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SUBJECTS

(1) Disadvantaged Regions and People: Is There a Way Forward?

(2) Role of Technology, Institutions and Irrigation in Agricultural Development.

(3) Economic Contribution of Women in Agriculture.

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DISADVANTAGED REGIONS AND PEOPLE: IS THERE A WAY FORWARD?

ROLE OF TECHNOLOGY, INSTITUTIONS AND IRRIGATION IN AGRICULTURAL DEVELOPMENT

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SUBJECT II
ROLE OF TECHNOLOGY, INSTITUTIONS AND IRRIGATION IN AGRICULTURAL DEVELOPMENT

An Implication of Groundwater Institutions on Reducing Negative Externality, Enhancing Economic Efficiency and Welfare in Karnataka

Kiran Kumar R. Patil*

ABSTRACT

The economic benefits and costs involved in an informal institutional arrangement of groundwater resource was analysed against control farm situation (non sharing farmers) in the present study. The sharing of well water among siblings was considered as an informal institution. Accordingly, a sample of thirty farmers sharing well water using snow ball sampling technique and a sample of seventeen farmers using simple random sampling were selected from central dry zone of Karnataka. In this study transaction costs and benefits of sharing water in irrigation well among siblings are estimated. The marginal productivity of groundwater irrigation due to the institution of sharing well water is estimated using linear regression with intercept dummy variable. The sustainable extraction path of groundwater is estimated using optimal control theory. The results indicated the absence of transaction cost in collective action, since sharing (a form of collective action which involves the cost of bringing siblings together providing information regarding importance of sharing water and the cost of convincing regarding sharing well water and the corresponding sustainable crop pattern, instead of drilling new well, which may result in reduced water in original well(s)) was among the siblings. Farmers who were sharing well water, experienced lower rate of failure of wells (23 per cent) when compared with farmers who were not sharing well water (for whom failure rate of wells was 46 per cent); had higher proportion of functioning wells (77 per cent) when compared with those not sharing (54 per cent). Similarly they experienced longer age of wells of 12.32 years, instead of 8.68 years; reduced negative externality (Rs. 1293 per well against Rs. 6692 per well), reduced cost of irrigation water per acre inch (Rs. 358 per acre inch against Rs. 599 per acre inch). Farmers who were sharing well water also realised higher net returns per rupee of functioning well (Rs.2,79,795 as against Rs.2,40,102) and net returns per rupee of irrigation water (Rs.10.83 against Rs. 7.23). The life of borewell could also enhance by 45 years instead of 8 years, by maintaining depth of wells.

Keywords: Groundwater, Transaction cost, Negative externality, Marginal productivity.

JEL: Q15, Q16

GROUNDWATER INSTITUTIONAL ARRANGEMENT

In Karnataka, due to Land Reforms Act of 1974, the sub-division and fragmentation of holdings are a rule than an exception. Since, groundwater is appurtenant to land, division of land does not divide the groundwater resource. Hence, when the owner of the landed property subdivides the land among heirs, the eldest son (usually) gets the land with the groundwater well, while the other siblings

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are compensated with appropriate land and other assets. However, this type of property division will add to mushrooming of irrigation wells since every heir of the landed property has the incentive to drill his/her irrigation well. This adds to potential negative externality. In the hard rock areas, in the absence of perennial source of water, groundwater resource becomes crucial for farming. The sub-division and fragmentation of holdings is a dynamic process of transfer of property rights on movable, immovable properties and natural resources such as forests, ground water, and surface water is becoming apparent.

The sharing of irrigation well among heirs which is a proxy for collective action from among relatives is an informal institutional arrangement focusing on the demand side of groundwater irrigation. In this context, an attempt has been made to analyse how groundwater resource is shared in the process of transfer of property rights through sub-division and fragmentation of holdings. The 'possession utility' is the key in the transfer of property rights. The possession utility serves as a key for both collective action leading to sharing of natural resource such as groundwater among heirs, or concentrating ownership of wells, motivating every property right holder to drill/construct different well/s.

Hypothesis

It is hypothesised that sharing of well water among siblings reduce reciprocal negative externality and leads to efficiency and welfare gains. Sharing of groundwater resource from irrigation borewell among heirs, is hypothesised to reduce failure of borewell/s, enhance the age of borewells, reduce the negative externality, reduce cost per acre inch of irrigation cost, increase net returns per rupee of irrigation cost, increase net returns per rupee of functioning well and result in sustainable extraction of groundwater.

