop choice may limit technology choice: tuber crops are best grown on furrows while cereals cannot be grown under sprinkler or drip. Caswell and Zilberman (1986) and Caswell *et al.* (1990) in their studies on California demonstrate that while the probability of drip irrigation adoption increases with higher prices, land quality and environmental considerations play a more prominent role. Green and Sunding (1997) find that technology choice primarily depends on land quality and crop choice. Varela-Ortega *et al.* (1998) arrive at similar conclusions for three irrigation systems in Spain. Hoyt (1984) notes that, in Texas, only dramatic price increases will induce capital investment in better technology.

Level of substitution

Within each application category, water can be substituted for capital and/or labour. For example, within the category of surface

[1] The potential of fertilizer and pesticides as substitute for water seems limited, at best. There is evidence that at some parts of the demand curve they behave as complements rather than substitutes.

[2] For the individual farmer this may lead to savings, but not necessarily at system level.

irrigation the most labour-extensive application is to simply flood the field, resulting in high water losses. Water application can be reduced dramatically at the expense of extra labour by field levelling, constructing bunds, using furrows or increasing the intensity of monitoring field conditions. Likewise, a labour-extensive way to operate a sprinkler system is to use a timing device so that the sprinklers are turned on at regular intervals. But this does not account for the rainfall that may occur during these intervals, and irrigation water may be lost. More water-efficient, but more capital-intensive, is to install moisture probes to determine the right time to sprinkle, based on actual water needs. This method does not account for rainfall that may occur in the days following irrigation. Even more efficient in terms of water use, but more capital-intensive, is a computerized system that uses actual water needs and weather forecast information.

There are clear limits to substitution. Below a certain point it is no longer possible or desirable to use more water to replace capital and labour. Too much water will damage crops, create erosion problems, cause waterlogging and flush away fertilizer. Consequently, there is a maximum amount of water a farmer will take, even if abundant water is available at zero cost. As a result, at low water prices water demand is not determined by price but by agronomic- and technique-related factors and water use is unresponsive to price. With the introduction of water pricing as a demand management tool, water use becomes elastic only beyond a certain threshold. The size of the threshold depends on initial water management practices and the substitutability of water for other inputs. The model developed in the following paragraphs explores the impact of these factors on water demand at low price ranges.

Demand curves

The water requirements of a crop depend on physical factors, such as climate, soils and crop characteristics. In general, the more the soil moisture is available to the crop, the higher the crop yield, up to a certain limit. At low water application rates an additional unit of water results in a substantial yield increase but the marginal product of water quickly declines at higher water levels. Beyond a certain level of water application crop yields suffer due to lack of aeration in the root zone. At that point, the marginal product of water becomes negative. A polynomial functional form, best captures the physical relationship between crop growth and soil moisture. Hargreaves (1977) proposes a cubic form. Following Dinar and Letey (1996) and Rosegrant *et al.* (2001), a quadratic functional form is adopted here:

$$Y_p = \beta_0 + \beta_1 W_c + \beta_2 W_c^{\,2} \tag{3.1a}$$

$$Y_c = Y_r \bullet Y_p \tag{3.1b}$$

Where, Y_r stands for relative crop yield, Y_p is potential yield, Y_c is crop yield, βs are regression coefficients and W is the amount of crop evapotranspiration. The crop production function depends on crop characteristics, soil and climate and is unique for each crop and location. This is reflected by the intercept β_0. In the representation given by the equation (3.1a and 3.1b) inputs other than water (e.g. agrochemicals) are kept constant at an optimum level.

