Measuring the Marginal Value of Water and Elasticity of Demand for Water in Agriculture

Data from a survey of groundwater sales between farmers in the upper Papagni watershed in Andhra Pradesh and Karnataka suggests that raising the marginal price of electricity to somewhere near its true cost could substantially mitigate the problem of over-extraction of groundwater. This is a pilot study from a small area, so that results call for larger surveys to more reliably estimate water demand curves. Larger surveys would also enable us to examine additional issues like how efficient is water allocation in surface irrigation systems; do marginal water values vary much more between river basins than within river basins; if not, then the rationale for inter-basin transfers becomes less compelling.

E SOMANATHAN, R RAVINDRANATH

I
Introduction

Why do water prices and demand elasticities matter? There are several reasons. First, there is some controversy over the efficiency of allocation of water in canal irrigation systems. While there is a large literature [Chambers 1989; Wade 1988; Shah 1993; Vaidyanathan 1999 are prominent examples] suggesting that allocation is inefficient and agricultural productivity could be improved through better distribution in the existing canal systems, this claim has never been quantified. Without such quantification, it is impossible to know how much of a gain agriculture could expect from improved water distribution. In the absence of knowledge of marginal water values (and demand elasticities), however, we cannot tell how much scope there is to improve productivity through reallocation.

A second, related, reason is the consideration of new investments in water distribution, such as the Indian river-linking project. Without knowledge of marginal water values in different basins, we cannot get a good estimate of the benefits of inter-basin transfers. It is possible that marginal water values vary a lot within basins so that improvements in the intra-basin distribution may yield considerable increases in agricultural productivity at a (presumably) lower cost than the transfer of water between basins.

A third reason relates to the overextraction of groundwater that is perceived to be a serious problem in several regions. The extent to which this could be mitigated by moving to a system of pricing electricity at the margin rather than by pump-capacity depends on how responsive water demand will be to the resulting increase in the cost of water.

While there is now a large literature on water prices in India obtained from data on groundwater transactions between farmers (surveyed by [Mukherji 2004]), to the best of our knowledge, this is the first study in India to attempt to measure the prices per cubic metre of water. The literature largely reports prices in terms of farmers' measures which are either in terms of rupees per hour of water pumped, or in terms of rupees per acre of land irrigated in a cropping season. It has focused on the price-cost margin in order to throw light on the extent to which the water market is non-competitive.

For determining how much of a potential gain exists from improving water allocation, however, we need water values that are comparable, and therefore, must be in the same units, that is, water volumes. The difficulty in doing this is that farmers themselves usually have no reason to measure such volumes.

We conducted a survey carried out by the Foundation for Ecological Security's staff in the upper Papagni watershed in the Kolar district of Karnataka and the adjoining Chittoor and Ananthpur districts of Andhra Pradesh. The pump owners in this area sometimes supply water to other farmers' fields in return for a share of the profit from the watered crop. Our estimates of water volumes delivered to crops are based on farmers' responses to questions on the frequency of watering, the depth of watering and the area watered. Because these are rough estimates and because of variable seepage, the actual volumes of water delivered may be measured with considerable error. Therefore, prices, measured as the seller's profit share divided by the volume of water delivered, may also contain considerable measurement error.

We address this issue by using the seller's water use during the buyer's growing season as an instrument for the water price. Since the seller's water use does not appear in the calculation of the water price, errors in measuring it will not be reflected in measurement errors in the water price. Using this instrument we obtain a point estimate of the own-price elasticity of water demand (conditional on soil type and taluk), of -1.03 with a p value of 0.082. This elasticity of -1 means that a doubling of the price of water would lead to a halving of the quantity demanded.

II
The Survey

The survey was carried out in October to December 2004 and the data pertain mostly to crops grown in the year preceding the survey although some data on the two preceding years were also obtained. The survey was carried out in the upper Papagni catchment in the talukas of Srinivaspur, Siddlaghatta and Bagepalli in Kolar district in Karnataka and in the mandals of Peddamandyam and Thamballapalle in Chittoor district and N P Kunta in Ananthpur district of Andhra Pradesh. The Papagni is a tributary of the Pennar and now has flowing water for only a few days in the year. Farmers say that it used to have water in it for eight months of the year. The reduction in dry season flows is probably due to a combination of deforestation, reducing percolation and groundwater withdrawal reducing stream recharge. The region is quite dry with an annual rainfall of 500 mm to 800 mm. While tank irrigation is common, tanks are now used mainly as percolation ponds to recharge borewells. Groundnut, maize, jowar and ragi are rain-fed crops while the irrigated crops include paddy, sugar cane, tomato, other vegetables, flowers, and mulberry.

