

Why is irrigation water demand inelastic at low price ranges?

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Abstract

With growing claims on scarce water resources, volumetric pricing is often proposed as part of reforms in agricultural water management. There is little evidence, however, that volumetric pricing is an *effective* tool in curtailing agricultural water demand. Difficulties in implementation and externalities in water use may render pricing less effective in reducing water than foreseen by planners.

Moreover, some empirical studies show that water demand is inelastic at low price ranges. Only beyond a certain threshold does irrigation water demand become responsive to increased water charges. Because prevailing water prices are generally low, this implies that only considerable increases can induce expected water saving behavior, which in turn will greatly reduce farmer income. Consequently, pricing may not be a politically feasible option to curtail water demand in places where farmers make up large part of the population.

Despite the important policy implications, no existing studies explain the existence of the inelastic region and the threshold price. This paper develops an illustrative numerical model that offers two possible explanations. First, because of existing institutional interventions in water management, such as rationing, there may exist a gap between the productive value of water and the price farmers actually pay. In this situation, pricing is only effective in curtailing demand if the price is raised above the point where price equals the productive value. Depending on the initial water price and the size of the allocation, this threshold may be an order of magnitude higher than the original price. The second explanation lies in the nature of the existing irrigation application technology and its associated efficiency. Where efficiency is high for non-price related reasons, pricing leads to reduced farmer income, while the impact on demand is limited.

I. INTRODUCTION

With growing population, increasing living standards 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 rainfed 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. Postel (1999) reports severe problems related to water scarcity and resources over-exploitation in the US, India, Pakistan, China, the Middle East and the Soviet Republics. She foresees 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.

Market based allocation mechanisms – such as water pricing and introduction of water markets - are often proposed as efficient and effective measures in demand management (Brooks, 1998). The three most common reasons for recommending water charges are (Perry 2001):

- 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.

Under-pricing leads to inefficient use of scarce water resources, especially where charges are not a direct function of consumption – for example where charges are fixed per hectare of crop. The introduction of volumetric water pricing reduces water wastage and generates revenue to continue essential services in future (Briscoe 1996, Rosegrant 1997, Kumar and Singh 2001). “Getting the prices right”, i.e. reflecting the social value of the resource, is a desirable way to allocate water efficiently (Johansson 2000, Dinar and Subramanian 1997). Griffin (1985) advocates volumetric pricing in Texas as ‘a simple device for conserving water supplies’.

There is little evidence, however, that volumetric pricing is an *effective* measure in water demand management. The development of the required institutional and physical infrastructure, lacking at 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 (2000 and 1999) shows that in Egypt and Iran costs of pricing to farmers and society outweigh projected benefits. Ray (2001) 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. Ahmad (2000) predicts for the Middle-East 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 development countries, there are millions of indirect beneficiaries such as the consumers who benefit as much or even more than the direct beneficiaries of irrigation (i.e. farmers). Consequently, it is 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 and 1992, Rhodes and Sampath 1988).

Finally, several researchers claim that irrigation water demand is inelastic below a threshold price, and elastic beyond (Varela-Ortega et al. 1998, OECD 1999). Consequently, to induce a reduction in demand, considerable price increases are required (either in general levels of charging, or through more complex multi-level charges). Political considerations may prevent such price increases (Ray 2001, Perry 2000).

This paper addresses the latter point and offers two plausible explanations for the inelasticity of water demand at low prices¹, namely existing rationing practices and irrigation technology related issues. The unconventional form of the demand curve has an important impact on the effectiveness of volumetric water pricing to curtail demand. Where prevailing water prices are low, only considerable increases induce water savings behavior.

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 any quantitative economic analysis, 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 very rarely determined in the market. Consequently, the value of water needs to be derived from modeling exercises, starting from production functions and setting up the farmer's optimization problem. This 'indirect' analytical approach was pioneered by Yaron (1967) and has since been built upon by subsequent researchers. Building on the analytical approach followed by Dinar and Letey (1996) and Rosegrant et al. (2001), this paper develops a stylized mathematical model to describe farmer behavior in response to increasing water charges. The model combines elements from physical crop-water models, evidence from water management practice and economic theory.

The remainder of this paper is organized as follows: section 2 provides a literature review on the impacts of water pricing. Section 3 develops and explains the basic model structure and equations. Section 4 describes the model implementation for a single farm. The modeling results analyze the impact of existing water application methods and rationing practices. Finally, section 5 contains concluding remarks.

II. LITERATURE REVIEW

While there exists a large body of descriptive and normative literature on water pricing, analytical studies that numerically assess the impact on farmer behavior are relatively few. Furthermore, most studies deal with the Western US and OECD countries and studies on developing countries are rare. This chapter provides an overview of existing literature.

II.1 Farmers responses to increased water charges

Gardner (1983)² 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

¹ Note that this implies a non-convex functional form of the demand curve.

² Cited in Ray (2001)

evidence that farmers respond in all of these ways (Ray 2001). For example, Weinberg et al. (1993) shows that if water charges rise above a certain point, water intensive crops are no longer optimal and farmers switch to other crops.