The variable W represents the amount of crop water evaporation. To get this amount to the plants it needs to be conveyed from source to fields and applied in the right quantities at the right time. The irrigation efficiency indicates the extent of water losses occurring in conveyance and application. Application efficiency at field level is defined as the amount of water beneficially used by crops (W) divided by the total amount diverted to the field (TotWat).

$$\text{Eff} = \frac{W}{\text{TotWat}} \tag{3.2}$$

Confronted with rising water charges, a farmer can reduce total water diversion by reducing the water layer on the field (W) through the adoption of deficiency irrigation or switching to a less water-demanding

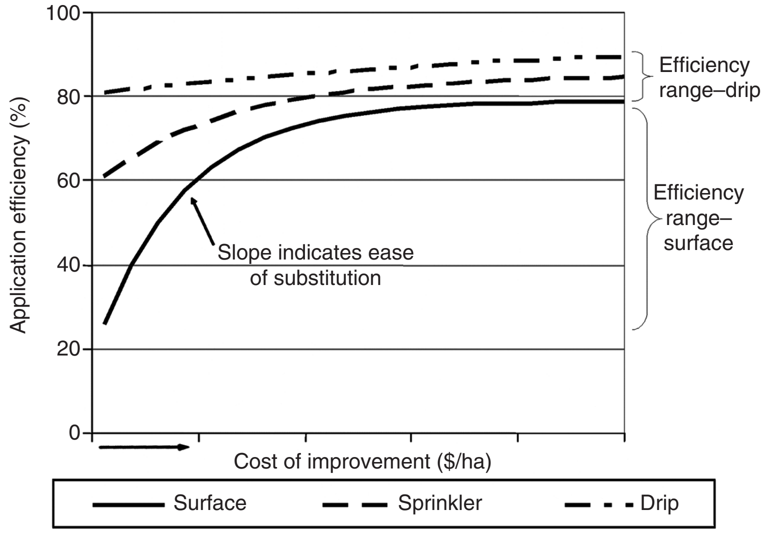

Fig. 3.1. Application efficiency cost curves.

crop.[3] Alternatively, a farmer can improve application efficiency (Eff) by substituting labour and/or capital for water, or, ultimately, leave land fallow. As explained above, for agronomic and technical reasons there is an upper limit to the amount of water a farmer takes, independent of price. Thus, water is applied with a minimum efficiency. An application efficiency of say 10% is undesirable because the large amount of water to meet crop water requirements (W) will cause problems as erosion, fertilizer loss, waterlogging and crop damage.

Figure 3.1 depicts the relation between application efficiency and cost of improvement for different technologies. The exact shape of these curves is site- and crop-specific and largely unknown. Three features are important for the discussion here. First, the curves do not intersect the *y*-axis at zero. In other words, an efficiency of zero does not exist and the minimum is well above zero. Second, additional labour/capital input exhibits a diminishing return. Third, the upper and lower bounds differ by technology. Efficiency in surface irrigation exhibits the widest range, while drip irrigation has the narrowest scope.

When these elements are incorporated in a simple farmer optimization model, the water demand curve reveals three zones (Fig. 3.2). At low ranges, price is not a determining factor in decisions related to technology choice and application efficiency and water demand is unresponsive to price. With increasing prices, the farmer may opt to slightly reduce the water layer on the field but because this will directly affect crop yields, demand is inelastic. Beyond a certain threshold, demand becomes elastic. At higher price ranges, demand becomes inelastic again, as water quantities approach the minimum amount needed for plant growth.

Price threshold

Several studies conclude that water demand becomes elastic only beyond a certain price threshold (Varela-Ortega *et al.*, 1998; OECD, 1999). Where prevailing prices are low relative to the threshold price, a considerable price increase is necessary to induce the desired reduction in demand. Political considerations may prevent such price increases

[3]Often crop choice is limited, due to climatic factors, the absence of marketing infrastructure, diet preferences and risks associated with other (cash) crops.

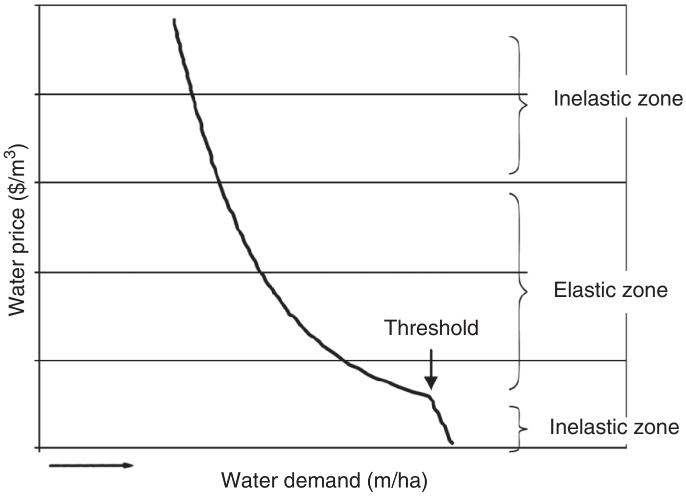

Fig. 3.2. Demand curve.