The survey was conducted in six talukas/mandals in the basin in which the Foundation for Ecological Security has a presence. In each taluka/mandal, five hamlets were randomly chosen from among those in which the Foundation was already engaged in watershed development, tree planting and other activities. In each hamlet, a complete list of wells was made. All suppliers of water to other farmers were surveyed and so were all the recipients of water. In each hamlet, additional farmers who owned wells were surveyed so as to take the total number of pump owners surveyed in each hamlet up to five, where this was possible.

It turned out that there were no water sales on the Andhra Pradesh side of the border, so our demand estimates are based only on the data from Karnataka. It is not clear why there were no water sales on the Andhra side of the border. The joint ownership of pumps makes it less likely that there will be any surplus water that can be sold. In Karnataka, 21 per cent of pumps in the surveyed hamlets had more than one owner, while in Andhra 32 per cent had. Although the joint ownership of pumps is more frequent in Andhra, since more than two-thirds of the wells have single owners, this fact alone is not sufficient to explain why there were no water sales in Andhra.

III
Value of Water

Table 1 presents summary statistics on the data used in the computation of water prices and estimation of the demand curve.

The quantity supplied to the buyer is computed as the product of the area watered, the number of weeks of watering, the depth of watering and the weekly frequency of watering. The price is computed as rupees paid to the seller divided by the quantity of water supplied. Sellers get one quarter, one-third, or one-half of profits from the buyer's crop.

We see from Table 1 that the mean price observed is Re 0.58 per cubic metre of water supplied. The variance is quite high with realised prices ranging from 0 to Rs 1.78 per cubic metre. We note that since profits are uncertain, and on occasion are zero or negative, the seller may receive a zero price for water. The table does not show zero prices (only one was observed) since we used only positive prices in estimating the elasticity, the log of a zero price not being defined.[1] The uncertainty in realised profits means that realised prices can be expected to be quite variable, even if there were no measurement error in volumes.

We used a second method to estimate the average value of water that uses the difference in prices between irrigated and unirrigated land. We asked the villagers in the surveyed hamlets in the study area the prices for irrigated and unirrigated land for each soil type in their village. Using these data, we regressed the price of land on dummy variables for irrigation and soil type and thus estimated the mean value of irrigation to be Rs 65,424 per hectare. Dividing this by the average interest rate from the survey of 18 per cent, we obtain the annual value added per hectare by irrigation to be Rs 11,776. Dividing this by the mean annual water use on irrigated land, we obtain the average value of water to be Re 0.31 per cubic metre. This is about three-fourths of a standard deviation less than the mean price of water obtained directly from the water sale data (Table 1).

Risk aversion on the part of buyers of land would lead to land prices underestimating the average annual return from land. Furthermore, past water supplies to the irrigated lands are likely to be overestimated future water supplies in a context in which aquifers are being depleted. Thus this method is likely to underestimate the average value of water. Thus, the fact that it is somewhat smaller than the mean marginal value as estimated from the water sale data is to be expected.

By way of comparison, Chowdhury (not dated) reports marginal water values of Re 0.09 to 0.68 per cubic metre for different regions in Bangladesh and cites a study in northwestern India giving a value of Re 0.90 per cubic metre. Shaw (2005) reports marginal water values in agriculture in the US from various studies ranging from Re 0.29 to Rs to 4.27 per cubic metre with most prices being less than Re 1 per cubic metre. All these estimates are based on estimating crop production functions, not from water trades. We are not aware of any other price estimates in India.

IV
Estimating a Demand Curve for Water

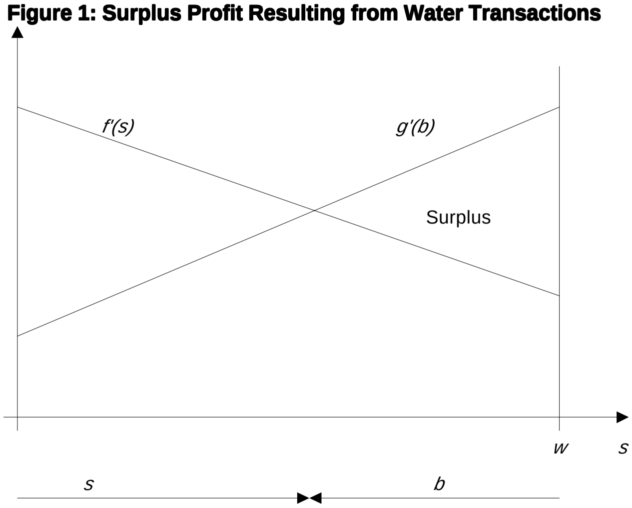
In our sample, nine out of 21 sellers sell to only one buyer, while others sell to two, three or four buyers. We first discuss the case of bilateral bargaining between a seller and a single buyer, and then deal with the case of multiple buyers by analogy. Suppose the total water available is *w* of which the seller uses *s* and the buyer uses *b* cubic metres. Conversations with pump-owning farmers during the survey indicated that they pumped all the water possible, being limited either by the quantity of water or the electricity supply. They usually store it in collection ponds. Thus $s + b = w$.