Sampling

Snow ball sampling[1], a non-probability sampling technique was employed in the selection of (n=30) sample farmers sharing borewell irrigation water among siblings from Central Dry Zone of Karnataka (Chitradurga district). Simple random sampling was employed in the selection of sample farmers (n=17) who were not sharing well water. The data on cropping pattern, land holdings, profile of irrigation borewell, investment on irrigation borewells, costs and returns from crops grown under borewell irrigation, were elicited from sample farmers for the agricultural year 2012-13 considered as a normal rainfall year.[2]

Definition of Borewell Failure

Initial failure of borewell refers to a borewell which did not yield any groundwater at the time of drilling and thereafter. Premature failure refers to the borewell which served below the subsistence life or the Pay Back Period (PBP). Economic life/age of borewell refers to the number of years a borewell yielded groundwater beyond the PBP.

Subsistence life of borewell refers to the number of years a borewell yielded groundwater for the PBP. The PBP is obtained by dividing the sum total of investment made on drilling, casing, IP set, conveyance structure, storage structure, drip/sprinkler structure, recharge structure, electrification charges of borewell by the life/age of irrigation borewell. The hypothesis is that an irrigation borewell is considered to have served its purpose, if it has at least paid back the total investment made for the purpose. This implies that PBP indicates the period in which a borewell recovered the investment made.

Economics of Groundwater Irrigation

The cost of cultivation is obtained as the sum of cost of human labour, bullock labour, machine hours, seeds and fertilisers, application of manure, plant protection measures, bagging, and transporting, cost of irrigation for each crop, interest on working capital at the rate of four per cent, risk premium at the rate of two per cent and management cost at the rate of five per cent on variable cost. Gross return for each crop is the value of the output and the by-product at the prices realised by farmers. Net returns from borewell irrigation are the gross returns from gross irrigated area minus the cost of production of all crops. The cost of cultivation of all crops in this study accordingly includes the cost of irrigation explicitly since volumetric measurements of groundwater applied are made for all crops.

Costing of Irrigation Water

The increasing rate of initial and premature failure of borewells has made it indispensible to consider investment on drilling and casing of irrigation wells as variable cost rather than fixed cost, as marginal cost enters into decision making. Therefore, total cost of groundwater irrigation is divided into two components such as variable cost and fixed cost. As the farmers do not pay for electricity to pump groundwater for irrigation, the variable cost of groundwater is considered as the amortised cost of drilling and casing of borewell for the economic life of irrigation well plus the Operation and Maintenance costs (O&M). The variable cost per acre inch is obtained by dividing the amortised investment on casing and drilling plus O&M cost by the volume of groundwater extracted in the year of collecting field data during the agricultural year 2012-13. However, farmers can use irrigation pumpsets and accessories for at least ten years, irrespective of failure of irrigation wells. Hence, the fixed cost of groundwater is the amortised cost (of pumpsets, conveyance structure, drip irrigation, water storage structure, and electrification charges) for the period of ten years. The amortised fixed investment is divided by the volume of groundwater extracted in the year (2012-13) to obtain the fixed cost of groundwater per ha cm or acre inch. The labour cost of irrigation is considered along with labour costs of other cultural operations. Thus, the annual cost of irrigation pertains to each irrigation borewell on the farm and is added across all borewells on farm. This total cost of irrigation is then apportioned for each crop according to the volume of groundwater used in each crop. Cost of irrigation per acre-inch = [Total annual cost of irrigation]/ [volume of water used for the crop in acre inches of groundwater used].

Amortised cost of borewell is worked out using following formulae (see Diwakara and Chandrakanth (2007):

Amortised cost of irrigation = (Amortised cost of borewell + Amortised cost of pump set + Amortised cost of conveyance + Amortised cost of over ground structure + Operation and maintenance cost of pump set and accessories) given by

$$\text{Amortised cost of BW} = (\text{Compounded cost of BW}) \times \frac{(1+i)^{AL} \times i}{(1+i)^{AL}-1]} \quad \text{....(1)}$$

where,
AL= Average age or life of borewell 'i' = discount rate considered = 2 per cent

$$\text{Compounded cost of B} = (\text{Historical investment on BW}) \times (1+i)^{(2013\text{-year of drilling})}$$

$$\text{Amortised cost of P and A} = (\text{Compounded cost of P and A}) \times \frac{(1+i)^{10} \times i}{(1+i)^{10}-1]} \quad \text{....(2)}$$

The working life of pumpsets and accessories (P and A) is considered to be ten years since farmers consider ten years as their economic life.

