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Competitiveness of Groundwater Market in Privatized Shallow and Deep Tubewells for Diversified Irrigation : An Assessment

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Summary

In recent years, the privatization and trade liberalization of irrigation policy has increased the number of tubewells (TWs) and the irrigated area in Bangladesh agriculture. But the area irrigated per unit of equipment has dramatically decreased, particularly in regard to deep tubewells (DTWs). The installation of new shallow tubewells (STWs) around the DTWs is the primary cause of this decline in DTW use. A remarkable amount of land has been irrigated for vegetable cultivation using the cheaper and less durable STWs, thus undermining the cost-effectiveness of DTW use in diversified irrigated regions and affecting the incentives of both DTW and STW owners. The monopolized water markets of DTW have responded to the competition from water markets that use STW by increasing their own command area. In this paper, an analytical framework is developed to help clarify the competition between STW and DTW in groundwater market and its effect on the economic viability of TW operation as a private business. Empirical evidence is provided by a case study conducted on a diversified crop irrigated region comprising 3 DTWs and 7 STWs. The results show that, although the prevailing groundwater market has a competitive structure, the STW enjoys more profit in the short run than the DTW.

1 Introduction

In 1989-90, 1.8 million hectares (ha) were irrigated by DTWs and STWs in Bangladesh. The fourth five-year plan (FFYP) (1990-95) targeted an expansion of groundwater irrigation to 3 million ha, with 63% of this area under total irrigation [2]. These targets were to be realized mainly through use of DTWs and STWs [13]. We found that the actual annual growth rate in the number of STWs and DTWs over the decade from 1982 / 83 - 92 / 93 was 16.96% and 5.83%, respectively, and the decrease in command area over the same period was 1.62% per STW and 4.84% per DTW (Table 1). These shifts were the result of irrigation-sector policy changes in the mid-1980s. These remarkable changes included the large scale privatization of minor irrigation (DTW, STW and low lift pump), the promotion of competition for the distribution and utilization of irrigation equipment, and the removal of siting restrictions with regard to the import of diesel engines. This last change allowed the private sector to import diesel engines without taxes or restrictions, and it continues to prompt the sale of STWs, and of old and new DTWs [5].

There has thus been a shift, begining in the early 80s, from a heavily subsidized DTW irrigation equipment sale program to a sale program characterized by gradual reductions in subsidy. In 1991, when the subsidized price was Taka 175,000, subsidy was reduced from 72% to 45%, and then to 30%, 15% and 0% in subsequent three years [9]. Today, DTW sales are entirely unsubsidized. Thus, this burden on the budgetary resources of the government has been largely transferred to the private sector.

Although the impact of the gradual withdrawal of irrigation subsidy has mostly affected DTW

Table 1 Number of Operated DTW and STW, Irrigated Area and Command Area per Tubewell Over the Year 1971-93 in Bangladesh

Year (July-June)	STW Operation (no.)	Per STW Command area (acre[1)])	DTW Operation (no.)	Per DTW Command area (acre)	Paddy-Urea fertilizer price ratio	Total Irrig. area (100,000 acre)
1971−72	389	4.00	906	32.37	−	NA
1972−73	933	10.00	1,237	30.53	−	29.89
1973−74	998	4.47	1,495	41.76	−	32.36
1974−75	777	8.72	2,699	43.67	1.36	35.57
1975−76	2,162	5.96	3,828	40.16	1.34	34.83
1976−77	2,804	5.84	4,455	36.20	1.27	30.13
1977−78	6,446	9.15	7,453	45.41	1.60	36.06
1978−79	8,374	10.57	9,729	52.77	1.71	36.81
1979−80	10,662	12.34	9,795	59.45	1.49	39.27
1980−81	20,922	11.72	10,732	56.16	1.49	40.51
1981−82	44,638	11.19	11,491	69.46	1.26	42.73
1982−83	62,253	11.86	13,794	72.45	1.08	45.70
1983−84	65,830	11.39	14,936	53.64	1.13	47.44
1984−85	73,066	10.16	16,901	64.50	0.96	51.21
1985−86	73,059	10.16	18,137	48.84	1.11	51.83
1986−87	80,773	11.13	18,744	51.09	1.01	54.34
1987−88	23,206	11.13	20,348	52.50	1.17	58.00
1988−89	47,122	10.83	22,436	55.27	1.15	67.64
1989−90	88,807	9.87	22,586	46.84	1.34	72.55
1990−91	283,141	9.87	32,468	46.84	0.82	74.79
1991−92	NA	NA	NA	NA	NA	79.80
1992−93	348,875	9.86	25,714	41.98	NA	80.37
Annual Growth Rate over 1982-83/92-93	**16.96**	**−1.62**	**5.83**	**−4.84**	**−3.01***	**5.27**