(Perry, 2001). To gauge the effectiveness of pricing as a demand management tool, it is thus essential to investigate the importance of the price threshold.

In the following paragraphs the sensitivity of technology on the threshold value is examined, using a numerical example using crop data from California. Crop production parameters are adapted from Dinar and Letey, 1996 and summarized in Table 3.1.

Little is known about prevailing application efficiencies and associated cost curves. This example, therefore, explores a wide range of values of substitutability, scope of improvement and initial efficiencies. Figure 3.3 presents a family of cost curves for an application technology of which the application efficiency ranges from 25% to 80%. That is, if farmers are free to take the amount of water they desire free of cost, they will choose to operate the system at 25% efficiency. The lowest curve represents a situation where efficiency improvements come at a high cost: $500/ha to increase efficiency from 25% to 50% (for comparison in this example, maximum crop revenue is $2500/ha). The 'high substitutability' curve indicates a low marginal cost of efficiency improvement: $150/ha to increase efficiency from 25% to 80%. Figure 3.4 depicts the resulting water demand curves. Water demand is elastic and thresholds are low and of minor importance, even in case of low substitutability of water.

Table 3.1. Crop data used in the numerical example. (From Dinar and Letey, 1996.)

Crop: cotton	Location: California		
Parameters			
β0	−0.13	Crop price ($/t)	1600
β1	2.30	Potential yield (t/ha)	1.7
β2	−1.20		

Note: In this table and throughout the book $ means US$.

The situation changes dramatically if the initial efficiency is set at 40% instead of 25% (Fig. 3.5). The dotted lines in Fig. 3.5 depict that part of the demand curve which is suppressed because of the high initial efficiency. The threshold level varies from negligible to considerable, depending on the ease of substitution. Figure 3.6 shows the family of demand curves for a technique whose scope of improvement is relatively limited (efficiency ranging from 60% to 80%). In this case, water demand is inelastic, unless the substitution of water comes at a very low cost.

This analysis makes clear that the threshold value depends on three interrelated

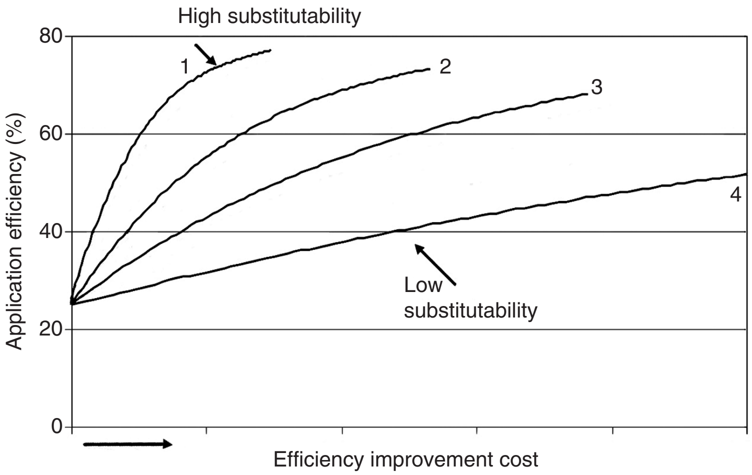

Fig. 3.3. Efficiency improvement cost curves (efficiency range 25–80%).

