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Tank irrigation management as a local common property: the case of Tamil Nadu, India

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Abstract

The objective of this paper is to conduct theoretical inquiries and empirical analysis on the issue of institutional evolution for resource management, focusing on irrigation water, a traditional local common property resource. Two management schemes for irrigation water, a community management regime (tank irrigation) and an individualised management regime (well irrigation), are compared in terms of rice production efficiency. Using farm household data collected by the authors in Tamil Nadu, India, it is found that the profit of rice production using well water only is low due to the high labour input required for well irrigation management. Then, estimation of the profit function reveals that the profit of farmers using both tank and well water is statistically significantly higher than that of farmers who use either well water only or tank water only. The result, based on game theoretical inquiries, implies that in equilibrium tank and well irrigation can coexist. Moreover, it is calculated that about 90% of farmers will use wells in equilibrium. Considering that well users are only 37% of all farmers at present, the number of wells will increase.

JEL classification: Q25

Keywords: India; Rice; Tanks; Wells; Irrigation

1. Introduction

The management of local common property resources is one of the most important issues in rural development in developing countries (Hayami, 1997). This paper takes tank irrigation as an example of local common property resources, and considers the evolution of institutions for the management of this resource.

Water in a tank is a local common property resource. This resource is distributed through canals to each rice field for private rice production. That is, the common water is privatised through canals, and hence this privatisation requires collective actions among water users. On the other hand, farmers can privatise common ground water through privately installed wells, which does not require collective action. These two modes of privatisation of water are interlinked in the following ways. First, surface water stored in a tank is a source of ground water, and therefore they have a physical relationship. Second, those who have private wells are less motivated to participate in tank irrigation management. That is, tanks and wells are competing in intrahousehold resource allocation. Therefore, the question of 'tanks or wells for local irrigation systems' is considered as a more general question of what type of property right regime is desirable for managing local common property resources.

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The issue of the relative efficiency of individualised management and community-based collective management for local commons has been long debated. By comparing community timber plantations with private timber plantations in Nepal, Sakurai et al. (1998) showed that collective management by community members is more efficient for protecting timber trees from animals and theft, while individual management is more efficient for taking care of trees in order to produce high quality timber. In the case of community forestry in Japan, there is evidence that management has been increasingly individualised as commercial timber production has become a main activity of community forestry (Sakurai, 1997). Kijima et al. (2000) showed that more timber trees were planted in community forests with individualised management than in those with collective management in Japan. The empirical findings of these studies indicate that the efficiency of the management of common property resources depends on physical nature of the resources and the products exploited from the resources. Hence, we cannot draw general conclusions.

We expect a similar situation in irrigation water management. When a tank has enough water, mutual supervision among community members can be an effective way to protect tank water from unauthorised use. However, once a tank deteriorates, collective actions do not work effectively for tank management because investment in private wells may be more beneficial to individual farmers than participating in the collective rehabilitation of the tank. Therefore, the question of relative efficiency between a collective irrigation system, i.e. tanks, and an individualised irrigation system, i.e. wells, must be answered empirically. However, no study has attempted to address this issue. [1] Thus, the objectives of this paper are (1) to conduct theoretical and empirical analyses of this issue, and (2) to consider how those two systems are interacting and evolving at the community level. For this end, we develop a household model and empirically estimate a profit function of rice production.

The organisation of this paper is as follows. This introductory section is followed by Section 2 in which we describe our study site in Tamil Nadu, India, where tanks account for a significant share of the source of agricultural irrigation. Then, in Section 3, we develop a farm household model that explains the optimal timing of investment in a private well and consider households' strategic behaviour for participating in collective tank management. Section 4 is devoted to empirical analyses by estimating a profit function to examine the effect of irrigation systems on the efficiency of rice production. A summary of findings and the implications of our study are in Section 5.