Source : BBS [3] and Hamid [8]
Note : * For the year over 1982/83−90/91, NA is not available.

irrigation development, there have been rapid changes in the number of STW in operation, and in the tota area they irrigate [3, 8] (Table 1). Together, STWs and DTWs represent 52% and 16% of the total irrigated area [3], respectively, because STW irrigation equipment is cheap, cost-effective and easy to install. Table 1 shows that the command area per unit of irrigation equipment for both STWs and DTWs has declined over the years, particularly after the privatization and trade liberalization policies of the mid 80s. Although the irrigated area per STW has decreased slightly, the area decline for DTWs is more pronounced, and even critical. The installation of new STWs around the DTWs is the main cause of the serious decline in the DTW command area [1, 2].

The annual growth rate in rice production was about 3% against a population growth rate of 2.4% per year over 1985-92 [6], and yet, despite quick development of irrigation, there was still a food shortage of 1.8 million ton. The agricultural development strategy aims for a self sufficient crop production increase of about 4% per year, which would require an increase of about 250,000 ha per year in the area under irrigation [10].

It is generally true that irrigated agriculture produces a substantial surplus for farmers, as compared to rain-fed agriculture [11, 12]. Thus, if possible, farmers would naturally prefer to increase their use of irrigated land for diversified crops. When STW and DTW areas compete, the market demand prices for irrigation water will be equal under both systems. The DTW will loose some command area, but also regain area by increasing diversified irrigation, provided the area under question is a diversified crop area.

If the owners increase the water charges, they run the risk of a decrease in demand from users. Therefore, farmers will respond by shifting some land to other irrigation schemes, the market demand price will equalize between the two TW types, and a competitive mode of operation will prevail in the groundwater market. TW irrigation may eventually be a viable as a private business, assuming water could be sold at a cost at least equal to the average total cost of the irrigation. Once subsidies are removed, the water charges would be increased to cover the average total cost, and the price of water might exceed the net contribution of irrigation water to the surplus generated by farmers. This could reduce the number of farmers demanding irrigation water and thereby reduce revenue and incentives for private TW ownership. As a result, the present development goal for irrigated agriculture may fail to achieve its target. It is therefore important to calculate what the impact of privatization and trade liberalization on the incentives of TW owners. This paper evaluates the competition between STW and DTW in groundwater market, as well as the economic viability of TW irrigation as a private enterprises.

2 Conceptual Framework

The demand for a TW depends on the demand for irrigation water, and thus on the demand for the crops to be irrigated. The derived demand for investment in irrigation equipment will depend on the increase in economic surplus generated from irrigation. If the TW is owned and its water used by one individual, there is a single decision maker and the problem is simple. However, in the agrarian structure of Bangladesh, while a TW may be individually owned, it will usually supply many water users of different socioeconomic classes. Their willingness to pay for water use will depend on their incentive structure. Based on Schultz's hypothesis, if farmers are responsive to economic incentive, then they will be willing to pay a water charge that reflects their demand for water [15]. A disparity between water charge and demand price per unit of water will thus indicate a sub-optimum level of TW-operation and the existence of disincentive either for the owners or the farmers. Below, using the recent study of Islam [9] as a model, we develop a conceptual framework to address the problem of TW operation as a private enterprise.

In a competitive water market, a business entrepreneur or TW owner will be motivated to enter the market until such time as his average total cost is minimized. Under such conditions he earns a 'normal' profit. However, if the market demand price for irrigation water remains higher than the minimum levels of average total cost, the TW owner will increase the water supply up to that point where the marginal cost is equal to the market demand price. The difference between the price and the average total cost is the 'extra profit' per unit of irrigation water. Conversely, if the market demand price remains below the average total cost, the enterpreneur will remain in business so long as he can recover his average variable cost. But if the price is below even the average variable cost the enterpreneur will exit the business.

To conceptualize the real-world complexities of TW irrigation we make the following assumptions :

a) TW owners (water suppliers) and the farmers (water users) are profit maximizers.
b) Both STWs and DTWs are in use during the dry (November-March) and wet seasons (April-October) for the irrigation of cultivated crops.
c) There are no constraint (i.e., social, technical or physiographical) on the expansion of the command area of a TW.
d) TW use is the only option suitable for irrigation (i.e., the farmer must choose between TW irrigation or none), and the pricing pattern are the same for both TWs.

We also considered three distinct historical phases in the groundwater irrigation market. In the first, which lasted until the mid 80s, the DTW enjoyed a monopoly by the government. The second phase began with the privatization of the DTW to the formal Bangladesh Rural Development Board (BRDB) farmer's cooperative association (*KSS*) and trade liberalization of the mid 80s. During this period, the STW entered the water market, and a competitive market structure developed between the two TW types in groundwater market. In the third phase in late 1980s, the government decided to sell the old and new DTWs to the individuals and informal groups, when the demand for irrigation water increasing for potato and vegetables and for monsoon rice production.

