Vol XXXIII
No. 1

JANUARY-
MARCH
1978

ISSN 0019-5014

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

SCALE ECONOMIES IN TUBEWELL IRRIGATION*

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This study is motivated by the practical question: What would be the optimum size of a tubewell if the vast groundwater resources of the Indo-Gangetic plains are to be exploited for public irrigation? Whether developing groundwater irrigation under public aegis is a superior option compared to the option of private ownership of means of groundwater irrigation is indeed a controversial issue. Though this issue is beyond the scope of this paper, two points in this connection may be noted.

Firstly, an understanding of the scale economies internal to a tubewell and its potential external diseconomies on others is of no small consequence for the resolution of the controversial issue. That a tubewell can impose external diseconomies on other users of groundwater—and even on users of stream flows—is known.[1] Since the magnitude of external diseconomies of tubewell irrigation can vary positively with the size of a tubewell, one has to reckon with the trade-off between the (internal) scale economies and the external diseconomies of tubewell irrigation. Neglect of this trade-off while choosing the least cost tubewell size can give rise to results that may be far from the optimum from the larger, social viewpoint.

Secondly, the case of public instead of private tubewells is much stronger for the eastern Gangetic plains of East Uttar Pradesh, Bihar and West Bengal than for the western plains of Indus and the Ganges in Punjab, Haryana and West Uttar Pradesh. For, the structure of land holdings and objective factors influencing investment in a tubewell in these two regions are such that the bulk of the holdings in the eastern Gangetic plains, unlike in the western plains, cannot afford installation of private tubewells.[2] Thus, in the absence of public tubewells the vast groundwater resources of the eastern plains are likely to remain largely unutilized. In point of fact, Hanumantha Rao has forcefully pleaded that "public tubewells may continue to be the major source for the exploitation of groundwater potential in this region."[3]

Public tubewells can be deployed for irrigation in two alternative ways: (1) each tubewell with its own separate irrigation command area and (2) tubewells for augmenting water supplies in a government canal system. While public tubewells are predominantly used at present as 'command' tubewells, augmentation tubewells are being increasingly planned, both as a means

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* A preliminary and highly condensed version of this paper appeared in the *Eastern Economist*, October 15, 1976. The results of this revised paper are at variance with the earlier findings, both in terms of emphasis and detail.

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1. For an exposition of external diseconomies of tubewell irrigation, see Dhawan (4) and (5). (Figures in parentheses denote references cited at the end of the paper.)
2. See Dhawan (6).
3. See Hanumantha Rao (9). A similar plea is made by this author for East Uttar Pradesh in (7).

for enlarging water supplies in a canal system and as an anti-waterlogging measure in canal commands with poorly drained land.[4]

SCOPE OF THE STUDY

The study is limited to assessing purely internal scale economies for tubewells with independent command areas, though some implications of the study for the development of augmentation tubewells are also indicated. The size range of tubewells studied is from 0.014 to 0.168 cubic-metre discharge per second, *i.e.*, 0.5 to 6.0 cubic-feet per second ('cusec'). While the least size considered here is about one-third the size of most public tubewells in the country (especially Uttar Pradesh), the largest size considered is probably nowhere in operation at the moment in the entire Indo-Gangetic plains. While an analysis of tubewells of size above 6 cusec will be meaningful, the non-availability of data prevents us from extending the exercise to such tubewells.

The outline of the paper is as follows: The availability of data, which has considerable bearing on the methods to be adopted in an analysis of scale economies, is taken up first. It is then followed by an exposition on methodology used in this paper. Next, the salient technical characteristics of the set of tubewells analysed are briefly spelt out, followed by a discussion about the cost structure of a tubewell. Tubewell being a capital-intensive activity, the scale economies in respect of capital cost are analysed in detail, followed by a brief analysis of the scale economies in operating costs. The results about the overall scale economies in tubewell irrigation are presented, followed by some policy implications. To the extent one can envisage that the underlying assumptions with regard to the geological characteristics of this study (*e.g.*, the assumption that 50 per cent of the bore depth is water-bearing) are fulfilled in the Gangetic plains of Bihar and West Bengal, the results have relevance for the entire eastern Gangetic plains.