2. Study site

Our study site is Tamil Nadu, India. Tank irrigation is a traditional system for producing rice in this state, and still has a significant share in terms of area irrigated. In the 1993–1994 harvest year, 47.9% of crop field in Tamil Nadu was irrigated, and the water sources were wells (46%), canals (29%), and tanks (24%) according to Palanisami et al. (1997). Although the share of tank irrigation is still high relative to other states in India, the share has been declining over time: it was 38% in 1960–1961. This decline was caused by the deterioration of tank performance due to lack of proper management. Furthermore, the deterioration of tanks has induced the wide adoption of private wells. [2]

There were 38,842 tanks in Tamil Nadu as of 1994–1995 harvest year (Palanisami et al., 1997). The tanks are not distributed evenly in this state; most of them are located in the northern part and the southern part of the state. Tamil Nadu consists of 21 districts, and out of them we selected four contiguous districts in the southern, tank-irrigated region: Madurai, Ramnad, Virudhunagar, and Sivagangai districts. Annual rainfall levels are different among the four districts ranging from 700 to 1000 mm. The share of tank-irrigated area in total irrigated area also differs: 17% for Madurai, 87% for Ramnad, 49% for

[1] There are several empirical studies on tank irrigation management in which tanks are considered as local common property resources (e.g. Easter and Palanisami, 1986; Sengupta, 1991; Singh, 1994; Bardhan, 2000). However, these studies do not address the question of institutional evolution.

[2] Dug wells or open wells are traditionally private in Tamil Nadu. In the past, manual labour and/or traction animals were used to exploit water from wells, but now the use of electric pumps has become common. Tubewells with electric pumps are also becoming popular in this state. Because of the declining ground water level, tubes are used even in dug wells to deepen the wells.

Virudhunagar, and 86% for Sivagangai. Based on the list of villages provided by district offices, we randomly selected three villages in each district, and hence we have 12 sample villages.[3] In each village, we conducted a group interview to collect information on the management of tank irrigation as well as village characteristics. All villages have at least one tank for agricultural irrigation, and some villages have more than one tank utilised for agriculture. If there was more than one tank in a village, we identified the most important tank through the group interview and collected information on this tank only. In addition, we interviewed six farm households randomly selected in each village. Consequently, we have 72 sample households over the 12 villages. The data collection was carried out in March 1998 by the authors.

3. Model

Our concern is how a farmer selects irrigation sources, common water in a tank or individualised water from a well. We present a model in which a farmer optimises the timing of investment in a private well while tank water is available.

Assuming a homogenous group of rice farmers that share the same command area of a tank, a farmer maximises the present value given by the following:

$$V = \int_0^T \left\{ A \prod^{TN} (1 - \theta + g(nm))^t - m \right\} e^{-rt}\,dt - I\,e^{-rT} + \int_T^{\infty} h(w, l, \mathbf{X}) A \prod^{WL} e^{-rt}\,dt \quad (1)$$

where T is the period when this farmer will invest in a private well, A is the size of the farmer's rice field, $\prod^{TN}$ the profit per area from rice production irrigated by the tank, $\prod^{WL}$ the profit per area from rice production irrigated by a well in the command area of the tank, and r is the discount rate. The profit per area by tank irrigation is declining at the rate $1 - \theta + g(nm)$, where θ is the physical rate of deterioration inherent to the tank and g is the effect of maintenance/rehabilitation activities on the rate of deterioration. We assume that θ is a fixed number between 0 and 1, and without any maintenance/rehabilitation activities the profit per area by tank irrigation is decreasing every period at the rate of $1 - \theta$. If farmers are conducting maintenance/rehabilitation activities, $g(\cdot)$ will be a positive number, which is a function of the product of m (each farmer's contribution to the maintenance/rehabilitation activities) and n (total number of farmers). In this model, the number of farmers participating in the maintenance/rehabilitation and the amount of each farmer's contribution are assumed to be exogenously determined and constant between period 0 and T. These assumptions are plausible since such activities are decided at community level. If $1 - \theta + g(nm) \geq 1$ holds, it means that the profit per acre is not decreasing over time. This could be possible in a short period of time, but we assume in the model that $1 - \theta + g(nm)$ is fixed at between 0 and 1 because the performance of tank irrigation is declining over time on average, even if farmers conduct maintenance/rehabilitation activities. That is, the effect of maintenance/rehabilitation is only to retard the inherent rate of deterioration.