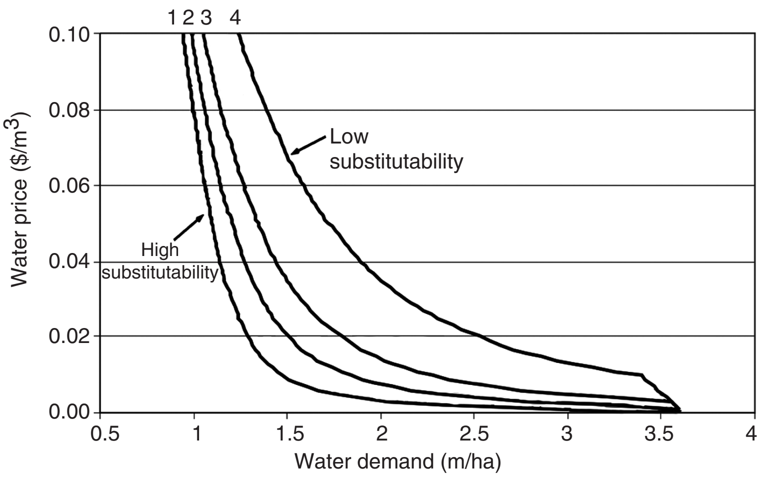

Fig. 3.4. Demand curves for efficiency range 25–80%.

factors, namely the prevailing application efficiency, the scope of efficiency improvement and the ease of substitution. These factors are, to a large extent, determined by technology choice and existing on-field water management practices, which are mostly unrelated to water price.

In this example, when the application efficiency is 25%, water demand is fairly elastic at low prices, even if efficiency improvements come at a relatively high cost. On the other hand, if the existing efficiency is 40% or 60%, reduction of water demand may require a substantial price increase depending on the ease of substitution.

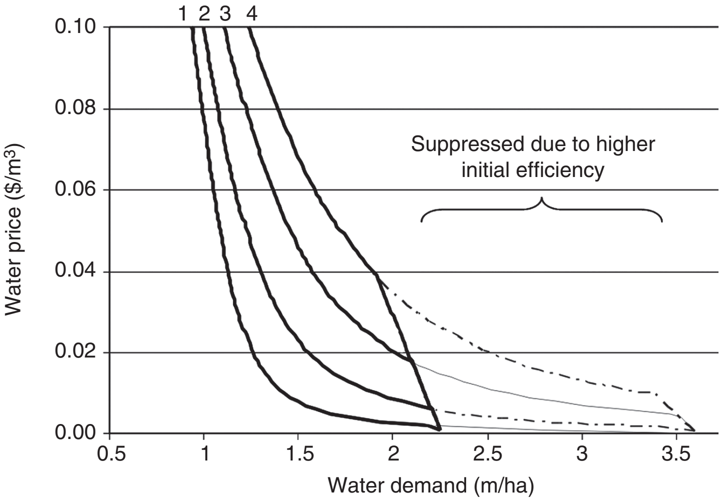

Fig. 3.5. Demand curves for efficiency range 40–80%.

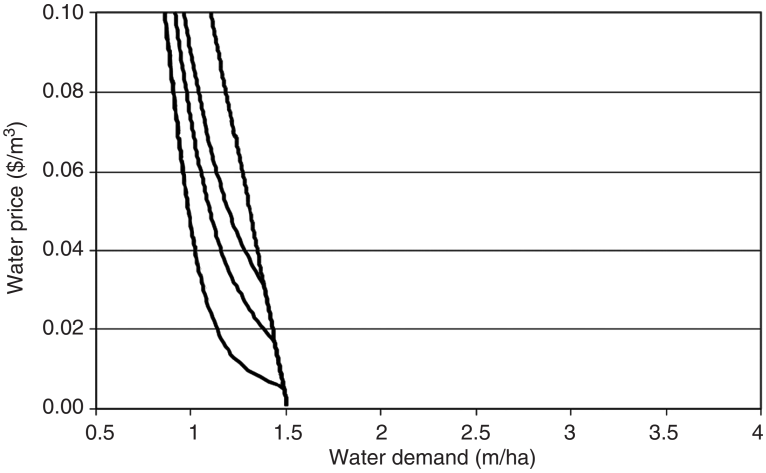

Fig. 3.6. Demand curves for efficiency range 60–80%.

Costs of water reduction

The existence of an inelastic section of the demand curve at low prices, or the lack thereof, has major implications for the cost of water reduction to farmers. Figure 3.7 shows the relation between water reduction and cost of water for the demand curves depicted in Fig. 3.5. Water reduction is expressed as a percentage of the maximum quantity demanded under price zero (i.e. 2.25 m/ha). Water costs, expressed as a percentage of total crop revenue, include water charges plus the costs of efficiency improvement.