THE DATA

Assessment of scale economies is known to be beset with problems, of which the foremost is the data problem. To begin with, firms (here tubewells) of varying capacities may not exist. The common, or rather the standard size for public tubewells in Uttar Pradesh, has been till recently 1.5 cusec ever since the mid-thirties when public tubewell irrigation commenced in this pioneer State. Secondly, cost information about the few tubewells of capacity greater than 1.5 cusec is not readily available. Even if such data are gathered from the unpublished records of the State Governments, these can pose serious problems of separating pure scale effect from other sizeable effects attributable to inter-tubewell variations in respect to technological, historical (age and prices) and acquifer characteristics.

4. This anti-waterlogging function of public tubewells has not received due attention in the controversy about public versus private tubewells. While all tubewells do play an important conjunctive role in optimal utilization of surface and groundwaters, it is the lack of prospect for intensive utilization of seeped water from canal irrigation in poorly drained lands that demands the installation of tubewells on public account.

Thus pure scale economies are better revealed by hypothetical cost estimates of tubewells of various sizes, provided these are underpinned with experience and expertise. Such hypothetical estimates are available in a technical memorandum of the U.P. Irrigation Research Institute (UPIRI).[5] Notwithstanding the fact that actual installation costs of irrigation works are notoriously much different from the engineers' hypothetical estimates, the credentials of the UPIRI are high in the irrigation world.[6]

However, a few modifications on the UPIRI data have been made in this paper. Firstly, while accepting the UPIRI estimates of capital cost of tubewells, cost on account of electricity transmission segment that is often borne by the State Electricity Board instead of the Tubewell Irrigation Department, has been duly taken into account. This macro view of capital cost in tubewell irrigation is needed in order to unearth true scale economies in respect of the scarce capital resource of the Indian economy. Secondly, annual operational cost on account of electricity consumption in the running of a tubewell has been assessed both on the basis of unavoidable power tariff now in force in Uttar Pradesh and the avoidable power tariff that is in direct proportion to annual electricity consumption. Thirdly, the UPIRI estimate of annual operational cost of a tubewell is firmed up by taking due account of other operational costs, *e.g.*, salary of tubewell operator; expenditure on overhead tubewell organization; and expenditure on tubewell repair.

METHODOLOGY

Unit cost of tubewell irrigation is obtained by dividing annualized cost of a tubewell by its annual water output. While annualizing capital expenditure on a tubewell, one needs information about the useful life of a tubewell, which is placed at 20 years in the UPIRI report.[7] However, it is important to note that different components of a public tubewell have different life spans. Whereas the pumpset and the accessories have a life of about ten years, the well assembly and the pump house may last for 20 years. Likewise, the life of the water distribution system is generally reckoned at 50 years.[8] A similar life can be assumed for electric transmission segment. In this paper, the following rates are used to annualize:

(1) electric transmission/water distribution system ... 2 per cent,
(2) tubewell assembly and pump house ... 5 per cent,
(3) pumping set ... 10 per cent.

As regards annual output of water per tubewell, it is determined primarily by the crucial variable annual running hours (H), which, when multiplied

5. Chawla, *et al.* (2). But for this source, the present study would have been inconceivable.
6. Of course, the engineers' expertise and experience are some among the numerous factors creating this disagreement. The other noteworthy factors are: deliberate under-statement of project costs so as to get go-head sanctions for a project; alterations in project design; price inflation; leakages in funds and materials; and increase in gestation period due to uncertainty about the availability of funds.
7. Actual replacement age for reconstructing an old tubewell is found to be about 18 years in Uttar Pradesh.
8. *Source:* Jain (8).

by the observed hourly water discharge of a tubewell, yields the needed information about water output per tubewell. A variety of factors, some on the demand side and some on the supply side, determine the value of 'H'.[9] It is assumed that the determinants of 'H' are neutral to the size of the tubewell. Thus, in the event of electricity rationing by the electricity authority the adverse effect on runnings hours of a tubewell is in no way related to its size. Likewise, the crop pattern in the tubewell command area is envisaged to remain unaffected by the size of the tubewell.