The amount of investment required to install a private well is given by I in the model.[4] The cost of constructing a well depends on ground water conditions in the tank command area, and therefore is assumed to be exogenous to the farmer. After period T, the farmer uses water from his/her private well but also from the tank if tank water is still available, and the profit from rice production becomes $h(w, l, \mathbf{X})A\prod^{WL}$. The function $h(\cdot)$ is the factor determining the performance of well irrigation, which depends on w (the number of wells in the command

[3] Villages on the list are the smallest administrative unit, which is called 'panchayat'. Some villages consist of several hamlets. The numbers of villages on the list are: 562 in Madurai, 426 in Ramnad, 448 in Virudhunagar, and 499 in Sivagangai. We consider that villages are evenly distributed among the four districts.

[4] Actually, it is not necessary to invest in a private well in order to utilise well water for irrigation because farmers can purchase well water from well owners. However, we ignore such a water market in the model for simplicity. In fact, no farmer purchased well water in our sample. A water market does exist, but transactions are not very common in the tank-irrigated region of Tamil Nadu. According to Palanisami et al. (1997), only 38 of 828 sample farmers, spread over 138 tanks, purchased well water for rice production.

area), l (the number of farmers participating in tank maintenance/rehabilitation activities after period T), and $\mathbf{X}$ (a vector of the farmer's/household's characteristics). Because the density of wells (the number of wells per area in the tank command area) negatively affects the performance of each well, we assume $h_1 = \partial h/\partial w < 0$. On the other hand, if tank rehabilitation/maintenance continues after period T, farmers with private well irrigation also benefit from tank water, and hence we assume $h_2 = \partial h/\partial l > 0$.

The optimal timing of investment in a well is obtained by differentiating Eq. (1) with respect to T as follows:

$$\frac{\partial V}{\partial T} = \left\{A \prod^{TN}(1-\theta+g(nm))^T - m\right\} \mathrm{e}^{-rT} + rI\,\mathrm{e}^{-rT} - h(w,l,\mathbf{X})A\prod^{WL}\mathrm{e}^{-rT} = 0 \quad (2)$$

where the first term is the marginal benefit from rice production with tank irrigation, and the second and the third terms are the marginal benefit from rice production with a private well. The optimal timing is derived by equating these two marginal benefits, and depends on all the exogenous variables in Eq. (2). If all the farmers in the command area have the same characteristics, the optimal timing of investment in a private well will be the same for all, that is, all farmers will invest in wells in the same period. This is unlikely because farmers are not homogenous. However, even if they were homogenous, not all farmers would invest in wells at the same time if we consider game-theoretic, strategic behaviour among farmers, which we show as follows.

Let us consider a random matching of farmer i and farmer j out of a homogenous group of n farmers cultivating in the command area of a tank. Each has two strategies at period T: one is to participate in tank maintenance/rehabilitation and use tank water, and the other is to invest in a well and use well water. Note that in the latter case the well user can also use tank water if the other farmer maintains the tank. The payoff matrix of the combinations of the two strategies is shown in Fig. 1, where a is the payoff when both i and j use tank water; b is the payoff to a tank user when the other invests in a well; c is the payoff to a well user when the other uses the tank; and d is the payoff when both i and j invest in wells. Based on Eq. (1),

		Farmer *j*	
		Tank	Well
Farmer *i*	Tank	a , a	b , c
	Well	c , b	d , d

Fig. 1. Payoff matrix of the irrigation game.

the payoffs are given as follows:

$$a = A\prod^{TN}(1-\theta+g((p+2)m))^T - m$$

$$b = A\prod^{TN}(1-\theta+g((p+1)m)^T - m$$

$$c = -rI + h(q+1, p+1, \mathbf{X})A\prod^{WL}$$

$$d = -rI + h(q+2, p, \mathbf{X})A\prod^{WL}$$

where p is the number of farmers using tank water and q the number of farmers using well water except for the two farmers, i and j. If there is no strategic behaviour among farmers, all the farmers will optimise the present value by investing in wells at the same period as discussed above, and hence we should have $w = n$ and $l = 0$ in the last term of Eq. (2). That is, all farmers will have wells and none will continue tank rehabilitation/maintenance activities. Therefore, Eq. (2) will be rewritten as

$$\frac{\partial V}{\partial T} = \left\{A \prod^{TN}(1-\theta+g\,(nm))^T - m\right\} \mathrm{e}^{-rT} + rI\,\mathrm{e}^{-rT} - h(n,0,\mathbf{X})A\prod^{WL}\mathrm{e}^{-rT} = 0 \quad (2')$$