where,
i = discount rate considered at 2 per cent

$$\text{Compounded cost of pumpset and accessories} = (\text{Historical cost of P and A}) \times (1+i)^{(2013\text{-year of installation of P and A})}$$

$$\text{Amortised cost of conveyance structure (CS)} = (\text{Compounded cost of CS}) \times \frac{(1+i)^{10} \times i}{(1+i)^{10}-1]} \quad \text{....(3)}$$

The working life of conveyance structure (CS) is also considered to be 10 years. The usual mode of conveyance of groundwater is through PVC pipe

where,
i = Discount rate considered at 2 per cent

$$\text{Compounded cost of CS} = (\text{Historical cost of CS}) \times (1+i)^{(2013\text{-year of installation of CS})}$$

$$\text{Amortised cost of micro-irrigation structure} = (\text{Compounded cost of MIS}) \times \frac{(1+i)^{10} \times i}{(1+i)^{10}-1]} \qquad \ldots.(4)$$

The working life of micro (drip) irrigation structure (MIS) is considered to be 10 years since farmers usually replace them after 10 years
where,
i = Discount rate considered at 2 per cent

$$\text{Compounded cost of MIS} = (\text{Historical cost of MIS}) \times (1+i)^{(2013\text{-year of installation of MIS})}$$

The amortised cost of overground storage structure is estimated as under

$$\text{Amortised cost of overground storage structure} = (\text{Compounded cost of OSS}) \times \frac{(1+i)^{10} \times i}{(1+i)^{10}-1]} \qquad \ldots.(5)$$

where,
i = Discount rate considered at 2 per cent

$$\text{Compounded cost of OSS} = (\text{Historical cost of OSS}) \times (1+i)^{(2013\text{-year of construction of OSS})}$$

Borewell Yield

The field measurements of the groundwater yield of borewells were made by recording the number of seconds taken to fill a bucket or over ground structure of groundwater of known volume. Initially the borewell was put on for ten minutes so that the initial pump yield bias is avoided. This was linearly extrapolated to obtain the groundwater yield in gallons per hour.

Groundwater Use in Conventional Irrigation System

The acre-inches (or ha cms) of groundwater used for each crop in each season (summer, *kharif, rabi*) in conventional system of irrigation is calculated as = [(area irrigated in each crop) * (frequency or number of irrigations per month) * (number of months of crop) * (number of hours for one irrigation for the cropped area in question) * (average yield of borewell in gallons per hour)] /22611gives groundwater use for each crop in acre inches.

Groundwater Use in Drip Irrigation System

The groundwater used for irrigation in each crop (acre inches) in drip irrigation = {Number of drips or emitters for the cropped area X groundwater discharged per emitter per hour (liters per hour) X No. of hours to drip irrigate the cropped area for one irrigation X frequency of irrigations per month (in number) X duration of crop irrigated in months /4.54/22611}.

Estimation of Reciprocal Negative Externality

According to Baumol and Oates (1988), an externality exists when an action of one agent results in unintended side effect which enters into the production/ consumption function of another agent, resulting into inefficiency and welfare loss, which is not regulated through price mechanisms or institutions.

The externality per borewell = (Amortised investment on drilling and casing of borewells over the subsistence life of borewell/s or economic life of borewell/s whichever is relevant) divided by (number of borewells which served PBP + serving economic life) minus (Amortised investment on drilling and casing of borewells over the subsistence life of borewell/s or economic life of borewell/s whichever is relevant) divided by all the borewells on the farm.

Estimation of Marginal Productivity of Groundwater Irrigation

The marginal productivity of groundwater irrigation across groundwater institution is assessed through fitting linear regression model with gross returns per farm as dependent variable. It was regressed on groundwater used per farm for irrigation and the intercept dummy representing informal groundwater institution. The intercept dummy takes the value 1 for farms sharing ground water irrigation among siblings, and 0 for farms not sharing irrigation water among siblings (control situation).

$$Y = \beta_0 + \beta_1 X + \beta_2 D + \varepsilon \qquad \text{....(6)}$$

where,
Y refers to the gross returns realised on the farm (Rs.),
X indicated the total groundwater used in acre inches on the farm,
D= intercept dummy takes the value 1 for the farms sharing well water among siblings otherwise it takes the value 0 (for control farmers of Central Dry Zone).
ε: represents stochastic error term
β_0, β_1, β_2 are the regression coefficient