Suppose profits of the seller and buyer, as functions of water use are respectively, $f(s)$ and $g(b)$. Thus their fallback profits, (the profits they would get if there were no water transfer from seller to buyer), are $f(w)$ and $g(0)$, for the seller and buyer, respectively. Thus the surplus profit resulting from the transaction is $f(s) + g(b) - [f(w) + g(0)]$ (the triangular area denoted "Surplus" in the Figure). Applying the Nash bargaining solution, we suppose that the amount paid to the seller is such that it results in their splitting this surplus equally. By using the Nash solution, we assume that efficient water use is achieved so that the seller's and buyer's marginal valuations for water are equalised: $f'(s) = g'(b)$. We have no guarantee that the price per cubic metre of water equals this common marginal valuation. But we do know that

Table 1: Summary Statistics

Variable	Description	Obs	Mean	Std Dev	Min	Max
P	Price (Rs/m^3)	43	0.58	0.38	.06	1.78
Q	Quantity (m^3)	43	4400	3511	617	17282
Q_tot	Total quantity (m^3)	43	16000	12920	1851	46908
Land quality	1=poor, 3=good	43	2.35	0.72	1	3
Soil type (omitted category)	Nallaregadi					
Soil type 2 dummy	Yerra	43	0.40	0.49	0	1
Soil type 4 dummy	Yerragurja	43	0.12	0.32	0	1
Soil type 5 dummy	Tellaburja	43	0.23	0.43	0	1
Soil type 6 dummy	Chouda	43	0.02	0.15	0	1
Soil type 7 dummy	Other	43	0.02	0.15	0	1
b_hectares	Buyer's crop area	43	0.25	0.11	0.07	0.41
Growing weeks	Buyer growing time	43	16.9	10.1	8	64

Figure 1: Surplus Profit Resulting from Water Transactions



this price must lie between the seller's average marginal value in the range from *s* to *w* (because this is what the seller forgoes per cubic metre in transferring water to the buyer), and the buyer's average marginal value in the range from 0 to *b*, (because this is what the buyer gains from the water transfer). Since the marginal valuations must be decreasing, otherwise there would not be a gain from a water transfer; we know that the marginal value of water for the buyer, which is the quantity of interest, must also be within this range. Thus the Nash bargaining price per cubic metre may not be exactly equal to the marginal value of water but it must be within some band around it. It is also easily seen that changes in the total supply of water *w* will shift both the Nash bargaining price and the buyer's marginal value in the same direction.

When there is more than one buyer, we may expect the price per cubic metre that the seller receives to be higher since his bargaining position vis-à-vis any one buyer is stronger because his fallback position is no longer to use all the water himself but to sell it to the other buyer. However, it will still be true that the price per cubic metre must lie within the same limits as must the buyers' common marginal valuation and that these limits and the common marginal valuation will move in the same direction with changes in the total supply of water.

With this understanding that the observed prices are not necessarily strictly equal to the buyers' marginal valuations, but are within some band around them, we now proceed to estimate the "demand curve". To do this, we use the fact that the total amount of water used by both buyer and seller is limited by availability and not by demand. Thus we may assume that it is exogenous to the price with the price being determined as a function of the total supply. Hence, we use two-stage least squares to estimate the log of quantity used by the buyer as a linear function of the log of the price with the log of total water supply as an instrument for the price. We use soil type, soil quality and taluk dummies as controls to capture demand-side factors.

The estimated price elasticity of demand is shown in the first column of Table 2. It is -0.80, and significant at the 1 per cent level. However, we note that the problem of measurement error leading to a spurious negative relation between quantity and price may be quite severe for this estimate. For several observations, the quantity used by the seller is zero, so that the total quantity used equals the quantity used by the buyer. Hence we drop those observations for which the quantity used by the seller is zero. The estimated elasticity of -1.08, reported in the second column of Table 2, is still significant at the 1 per cent level.

However, even this estimate may be contaminated by measurement error because of the buyer's water use being a component of the total water use. Therefore, we use the owner's water use as an instrument instead of using total water use. The estimated elasticity of -1.03, reported in the third column of Table 2, is significant at the 10 per cent level ($p = 0.082$). We note that the *p*-value from the first-stage regression is quite high at 0.18. This means that an estimate of elasticity may be biased, especially given the small sample size. This problem will not carry over to large sample surveys.