Many of the studies focus on Gardner's last point, namely investments in more efficient water application techniques. It is a general perception that water use efficiency in agriculture is low and that water savings through improvements in efficiency can be significant (Molden et al. 2000). Irrigation efficiencies at farmer fields can be as low as 30%, implying that only 30% of the water is beneficially used by crops while 70% is 'wasted'³. Much of the water pricing literature focuses on the question if and how farmers can be induced to increase water use efficiencies in their fields. The debate centers at the effectiveness of volumetric pricing, as opposed to rationing, to curtail water demand.

Bernardo and Whittlesey (1989) use a mathematical programming model to show that farmers in Washington State substitute water with labor, by switching to a more water efficient mode of operation of their irrigation technology. Consequently, under restricted supply (rationing), water use can be reduced up to 35 percent for surface irrigation and 25 percent under center pivot schemes, without greatly affecting farmer income. Hoyt (1984) reaches similar conclusions in a modeling exercise on farmer response to increasing pumping cost as result of declining aquifer levels in Texas High Plains. His modeling results imply that if water supply is restricted by 20%, farmers profit will not be affected significantly. However, increased water extraction costs and crop prices have no significant impact on the efficiency of water use. He argues that due to the inelastic demand for irrigation water, reliance on price mechanisms to conserve water, have limited impact in the short run. Only if prices increase dramatically, capital investments in more efficient irrigation technology become viable- at considerable profit loss to farmers. Berbel and Limon (2000) estimate that farm income in Spain will decrease 40% before water demand decreases significantly. Ogg and Hollegon (1989), using econometric curve fitting techniques to assess farmers' response to increased pumping costs in the Western US, conclude that a water tax will result in relatively modest reductions in per hectare water use. Reductions in water use may require a large tax and painful adjustments as some farmers have to stop irrigating.

Dinar and Letey (1996) develop an analytical model to compare the effectiveness of water pricing to curtail water use in four regions in California. They conclude that price policies were found less effective in regions where water is relatively abundant and the price is relatively low. Water quantity reduction policies were found to be more effective than water price policies.

The impact of existing irrigation infrastructure is shown by a study from Spain. Varela-Ortega et al. (1998) compares the price elasticity of water demand in three regions in Spain. They concluded that in the 'old' irrigation schemes where water application techniques were relatively inefficient, the response to increasing water charges was much higher than in the modern systems with drip systems. The authors conclude that the technical endowment in an agriculture district has a major effect on its response to water pricing. The higher the technical proficiency, the less responsive the district is to the water pricing.

They further state that the adoption of irrigation technologies does not depend significantly on water price level, but on structural factors, agronomic conditions and financial constraints. Green and Sunding (1997) endorse the latter finding with empirical evidence from California. They conclude that technology choice may be driven by water price at some

³ Seckler (1996) and Molden (2001) explain that this water is not necessarily lost, but can be recaptured and beneficially reused by downstream users.

locations, but mostly it critically depends on land quality and crop type. Caswell and Zilberman (1986 and 1990) in their studies on California demonstrate that the probability of adopting drip irrigation technologies increases with higher water prices, although land quality and environmental considerations seem to play a more important role in technology choice. Burt et al. (2001) argue that adoption of drip irrigation not necessarily lead to 'water savings'. They emphasize the importance of distinguishing between water diverted, water transpired by plants and evaporated from bare soil. Evaporation from bare soil under drip is higher than under furrow irrigation.

Huffaker et al. (1998) point to the importance of the distinction between instream flows and consumptive use in water pricing impact assessment in the Western US. They refute the presumption that increased block price leads to agricultural water conservation. Higher prices encourage farmers to reduce demanded irrigation deliveries, but also lead to higher efficiency. Water price should be assessed based on consumptive use instead of water deliveries.

Using empirical evidence from Iran to assess the effectiveness of water pricing, Perry (2000) raises two main issues. First, he points to externalities in irrigation water use. Although field use efficiency is low, return flows from 'inefficient' users are being reused by downstream farmers, either by recapturing drainage flows or 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 is less than generally foreseen. The second point concerns the low farmer responsiveness at observed prices ranges. To be effective in curtailing demand, water prices need to be raised significantly, in the case of Iran by a factor of 10. Under the prevailing political circumstances such price rises are probably infeasible.

The limited farmer responsiveness at low water prices is supported in several other studies. Ray (2001), in her study on water pricing in India, uses an analytical model to show that in order to induce the water-conserving response under existing allocation practices, a six-fold price increase would be needed. She adds that under the prevailing political circumstances in India, this is very unlikely. A comparative study among OECD countries reveals that, despite the wide range of observed or modeled price elasticities in irrigation water demand, at low water prices they are consistently low (OECD 1999). The study states that only above a certain threshold price, demand becomes elastic. The US Bureau of Reclamation (1997) reports similar evidence. Briscoe (1996) claims that in the western United States water demand elasticity is low because the users' reaction to price changes depends on the original price and irrigation costs are held artificially low. Dinar and Letey (1996) observe that because (surface) water is a quantity-rationed input, small water price increases would not alter producer decisions and would not induce water conservation. Irrigation water demand curves in Spain exhibit a perfectly inelastic stretch at low prices and become elastic beyond a certain threshold (Varela-Ortega et al, 1998).