From Eq. (2′), the following inequality is obtained under the assumption concerning the functions g and h, i.e. $g' > 0$, $h_1 < 0$, and $h_2 > 0$:

$$a < A\prod^{TN}(1-\theta+g(nm))^T - m = -rI + h(n,0,\mathbf{X})A\prod^{WL}\mathrm{e}^{-rT} < c \quad (3)$$

In addition, $b < a$ and $d < c$ hold under the same assumption for the functions g and h. Hence, we have

$b < a < c$. However, the position of d in this inequality is not determined. There are three possible cases as follows.

1. $b < a < d < c$
   This is the case where well irrigation is always more profitable than tank irrigation regardless of the number of wells in the command area. Therefore, investing in a well is the unique dominant strategy. This will happen when tank performance is very low, and generates the prediction that all farmers will have wells in the end.
2. $b < d < a < c$
   In this case, the profit when both farmers use tank irrigation is greater than that when both farmers rely on well irrigation ($d < a$). But if one of the farmers invests in a well, that farmer's profit will be greater than that when both use tank irrigation ($a < c$), and the other who continues using tank water, will have lower profit than when both use well water ($b < d$). That is, the tank user will have the worst payoff if the other invests in a well. This is a well-known prisoners' dilemma game, and the unique Nash equilibrium is that both invest in a well. If this is the case, although collective tank management provides the socially optimal outcome, farmers tend to deviate from the collective action to invest in a private well. Hence, eventually the tank will be abandoned.
3. $d < b < a < c$
   This case is similar to case (2) except for the inequality $d < b$. Unlike case (2), the farmer who continues using tank still has better payoff than when both use well water. That is, when both use a well, the payoff is the worst. This is the so-called chicken game, which has three Nash equilibria (Ostrom et al., 1994). Among the three equilibria, two are pure-strategy Nash equilibria in which one farmer uses tank water and the other uses a well. The third is a mixed-strategy equilibrium in which each farmer randomises his/her strategies between tank and well, and the probability of investing in a well is given by $(c - a)/(c - a + b - d)$ in equilibrium. Although there are three Nash equilibria, the two pure-strategy equilibria are not evolutionary-stable, unlike the mixed-strategy equilibrium (Maynard Smith, 1982; Weibull, 1995). This implies that considering a group of rice cultivators, the proportion of tank users and well users will evolve to this equilibrium. Who will be well users and who will be tank users in the group will be determined by chance or will depend on factors other than rice production.

The analysis based on the model above implies that not all farmers will have a private well in the long-run even if we assume a homogenous group of farmers. In addition, there will be cases where tanks and wells can coexist stably. As discussed above, it depends on the relative profitability of the two irrigation systems.

4. Empirical analysis

To examine the relative profitability of the two irrigation systems, we estimate a profit function for rice production using the data collected in our household survey. Out of 72 households surveyed over 12 villages, 60 households cultivate a plot in a tank command area to produce rice. Note that they are not sharing the same tank, and hence it is possible to have diversity in the household sample in terms of the source of irrigation water and to utilise village level variables such as well density and wage rate. Among 60 rice producers, 38 households use tank water only, 16 households use well water only, and 6 households use both.

Table 1 presents the characteristics of surveyed 12 tanks. Half of them are managed by the Tamil Nadu state government, and the other half are managed by the authority of each village. In the four districts we selected, there are 1651 state managed tanks and 8188 village managed tanks in total (Palanisami et al., 1997). Thus, the proportion of state-managed tanks is higher in our sample than in the population. This is because we selected the most important tank in each village, which tends to be large and managed by the state.[5] As expected, most tanks could not supply enough water to irrigate the whole command area in

[5] In the process of land reform, tanks whose command area was more than 40 ha came under state-control, and tanks whose command area was less than that came under village-control. Although the sizes of the command areas have changed since then, state-managed tanks tend to have much larger command areas than village-managed tanks even today.