Figure 1 shows the economic model of competition between DTW and STW operation by TW owners. A similar model was used by Islam [9] to determine both the water charge and the amount of land irrigated by the farmers under different water charges between public and private DTW operation. In his study, a competitive water market was observed between public and private DTW operation in the case of irrigation winter *boro*-paddy. In our study, special emphasis is given to the year-round competitiveness of the STW and DTW operation in groundwater market. In the figure 1 the horizontal axis indicates the irrigated or actual command area in proxy of output (irrigation water) and the vertical axis indicates the cost and price for water under TW irrigation. The curve labeled ACd shows the average total cost for DTW, which includes the average variable cost (AVC) and the average fixed cost (AFC). At zero acres irrigated, the cost is equivalent to total fixed cost (TFC), where the AVC is zero. The MCd, the marginal cost curve for DTW, shows the change in total variable cost (TVC) due to increasing unit irriga-

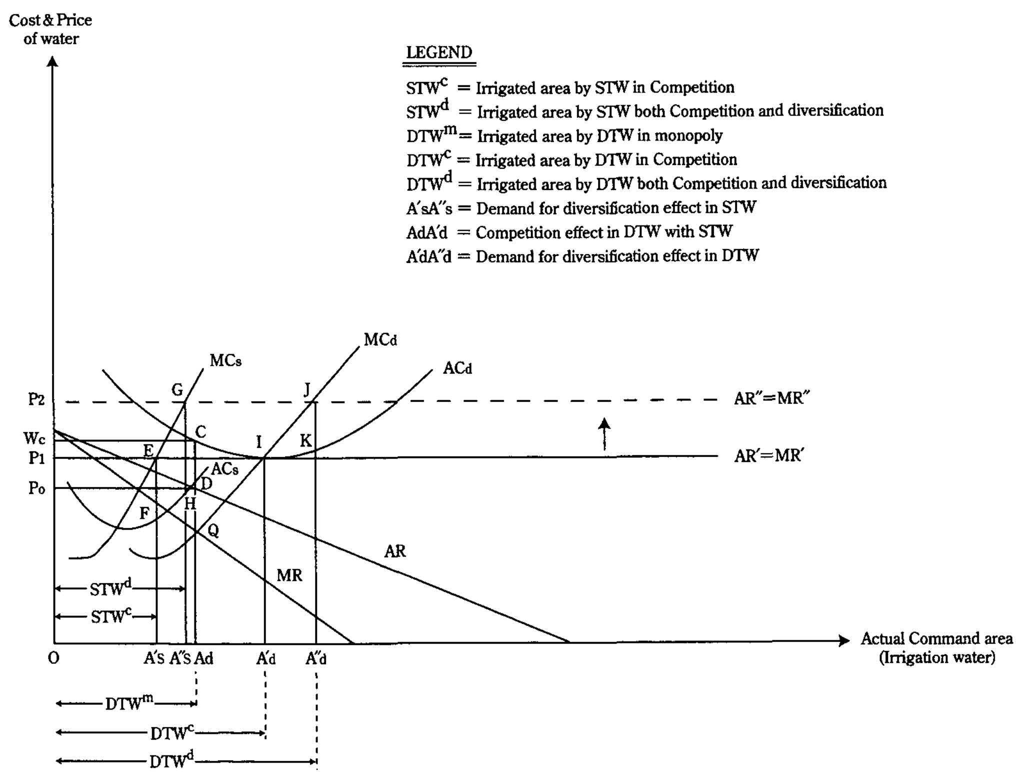

Figure 1　Economic Model of Competition Between DTW and STW Operation in Groundwater Market

tion. When the AC curves are falling, the MC lies below them and cuts them at their minimum point.

The curves marked AR and MR are the market demand and marginal demand curves for irrigated land under DTW prior to installation of STW. The MC_d and MR are equal at Q, and the price per unit of irrigation water is decided P_o where the loss by CD. The loss subsidized by the government until the mid 80s. In the mid 80s, the privatization of the DTW has been started for reducing the subsidy and for increasing capacity utilization of the DTWs, and for trade liberalization, a numerous less expensive STW entered in the groundwater market by the individual private owners.

After the competitive entrance of the STW in the groundwater market, the MC_s and AC_s are the marginal and average cost for the STW operation, the AR′ is the market demand that is the same with MR′ in the competitive market and parallel to horizontal axis. Because in the competitive water market either DTW or STW owner could not decide the price, they are the price taker only, and the price for both TW are the same and the price of water decided at P_1. In this situation, the DTW could only earn a normal profit at I while, the STW earns an extra profit by EF per unit of irrigated land. Because the DTW owned by the *KSS*, it just charge the water fee only for covering the cost of irrigation water. But the irrigated command area increase from OA_d to OA'_d per unit of DTW and for STW the irrigated command area is OA'_s, the increasing area $A_dA'_d$ is the competition effect in the DTW.