Bontemps et al. (2001) explore the impact of the farmers' response to risk on water demand. They conclude that the demand curve is not convex, but exhibit four distinct sections. At very small quantities, where the farmer considers water as an essential input to crop growth, the demand is inelastic.

II.2 Conclusions from literature

Four observations emerge from literature review.

First, most writers fail to distinguish between water applied to the field, and water actually consumed by the crop – referring to reductions in “demand” as equating to physical water savings.

Second, the response of water use to increased water charges is low within the observed price ranges. In other words, water demand is inelastic at prevailing (i.e. low) prices. Only dramatic price increases, by a factor of five or ten, will induce water savings, either by investments in irrigation application efficiency or a shift to less water intensive crops. This raises the question whether the use of pricing as demand management tool is politically feasible.

Third, the response on increased water charges depends on the existing irrigation infrastructure and technology. Where irrigation efficiency is low and on-farm improvements are relatively cheap, for example in gravity irrigation schemes, farmers react to pricing by substituting water for labor and capital. With increasing water charges, they start operating the water application technology more efficiently, switch to another crop and ultimately change to another technology. Where irrigation efficiency is already high and additional improvements come at a high cost, for example in drip irrigation systems, water demand is more inelastic.

Fourth, externalities, both positive and negative, play a dominant role in water demand management. Water is a flowing and difficult-to-control resource. Externalities, such as recycling of irrigation return flows, influence the effectiveness of pricing in curtailing demand. Because of these externalities, the aggregate water savings at basin level are smaller than at farm level (Molle 2001, Perry 2000). However, none of the studies has attempted to quantify this effect.

This paper addresses the second and third point. It develops a modeling framework that illustrates and explains the impact of existing infrastructure and price range on the effectiveness of water pricing to curtail demand. The first and the fourth point will be addressed in a subsequent paper.

III. A STYLIZED FARM LEVEL MODEL

The impact of water pricing is difficult, given the complexities of irrigated agriculture, to observe in practice or deduce directly from field data. It requires modeling. This paper models farmer’s response to increased water charges, using physical crop-water relationships, insights from irrigation engineering and economic theory. This section develops the model equations and describes how it compares with other models cited in literature. The model differs from previous economic models in that it explicitly incorporates irrigation efficiency as a function of capital and labor input.

III.1 Crop production function

Crop production functions in irrigated agriculture⁴ provide the relation between the amount of soil moisture available to the crop and crop yield. Crop production functions can be

⁴ Also called water production functions after Hexem (1978) but this is a misleading name since farmers produce crops, not water.

estimated using data from experimental farms and econometric curve fitting techniques. The most comprehensive study was done by Hexem and Heady (1978) who estimated crop production functions for 5 irrigated crops at 8 different locations in the US⁵. However, econometric based studies are very data intensive, expensive, and site specific.

A more promising general approach, pioneered by Yaron (1967), uses a physically based crop-water model to generate a consistent data set, relating crop yield to water and other inputs. The generated data set is then used to fit a crop production curve⁶. The advantages of this method include transferability to other sites, flexibility and limited data requirements.

The water requirements of a crop depend on physical factors, such as climate, soils and crop characteristics. In general, the more 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 Hexem (1978), Dinar and Letey (1996) and Rosegrant et al. (2001), this model adopts a quadratic production function of the form:

$$Yrel_c = b_0 + b_1 W_c + b_2 W_c^2 \quad (1a)$$

$$Y_c = Yrel_c \cdot Ypot_c \quad (1b)$$

$Yrel_c$ denotes the relative yield of the c^{th} crop, defined as the actual yield divided by the potential yield. The potential yield is the maximum obtainable yield if water is applied at the exact right time in the exact right quantities. W_c stands for the cumulative soil moisture availability for crop c , in meters per season⁷. $Ypot$ is the potential yield and Y_c is the actual crop yield in tons per hectare. The values of β_i , the regression coefficients, are determined by curve fitting techniques. The crop production function depends on crop characteristics, soil and climate and is unique for each crop at each location. In this functional form, all inputs except water, are kept constant at an optimum level.

III.2 Irrigation efficiency function

The variable W in the crop production function reflects the seasonal soil moisture that is available for crop evapotranspiration. To make this water available to the crop, 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 that occur in conveyance and application. While numerous definitions exist, in this context irrigation efficiency is defined as that part of the total diversions to a farm that is beneficially used by crops. Hence, an irrigation efficiency of 40% implies that 40% of the water applied to the farm is consumed by the crops, while 60% is 'lost'⁸.