The second problem with using the owner's water use as an instrument, however, is that it is not exogenous, unlike the total water use. Increases in the buyer's demand for water will raise the marginal value of water, inducing the seller to use less. Thus the price variation used in this estimate comes partly from the demand side, causing the buyer's quantity to vary positively with the price. Therefore, this is likely to be an underestimate of the elasticity of demand. This problem is unrelated to sample size. Removing this bias will require the use of better instruments for the price. However, this problem may not be too great since we control for soil quality, which is likely to be a major determinant of the buyer's demand. Moreover, we can at least get a lower bound for the price-elasticity.

V
Impact of Per-Unit Pricing of Electricity

With this information in hand, we can make some rough calculations about the efficiency of energy use and the impact that per-unit pricing of electricity would have on groundwater use in the short run. The short run refers to the period in which only the existing wells and pumps continue to be used, so that their costs can be taken as sunk. As we will see below, the long-run impact of per-unit pricing of power is likely to be much greater.

Since the elasticity of demand for water is about -1, a doubling of the marginal cost of water would result in a halving of water use in the short run. However, this is only true when the marginal cost is high enough as to equal or exceed the current marginal value of water.

When the cost of electricity is *c* Rs/kWh, and the depth of water is *d* metres, then the cost of pumping water to the surface is $cd/360$ Rs/m^3. Table 3 shows that the average marginal costs of pumping from the sample wells were 17, 34 and 51 paise per cubic metre at electricity prices of Re 1, Rs 2 and Rs 3/kWh respectively, and given average water depth of 62 metres.

Using the formula, we find that at Re 1/kWh, in about 15 per cent of the cases the cost of pumping water will exceed its price. At Rs 2/kWh, the cost of pumping exceeds the price of water in about 30 per cent of cases, and at Rs 3/kWh the cost of pumping exceeds the price of water in about 54 per cent of cases.

Table 2: Price Elasticity of Demand for Water

Instrument for Price	Log Water Quantity (2SLS)		
	Total Water Use	Total Water Use (Owner's Water Use +ve)	Owner's Water Use
p-value of instrument in first stage	0.003	0.048	0.182
Ln price	-0.80***	-1.08***	-1.03*
	(0.25)	(0.36)	(0.55)
N (number of sales)	56	40	40
Number of sellers	20	15	15
R^2	0.58	0.66	0.68

Notes: Robust standard errors in parentheses are clustered by the seller.
* and *** denote significance at the 10 and 1 per cent levels respectively.
Control variables not shown include land quality, soil type dummies and taluk dummies.

At Rs 3/kWh, the cost of pumping would be more than double the marginal value of water in about a quarter of the cases. Given a demand elasticity of about -1, this would mean that water use would decline by more than a half in a quarter of the cases and by less than a half in another quarter of the cases. Thus, it is clear that pricing electricity at or near its actual cost per kWh is likely to result in a substantial decline in pumping and water use, even in the short run, but this decline would probably be less than 50 per cent.

To examine the long-run impact of marginal-cost pricing of electricity, we need to take into account decisions to sink new wells and buy new pumps or to incur fixed costs of deepening existing wells. Farmers will make these investments only if the expected value of the annual flow of water from such an investment exceeds the annualised cost of the investment. Table 3 includes some descriptive statistics on costs using data from all sampled pump owners from both states.[2]

It is clear that the expected cost of pumping of Rs 1.64 per cubic metre is higher than the average price of Re 0.58/cu m from the sample of buyers. However, we note that the expected cost is much higher than the median cost (not reported in the table) of Re 0.65 per cubic metre. Furthermore, the price from the data on sales is likely to be close to the marginal value of water, while its average value is likely to be higher than its marginal value for each pump owner. Therefore, we cannot immediately conclude that on average, the investments in wells have been loss-making propositions.

We can directly compare average costs with prices for those pump owners who were also sellers. We find that of 20 water sellers, only eight of them (40 per cent) had average prices above the average cost. When we consider what their costs would have been if electricity cost Re 1/kWh, we find that only six of them would have had prices above the average cost. If electricity cost Rs 2 or Rs 3/kWh, then only four (20 per cent) of them would have had prices above the average cost. Therefore, while the sample is small, it suggests that investment in wells and pumps is already at best only marginally profitable, so that pricing electricity close to its real cost would result in a large decline in the groundwater extraction in this region in the long run.