The individual private or informal groups will not interested to investment in the tubewell operation as they could not benefiited more than other opportunity cost. However, the demand for irrigation water increased for diversified crops in time being, so, there is a possibility of earning an extra profit by the DTWs also. AR″ is the shift of the market demand curve of irrigation water for irrigation into potato and vegetables and for supplementary irrigation for monsoon rice production. As demand increased from AR′ to AR″, the price of irrigation water is also increased from P_1 to P_2. The DTW command area is $0A''_d$ and for STW is OA''_s, where the addition increased of water supply for the DTW is A'_d to A''_d, the effect of diversification of irrigation water. In case of STW, the diversification effect is found from A'_s to A''_s. The effect of diversification of irrigation in the water market both for STW and DTW due to increase in demand for irrigation into potato and vegetables and for supplementary irrigation into the monsoon rice production. Due to diversification, the DTW could earn an extra profit by JK for per unit of irrigated land and for STW it is GH which is greater than JK, the additional extra profit by the STW is the (GH–EF) due to diversification of irrigation. Thus, it is conclusive that without diversification of irrigation, DTW could stay in water business with normal profit, but for diversified irrigation both DTW and STW could earn an extra profit, but STW earn more extra profit than DTW in the short run.

To clarify the competition and economic profitability both for STW and DTW, we present the following mathematical expression followed by a recent study [14]. The TW owners' profit (π) ; $\pi = wA - c(A)A - F$; where, w = water charge per unit of area (Taka[2] / acre), c = average vairable cost (Taka / acre), A = command area of the respective TWs (acre), and F = average fixed cost (Taka / acre). If TW owners maximize his profit, then first order condition is : $d\pi / dw = A + w.(dA / dw) - c.(dA / dw) = 0$

Dividing through by A, we get, $w = e.c / (e - 1)$

Where, $e = -(w / A).(dA / dw)$ is the price elasticity of demand for irrigation.

When e is very large, it moves to infinity, since, in a perfectly competitive market, w and c are more likely to be equal. As e declines and moves toward unity, since, in a monopoly power and the difference between w and c is high. A tubewell owner will not operate when $e < 1$.

Based on the above conceptual framework, we gathered empirical evidence to investigate competition between TW owners and the economic viability of TW operation as a private business.

3 The Data

The data was collected in a sample survey from a typical village called Chandiara, under Chandina *thana* (a local administrative unit is less than the district) of Comilla district in Bangladesh. It was typical for its higher concentration of DTWs and STWs, and the competitive mode of its water market for diversified irrigation. By choosing the particular village, we hoped to determine both the impact of the privatization of irrigation and that of the newly competitive structure of TW operation on the economic incentives both for DTW and STW owners. Data relating to the management of the village's 3 DTWs and 7 STWs was collected by direct questionnaire. The collected data related mainly to the crop year and irrigation period of 1995 and was used for empirical specification and estimate of the conceptual model.

4 Results and Discussion

4. 1 Irrigation Profile

The study village is located in a high rainfall zone in a flooded and fertile region of eastern Bangladesh. It experiences an annual average of 2000 mm of rainfall [3]. The land type is medium - to - medium high and the soil type loamy - to - sandy loam, characteristics highly suitable to the cultivation of any crop. This area generally receives about 30 cm of flooding during the monsoon season. The high water table has developed a concentration of both STWs and DTWs that allows for year-round irrigation. Before developed irrigation facilities, the cropping system consisted of the local potato / wheat and some winter vegetables in the dry season, and the local *aus* (April-mid July) and transplanted *amon* (mid July-November) in the wet season.

In 1972, the Bangladesh Agricultural Development Corporation (BADC) installed three DTWs (DTW No. 1, 2, and 3 in Figure 2) on a rental basis for use solely with the winter *boro* paddy production. That is, the farmer paid the BADC a nominal rent for use of the DTWs over the winter season, and the DTWs were managed by informal groups of farmers. The informal group consists of the water users of the respective DTWs. BADC provided numerous supportive measures, such as the supply of oil, fuel, mechanics and spare parts for repair and maintenance of the equipment at no cost. Individual management committees oversaw the standardization and collection of water charges, the decisions of start engine, the conveyance of irrigation water into the farmers field etc.