⁵ Examples include Heady (1972), Hoyt (1982), Ayer (1983), Bernardo and Wittlesey (1989), Albersen et al. (2000)

⁶ Examples of this approach are given by Yaron (1980), Letey (1993), Dinar and Letey (1996), Rosenzweig et al. (1999) and Rosegrant et al (2001).

⁷ Following Dinar and Letey (1996 page 39-40), this model uses a seasonal model as opposed to a transient model, and hence it uses total quantities per season and does not address timing of water application. They conclude that the seasonal and transient models agree and did not affect their general conclusions. I assume this true for this model although I did not check this.

⁸ Seckler (1996) and Molden (2001) explain that -seen from a basin perspective- this statement is not true: water is not necessarily lost if it can be reused by downstream users

In most studies irrigation efficiency is an exogenously determined and static parameter. Bernardo and Wittlesey (1980) and Varela-Ortega (1998) include irrigation efficiency as a parameter that is given for each locality but is independent of water pricing scenarios. Hoyt (1984) uses a vector of irrigation technology inputs related to efficiency. Dinar and Letey (1996) use the parameter ‘Uniformity Coefficient’ (*CUC*) in the crop production function as proxy for irrigation efficiency. Per irrigation technology they assign a fixed value. In an extension of their basic model the uniformity coefficient is entered as function of investment in irrigation technology. Because they introduce the variable *CUC* in the crop production function, they relate efficiency to crop growth rather than the amount of water applied.

Empirical evidence shows that irrigation efficiency plays a major role in the impacts of water pricing. This model introduces irrigation efficiency explicitly as a function of capital and labor inputs. For simplicity, this paper assumes that rainfall is negligible and all water originates from irrigation. The definition of irrigation efficiency thus becomes:

$$Efficiency = \frac{W}{TotWat}$$

W is the seasonal soil moisture availability and *TotWat* denotes the total amount of water applied to the farm.

At farm level irrigation efficiency primarily depends on the irrigation application technology – gravity, sprinkler or drip - and additional input for its operation and maintenance. Each technology comes with a minimum level of efficiency that can be improved, up to a certain maximum level, by additional on-farm labor inputs. For example, the efficiency of surface irrigation, a capital extensive technology, varies somewhere between 30% and 80%. The efficiency of drip irrigation, the most capital-intensive technology, ranges somewhere between 75% and 90%. Within the category of gravity irrigation technology, the most labor extensive form is to simply flood the field, resulting in high water losses. The application can be made more efficient by constructing field bunds at the expense of extra labor. Even more efficient, but more labor intensive, is to construct furrows. The relationship between efficiency and per hectare labor input in field application is given by equation (2) and depicted in figure 1.

$$Eff_i = Min_i + (Max_i - Min_i).(1 - EXP(-k_i.L)) \quad (2)$$

where Eff_i denotes the farm level irrigation efficiency of technology *i*, measured in percentages; Min_i and Max_i represent the minimum and maximum efficiency inherent of technique *i*, in percent. *L* is the labor input in technology operation, measured in labor days per season. The coefficient k_i reflects the relative contribution of *L* to the improvement of the efficiency. The subscript *i* represents the irrigation technology, i.e. gravity, sprinkler or drip.

The functional form of the irrigation efficiency function is chosen to accommodate the following practical observations:

- Additional labor input has a diminishing return (hence, the exponential form).
- The marginal efficiency improvement per labor input is greater for drip than for surface irrigation, since one unit of labor in a drip system has more capital to work with. This translates in a steeper curve for drip than for surface.

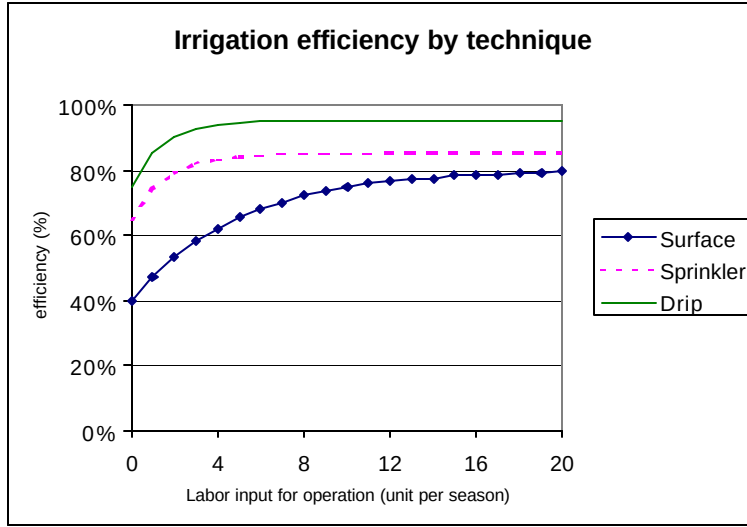


Figure 1 Irrigation efficiency functions by technique

III.3 Total water diversion

The total amount of soil water available to all crops amounts to:

$$W_{tot} = \sum_c W_c \quad (3)$$

Consequently, the amount of water that a farmer needs to divert to his farm, using application technique i , totals:

$$TotWat_i = \frac{W_{tot}}{Eff_i} \quad (4)$$

where Eff_i is the irrigation efficiency of technique i , given by equation (2).