Table 1
Characteristics of sampled tanks

District	Sivagangai			Ramnad			Madurai			Virudhunagar		
Village ID	A	B	C	D	E	F	G	H	I	J	K	L
Responsibility for tank management	Village	State	State	State	State	Village	State	Village	Village	State	Village	Village
Number of households using the tank in question	350	200	60	100	206	16	70	N.I.[a]	5	30	75	50
Number of villages sharing the tank in question	5	1	5	1	3	1	3	3	1	1	10	1
Water users association	No	No	Yes	No	Yes	No	Yes	No	No	Yes	Yes	No
Size of tank command area (ha)	50	75	120	235	183	41	146	61	4	47	122	18
Area irrigated in the past 6 years (% of command area)	57	67	0	33	59	61	48	87	70	67	100	56
Number of wells in the tank command area, currently	7	5	15	0	0	0	15	6	6	50	1	7
Number of wells in the tank command area, 10 years ago	0	2	3	0	0	0	10	0	3	5	1	7
Number of maintenance/rehabilitation activities in the past 6 years	6	2	0	0	0	0	0	0	1	4	6	1

[a] N.I. stands for no reliable information was available.

Table 2
Characteristics of sampled households[a]

Irrigation source	Tank only	Well only	Both
Number of households	38	16	6
Size of rice field (acre)	2.1 (2.1)	1.2 (0.8)	1.6 (1.7)
Age of household head	48 (12)	50 (12)	44 (15)
Years of schooling of household head	5.9 (4.4)	4.1* (3.5)	9.3* (5.1)
Number of household members	4.3 (1.7)	3.9 (1.5)	4.7 (1.6)

[a] Standard deviations are in parentheses.
* Statistically different at the 5% significance level.

Table 3
Revenues, costs and profits from rice production by irrigation source (Rs. per acre)[a]

Irrigation source	Tank only	Well only	Both
Profit	770 (1380)	−450* (1090)	730 (590)
Revenue	1630 (1300)	1530 (600)	1850 (430)
Expenditure			
Ploughing	32 (96)	39 (50)	25 (39)
Fertiliser	220 (190)	280 (220)	240 (120)
Seed	91 (67)	170* (83)	79 (25)
Transplanting/broadcasting	71 (120)	120 (49)	56 (51)
Weeding	290 (390)	160 (110)	170 (100)
Insecticide	36 (91)	35 (40)	15 (10)
Water management	120 (160)	1040* (1050)	460 (420)
Water fee/pump cost	0.90 (3.8)	140* (250)	78 (63)

[a] Standard deviations are in parentheses.
* Statistically different from the others at the 5% significance level.

the past 6 years; the percentage of area irrigated in the total command area ranges from 0 to 100%, and equals 59% on average. On the other hand, the number of wells in the command area has increased in the past 10 years in the majority of cases. These findings roughly support the premise of our model that declining tank performance has induced investment in private wells. In 6 tanks out of the 12 surveyed, maintenance/rehabilitation activities were undertaken by farmers and/or employed labourers in the past 6 years. However, from our limited sample, it is not clear if such activities have had any significant effect on tank performance or on investments in private wells. In short, the 12 tanks have enough diversity in terms of tank performance, number of private wells, and maintenance/rehabilitation activities. This cross-sectional diversity in the data set is important for our empirical analysis, where no time series data is available.

Characteristics of sampled rice cultivators by irrigation sources are shown in Table 2. As expected, the average size of rice fields irrigated by tank alone is larger than for the other cases, but the difference is not statistically significant. On the other hand, "years of schooling of household head" is significantly longer for farmers using both water sources than for farmers using a well only. The reason for this is unknown, but it may reflect the fact that household heads using both water sources are younger on average than those using wells only, although the difference is not statistically significant. Except for this, there is no significant difference among the three types of rice cultivators. Hence, we consider that the choice of irrigation sources is largely determined by village/tank level factors and is exogenous to each household.[6]

[6] This assumption does not contradict the household model we presented in Section 3, in which a household selects irrigation sources, because our sample households are from 12 tanks diversified in terms of tank performance as well as number of wells. If we observed declining tank performance and an increasing number of wells for a single tank over a long period, the choice of irrigation sources would be endogenous.