Sustainable Extraction of Groundwater

The optimal control theory is used in optimal allocation of scarce natural resources over a given time horizon, which will maximise the discounted net benefits from extraction of the resource over time period. The present value of net benefit over time for a given borewell farm is constrained by the equation representing the hydrological behaviour of groundwater. The solution is derived by formulating the present value Hamiltonian function. The Hamiltonian function is used to derive the optimal path of groundwater extraction and corresponding pumping lift.

$$\text{Gross Margin} = \int_t^T e^{-rt}\,(GR_t - TC_t)d = \int_t^T e^{-rt}\left[aw_t - \frac{b}{2}w_t^2 - (I + EP_t)w_t\right]dt$$

The Hamiltonian function is formulated as under

$$H_t = e^{-rt}\left[aw_t - \frac{b}{2}w_t^2 - Iw_t - EP_t w_t\right] + \lambda\left[\frac{\{(1-\theta)w_t - R\}}{AS}\right]$$

The Hamiltonian function can be maximized by applying Pontrayagin's maximum principle, and the three conditions of optimality are below,

First condition: maximum condition equation for groundwater extraction

$$\frac{\partial H_t}{\partial w_t} = 0$$

Second condition: adjoint equation for co-state variable

$$-\frac{\partial H_t}{\partial P_t} = \lambda_{t+1} - \lambda_t = \lambda^*$$

Third condition: equation of motion for groundwater stock

$$\frac{\partial H_t}{\partial \lambda} = P_{t+1} - P_t = P_t^*$$

The optimal solution equation for groundwater extraction

$$w_t = c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t} + \frac{R}{(1-\theta)}$$

The optimal solution equation for pumping lift (P_t)

$$P_t = \frac{(1-\theta)}{AS}\left[\frac{c_1}{\lambda_1}(e^{\lambda_1 t} - 1) + \frac{c_2}{\lambda_2}(e^{\lambda_2 t} - 1)\right]$$

RESULTS AND DISCUSSION

Sharing Irrigation Borewell as an Informal Institution

Sharing of borewell irrigation water among heirs/siblings is an informal institution. For sharing to be effective, parents/elders in the family serves as line of control. They exercise their control regarding cropping pattern to be followed by the heirs, pattern of sharing various costs incurred towards drilling of borewell as well as for its maintenance and about period of rotation for irrigation water. In the study area, borewell was shared among minimum of two heirs to maximum of seven heirs. The modal value was among three heirs. If water is shared among two heirs, then for every alternative day the respective heirs can irrigate their fields. Similarly, if irrigation borewell is shared among three heirs, then weekly twice each heir can irrigate their farms. Depending upon the availability of groundwater (yield of irrigation borewell) and number of heirs among whom irrigation borewell is shared, cropping pattern was decided. If number of heirs is more, then usually less water intensive high value crops like flower crops were preferred.

Cropping Pattern

The cropping pattern of farmers sharing groundwater among siblings and control farmers in Central Dry Zone are similar. The shared well farms (23 crops and SI =0.92) have more diversity in crops compared with control farms (17 crops and SI = 0.90) as reflected in the number of crops grown over three seasons and magnitude of Simpson Index respectively. The cropping pattern is dominated by cereals (30.42 per cent and 31.03 per cent) and is followed by vegetables (24.17 per cent and 27.08 per cent) in the case of both shared well and control farmers, respectively. The area under flower crops was more under shared well condition (18.76 per cent) compared with that of control farm situation (7.75 per cent). Amongst perennial crop component, arecanut crop dominated both scenarios. The cropping and irrigation intensity were relatively higher on shared well farms (202.29 per cent and 233.06 per cent) compared with control farm (186.06 per cent and 199.69 per cent) (Table 1A and 1B).

TABLE 1A. CROPPING PATTERN OF SHARED WELL FARMS IN CDZ (2012-13)

Season (1)	Crops (2)	Area (acres) (3)	Proportion of GCA (4)
Kharif	Maize (rain fed)	27.5	8.28
	Sunflower (rain fed)	38.5	11.6
	Jowar (rain fed)	6	1.81
	Onion	38.5	11.6
	Cucumber	2	0.6
	Cotton	0.75	0.23
	Ragi (rain fed)	2	0.6
	Leafy vegetables	14.5	4.37
	Sub-total of *kharif*	129.75	39.09
Rabi	Jowar (rain fed)	19	5.72
	Bengal gram (rain fed)	13	3.92
	Maize	14	4.22
	Chrysanthemum	13.5	4.07
	Cucumber	2	0.6
	Onion	3	0.9
	Leafy vegetables	7.25	2.18
	Sub-total of *rabi*	71.75	21.61

(*Contd.*)

TABLE 1A (CONCLD.)