III.4 Farmer's optimization problem

The basic assumptions in this model are that the farmer maximizes profit; he is a price taker who cannot influence prices by his individual decisions. The farmer has access to full information⁹ and there is no uncertainty or risk due to climate or fluctuating prices. Finally, there are no limitations to available labor and capital.

The farmer's decisions, that have bearing on water demand, relate to cropping pattern, water application level, choice of irrigation technology and level of labor input in its operation. In other words, the farmer maximizes profit by choosing the appropriate value of A_c , W_c , i and L . The maximization problem is formulated by:

$$Max p = \sum_c A_c Y_c P_c - WatTot_i P_w - L P_L - FIX_i \quad (5)$$

⁹ Refer to Tsur (2000) for examples on how to incorporate asymmetric price information

where π is profit in US\$; P_c is the crop price in ton per hectares; P_w is the price of water in US\$ per meter of water applied to one hectare¹⁰; P_L is the price of labor in US\$ per day and FIX_i is fixed capital cost of application technique (annualized) in US\$ per year.

Apart from the definitions given by equations 1, 2, 3, and 4, the farmer's maximization problem is constrained by the farm size:

$$\sum_c A_c \leq A_{tot} \quad (6)$$

where A_c is the area cultivated with crop c and A_{tot} is the total area available to farmer per season, both measured in hectares.

The farmer's optimization problem involves a joint discrete-continuous choice. For analytic simplicity, the decision analysis is conducted in two stages: First, optimal water use is determined for each distinct technique, and second, profits are compared across techniques. The technique with the highest profit is selected (Dinar and Letey, 1996). If none of the techniques is profitable, the farmer does not operate at all.

IV. AN ILLUSTRATIVE MODEL IMPLEMENTATION

This chapter provides some numerical results from the basic model, which explain the impact of irrigation technology and existing rationing practices on the form of the demand curve. For analytical simplicity, in base scenario there is only one farmer who can choose between two crops (cotton and alfalfa) and three irrigation techniques (gravity, sprinkler and drip). Two different scenarios are tested. In the first scenario the farmer has unlimited access to water. In the second, water available to the farmer is subject to an exogenously defined maximum allocation.

The model is capable of simulating the responses to increased water charges as mentioned in the literature review: improve irrigation efficiency, switch to less water intensive crops, apply less water to the crops and/or leave part of the farm area fallow. If the price rises above a certain level the farmer stops making profit and goes out of business.

IV.1 Data and parameters

In the basic model, the number of crops is limited to two. Alfalfa represents a water intensive and low value crop. Cotton stands for a high value, low water demanding crop. For this illustrative application of the model, data on crop production functions and prices are adapted from a published study of the Imperial Valley Irrigation scheme in California (Dinar and Letey 1996). Since data on irrigation efficiency functions are not available, own estimates are used. Tables 1, 2 and 3 provide details.

IV.2 Numerical results from the base scenario

In the base scenario the farmer has access to unlimited water supply. Solving the farmer's maximization problem for various values of P_w results in the water demand curve depicted in figure 2.

¹⁰ A price of 100 US\$ dollar per hectare-meter correspond with 0.01 US\$/m³.

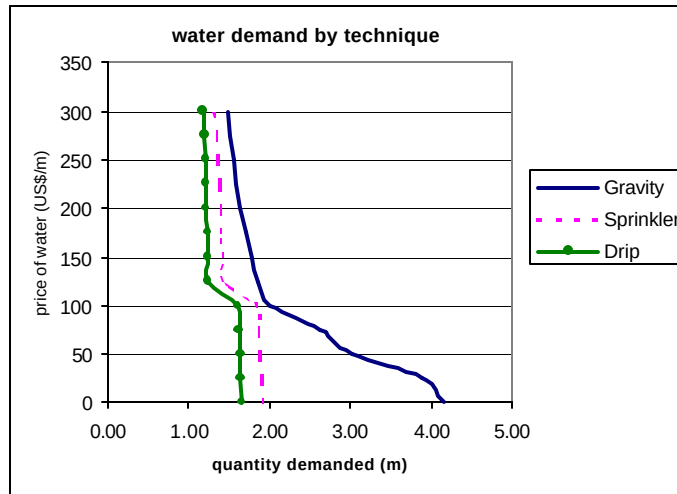


Figure 2 Water demand curves by water application technique

The water demand curve derived from this model shows that, even if the price of water is zero, the farmer diverts a defined amount of water. This observation violates the monotonicity assumption in economics¹¹, but is in accordance with practical experience. Even in places where water is virtually free of cost, farmers limit their water application, because too much water will damage their crops. This can also be deduced from the quadratic production function.