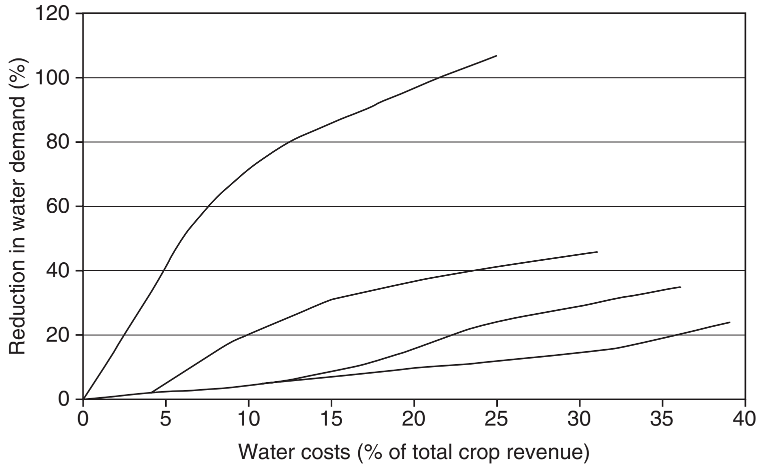

Fig. 3.7. Cost of water reduction.

Unless the ease of substitution is high, considerable impacts on farm income are implicit for using water pricing as a means to limit demand. Empirical evidence supports this finding. Perry (1997) estimates for Egypt that inducing a 15% reduction in water demand through volumetric pricing would decrease farm incomes by 25%. Berbel and Gomez-Limon (2000) estimate that farm income in Spain will decrease by 40% before water demand decreases significantly. Bernardo and Whittlesey (1989) and Hoyt (1984) conclude that in the Washington State and Texas farmers substitute water with labour, by switching to a more water-efficient mode of operation. But to induce these water savings by pricing (as opposed to restricting supply) results in a significant income loss to farmers and painful adjustments as some farmers may have to stop irrigating.

In countries where low-income farmers make up a large part of the voting population, pricing may not be a feasible demand management option from a social and political point of view.

Scaling up

Volumetric water pricing in agriculture is geared towards influencing water use behaviour of individual farmers. The aggregated impact of pricing at a scale larger than a farm may be governed by different processes and scaling up the impacts of pricing by aggregating individual responses may lead to erroneous conclusions.

Efficiency of water use is a scale-dependent concept. From a river basin perspective, drainage water from 'inefficient' farms is not necessarily lost, but can be reused by downstream users, water quality allowing (Seckler, 1996). Molden *et al.* (2000) show that, for Egypt, farm-level efficiency is as low as 40%, but overall basin efficiency is 90%. This implies that 90% of all diverted water is beneficially used for crop growth. Water 'wastage' is negligible and the scope for water savings, induced by pricing or other measures, is very small.

Although field efficiency is low, return flows from 'inefficient' users may be reused by downstream farmers, either by recapturing drainage flows or by pumping excess seepage. Pricing induces upstream farmers to use water more efficiently and thus create less return flows. Downstream farmers have to divert more water to compensate for this loss. Consequently, at the aggregate level of river basins, the reduction of water diversions as a result of pricing may be less than foreseen (Perry, 2001). A proper assessment of the impact of water pricing at basin scale requires a knowledge of hydrological interaction between users.