Table 4
Estimated profit function[a]

	Coefficients
Household variables	
Constant	8260 (4250)**
Dummy for farmers using only well (WELL)	3600 (1840)*
Dummy for farmers using only tank (TANK)	3920 (1910)**
Size of rice field (acre)	268 (124)**
Size of household (number of household members)	−157 (73)**
Age of household head	−229 (129)*
Age of household head squared	2.30 (1.26)*
Years of schooling of household head	24.8 (31.6)
WELL × well density	−45600 (20700)**
TANK × well density	−45100 (20800)**
Village variables	
Well density in tank command (no./ha)	44700 (20900)**
Wage rate for male (Rs. per day)	−460 (209)**
Wage rate for female (Rs. per day)	109 (109)
Price of chemical fertiliser (Rs./kg)	−405 (503)
R^2	0.49
Number of sample	60

[a] Dependent variable is profit in Rs. per acre deflated by the farm-gate price of paddy. Standard errors are in parentheses.
* 10% significance level.
** 5% significance level.

Table 3 compares profit per acre among these three types of rice farmers on average, where all figures are deflated by the rice price observed in each village. As shown in the table, production per acre does not differ among the three, but the cost of production does. The cost of seed and the cost of water (management labour and water fee/pump maintenance costs) are higher for farmers using only well water. Although the other costs do not differ significantly among the three types of farm, high seed and water costs reduce the average profits of well users significantly compared with others. Most wells in the study area are equipped with an electric pump, but electricity for agriculture use is free of charge in Tamil Nadu. Moreover, the initial investment in a well is considered to be a sunk cost and accordingly is not included in the calculation of short-run profit presented in the table. Therefore, the high cost of well irrigation is not due to electricity or investment but due to household labour input to control water. Note that the cost figures in the table include household labour evaluated at the market wage in each village. Thus, this labour cost is not actually paid by well users, but it indicates the inefficiency of private well irrigation relative to tank irrigation.

In order to identify the determinants of the profits per acre shown in Table 3, and particularly to examine the effect of irrigation sources on profit, we estimate a profit function. The result of OLS regression analysis is presented in Table 4. We assume that the type of irrigation is predetermined in the short-run and hence is exogenous to farmers. We add a variable for well density in the tank command area and interaction terms with the variables for irrigation type since well density may affect the performance of well and tank irrigation as discussed in the Section 3. Regarding household variables, most of the results are as expected. The area of the rice field has a positive significant effect on the profit per acre, which suggests that there are economies of scale. This may be explained by the inefficiency of labour use in water management in a small field, that is, labour input cannot be adjusted to field size if it is small. The number of household members has a negative coefficient, probably because large households tend to be diversified in income sources to non-agricultural activities

Table 5
Effect of irrigation source and well density on profit (Rs. per acre)[a]

	Coefficient	S.E.	Significance level (%)
Effect of well only use	−33330	15000	5
Effect of tank only use	−3760	1710	5
Effect of well density when well use only (no./ha)	−857	378	5
Effect of well density when tank use only (no./ha)	−419	652	Not significant

[a] Based on the estimates shown in Table 4.

Table 6
Irrigation source and relative profitability (Rs. per acre)[a]

Profit difference	Estimated value	S.E.	Significance level (%)
$c - a$	7890	3660	5
$b - d$	905	331	1
$a - b$	111	172	Not significant
$(c - a)/(c - a + b - d)$	0.90	0.056	1

[a] The variables *a*, *b*, *c*, and *d* are the payoffs for each strategy. See figure for explanations.