The results further illustrate the critical role of irrigation efficiency in the effectiveness of water pricing. It supports the hypothesis that the effectiveness of water pricing as demand management tool critically depends on the water application technique and level of operation already in place. Where irrigation efficiency is low and on-farm improvements are relatively cheap, for example in gravity systems with flood irrigation, pricing may lead to substituting water for labor and capital i.e. operate the water application technology more efficiently, switch to another crop and/or change to another technology¹². The farmer can cut down on water diversions substantially, without excessive profit loss. In drip irrigation schemes, where irrigation efficiency is high and additional improvements come at a high cost, water pricing primarily leads to profit loss to farmers, while water reduction is very limited.

IV.3 Low elasticity at low prices: a non-convex demand curve

This section explains the non-convexities in the demand curve at low prices. For irrigation policy impact assessment, the lower price end of the demand curve is critical, because in general observed water charges are low.

The model numerically shows the importance of the irrigation efficiency function. In this application for illustrative purposes two different farmers are compared. For both farmers, the

¹¹ This assumption tells that demand curves should be monotonically decreasing. In other words, as the price of water approaches zero, the quantity demanded goes to infinity.

¹² Obviously, technology and crop choice are highly simplified in this model, since its main objective is to show the importance of irrigation efficiency per se. For technology choice refer Caswell and Zilberman (1985 and 1986) and Green and Sunding (1997).

water price in the benchmark is close to zero and all conditions, except irrigation technology, are equal. Farmer 1 uses an irrigation technology with a minimum efficiency of 25%. As the water price rises, she will employ *additional* labor to improve on efficiency (i.e. she substitutes water for labor)¹³. Farmer 2 operates his irrigation technology at an efficiency level of 50% at price zero, and improves efficiency as water charges increase (figure 3). As figure 4 shows, the higher the irrigation efficiency in the benchmark, the larger the inelastic section at the bottom of the demand curve. Hence, the initial irrigation efficiency can explain the low elasticity at low prices.

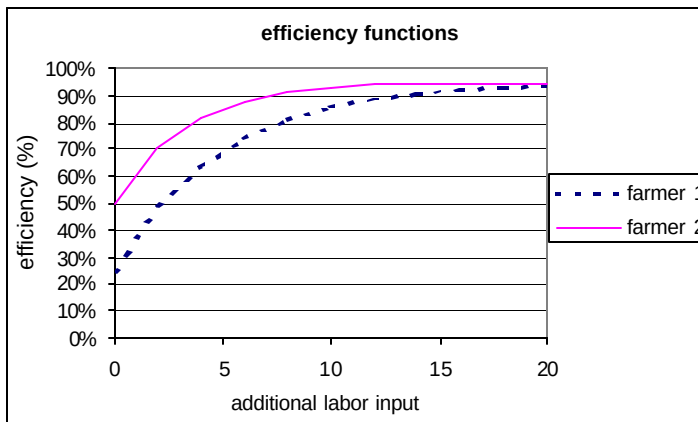


Figure 3 Efficiency functions

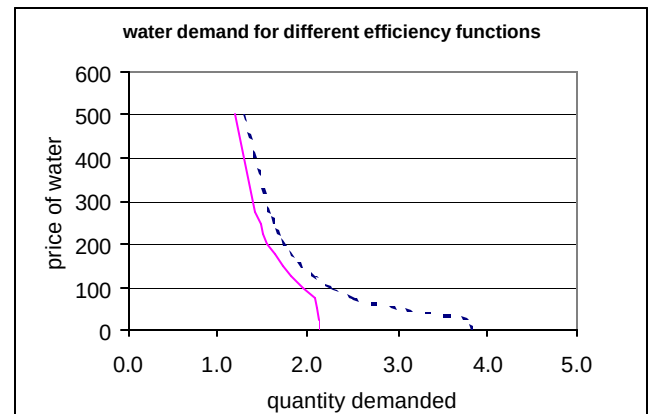


Figure 4 Resulting demand curves

The question remains, why would farmer 2 choose to operate at a higher efficiency than farmer 1, even though the water price is zero? There are several, non-price related, reasons. For example, for reasons of erosion control and better fertilizer application, he may opt for furrow irrigation instead of flood irrigation. Favorable subsidy schemes for advanced irrigation techniques may induce him to switch to drip irrigation, because drip gives higher per hectare and minimizes salinity problems. Further, the capacity of the existing infrastructure (canal dimension, pump capacity) may limit the maximum amount of water he can apply to his field (this is, *de facto*, a form of rationing).

The results in table 4 indicate that the *initial* irrigation efficiency is an important factor determining the impact of water pricing. Where efficiency, for agronomic and technical reasons, is already high, increased water charges initially leads to income loss to farmers. Water demand gets responsive only beyond a certain threshold price.

IV.4 The impact of existing rationing practices

In many parts of the world, irrigation managers allocate water to individual farmers, or farmer groups. Farmers' access to water is bounded by a maximum, which is below the 'free market' amount. A good example of this allocation mechanism is Warabandi. Warabandi is practiced at the large-scale (over millions of hectares) irrigation schemes in India and Pakistan. The system is designed to provide a rationed and equitable service (in proportion to landholding) 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

¹³ Note that the X-axis in figure 4 depicts the additional labor input, as result of rising water charges. In the benchmark the additional labor input is zero.