Season (1)	Crops (2)	Area (acres) (3)	Proportion of GCA (4)
Summer	Maize	19.5	5.87
	Jowar	5	1.51
	Ragi	8	2.41
	Onion	8	2.41
	Cucumber	5	1.51
	Sub-total of summer	45.5	13.71
Perennials*	Arecanut	33.2	10
	Crossandra	48.75	14.69
	Coconut	3	0.9
	Sub-total of perennials	84.95	25.59
	Gross cropped area (GCA)	331.95	
	Net cropped area (NCA)	164.1	
	Cropping intensity (per cent)	202.29	
	Gross irrigated area	237.95	
	Net irrigated area	102.1	
	Irrigation intensity (per cent)	233.06	
	Simpson index of diversity in cultivated crops	0.92	

TABLE 1B. CROPPING PATTERN OF CONTROL FARMERS IN CDZ (2012-13)

Season (1)	Crops (2)	Area (acres) (3)	Proportion of GCA (4)
Kharif	Sunflower (rain fed)	23	15.19
	Ragi (rain fed)	5	3.3
	Maize	13	8.58
	Onion	18.2	12.02
	Leafy vegetables	10.2	6.73
	Carrot	2.2	1.45
	Brinjal	0.2	0.13
	Sub-total for *kharif*	71.8	47.41
Rabi	Jowar (rain fed)	18	11.89
	Bengal gram (rain fed)	14	9.24
	Maize	5	3.3
	Cucumber	2	1.32
	Chrysanthemum	7.2	4.75
	Leafy vegetables	5.25	3.47
	Sub-total of *rabi*	51.45	33.97
Summer	Maize	6	3.96
	Onion	3	1.98
	Sub-total of summer	9	5.94
Perennials*	Arecanut	16.2	10.7
	Crossandra	3	1.98
	Sub-total of perennials	19.2	12.68
	Gross cropped area (GCA)	151.45	
	Net cropped area (NCA)	81.4	
	Cropping intensity (per cent)	186.06	
	Gross irrigated area	97.45	
	Net irrigated area	48.8	
	Irrigation intensity (per cent)	199.69	
	Simpson index of diversity in cultivated crops	0.90	

*The gross cropped area for perennials is considered as twice their net cropped area.

Profile of Irrigation Wells

The number and percentage of functioning irrigation borewells in shared well farms (37 and 62 per cent) is higher compared with control farm situation (22 and

53.65 per cent). The average age of functioning borewell in shared well farms (12.32 years) is higher compared with control farms (8.68 years). In shared well farms, 15 per cent of the borewells have served for payback period with an average life of 10.56 years. The number and percentage of initially failed borewell is lower in shared well farms (9 and 15 per cent) compared with control farms (18 and 43 per cent). This *prima facie* indicator of performance is due to the sustainability of sharing irrigation well water, a family and informal institution in Central Dry Zone over control situation (Table 2).

TABLE 2. PROFILE OF IRRIGATION BOREWELL ACROSS GROUNDWATER INSTITUTION AND CONTROL FARM SITUATION

Particulars (1)	Institution of water sharing among 1 to 7 siblings (n=30) (2)	Central dry zone (n=17) (3)
Number of borewells among sample farms	60	41
Number of borewells per farm	2 (1-6)	2.4 (1-6)
Number of initially failed bore wells in the sample (per cent)	9 (15)	18 (43.90)
Number of prematurely failed borewells in the sample (per cent)	5 (8.3)	1 (2.43)
Number of borewells which exactly served for subsistence or payback period (PBP) (per cent)	9 (15)	0 (0)
Life of borewells which served for subsistence or PBP in years	10.56 (5-31)	Not applicable
Number of functioning borewells in the sample (per cent)	37 (61.66)	22 (53.65)
Average age of functioning borewells (years)	12.32 (1-31)	8.68 (1-20)
Range of drilling year of borewells	1972-2013	1992-2013

Figures in parentheses indicates range.

Investment on Irrigation Borewells Across Groundwater Institution and Control Farm Situation

The depth of irrigation borewells in Central Dry Zone hovers around 300 feet and accordingly uses irrigation pumpsets of lower hp ranging from 5 hp to 6 hp. The yield of irrigation borewell remains akin and is about 1800 gallons per hour. Investment on borewells *inter alia* has largely been a function of depth of borewell, horse power of irrigation pumpsets and the number of initially and prematurely failed wells. The economic investment on all borewells per farm was comparable on farms sharing irrigation water among siblings (Rs. 1,76,067) and control farms in Central Dry Zone (Rs. 1,72,023). The stock concept of investment made on irrigation borewell indicated by the nominal investment made on all wells per acre of gross irrigated area was lower on shared well farms (Rs. 22,203) compared with control farms (Rs. 30,021) by 26 per cent. Similarly, the flow concept of investment at current prices reflected in the ratio of variable component of amortized cost per functioning well to gross irrigated area was lower on shared well farms (Rs. 1,657) compared with control farms (Rs. 3,964) by 58 per cent (Table 3).