A sceptic may question the relevance of this exercise since in the last few years all attempts at unit pricing of electricity for farmers have failed. It is beyond the scope of this paper to address the feasibility of changing the pricing scheme. Nevertheless it is worth pointing out that all attempts at instituting such pricing have so far been motivated by budgetary concerns, and as such, have sought to lower farmers' welfare. A reform motivated by efficiency considerations would provide the budgetary support to farmers through cash payments rather than electricity, thus inducing them to use it more efficiently while not making them worse off.

Table 3: Descriptive Statistics of Costs

Variable	Obs	Mean	Std Dev	Min	Max
Installation cost of well and pump (Rs)	130	79700	55100	14000	360000
Annual variable cost (Rs/year)	130	2500	3700	0	20000
Annual interest cost (Rs/year)	130	14000	10300	1776	61320
Annual depreciation (Rs/year)	130	7970	5500	1400	36000
Total annual cost (Rs/year)	130	24500	16300	4055	98820
Water used (cu m/year)	129	44000	40000	823	235367
Area irrigated (hectares)	129	1.32	0.92	0.10	4.86
Annual cost per cu m (Rs/cu m/yr)	119	1.64	3.05	0.025	21.87
Annual cost per irrigated hectare	119	29100	48750	1246	492060
Marginal cost (Rs/cu m) at Re 1/kWh	118	0.17	0.08	0.01	0.51
Marginal cost (Rs/cu m) at Rs 2/kWh	118	0.34	0.17	0.03	1.02
Marginal cost (Rs/cu m) at Rs 3/kWh	118	0.51	0.25	0.04	1.52
Water depth in well (m)	118	62	30	5	183

VI
Conclusions

We find an average price of Re 0.58 per cubic metre of water with a large standard deviation of 0.38. This is estimated directly from data on sales of water by pump-owning farmers to other farmers. We also used data on prices of irrigated and unirrigated land together with data on interest rates and water use per hectare of irrigated land to estimate the value of water by an alternative method. This gave an average value of water of Re 0.31 per cubic metre based on a price differential between unirrigated and irrigated land of about Rs 65,000, an interest rate of 18 per cent per annum, and an average water use of 38,000 cubic metres per year on irrigated land.

Our estimates of the elasticity of demand are about -1, though it is necessary to keep in mind that the standard deviations of the estimates are fairly large. Calculating water prices per unit volume allows us to estimate the effect that per-unit pricing of electricity is likely to have if it is instituted. We find that this is likely to result in a large decline in groundwater use. However, due to the small sample size, these results should be seen as indicative, not definitive.

This suggests that larger surveys to obtain better estimates are likely to attain interesting results. This study should be seen primarily as a pilot study that shows that it is, indeed, feasible to obtain comparable measures of water prices and water demand elasticities. Such comparable measures can be used to examine the efficiency of water allocation in irrigation systems within and across the river basins. They will be an important input for studies that seek to examine the gains from improved water allocation and management. EPW

Email: e.somanathan@gmail.com
ravi@fes.org.in

Notes

[We are grateful to the Foundation for Ecological Security, especially the teams in Chintamani and Madanapalle, for conducting the survey and bearing all related expenses. Somanathan is grateful to the Planning and Policy Research Unit of the Indian Statistical Institute for financial support for travel, software, and research assistance. We thank Sharmistha Sinha and Kim Lehrer for research assistance.]

1 Actually, in Table 1 we have used only the observations that were used in estimating the demand curve with our preferred specification. When all 61 observations are used, the average price goes up by about 10 paise per cubic metre and the variance increases to 61 paise per cubic metre.

2 The costs are comparable to those reported by Narendranath et al (2005).

References

Chambers, R (1989): *Managing Canal Irrigation*, Cambridge University Press, Cambridge.

Chowdhury, N T (not dated): *The Economic Value of Water in the Ganges-Brahmaputra-Meghna (GBM) River Basin*, Goteborg University, Sweden.

Mukherji, A (2004): 'Groundwater Markets in Ganga-Meghna-Brahmaputra Basin: Theory and Evidence', *Economic and Political Weekly*, July.

Narendranath, G, U Shankari and K R Reddy (2005): 'To Free or Not to Free Power: Understanding the Context of Free Power to Agriculture', *Economic and Political Weekly*, December.

Shah, T (1993): *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*, Oxford University Press, Bombay.

Shaw, W D (2005): *Water Resource Economics and Policy*, Edward Elgar, Cheltenham.

Vaidyanathan, A (1999): *Water Resources Management: Institutions and Irrigation Development*, Oxford University Press, New Delhi.

Wade, R (1988): *Village Republics: Economic Conditions for Collective Action in South India*, Cambrige University Press, Cambridge.