Evidently, if all the annual costs of a tubewell are unavoidable, the analysis of scale economies is unaffected by the value chosen for 'H'. A proximate case of this type arises when one part, flat electricity tariff (in direct proportion to horse power of the tubewell motor) is in operation, as is the situation today in Uttar Pradesh. If one or more costs are avoidable, the value of 'H' chosen does impinge on the scale analysis. In this situation, unit cost of tubewell water is sensitive to the value of 'H'. In order to see how far our results are sensitive to the choice of 'H', it is proposed to carry out the analysis for different values of 'H'. There are 8,760 hours in a year, and the chosen values of 'H' are: 2,000, 3,000, 4,000, and 5,000 hours.

An attempt has been made to summarise individual sources of scale economies (or diseconomies) by fitting the following regression equation to the cost data:

$$C = a.x^b$$

where C is the cost of a tubewell item;

x is a measure of the tubewell size.

If 'b' is one, constant returns to scale exist. If 'b' is less than one, scale economies are in operation over the range of tubewell sizes considered. Likewise, 'b' greater than one is indicative of scale diseconomies. In terms of scale analysis, $(1-b)$ is a measure of scale economies/diseconomies: $(1-b)>0$ is a measure of scale economy; $(1-b)=0$ is a situation of no scale economy; and $(1-b)<0$ is a measure of scale diseconomy. However, this elegant approach to evaluating the nature and magnitude of scale economies is unsuitable in cases where scale economies exist upto a point, followed by either diseconomies or constancy of economies. Cubic functions, like $C = \alpha X + \beta X^2 + \gamma X^3$, would take care of a situation in which scale economies are followed by diseconomies, and their first derivative, when equated to zero, yields the point of inflexion where economies turn into diseconomies.[10] In case scale economies follow an L-shaped path—as has been found in some studies on industrial activities—, no elegant function for summarising such a behaviour of economies of scale exists. Here, a graphical view of the data about scale economies has to precede the stage of fitting the statistical functions to the data.

9. Demand factors influencing the running hours of public tubewells have been investigated in Dhawan (3).

10. Instead of a cubic function, a quadratic form can be employed to represent the theorists' U-shaped cost curve if unit instead of total cost is analysed.

TECHNICAL FEATURES OF TUBEWELLS

The salient technical information in respect of tubewells is summarised in Table I. As the size of the tubewell, measured in terms of water discharge capacity, increases from 0.014 m^3/second to 0.168 m^3/second, the bore depth of the tubewell rises steadily from about 67 metres to 149 metres, and the length of the slotted pipe—through which water in underground formations surrounding the pipe of the tubewell flows into the tubewell—increases from 18.6 metres to 59.5 metres. These estimates are underpinned, among other things, by the following noteworthy considerations:

TABLE I—SALIENT TECHNICAL FEATURES OF TUBEWELLS

Sr. No.	Discharge capacity (m3/second)	Bore depth (metres)	Bore diameter (cm.)	Length of slotted pipe (metres)	Pump-set capacity (HP)	Length of water courses (km.)		Number of delivery tanks	Average discharge per water route (m3/second)	Drawdown (metres)
						Lined	Unlined			
1. ..	.014	67	40	19	5.0	0.5	1.1	1	.014	2.8
2. ..	.028	83	45	26	10.0	1.1	2.1	1	.028	3.8
3. ..	.042	97	50	33	15.0	1.6	3.2	1	.042	4.6
4. ..	.056	107	55	39	20.0	2.1	4.3	1	.056	5.2
5. ..	.070	119	55	45	25.0	2.7	5.3	2	.035	5.7
6. ..	.084	119	60	45	32.5	3.2	6.4	2	.042	6.5
7. ..	.098	127	60	49	40.0	3.7	7.5	2	.049	6.9
8. ..	.112	132	65	51	45.0	4.3	8.5	2	.056	7.4
9. ..	.126	136	65	53	52.5	4.8	9.6	3	.042	8.0
10. ..	.140	141	70	56	60.0	5.3	10.7	3	.047	8.4
11. ..	.154	143	70	57	67.5	5.9	11.7	3	.051	9.0
12. ..	.168	149	75	60	75.0	6.4	12.8	3	.056	9.3

(1) Water occurring in first 30 metres (about 100 feet) of boring is not tapped with strainer pipe. It is left untapped with housing pipe.[11]

(2) Fifty per cent of the bore depth in the alluvial formation is water-bearing and the rest is non-water-bearing.[12] Thus equal lengths of slotted and blind pipes have been provided in each tubewell.