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 under-irrigating a still larger area.. This approach encourages maximum output per unit of water, rather than maximum output per unit of land (Perry 1999).

To accommodate rationing in the model, an additional constraint is added to the optimization problem:

$$TotWat_i \leq W_{allocated} \quad (7)$$

This application shows the impact of rationing practices, *that are already in place*, on the effectiveness of pricing to curtail demand. The maximum allotment to the farmer ($W_{allocated}$) is fixed at 2.0 meters. For simplicity, the crop choice is set at cotton and the technology is fixed at gravity. Solving the farmer's maximization problem for various value of P_w results in the water demand curve depicted in figure 5.

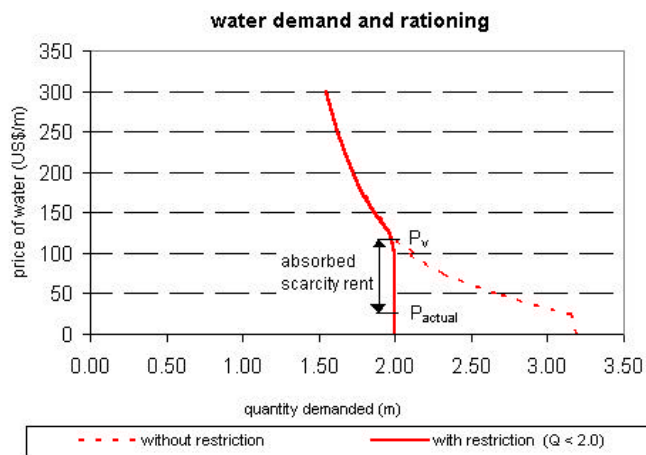


Figure 5 Water demand curve under restricted water supply

The dotted line in figure 5 reflects the hypothetical demand curve without rationing. The solid line depicts the actual demand curve when the farmer is entitled to a maximum allocation of 2.0 m. Say, the actual price is 0.001 US\$/m³ (point P_{actual}). The figure shows that because of existing rationing practices, the productive value of the last unit of water (P_{value}) is much higher than the price actually paid (P_{actual}). The gap signifies the absorbed scarcity rent.

Below the threshold (P_{value}) demand is perfectly inelastic. 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 substantially¹⁴. 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 P_{actual} and P_{value} is bridged.

These observations imply that where irrigation water is rationed, water pricing is effective as demand management tool, *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. Ray (2001) reports a required price hike of 6 times for India; Perry (2000) estimates a 10-fold increase for Iran. This raises doubts concerning the political feasibility.

¹⁴ Society benefits depending on how water revenues are invested

Figure 6 compares farmer profit under pricing and rationing. To achieve a reduction in water diversions to the level of 2.0 meters per hectare by pricing, the price needs to be set at 125 US\$/m-ha, resulting in a farmer profit loss of 29%, compared to the zero price case. Rationing the water at 2.0 meters per hectare result in a profit loss of 6% compared to the unlimited supply scenario

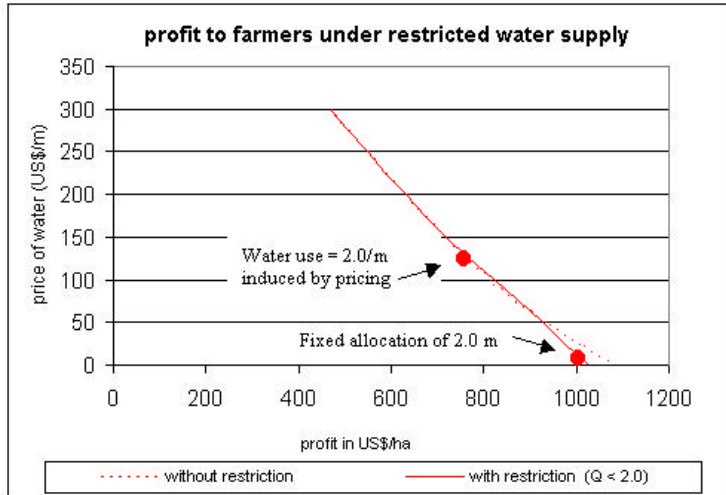


Figure 6 Profit to farmers under rationing and pricing

To induce water savings by volumetric pricing, comparable to those under rationing, the price of water needs to be set at a sufficiently high level. This will result in substantial fall in profit to farmers – 25% in the example above. This conclusion is consistent with that of Perry (1997): on the basis of quite different techniques than those applied here, he estimated that inducing a reduction in water demand in Egypt through volumetric pricing would decrease farm incomes by 25%. In countries where farmers make up large part of the voting population, pricing may not be a feasible demand management option from a political point of view.