TABLE 3. INVESTMENT ON IRRIGATION BOREWELL ACROSS GROUNDWATER INSTITUTION AND CONTROL FARM SITUATION

Particulars (1)	Institution of water sharing among 1 to 7 siblings (n=30) (2)	Control farm situation (n=17) (3)
Depth of borewell in feet (range)	274 (74-580)	257 (80-480)
Horse power of IP set (range)	5 (5-12)	6 (3-10)
Yield of functioning well in gallons per hour (range)	1803 (916-3000)	1866 (1167-2333)
Water used per farm in acre inches (range)	88.75(16.25-238)	71.63(18-135)
Investment on micro irrigation per farm in current prices (Rs.)	79751 (59438-130020)	NA
Nominal investment on all borewells per farm (Rs.)	176067 (67378-604143)	172023 (82128-320073)
Nominal investment per functioning borewell (Rs.)	114825 (67231-369797)	132927 (82128-263479)
Amortised cost of drilling and casing per borewell (Rs.)	4249	7748
Amortised cost on drilling and casing per functioning borewell (Rs.)	5542	14440
Total variable cost per functioning borewell (Rs.)	13137	22713
Annual negative externality per borewell (Rs.)	(Rs 5542 - 4249 =) 1293	6692

Note: Figures in parentheses indicate range.

Transaction Costs and Benefits from Collective Action

Property rights to groundwater are ambiguous. However property rights to borewell are clear. Even though such an absolute truth exists, farmers behave in a manner where property rights to groundwater are clear and hence they invest on drilling irrigation borewells indiscriminately. Accordingly, the investment made on borewells was Rs. 1,72,023 on control farms and Rs. 1,76,067 on farms sharing irrigation water among siblings. And the associated variable cost of groundwater per acre inch was Rs. 415 per acre inch on control farms and Rs. 199 per acre inch on shared well farms. It is imperative to note that sharing the groundwater will bring down the cost of groundwater by 78 per cent compared with control farm. Despite the high investment on wells per farm and associated increase in cost of groundwater, farmers still prefer to further invest on new borewell rather than sharing their well water since sharing substantially reduces water cost. During reconnaissance survey there was no single instance of farmers sharing their well water through collective action. However, there were farmers who shared their well water with siblings. Therefore, in this study farmers who share their well water among siblings have been sampled. Accordingly, the collective action leading to zero transaction costs of sharing well water is of no consequence since the well water is shared among siblings. Though, the transactions costs of collective action has not been considered in accounting for the economics of borewell irrigation for shared well farmers, these farmers are deriving economic advantage in terms of higher proportion of well success (0.62) and lower proportion of initial and premature failures (23 per cent) compared with control farm situation.

Economic Benefits Realised Through Sharing of Well Water Among Siblings

Shared well farmers realised increased gross returns per farm (Rs.9,39,545) over control farms (Rs.6,44,396) by 46 per cent. The gross returns per acre of gross irrigated area realised on shared well farms (Rs.1,18,455) were higher than control farms (Rs.1,12,414) by 5.37 per cent. The gross returns per functioning well on shared well farms (Rs.7,61,794) surpasses that on control farms (Rs. 4, 7,942) by 53 per cent. The gross returns per acre inch and gross returns per rupee of water accrued to shared well farmers (Rs.10,586 and Rs.28) are higher than control farms (Rs.8,996 and Rs.15) by 18 and 87 per cent, respectively (Table 4). Net returns per functioning well and net returns per rupee of irrigation realised by shared well farms Rs.2,79,795 and Rs.10.83 are higher compared with control farms Rs.2,40,102 and Rs.7.23 by 16.5 and 50 per cent, respectively. The per acre inch cost of groundwater on shared well farms (Rs.358 per acre inch) was substantially lower by 67 per cent compared with control farms (Rs. 599 per acre inch). The negative externality borne by shared well farms (Rs.1,293) was impressively lower by 417 per cent compared with control farms (Rs.6,692). The results were in accordance with the findings of Manjunatha *et al.* (2011) which indicated that the number of failures was more among individual owned wells compared with shared well farmers, the irrigation cost per acre inch was lower on shared well farms (Rs.206) compared with individual owned farms (Rs.629) and the net returns realised per acre inch and net returns per functioning well were more on shared well farms compared with (Rs. 1,459 and Rs.1,53,971) individual owned farms (Rs.1,439 and Rs. 83,804).