11. The engineering justification for doing so is to minimize the externality of tubewell working on other users of groundwater resource. The success of this measure would depend upon how far the water-bearing strata are inter-connected (hydrologically), *i.e.*, water from one stratum moves to the other below when it is withdrawn from the lower one.

12. This proportion of water-bearing strata is probably based on the information gathered during the boring of numerous tubewells in the Gangetic plains portion of Uttar Pradesh over the last 40 years.

The standard length of water distribution courses of a common public tubewell of 0.042 m^3/second discharge capacity is 4.8 km., of which one-third is lined to minimize water seepage to beneficiaries located at a distance from the tubewell. The UPIRI varied this length in proportion to discharge capacity of a tubewell, with the common size tubewell serving as a starting point in estimation. In order to cope with increased tubewell discharge, the water-carrying capacity of the courses is raised suitably, as also the number of routes per tubewell. Thus, the water discharge envisaged per water-course route varies between 0.035 m^3/second and 0.056 m^3/second for tubewells above the common size. That the envisaged water distribution system for tubewells of high discharge capacity may create serious organizational problem is certainly a matter for concern that cannot be brushed aside in the context of optimum size of a public tubewell. May be, the basis of selling tubewell water would have to be changed from the volumetric basis to area irrigated basis if one has to successfully cope with the task of organizing water supplies to thousands of farmers located far away from the tubewell site.

In the case of augmentation tubewells, the capital and maintenance cost on account of the water distribution system is determined by (*a*) whether the canal is lined and (*b*) the extent to which one wishes to minimize the problem of induced seepage from unlined canals. If augmentation tubewells are to pump water into a lined canal, *e.g.*, in Karnal district in Haryana, the distribution cost is negligible as the tubewells can be sited just off the canal 'bunds'. In the case of an unlined canal, tubewells may have to be sited as much as one km. away from the canal, with the result that water channels for conveying tubewell water to the canal have to be constructed. Evidently, the cost in such a case will be much less than that for the water distribution system in the case of a command tubewell.

COST COMPONENTS

The main capital cost items of a public tubewell are listed in Table II, while the principal vector of prices underlying these estimates is given in Table III. What is noteworthy about the capital cost structure is the remarkable change in the importance of the four principal segments of a tubewell as the size of a tubewell increases. While electricity transmission segment cost[13] is of greater significance for the lowest size tubewell, water distribution segment comes to figure more and more predominantly as the size of the tubewell increases. This changing capital cost structure is brought out in Table IV, in which the percentage shares of the four segments in total capital cost are set out.

Recurring or operating costs of a tubewell are on account of electricity, establishment charges and annual repairs. Within establishment charges one may distinguish between the overhead tubewell organization and the salary of tubewell operator, because both these two items differ for command and augmentation tubewells. In the case of augmentation tubewells, one tubewell operator can mind more than one tubewell simultaneously because

13. *Source:* Jain (8).

TABLE II—COMPONENTS OF CAPITAL COST OF A TUBEWELL

(Rs.)

	Tubewell discharge capacity (m^3/second)	Capital cost on account of tubewell assembly						Capital cost of pumping set	Capital cost of water distribution system	Electric transmission	Total capital cost (8+9+10+11)
		Housing pipe	Slotted pipe	Blind pipe	Boring and lowering of assembly	Miscellaneous	Total (3+4+5+6+7)				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1.	.014	2,054	1,373	672	6,720	6,822	17,641	12,540	17,004	25,000	72,185
2.	.028	4,300	2,751	1,342	8,280	8,350	25,023	14,100	33,942	25,000	98,065
3.	.042	4,300	4,077	1,986	9,660	9,812	29,835	16,500	56,608	25,000	127,943
4.	.056	5,005	5,445	2,650	13,425	11,767	38,292	19,500	73,706	25,000	156,498
5.	.070	5,005	7,488	3,987	14,900	12,926	44,306	22,800	93,320	25,000	185,426
6.	.084	5,005	10,593	6,392	14,900	14,379	51,269	26,100	111,417	25,000	213,786
7.	.098	5,005	12,331	7,437	15,925	15,658	56,356	31,950	128,897	25,000	242,203
8.	.112	7,524	14,114	8,509	16,500	18,478	65,125	34,500	147,694	25,000	272,319
9.	.126	7,524	18,926	12,613	16,975	19,799	75,837	38,250	166,257	25,000	305,344
10.	.140	7,524	20,965	13,970	17,675	22,320	82,454	41,560	183,885	25,000	332,899
11.	.154	8,076	22,744	15,237	17,900	23,943	87,900	43,500	202,625	25,000	359,025
12.	.168	8,459	25,184	16,777	18,625	25,509	94,554	44,400	221,142	25,000	385,096