V. CONCLUDING REMARKS

In the literature, several studies mention that water demand is inelastic at low price ranges and becomes elastic beyond a certain threshold price. This implies that, where prevailing prices are low, only substantive increases -in the order of 5 or 10 times- can induce water saving behavior. Some researchers attribute this unconventional (i.e. non-convex) form of the demand curve to physical characteristics of water.

This analysis offers two alternative explanations. First, institutional interventions, such as rationing, truncate the demand curve. Because of existing rationing practices, there exists a gap between actual price and productive value. Water demand becomes elastic only above a certain threshold (i.e. where price equals the productive value). The second explanation lies in the nature irrigation application technology and the associated efficiency function. Each technology has an inherent minimum efficiency, greater than zero. For technology related and agronomic reasons, a farmer may choose to operate at an efficiency level well above the minimum, even under a zero price scenario. The lower bound of the efficiency function explains the ‘kink’ in the demand curve and the ‘threshold’ price at which water demand becomes elastic.

The second explanation hinges on two assumptions: First, the production function reaches a maximum beyond which the marginal product of water becomes negative or zero. Secondly, the irrigation efficiency function exhibit a clear under-bound greater than zero. Both assumptions are backed with practical experience: plant yields suffer from too much water, and a zero percent efficiency is never observed¹⁵.

This analysis further shows that severe impacts on farm income are implicit in using water pricing as a means to limit demand, as compared to the rationing solution. Economists may argue that pricing is a just measure, because under rationing farmers benefit from the scarcity value of water at the expense of the society as a whole. Sampath (1983 and 1992) questions the validity of this statement, if the indirect irrigation benefits to society in terms of food security, outweigh direct benefits to farmers. A quantitative analysis to shed light on this debate would be extremely helpful in the water pricing debate.

Technology and its operation determine to large extent agricultural water use efficiency (apart from physical factors such as soils and climate). Irrigation efficiency plays a major role in the impact of water pricing. Yet, very few reliable field measurements on irrigation efficiency are available, since efficiency is very difficult to measure. Analyses, both hydrological and economic, rely on rather crude estimates of water use efficiency, based on water balance studies. Typically, irrigation efficiency is incorporated as a static parameter, based on general perceptions on technology performance, but independent from on-farm investment in its operation. Much of the controversy concerning the effectiveness of water pricing in curtailing demand, may relate to the perceived on-farm water use efficiency and the ease to improve it.

Water use efficiency is a scale dependent concept due to the recycling of return flows by downstream users (Molden et al. 2001). A proper analysis of the impacts of water charges requires consideration beyond the individual farm level. Hydrological interactions between farms through the reuse of return flows, have an important bearing on the impact of water pricing at the aggregate level of river basins. Most papers on water pricing fail to distinguish between water diverted and water consumed by crops, equating reduction in demand to physical water savings. Where reuse of return flows make up for a substantive part of downstream water supply, this failure leads to 'dry' water savings (Seckler 1996) as opposed to real 'wet' savings. Further, risk plays an important role in farmer decisions. These important issues are not addressed in this paper but need to be incorporated in the analysis at a later stage.

Despite these limitations, the results have important implications for future modeling efforts: first, water demand elasticity is not constant but depends on price range. Secondly, functional forms that are commonly used in economic analysis (Cobb Douglas, CES) may not adequately reflect water demand in agriculture.

¹⁵ Several functional forms (linear, cubic and exponential) were tried for the production and efficiency function. As long as the above mentioned assumptions were met, the demand curve exhibits a inelastic section at low prices.

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Table 1 crop production parameters

Crop production function: $Y = b_0 + b_1.W + b_2.W^2$		
	Alfalfa	Cotton
b0	0.03	-0.132
b1	1.5	2.3
b2	-0.6	-1.2
Ypot*	25.2	1.7

For Imperial Valley California, adapted from Dinar and Letey (1996) (p.31)

* Ypot = potential yield in ton/ha

Table 2 Irrigation efficiency parameters

Irrigation efficiency function: $Eff = Min + (Max - Min) \cdot (1 - \exp(-\gamma \cdot L))$			
	Gravity	Sprinkler	Drip
Min	30%	65%	75%
Max	80%	85%	95%
γ	0.4	0.6	0.7

No data available, from own estimates

Table 3 Prices

	Price	Unit
P _{Alfalfa}	110	US\$/ton
P _{Cotton}	1600	US\$/ton
P _{Labor}	60	US\$/day
FIX _{gravity}	50	US\$/year/ha
FIX _{sprinkler}	200	US\$/year/ha
FIX _{drip}	300	US\$/year/ha
Fixed farm costs	1500	US\$/year/ha

Crop prices adapted from Dinar and Letey (1996) pp. 151-155

Table 4 Comparison of the impact of pricing between farmer 1 and 2

Water price (dollar cent/m ³)	change in price	Farmer 1		Farmer 2	
		reduction diversions	reduction profit	reduction diversions	reduction profit
0.0					
0.25		2%	9%	1%	5%
0.50	100%	23%	16%	2%	10%
0.75	200%	34%	23%	3%	15%
1.00	300%	41%	28%	8%	20%