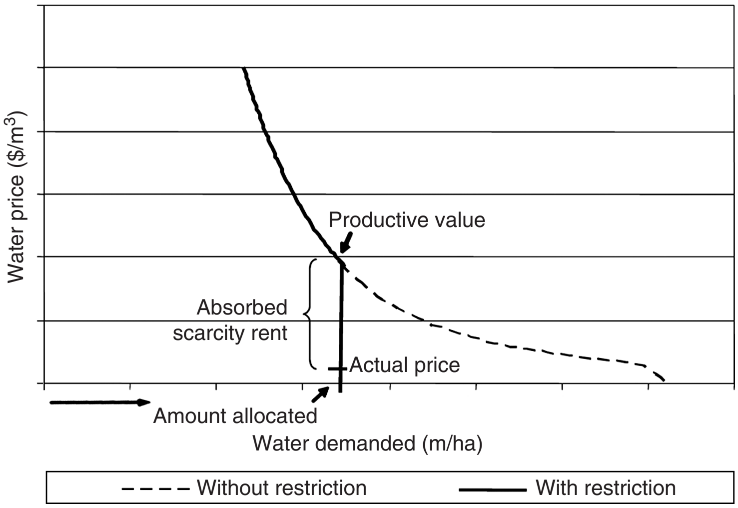

Fig. 3.8. Water demand and use under restricted supply.

Impact of Existing Rationing

In many parts of the world, farmers are not free to take the amount of water they prefer. Farmers' access to water is bounded by water rights or by fixed allocations. Also the size of canals, inlets or pipes may limit the amount of water a farmer can take (this could be called technological rationing as opposed to institutional rationing).

Where water is scarce and water prices low, the amount allocated is likely below the 'free market' amount (i.e. the amount of water that farmers would be willing to take at the prevailing price). A good example of an allocation mechanism in water-scarce areas is *warabandi*, which is practised on a large scale (over millions of hectares) in irrigation schemes in India and Pakistan. The system is designed to provide a rationed and equitable service (in proportion to landholdings) to all farmers under conditions of extreme water scarcity. Instead of planning for full irrigation of a small part of the area, the available water is spread over a large number of farms, thus giving farmers a choice between fully irrigating part of their land with water-intensive crops, or irrigating a larger area of less water-intensive crops, or deliberately underirrigating a still larger area. This approach encourages maximum output per unit of water, rather than maximum output per unit of land (Bandaragoda, 1998).

Figure 3.8 depicts the relation between water price, demand and actual use. The dotted line represents the demand curve. The solid line shows the actual use.

At low prices water use is constrained by rationing. Farmers optimize water use by choosing an appropriate crop, level of risk and efficiency according to its limited availability, independent of price. Consequently, water use is unresponsive to price. At a certain threshold, pricing becomes effective in reducing demand. This is the point where price equals the productive value of an additional unit of water (price equals marginal product).

If the price of water is set below the threshold and the maximum allocation is still in place, farmers start 'paying off the absorbed scarcity rent'. In other words, water diversions remain constant but farmer profit suffers substantially.[4] If the rationing system is fully replaced by water pricing allocation, and the price is set below the threshold, farmers will divert *more* water, until the gap between actual price and productive value is bridged.

These observations imply that where irrigation water is currently rationed, the

[4]Society as a whole may benefit depending on how water revenues are invested.

introduction of water pricing as a demand management tool is effective, *only if* the price is set above a certain threshold, i.e. the productive value of the last unit allocated under the rationing scheme. Depending on the initial water price and the size of the allocation, this threshold may be several times the original price. The lower the price actually paid and the more binding the existing allocation to farmers, the bigger is the gap between price and productive value. For Iran, Perry (2001) estimates that the productive value of water is $0.04, while the farmers at present pay $0.004. To induce water savings by pricing, a tenfold increase is required. Ray (2002) in her study on water pricing in India shows that in order to induce the water-conserving response under existing allocation practices, a sixfold price increase would be needed. She adds that under the prevailing political circumstances in India, this is very unlikely.

Conclusions and Discussion

The price of water is only rarely determined in the market. Consequently, models are needed to derive demand as a function of price. Many analytical studies implicitly assume an ideal situation, free of price distortions and externalities. But the introduction of volumetric water charges as a demand management tool does not happen in a void. Water management practices already in place before the introduction of pricing have an important bearing on its effectiveness as a demand management tool. This chapter explores the impact of technology choice, application efficiency and prevailing rationing practices on water demand elasticity.

At low water prices, farmers' decisions concerning technology choice and water use primarily depend on crop choice, land quality, agronomic considerations and structural factors (e.g. availability of capital and labour). Where water is restricted – either by institutional rationing or limits imposed by technology – farmers optimize water according to its limited availability. At prevailing (low) prices, the amount of water diverted is independent of price and water demand is unresponsive to price. It is only beyond a certain threshold that demand becomes responsive to price.