TABLE III—VECTOR OF PRICES UNDERLYING ESTIMATES OF CAPITAL COST OF TUBEWELLS

Sr. No.	Name of the item		Unit cost/price
1.	Housing pipe and blind pipe		Rs. 4 per kg.
2.	Slotted pipe		Rs. 4 per kg. plus Rs. 6 for making 100 slots
3.	Boring charges		Rs. 100 per metre for first 100 m. Rs. 125 per metre for next 50 m.
4.	Unlined water courses		Rs. 1,570 per km.
5.	Lined water courses	— 0.014 m³/second discharge capacity	Rs. 14,260 per km.
		— 0.028 m³/second discharge capacity	Rs. 17,570 per km.
		— 0.042 m³/second discharge capacity	Rs. 21,840 per km.
		— 0.056 m³/second discharge capacity	Rs. 22,080 per km.
6.	Land		Rs. 2,500 per hectare
7.	Well development		Rs. 50 per metre
8.	Pump house		Rs. 3,000
9.	Pea gravel		Rs. 110 per cubic-metre

Note:—The list is far from complete.

TABLE IV—CHANGING COST STRUCTURE OF A TUBEWELL

Sr. No.	Tubewell size (m^3/second)	Percentage share in total capital cost			
		Tubewell assembly	Pumpset	Water courses	Electric transmission
1.	.014	24.4	17.4	23.6	34.6
2.	.028	25.5	14.4	34.6	25.5
3.	.042	23.3	12.9	44.2	19.6
4.	.056	24.5	12.5	47.1	15.9
5.	.070	23.9	12.3	50.3	13.5
6.	.084	24.0	12.2	52.1	11.7
7.	.098	23.3	13.2	53.2	10.3
8.	.112	23.9	12.7	54.2	9.2
9.	.126	24.8	12.5	54.4	8.3
10.	.140	24.8	12.5	55.2	7.5
11.	.154	24.5	12.1	56.4	7.0
12.	.168	24.6	11.5	57.4	6.5

he has not to look after the task of water deliveries to different beneficiaries. As regards command tubewells, one tubewell operator per tubewell is the minimum requirement. Also, each tubewell operator needs to be provided with assistance if he has to deal with large number of farmers because of the large size of a tubewell. In arriving at the number of assistants per tubewell operator, the author has been guided by the number of separate delivery tanks per tubewell, whence one assistant for each additional delivery tank is provided. The number of assistants is varied as follows:

Size of tubewell (m^3/second)	No. of assistants
0.014 to 0.056	Nil
0.070 to 0.112	One
0.126 to 0.168	Two

Annual cost on account of the salary of a tubewell operator is being provided at Rs. 4,000, and that for the assistant at Rs. 2,500. The recurring expenditure on account of overhead organization, which essentially comprises repair and maintenance persons like mechanics and electricians, is being taken at Rs. 1,000 per tubewell, irrespective of the size of the tubewell. Expenditure on account of repairs is being provided for at the rate of 3 per cent of capital cost of a tubewell, even though repair costs may rise less than proportionately with tubewell size.

Cost on account of electricity consumption is determined by (*i*) horse power of tubewell motor, (*ii*) annual running hours and (*iii*) the basis of power tariff. In case of unavoidable power tariff, provision is being made at the rate of Rs. 100 per horse power of pumpset motor.[14] However, electricity cost on an avoidable power tariff is reckoned at Re. 0.15 per kWh.[15]

Besides the operating costs, account has to be taken of (*i*) interest on capital expenditure and (*ii*) depreciation charge. In this paper, interest charge is being provided at 10 per cent, which is the rate being charged by the institutional sources financing public investments in rural development. (The basis of depreciation charge has already been spelt out earlier in the methodology section.)