In 1985, following the imposition of the privatization policy, one STW (No. 7) was installed by a private owner around the potential command area of the DTW No. 3. Though he originally purchased the STW to irrigate his own *boro* and vegetables, the owner increasingly sold water to other farmers in response to the heightened demand for vegetable irrigation. In the privatization policy, BADC used to sale old and new DTWs only to the BRDB sponsored *KSS*. BRDB is responsible for sanction of DTW loans from *Sonali* Banks while the installation and repair and maintenance of DTWs are the responsibility of BADC. *KSS* is responsible for all formal books and accounts of the schemes for occasional audit by BRDB personnel's. All kinds of management activities such as fixation of water charge, collection of water charge, decisions of start engine and conveyance of water into the farmers field etc., were done by the management committee of the respective *KSS*. Following this sales program, one DTW (No. 2) was sold to a *KSS* with subsidized price in 1988.

Further reforms to irrigation policy followed and, it was said that now old or new DTWs can also sold to an individuals or informal group of individuals (3–5 members) or any institutions, from BADC either for cash or with a loan advanced through commercial banks. BADC is responsible only for the installation of DTWs. Owners of

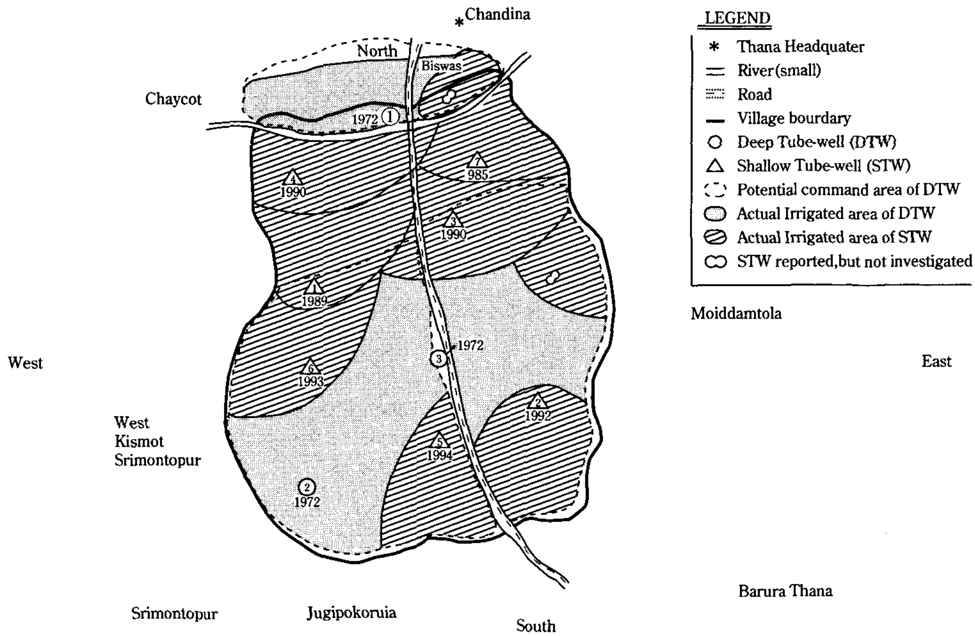

Figure 2 A Hypothetical Sketch of the Studied Tubewells Indicating the Command Area,1995

DTWs are responsible for maintenance and repairing of DTWs, fixation of water charge, collection of water charge, decisions of start engine and conveyance of water into the farmers field etc., and taking decisions about overall management. Under the latest policy, the another two DTW (No. 1, No. 3) were sold with subsidized price to the individuals in 1992 and 1993, respectively, and no any support from the BADC. In the latest policy, the private traders were also allowed to import cheaper diesel engine, and the sitting restrictions of the TWs were removed, that induced the diffusion of new STW technology to compete with the DTW in high water table. In our study village, it was found that about 5 STWs (No. 1, 2, 3, 5, 6) were installed inside the potential command areas of the previous three DTWs (No. 1, 2, 3) over 1990–94 by the individual owners, main objective is to selling water as a private business (Figure 2). However, another one STW (No. 4) was installed in 1990 which could not affect any TWs command area, and the two other STWs were installed inside the potential command areas of DTW No. 3 and 1, respectively (these are not investigated due to frequent absent of the STW owners during the survey). Thus, the old DTWs were threatened by the new, cheaper STWs in terms of irrigated command area and water charges. Almost all of the plots in this area now have year-round access to irrigation water and the opportunity to buy water for vegetable production. In our study, the DTW no. 1 is located to an another village side, thus that DTW also competes with the STWs in that village which could not include here. Although due to deregulation, all DTWs are threaten by the newly installed STWs in their potential command area, but still DTW No. 2 in our study is better in terms of actual command area than other two DTWs (No. 1 and 3) . This DTW is operated by a *KSS*, the *KSS* members are committed to continue irrigation from this DTW. The characteristics of groundwater market before and after privatization in irrigation policy is presented in Table 2, and shows a competitive market structure after privatization and trade liberalization

Table 2 Characteristics of Groundwater Market in the Study Area Before and After Privatization in Irrigation Policy