When prevailing prices are low relative to the threshold, considerable increases are necessary to induce the desired reduction in demand. Political considerations may prevent such increases. To gauge the effectiveness and feasibility of pricing as a demand management tool, it is crucial to investigate the importance of the threshold.

Where water is rationed, the threshold level mainly depends on the size of the allocation relative to the 'free market' amount (i.e. the amount of water farmers would be willing to take at prevailing prices). In water-scarce areas with low prevailing prices and very restrictive allocations, the required increase may be prohibitive.

The analysis presented in this chapter reveals that, where water is freely available, the threshold value depends on three interrelated factors: (i) the field application efficiency prior to the introduction of pricing as a demand management tool; (ii) the scope of efficiency improvement; and (iii) the ease of substitution (i.e. the marginal costs of efficiency improvement). These factors are, to a large extent, determined by technology choice and existing on-field water management practices, which are mostly unrelated to water price. When prevailing application efficiencies are low, say around 25%, demand is fairly elastic at low prices, even if efficiency improvements come at a relatively high cost. On the other hand, if the existing efficiency is 40% or 60%, reduction of water demand may require a substantial price increase, depending on the costs of substitution. This may lead to considerable income losses to farmers.

Although this conclusion may seem obvious, the implications are by no means trivial. Reliable information on field application efficiencies is not available, except for local case studies often implemented in an experimental set-up. Estimates are typically based on common perceptions and rules of thumb rather than on measurements. In this context, it is important to distinguish between field application and irrigation efficiency. The latter is substantially lower than the former because it includes conveyance and operational losses in the main irrigation system.[5] System losses are beyond the control of individual farmers, and thus unresponsive to water pricing charged to individual farmers. In large irrigation schemes, system losses may be more important than those occurring at the field level. Without reliable estimates on field application efficiencies prior to the introduction of pricing, its effectiveness as a demand management tool remains subject to personal judgements and opinions.

This issue is further complicated due to the scale dependency of irrigation efficiency. From a river basin perspective, drainage water from 'inefficient' farms is not necessarily lost, but can be reused by downstream users – water quality allowing. Pricing induces upstream farmers to use water more efficiently and thus create less return flows. Downstream farmers have to divert more water to compensate for this loss. Consequently, at the aggregate level of river basins, the reduction of water diversions as a result of pricing may be less than foreseen. A proper analysis of the impacts of water charges requires consideration beyond the individual farm level.

[5] $E_{ir} = E_{ap} \cdot E_{sys}$ where E_{ir} is irrigation efficiency, E_{ap} field application efficiency, and E_{sys} is system efficiency (conveyance and operational losses in main system). A rule of thumb for surface irrigation commonly used by irrigation engineers: E_{ap} = 50–70%, E_{sys} = 60–80%, resulting in an overall E_{ir} = 30–55%.

Results of this analysis depend on the model formulation, its underlying assumptions and parameter values. The model uses total seasonal demand curves without accounting for short-term rainfall variability. There may be short periods of zero responsiveness (after rain) or short periods of high elasticities (after unseasonal drought). The analysis here neglects these and provides an 'average' picture over the entire growing period. Further, the analysis is based on crop data for cotton in California. A sensitivity analysis revealed that as long as the crop production function is polynomial (with a clear maximum), the resulting form of the demand curves (with a threshold) does not change. The efficiency cost functions are assumed for want of data. The wide range of values tested most likely cover all plausible parameter values. The conclusions of this analysis are independent of the exact functional form of the efficiency function as long as efficiency has a clear upper and lower bound and the minimum efficiency is greater than zero.

The analysis in this chapter focuses on the impact of water management practices existing prior to the introduction of pricing. It does not include several potentially important factors influencing effectiveness of pricing, such as uncertainty in water supply (Perry and Narayamurthy, 1998), risk due to fluctuations in revenue (Bontemps *et al.*, 2001) and difficulties related to implementation (Tsur, 2000; Molle, 2001; Perry, 2001). The inclusions of these factors, which are considered outside the scope of this chapter, will improve the analysis but may not significantly affect its conclusions.

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