Thus, the annual cost of tubewell irrigation in this paper comprises the following five items:

(1) electricity bill,
(2) establishment charges,
(3) expenditure on annual repairs,
(4) interest charge, and
(5) depreciation charge.

While the estimates of electricity cost at various levels of working of a tubewell are set out in Table V, the other four components of annual cost are shown in Table VI. The estimates of unit cost of tubewell water for various sizes of tubewells are given in Table VII.

14. It may be pointed out that the current unavoidable power tariff for pumpsets in Uttar Pradesh is about Rs. 180 per horse power. Since capital cost on account of transmission segment is borne by the public tubewell, there is need for providing for cost on account of power generation and its transmission on high tension lines only.

15. In the UPIRI memorandum, electricity cost is computed on the basis of Re. 0.15 per kWh. As compared to this price, economic price of electricity for the rural areas is generally considered to be Re. 0.30 to Re. 0.40 per kWh, while the resource cost is taken at Re. 0.25 per kWh.

TABLE V—ELECTRICITY BILL

Sr. No.	Tubewell size (m³/second)	Electricity bill for running hours equal to 2,000	3,000	4,000	5,000	6,000	7,000	Electricity bill on basis of flat (unavoidable) tariff
1. ..	.014	1,119	1,679	2,238	2,686	3,358	3,918	900
2. ..	.028	2,338	3,357	4,676	5,371	6,714	7,833	1,800
3. ..	.042	3,357	5,036	6,714	8,058	10,072	11,751	2,700
4. ..	.056	4,476	6,714	8,952	10,742	13,428	15,666	3,600
5. ..	.070	5,595	8,393	11,190	13,429	16,786	19,584	4,500
6. ..	.084	7,273	10,910	14,546	17,456	21,820	25,457	5,850
7. ..	.098	8,952	13,428	17,904	21,485	26,856	31,332	7,200
8. ..	.112	10,071	15,107	20,142	24,171	30,214	35,250	8,100
9. ..	.126	11,749	17,624	23,498	28,198	35,248	41,123	9,450
10. ..	.140	13,428	20,142	26,856	32,227	40,284	46,998	10,800
11. ..	.154	15,107	22,660	30,214	36,256	45,320	52,873	12,150
12. ..	.168	16,785	25,178	33,570	40,285	50,356	58,749	13,500

TABLE VI—COMPONENTS OF ANNUAL COST (OTHER THAN ELECTRICITY) OF A TUBEWELL

(*Rs.*)

Sr. No.	Tubewell capacity	Establishment	Repairs	Depreciation	Interest	Total annual cost (other than electricity) (3+4+5+6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	.014	5,000	2,166	2,976	7,219	17,361
2.	.028	5,000	2,942	3,840	9,807	21,589
3.	.042	5,000	3,838	4,774	12,794	26,406
4.	.056	5,000	4,695	5,839	15,650	31,184
5. . ..	.070	7,500	5,563	6,861	18,543	38,467
6.	.084	7,500	6,414	7,901	21,379	43,194
7.	.098	7,500	7,266	9,091	24,220	48,077
8.	.112	7,500	8,170	10,160	27,232	53,062
9.	.126	10,000	9,160	11,442	30,534	61,136
10.	.140	10,000	9,987	12,457	33,290	65,734
11.	.154	10,000	10,771	13,298	35,903	69,972
12.	.168	10,000	11,553	14,091	38,510	74,154