	Features	After Privatization	Before Privatization
Physical and technical aspects	***Irrigation season***	Both dry and wet seasons and almost all crops under irriation.	Only dry season for *boro* rice production.
	Irrigation equipment	Both shallow and deep tubwells are used for all crops for the high water table.	Only deep tubwells are used for dry season, otherwise no irrigation. Because of siting restriction of the tubwells.
	Availability of irrigation water	Almost all the plots in this area are able to get irrigation water from the TWs.	Only the nearby plots of the TW were able to get irrigation water.
	Difference in cropping system	Small and insignificant difference between the TW owners and water users.	Large.
TW owner's and water user's behavioural aspects	***Objective function***	To maximize income from water selling, plus for their own land irrigation. In some cases, return from water sales become the key objective of TW owners.	Mostly meet for own irrigation needs and the second objective is to sell the residual to others.
	Number of buyer and sellers of water	Numbers of sellers are few but the buyers are numerous.	Numbers of buyers and sellers are few.
	Nature of buyers and sellers	Sellers are competitive with each other, while the buyer has also the options to choose the scheme in a competitive water market.	Sellers are not competitive but enjoying monopoly power in the water market and the water buyers have no option for the monopolistic market situation.
	Role in decision making	Water users are well known about the functioning of management of the scheme.	Framers are not well known, how the scheme is operated.
Economic aspects	***Proportion of water sale***	Quite high, almost 80-95% for DTWs and 40-90% for the STWs.	Small, around 30-50% of the water sold.
	Elasticity of demand	The demand for elasticity is high.	Comperatively low.
	Nature of water market	The functioning of this situation a competitive market structure, which help both for water users and owners.	The functioning of this situation a monopolistic market structure, which help for the TW owners.

in groundwater market. Thus, it may be expected that the command area of DTW is decreasing due to installation and competition with new STWs. In our study village, due to availability of irrigation water and favorable geophysical condition, the demand for diversified irrigation into potato and vegetables, and supplementary irrigation for monsoon rice production have increased. Thus, the average command area of the TWs have increased by irrigation intensity, that makes more profitabile of TW operation in competitive groundwater market.

4. 2 The Structure of Water Market

The reduction of engine prices and the removal of the siting restriction has induced competition in the irrigation water market. These inducements to competition have allowed individuals or groups of farmers to buy tubewells for irrigating their own land and for selling water to other farmers. Wherever the water table allows for installation of STWs, these new and cheaper engines continue to encroach on the command areas of the old DTWs [2]. There were on average 25 irrigating farmers served by each STW (ranges 9–32) and 59 water users in each DTW of diversified irrigated region (ranges 47–77). The 5 STWs were newly installed over 1990–94 and reduced the potential command areas of the old DTWs in our study village. Both types of TW competed for command area by expanding irrigation for potato and vegetables production and by supplementing irrigation for monsoon rice production. The degree of competition of the individual TW is presented in Table 3. The degrees of competition are measured by elasticity of demand for irrigation following a recent study [14]. It is found that STWs have some degree of monopolistic power compared to DTWs. The elasticity of demand for irrigation for potato and vegetable cultivation was found to be more elastic than that for aggregate crop production (Table 3). This indicates that irrigation demand for vegetable production is more competitive than that for aggregate crop production due to the comparatively higher price of vegetables. The demand for irrigation for potato and vegetable is higher in the irrigated STWs for less aggregate cost and reliable sources of water supply in time. In case of DTW (No. 1, and 3) the irrigation demand for vegetable are negative, means that if the owners would like to increase the water charge for vegetable production, the irrigated area will be decreased and / or shift to nearby STWs, but one DTW (No. 2) which is controlling by a *KSS* shows highly elastic due to the less competition with STW, and *KSS* members are committed to continue irrigation from the respective DTW.

4. 3 Changes in Command Area

We previously discussed the possibility that the command area per DTW would prove to have decreased over the area studied. In most diversified irrigated regions, both DTW and STW owners can potentially expand their irrigated command area, due to the change from a monopoly market structure to competitive one, and to the increasing demand for irrigation water for diversified cropping.

Table 3 The Elasticity of Demand for Irrigation Water in the Studied Tubwells

Tubwell Type and no.*		Year of installation	Power source	Total no. of irrigators per TW	Elasticity of irrigation demand for aggregate crops	Elasticity of irrigation demand for potato& vegetables**
STW	1	1989	Diesel	23	1.89	15.25
	2	1992	Diesel	29	1.95	15.83
	3	1990	Diesel	21	1.73	3.37
	4	1990	Diesel	32	2.89	4.26
	5	1994	Diesel	9	1.48	3.26
	6	1993	Electricity	29	1.93	8.52
	7	1985	Diesel	28	3.94	7.50
Avarage of STW				**25**	**2.04**	**6.34**
DTW	1	1972#	Electricity	51	4.65	− 6.47
	2	1972##	Electricity	47	3.07	33.89
	3	1972###	Electricity	77	4.62	− 5.66
Average of DTW				**59**	**3.82**	**12.34**

Source : Calculated from Field Suvey Data, 1995

Note : * The number indicates in the Figure 2.