and consequently allocate fewer resources to farming. The estimated coefficients for the age of household head and its squared term imply that rice production by younger household heads are more profitable but that this effect diminishes as household heads age. Contrary to expectation, the education level of the household head is not estimated to have a significant effect on profit. As for village variables, the male wage rate decreases the profit, while the female wage rate has no effect. Since transplanting and weeding are usually done by females, while water management is a male job, these results are consistent with the results of Table 3 that labour input for water management negatively affects profitability. The price of chemical fertiliser has no significant effect on the profit per acre. [7]

The coefficients for the variables irrigation type, well density, and their interactions are statistically significant. The effects of irrigation type and well density can be calculated using the estimation results in Table 4. As shown in Table 5, those who use well only have significantly lower profit than the others. In addition, those who use tank only have significantly higher profit than those who use well only but significantly lower profit than those who use both water sources. When a farmer uses well water only, one additional well per hectare decreases his/her profit per hectare by Rs. 857, but when a farmer uses tank water only, additional wells have no significant effect on his/her profit. These results imply that the inequality $d < b < a < c$ holds, and therefore the structure of the payoff matrix is a chicken game as discussed above. Based on the estimated coefficients, the relative profitability in Rs. per acre for average levels of household characteristics is calculated as $c-a = 7890$, $b-d = 905$, and $a - b = 111$ as shown in Table 6. Using these numbers we obtain 0.90 for $(c - a)/(c - a + b - d)$, that is, the percentage of well users will be 90% in equilibrium. Note that these well users use tanks also, since tanks are available at the equilibrium, and that no one will be better off if he uses wells only. Also note that the choice of irrigation source is determined by factors other than the economics of the rice sector, such as by chance, inertia, etc.

Because the percentage of well users is 37% at present, this result predicts that private wells will increase in the future. Since the relative profitability suggests a chicken game as discussed, it is predicted that

[7] The profit function is also estimated separately for each type of irrigation source: tank only and well only. The cases of using both irrigation sources are too few (six households) to allow separate estimation. As shown in Appendix A, variables for household characteristics do not have significant effects on the profit. Rather, the profit is determined by village level factors.

tank users and well users will coexist at the equilibrium.

5. Conclusion

This study compares the efficiency of rice production between tank irrigation and well irrigation systems in order to explore an appropriate management scheme for water, a local common property good. Our results suggest that the privatisation of irrigation water by wells is more costly than using tanks, since private wells require more labour input for irrigation management, although rice production per acre does not differ between the two systems. Nevertheless, farmers will invest in wells as long as there are others managing tanks, and tank water is available, since the combined use of tank and well water is most profitable. Thus, our analysis indicates that producers will in effect play the 'chicken game', so that neither tanks or wells will dominate the supply of water. Both will coexist in an evolutionary-stable equilibrium.

Using the estimation results of the profit function, it is calculated that about 90% of farmers will use wells in equilibrium. Considering that well users are only 37% at present, the number of wells will increase in the future. A policy implication of this result is that tanks should be maintained in spite of the increasing adoption of private wells, but at the same time investment in private wells should not be discouraged, but rather promoted so that the two irrigation systems can coexist. What is needed is to develop institutions for maintaining tank irrigation while promoting private well irrigation.

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Appendix A

Estimated profit functions for individual irrigation sources are given in the following table. Dependent variable is profit in Rs. per acre deflated by the farm-gate price of paddy. Standard errors are in parentheses. Asterisks (**) and (*) indicate 5 and 10% significance level, respectively.

Irrigation source	Tank only	Well only
Household variables		
Constant	15600 (7860)*	12.0 (13700)
Size of rice field (acre)	280 (143)*	417 (345)
Size of household (number of household members)	−143 (102)	−262 (681)
Age of household head	−226 (179)	−209 (388)
Age of household head squared	2.22 (1.75)	2.18 (3.90)
Years of schooling of household head	19.6 (38.0)	−3.55 (79.6)
Village variables		
Well density in tank command (no./ha)	−765 (733)	−1620 (681)*
Wage rate for male (Rs. per day)	−504 (283)*	−1050 (283)**
Wage rate for female (Rs. per day)	52 (166)	469 (546)
Price of chemical fertiliser (Rs./kg)	−446 (299)	1860 (892)*
R^2	0.35	0.74
Number of sample	38	16

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