TABLE VII—UNIT COST OF TUBEWELL WATER: RUPEES PER THOUSAND CUBIC METRES

Sr. No.	Tube-well size (m^3/second)	On the basis of avoidable power tariff when running hours are				On the basis of unavoidable power tariff when running hours are			
		2,000	3,000	4,000	5,000	2,000	3,000	4,000	5,000
1.	.014	183.3	125.9	97.2	79.6	181.2	120.8	90.6	72.5
2.	.028	118.7	82.4	65.1	53.5	116.0	77.3	58.0	46.4
3.	.042	98.4	69.3	54.8	45.6	96.3	64.2	48.1	38.5
4.	.056	88.4	62.7	49.8	41.6	86.3	57.5	43.1	34.5
5.	.070	87.4	62.0	49.3	41.2	85.3	56.8	42.6	34.1
6.	.084	83.4	59.6	47.7	40.1	81.1	54.1	40.5	32.4
7.	.098	80.8	58.1	46.8	39.4	78.3	52.2	39.2	31.3
8.	.112	78.3	56.4	45.4	38.3	77.1	51.4	38.5	30.8
9.	.126	80.3	57.9	46.6	39.4	77.8	51.9	38.9	31.1
10.	.140	78.5	56.8	45.9	38.9	75.9	50.6	38.0	30.4
11.	.154	76.7	55.7	45.2	38.3	74.1	49.4	37.0	29.6
12.	.168	75.2	54.7	44.5	37.8	72.5	48.3	36.2	29.0

SCALE ECONOMIES IN CAPITAL COST

There are considerable scale economies in capital cost of tubewell irrigation. The source of greatest economy is the electricity transmission segment. In terms of our formulation, the scale economy is (+) 1.0 in the size range of tubewells considered.[16] Substantial scale economies exist in the case of pumpset cost as well as main tubewell assembly cost. More precisely, the scale economies are of the magnitude of (+)0.42 in the case of pumpset cost and (+)0.30 in the case of tubewell assembly cost. The sources of economy/diseconomy in respect of major components of tubewell assembly are as follows:

Housing pipes	(+) 0.50
Boring and lowering of pipes	(+) 0.57
Blind pipe	(+) 0.62
Slotted (strainer) pipe	(—) 0.21
Miscellaneous components	(+) 0.45

It is in the water distribution segment that one comes across scale diseconomies. Though the magnitude of the coefficient of scale diseconomy appears to be very small, namely, (—) 0.03, the water distribution segment acquires increasing importance with the size of a tubewell. Whether such diseconomies would be experienced in the case of piped water distribution system has not been investigated.[17]

A word about the nature of large economy in pumpset cost would be in order. As per expectations, the size of the horse power of the tubewell motor rises somewhat faster than the rise in the discharge capacity of the tubewell. This would give rise to scale diseconomy if the price of a pumpset

16. There is an element of over-statement here, because our assumption of constancy of installation cost for electricity transmission over the entire size range is too strong to be true in practice. The size of the conductor, the transformer, the pole, etc., is bound to vary in a step manner as the size of the electric motor rises. However, the rise in cost on this is expected to be far less than proportionate compared to the rise in the size of a tubewell.

17. In view of the very small size of holdings in the densely populated eastern Gangetic plains, the task of land acquisition for the water distribution system becomes difficult. This has led, among other things, to the use of underground pipes for water conveyance in this region.

were proportional to horse power of the pumpset. Since the manufacturers of pumpsets realise substantial scale economies in the production and marketing of pumpsets, they pass on the benefits to the buyers by following what may be described as an inelastic price policy, *i.e.*, the larger the pumpset, the lower the cost per unit of size of the pumpset.[18]

All said and done, there is evidence of the operation of scale economies in capital cost of a tubewell. Excluding the electricity transmission segment, the scale economy works out to be (+) 0.16, but including the electricity transmission segment the scale economy may be of the order of (+) 0.20.

SCALE ECONOMIES IN OPERATING COST

The three principal operating costs of a public tubewell are: energy or electricity bill, repairs to tubewell system and establishment charges. Electricity bill shows a positive evidence of scale diseconomy, whose magnitude is (—) 0.10. The source of this diseconomy is the increased depth from which tubewell water has to be lifted as the discharge capacity of a tubewell increases.[19] It may be mentioned that the magnitude of this scale diseconomy is invariant or insensitive to (*a*) price of electricity or the basis of power tariff and (*b*) number of annual running hours for a tubewell.

While the scale economies in the cost of repairs are considerable, one has to keep in mind two points in this connection. One, the cost estimates are open to criticism because these are reckoned simply as 3 per cent of the capital cost. Since there are definite scale economies in capital cost of a tubewell, scale economies in repair costs follow, irrespective of what percentage of capital cost is assumed for the repair costs. Two, a tubewell with larger command may reduce the timeliness with which repairs in the water distribution system are carried out. As the distance between the tubewell site (where the tubewell operator sits) and the point of fault in the water distribution system increases, time lag in the detection of fault rises. Of course, expenditure of additional cost on patrolling of the water distribution system can solve the problem of timely information.