** The cost for power is considered all TWs are operated by diesel, both rice and vegetables irrigation it needs same diesel.

Privatized in 1992 to an individual.

Privatized in 1988 to the *KSS*.

Privatized to an individual in 1993.

Initially, most irrigation was limited to the winter *boro* paddies. It was found that average annually a DTW irrigated 27 acres of *boro* paddy, a supplementary irrigation of 63 acres to the monsoon rice (*aus* and *amon*), and 3–5 times of irrigation was provided to the 29 acres of vegetables production (Table 4). About 8–10 times irrigation was required for *boro* paddy for the season ; thus, if we converted based on the *boro* irrigation area, the converted command area is the equivalent of 43 acres of a *boro* paddy irrigated area (Table 4). The sum of the actual command area is 119.7 acres per DTW. The sum of the actual command area, and the converted command area based on the *boro* irrigation per STW are respectively, 30.7 acres and 15.1 acres. It is generally agreed that the maximum capacity for DTWs is 100 acres, and that for STWs is 20 acres, but may differ location to location. If we consider this figure, the capacity utilization was 43% for DTW and 75% for STW in our study village. Thus, our study indicates that the capacity utilization has increased for both DTW and STW due to the changes in the water market structure, and increased irrigation demand for diversified cropping in recent years (from Figure 1).

Table 4 Average Command Area of the Studied Tubewells in Chandiara Village in 1995

Tubwell Type and no.*		Year of installation	Irrigated command area (acre)				
			Winter rice	Vegetables	Monsoon rice	Actual area (Total crop basis)	Converted area based on *boro* irrigation**
STW	1	1989	12 (10)	9 (5)	6 (1)	27	17.1
	2	1992	13 (10)	7 (5)	6 (1)	26	17.1
	3	1990	12 (10)	13 (5)	20 (1)	45	20.5
	4	1990	10 (10)	8 (5)	16 (1)	34	15.6
	5	1994	6 (10)	6 (4)	4 (1)	16	8.8
	6	1993	12 (10)	8 (3)	20 (1)	40	16.4
	7	1985	7 (10)	8 (3)	12.5 (1)	27.5	10.6
STW average			**10.3** **(10)**	**8.4** **(4.3)**	**12** **(1)**	**30.7**	**15.1**
DTW	1	1972#	24 (10)	24 (3)	40 (1)	88	35.2
	2	1972##	36 (10)	38 (3)	70 (1)	144	54.4
	3	1972###	20 (10)	27 (4)	80 (1)	127	34.8
DTW average			**26.7** **(10)**	**29.6** **(3.5)**	**63.4** **(1)**	**119.7**	**43.4**

Source : Field Suvery, 1995

Note : Figure in the parentheses indicated the no. of irrigation for the respective crops.

* The number indicates in the Figure 2.

** For irrigated area of the respective crops are converted on the basis of *boro* rice irrigation that needs on avarage 10 irrigation.

#　Privatized in 1992 to an individual.

#　Privatized in 1988 to the *KSS*.

###　Privatized to an individual in 1993.

4. 4 Irrigation Water Charge

Irrigation water charges and systems of payment were almost identical for STW and DTW, although they varied according to the crop under irrigation. The water charge for both the DTWs and STWs studied was fixed at Taka 2,500 for one acre of *boro* rice cultivation per season. The payment was made in 3 installments, 33% upon land preparation, 33% upon vegetative growth, and a final third before the harvesting of *boro* rice. For other crops, the charge was fixed on a times-of-irrigation basis for per acre of land, and ranged from Taka 250–330 for various vegetables, or Taka 330–420 for *aus* or *amon*, and payments should be done at the time of irrigation. Thus, the average water charge per acre of converted command area that equivalent of *boro* paddy irrigated area stands about Taka 2,707 in DTWs and Taka 2,693 in STWs, respectively. These results show the prevalence of a competitive power structure in the groundwater market.

4. 5 Economic Viability of Tubewell Irrigation

Return to irrigation investment is calculated from the view point of water sellers of both DTW and STW. The net surplus to the TW owners is calculated by substracting the investment cost and all operation and maintenance (O & M) costs from the gross revenue from TW operation. The investment cost at the beginning of the project life includes the costs of engines, pumps, filters and the cost of the bricking canal. On the basis of previous experience, the life of the STW (Chinese engine ranges 6–12 hp) is taken 5 years and that of the DTW (22–30 horse power) at 20 years [7, 4]. The O & M costs include the costs of diesel and mobil fuel, electricity, repair and maintenance, driver and lineman salaries, and interest on operating capital. The purchase and operation of the TW is paid by the owner, who receives only the water charge from the various crops under its irrigation. Thus, the large command area of the TWs enjoyed a higher revenue. Although the DTW is technically more powerful than the STW, and although it has a much higher command area, its average cost is also much higher.