TABLE 4. TRANSACTION COST AND BENEFITS OF COLLECTIVE ACTION IN SHARING BOREWELL IRRIGATION WATER IN CDZ

Particulars (1)	Shared well farmers, CDZ (2)	Control farmers, CDZ (3)	Per cent change (4)
Gross returns per farm (Rs.)	939545	644396	46.00
Gross per acre of gross irrigated area (Rs.)	118455	112414	5.37
Gross returns per functioning well (Rs.)	761794	497942	53.00
Gross returns per acre inch of groundwater use (Rs.)	10586	8996	18.00
Gross returns per rupee of irrigation water (Rs.)	28	15	87.00
Net returns per functioning well (Rs.)	279795	240102	16.50
Net returns per rupee of irrigation water (Rs.)	10.83	7.23	50
Negative externality (Rs.)	1293	6692	-417
Cost per acre inch of groundwater (Rs.)	358	599	-67
Transaction cost	Collective action led to zero transaction cost because borewell water is shared among siblings		

Estimated Marginal Productivity of Groundwater Irrigation

The gross return function is estimated by regressing gross returns per farm (Y) on groundwater used per farm and dummy variable capturing the impact of institution in Central Dry Zone using the following expression,

$$Y = \beta_0 + \beta_1 X + \beta_2 D + \varepsilon$$

where, X = groundwater used per farm in acre inches, D represents dummy variable taking value 0 for farms not sharing well water among siblings (control farmers) and 1 for farms sharing well water among siblings.

The estimated gross return function is expressed as Y= 235689+5706 X+ 211782D

The estimated gross returns at the mean level of groundwater use (72 acre inches) on control farm situation is

Y= 2, 35,689+ 5,706 X

Y=2, 35,689+5,706 (72) = Rs.6, 46,521 per farm

Similarly, the estimated gross returns per farm on shared well farmers at mean level of groundwater use is

Y= 2, 35,689+5,706 X+ 2, 11,782

Y=2, 35,689+5,706 (88.75) + 2, 11,782 = Rs 9, 53,879 per farm

The marginal productivity of groundwater is Rs. 5,706 per acre inch on the shared irrigation well farms. The institution of sharing of irrigation well water among siblings shifts the gross returns realised per farm to Rs. 4.47 lakhs per farm. The estimated gross return realised per farm was higher for farms sharing groundwater with siblings (Rs.9,53,879) compared with control farms (Rs.6,46,521) by 48 per cent (Table 5).

TABLE 5. MARGINAL PRODUCTIVITY OF GROUNDWATER IRRIGATION ACROSS GROUNDWATER INSTITUTIONS

(Dependent Variable: Gross returns per farm in Rs.)

Particulars (1)	Pooled sample (Shared well and control farms, CDZ) (n=47) (2)
Intercept	235689 * (1.97)
Total water used in acre inches (X)	5706** (5.13)
Dummy for institution (D)	211782 (1.85)
Adjusted R Square	0.42
F statistic	16.98**

Notes: Figures in parentheses indicate't' value. * and ** indicate 5 and 1 per cent level of significance of the estimates and the model.

Functional form: $Y = \beta_0 + \beta_1 X + \beta_2 D + \varepsilon$.

Dummy variable takes the value 0 for control farms (without institution) and takes the value 1 for farms (with institution).

Sustainable Path of Groundwater Extraction

The results of the optimal control path of extraction are applicable with the assumption that all the farmers in the aquifer will follow the optimal path. The optimal control path of groundwater extraction for farmer who is sharing groundwater for irrigation, indicates that the steady state equilibrium is achieved over 45 years since the steady state pumping height is attained. This path of time =45 years is the largest when compared with control farm situation where t = 8 years. The discounted net benefit realised per well at steady state equilibrium was Rs. 78,349 per well for shared well farmers and Rs. 317891 for control farm situation (Table 6).