In short, there are scale diseconomies in operating costs, the magnitude of the scale diseconomy varying with the basis of power tariff and the assumption with regard to the annual running hours per tubewell.

OVERALL SCALE ECONOMIES

The scale diseconomies in operating cost of tubewell irrigation are not strong enough to offset the scale economies in capital cost at any size of tubewell. In point of fact, one does not come across a U-shape in unit cost of tubewell irrigation in the range of tubewell sizes analysed for scale economies

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18. It is partly this inelastic price basis that has promoted the installation of pumpsets/motors/engines of excessive capacity by farmers in this country. The disbursers of institutional finance are said to have aggravated this phenomenon of excessive capacity, because they may collude with the sellers of pumpsets to sell larger pumpsets so as to inflate the size of the loan to the farmers—on which they are said to obtain illegal costs from the sellers.

19. In technical terms, the 'drawdown' of a tubewell rises with size, as can be ascertained from Table I.

in this paper. This result is at variance with the UPIRI result because the methods of analyses and the concepts of costs do differ though the data base is the same in both the studies.[20] More precisely, the scale economies exist upto the size level of 2.5 cusec (0.070 m^3/second) tubewell in the UPIRI study, whereas these prevail upto 6.0 cusec (0.168 m^3/second) tubewell in our paper. However, the two following observations about the behaviour of unit cost of tubewell irrigation need to be noted.

Firstly, in both the UPIRI and our study the tubewell of 2.5 cusec is such that the rise/decline in unit cost of tubewell irrigation beyond this capacity is of marginal significance. The differences in unit cost, which become narrower with an increase in the number of running hours per year, are small enough to warrant the safe conclusion of constant unit cost beyond 2.5 cusec size. Secondly, the unit cost of tubewell irrigation diminishes rapidly upto the tubewell size of 1.5 cusec (0.042 m^3/ second).

POLICY IMPLICATIONS

In the case of public tubewells with independent command area, the Tubewell Irrigation Department in Uttar Pradesh can go in for setting up tubewells of capacity greater than 1.5 cusec, say of 2.5 cusec, as recommended by the UPIRI in its memorandum. While this author, unlike the UPIRI, does not perceive any scale diseconomies beyond this size, he would caution against the setting up of tubewells of capacity greater than 2.5 cusec on two grounds. Firstly, one has to contend with the danger of external diseconomies. Secondly, one must reckon with increasing proportion of evaporation and seepage losses as the size of a tubewell increases. In other words, the effective output of a tubewell, measured by the volume of water finally delivered to beneficiaries at their field inlets, tends to differ more and more from the rated output as the length of the water distribution network increases with tubewell size.

If a public tubewell is to be employed in the role of an augmentation tubewell, the larger the size of the tubewell is, the lower will be the unit cost of tubewell water that is lifted for augmenting canal supplies. However, while exploiting these scale economies, which are internal to the public tubewell, one has to reckon with the external diseconomies of a tubewell. The greater the number of other users of groundwater in the vicinity of a tubewell, the more the external diseconomies. Big tubewells need not cause serious externalities where users of groundwater sources are few. This condition is likely to be fulfilled where water supplies from an augmented public canal improve substantially enough for beneficiaries in the vicinity of the augmentation tubewells so that they no longer need to maintain their own sources of groundwater irrigation. Evidently, this condition cannot be fulfilled if the water raised by the augmented tubewells is earmarked for use at places away

20. The result is also at variance with Bhatia and Mehta's finding that a tubewell of 1.0 cusec is of optimum size. Though they consider tubewells in the range 0.34—2.0 cusec, they are primarily concerned with exploring scale along with technological options for shallow tubewells. For more details, see Bhatia and Mehta (1).

from the location of tubewells in whose vicinity many private users of groundwater exist. This is precisely what has created problems in the case of augmentation tubewells of the Western Yamuna Canal in Haryana. Here, the tubewell water is clearly earmarked for Hissar district, whereas the augmented tubewells are located in Karnal district having many private shallow tubewells and other wells.

To conclude, the optimum size for public tubewells is governed *inter alia* both by internal scale economies and external diseconomies of tubewell irrigation.

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