The summarized results for cost and revenue per acre converted command area based on *boro* irrigation are presented in Table 5. It was found that the per acre average total cost of irrigation with DTW in the study village is Taka 2,243, is higher than Taka 1,679 for the STWs. The net return of the TW owners from per acre under DTW irrigation stands at Taka 464 and for STW stands at Taka 1,014, respectively (In figure 1, indicates JK and GH respectively), the higher net re-

Table 5 Costs and Returns of Tubewell Operation of the Owners in the Study Village

(Taka per acre of converted command area based on *boro* irrigation / year)

Tubwell Type and no.		Power source	O&M cost (AVC)	Investment cost (AFC)	Gross cost (ATC)	Gross revenue (ATR)	Net return (NR)	Internal rate of return (%)
STW	1	Diesel	1,192	389	1,581	2,530	949	66
	2	Diesel	1,230	400	1,630	2,530	900	62
	3	Diesel	1,092	186	1,278	2,580	1,302	168
	4	Diesel	1,830	360	2,190	2,800	610	54
	5	Diesel	890	546	1,436	2,765	1,329	79
	6	Electricity	1,298	225	1,523	2,703	1,180	122
	7	Diesel	1,945	479	2,424	2,598	174	14
STW average			**1,334**	**345**	**1,679**	**2,693**	**1,014**	**74**
DTW	1	Electricity	2,036	324	2,360	2,595	235	11
	2	Electricity	1,760	161	1,921	2,607	686	153
	3	Elecricity	2,333	294	2,627	2,980	353	21
DTW average			**1,999**	**244**	**2,243**	**2,707**	**464**	**35**

Source : Calculated from Field Data, 1995 turns makes more profitable of the STW operation. The internal rate of return[3] (IRR) was 74% for STW and 35% for DTW (Table 5). We can conclude from the above that the competitive groundwater market still a profitableness for both TWs, but the STW will generally enjoy greater profitability than the DTW.

5 Summary and Conclusions

This study examines the competitiveness of DTW and STW irrigation, and the economic viability of TW operation as a water-selling business. A case study was conducted on a typical Bangladesh village with a diversified crop irrigated region comprising 3 DTWs and 7 STWs. The evidence shows that STWs are competing with the DTW command areas for diversified irrigation, and a remarkable amount of land is irrigated by the cheaper and less durable STWs. Both the STW and DTW command areas are increasing due to the change from a monopoly to competitive groundwater market structure, and to the increasing demand for diversified irrigation. Both for the STW and DTW, the elasticity of demand for vegetable irrigation was much higher than that of aggregate crop irrigation, while the elasticity of demand for STW was lower than that for DTW over all irrigation types. This indicates that the STWs have some degree of monopolistic power compare to DTWs. This finding can be attributed to the lower cost and easier management of aggregate irrigation. While the capacity utilization of the STW is still much higher than that of the DTW, due to the easier management and divisibility of the former, the capacity utilization for both TWs has increased in recent years as direct result of the changed market structure and the increased demand for diversified irrigation. The water charge on a per acre basis was almost the same for DTW and STW, although it varied according to the crop under irrigation.

Net return was satisfactory for both TW types, but STW owners earned more profit due to the smaller expense and greater cost-effectiveness of their equipment. The rate of return on investment was 2 times higher for STW (74%) than for DTW (35%), but both rate of return is much higher than the bank interest rate (10–12%), that may encourage further investment in groundwater market.

Thus, the study implies that recent policy changes in the irrigation sector in Bangladesh, the groundwater market becomes competitive from monopoly structure. The derived demand for diversified irrigation into potato and vegetables and for supplementary irrigation in the monsoon rice production are increasing for competitive market structure. The diversification of cropping systems with rice is crucial to the continued existence of DTW owners in the groundwater market, and thus to the maintenance of the new competitive market structure.

Notes:

1) Acre is the unit of land measurement in Bangladesh, 1 acre = 0.40 hectare approximately.

2) Taka is the monetary unit of Bangladesh, Taka 40.00 = 1 US dollar in 1995 approximately.

3) The formula for calculating the internal rate of return (IRR) is the following:

$$\sum_{t=0}^{n} B_t / (1 + IRR)^n = \sum_{t=0}^{n} C_t / (1 + IRR)^n$$

Where, n = 5 years for STW, and 20 years for DTW

B_t = Gross revenue of the t-th year

C_t = Gross cost of the t-th year

IRR = Internal rate of return.

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