TABLE 6. SUSTAINABLE VOLUME AND DEPTH OF GROUNDWATER EXTRACTION

Categories of sample farmers (1)	Steady state equilibrium attained at time t in years (2)	Steady state level of ground water extraction (acre inches) (3)	Steady state pump height (ft) (4)	Net present value at the steady state equilibrium (Rs.) (5)	Nominal investment on irrigation well per farm (Rs.) (6)
Shared well farmers	45	26.81	327	78349	176067
Control farms	8	46.46	320	317891	172023

Sustainable groundwater extraction path for shared well farmers in Central Dry Zone

$$Wt = -3723.76 + e^{0.019t} + 9127\, e^{0.00001t} + 3236.57$$

Sustainable groundwater extraction path for control farmers in Central Dry Zone

$$Wt = -5905.94 + e^{0.0199t} + 6870.833\, e^{0.000004t} + 5635.10$$

Sustainable depth of water extraction for Shared well Farms in Central Dry Zone

$$Pt = 3600 + 0.0022\, [-195987.37(e^{0.0199t} - 1) + 912718000\, (e^{0.00001t} - 1)]$$

Sustainable depth of water extraction for Control farmers in Central Dry Zone

$$Pt = 3840 + 0.001319\, [-296780.9(e^{0.0199t} - 1) + 1579501839\, (e^{0.00000435t} - 1)]$$

CONCLUSION

The economic benefits and costs, marginal productivity of groundwater and sustainable use of groundwater resource were assessed for a snowball sample of farmers sharing borewell irrigation among siblings against control farm situation. The results indicated that no transaction costs were involved since irrigation wells were shared among siblings but rather sharing of irrigation well provided various economic advantages over control farm situation such as higher percentage of functioning borewells (62 per cent over 53.65 per cent) with longer age (12.32 over 8.68 years), higher net returns per functioning well and net returns per rupee of irrigation by 16.5 and 50 per cent, respectively, impressively lower negative externality by 417 per cent, lower cost of irrigation per acre inch by 67 per cent. The marginal productivity of groundwater was estimated as Rs. 5,706 per acre inch and the institution of sharing well water for irrigation shifted gross returns per farm to Rs. 4.47 lakhs. Optimal control path indicated that steady state equilibrium will be attained 46 years in the case of shared well farms. The economic potential of groundwater sharing among relatives has wide applications possible through creating awareness, by linking with Karnataka Land Reforms Act. The Karnataka Land Reforms Act needs to be amended to include groundwater irrigation while defining irrigation. Currently irrigation refers to mainly surface water irrigation, and not groundwater irrigation, despite the fact that more than 70 per cent of irrigated area in India is from groundwater resource. Thus, groundwater sharing in Land Reforms Act need to be amended and treated as 'consolidation' of holdings through groundwater. The farmers sharing groundwater among siblings have experienced the lowest reciprocal negative externality hence they need to receive incentive in the form of preferential treatment in receiving benefits from developmental programmes. Following optimal path of groundwater extraction will enhance the life of borewell substantially maintaining the depth to groundwater. However this needs to be undertaken by all farmers in the aquifer and needs policy support creating awareness among the farmers.

NOTES

1. http://changingminds.org/explanations/research/sampling/snowball_sampling.htm browsed on July 18th 2014
2. http://planning.kar.nic.in/docs/economic%20survey%20201314/Web%20Eng/16%20AGRICULTURAL%20AND%20ALLIED%20SECTORS.pdf browsed on 18th July 2014

REFERENCES

Baumol, W.J. and W.E. Oates (1988), *Theory of Environmental Policy*, Second Edition, Cambridge University Press, p. 17.

Chaitra, B.S. and M.G. Chandrakanth (2005), "Optimal Extraction of Groundwater for Irrigation: Synergies from Surface Water Bodies in Tropical India", *Water Policy Journal*, IWA Publishing, Vol.7, pp.597-611.

Diwakara, H. and M.G. Chandrakanth (2007), "Beating Negative Externality Through Groundwater Recharge in India: A Resource Economic Analysis", *Environment and Development Economics*, Vol.12, pp.271-296.

Manjunatha, A.V.; E.A. Nuppenau, B.T.S. Amjath and M. Puran (2011), "Individual and Family Owned Borewells: Does Sharing Induce More Sustainable Groundwater Use?", prepared for the presentation at the *10th Conference of the European Sociological Association* (ESA) on Social Relations in Turbulent Times, Geneva, Switzerland, 7-10 September.

Patil, Kiran Kumar R. (2014), "Economics of Coping Mechanisms in Groundwater Irrigation: Role of Markets, Technologies and Institutions", Unpublished PhD Thesis submitted to the Department of Agricultural Economics, University of Agricultural Sciences, Bangalore, July 2014.