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Economics of Groundwater Irrigation in Nepal: Some Farm-Level Evidences

Humnath Bhandari and Sushil Pandey

This article examines the economics of groundwater irrigation and shallow tubewell (STW) ownership decision making, using farm-level data collected from 324 households in Nepal. STW irrigation generated a significant positive effect on rice yield and farmers' incomes. Based on a probit model, the farm size, land fragmentation, access to electricity, and access to credit were found to significantly influence farmers' decisions to own STWs. Although the water market benefited poor farmers, it is too small and monopolistic. Policy reforms needed to make groundwater accessible to the poor majority include effective credit programs, investments in rural electrification, and public sector support for promoting suitable pumping technologies.

Key Words: groundwater irrigation, probit model, shallow tubewell

JEL Classifications: C25; O33

Irrigation is a key input to agricultural growth. Rapid spread of the Green Revolution in Asian countries was largely facilitated by an expansion of surface irrigation. However, the increasing costs, long gestation period, and concerns about potential negative environmental effects of large-scale surface irrigation schemes have constrained the expansion of the area under surface irrigation in recent years (Dhawan; Rosegrant, Cai, and Cline). In Nepal, surface irrigation schemes provide supplemental irrigation during the wet season to only 40% of the net sown area. As a result, much of the agricultural production occurs mainly under rainfed conditions.

Groundwater (GW) irrigation offers a po-

tentially viable alternative to surface irrigation because of its limited capital requirement and low recurring cost. In addition, farmers can better control the use of GW for a more timely supply of water relative to the surface-water schemes (Bhandari; Shah). With its rich reserve of GW, Nepal could benefit substantially from irrigation based on this source of water.

GW can be extracted through different technologies. These include deep tubewells, dug wells, artesian wells, and shallow tubewells (STW). In areas where the GW table is high, STW¹ can be effective mechanisms for water extraction. Small landholding, high land fragmentation, undulating and rough topography, and limited capacity of farmers to invest in other types of wells favor the use of STWs for water extraction (Koirala; Shah). In addi-

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¹ A STW is a well, drilled to extract subsurface water through a pump. In Nepal, wells of 2–4 inch diameter are drilled up to a depth of 40 m to extract water by pump. Electric-operated pumps of 1–1.5 hp and diesel-operated, centrifugal pumps of 5–10 hp are used to pump water from these shallow wells.

tion, the evolution of the GW market has increased the access to water by small holders who find their farms to be too small for the investment in shallow tubewells to be viable. As a result, the use of STWs has expanded rapidly in the Indo-Gangetic plains. Following this broader trend in the region, the government of Nepal has also initiated programs to facilitate the expansion of STWs in the southern plains (or Terai), which is the major food basket of the country.

The Terai (or the southern plain belt) of Nepal has a large potential for exploiting shallow and deep aquifers (Kayastha). It has been estimated that 6 billion m³ could be safely extracted for multiple uses, and more than 600,000 hectares could be irrigated using GW resources (CMS). The Agricultural Perspective Plan (APP) of Nepal, which is a 20-year agricultural development guideline, has emphasized GW as a cost-effective and environmentally sound alternative source of irrigation in the Terai of Nepal.

The current rate of STW installation in Nepal is about 3,000 units per year, in contrast to the target of 8,000 units per year (APP). By 1995, about 400 deep tubewells (DTW)² and more than 37,000 STWs were installed in the Terai, irrigating about 168,000 hectares, which accounts for 19% of the irrigated area (APP). According to APP, the total GW-irrigated area could be increased from 107,000 hectares in 1991–1992 to 612,000 hectares at the end of year 2014. The Terai could sustain over 300,000 STWs (WI). APP envisaged an investment of U.S.\$298 million in irrigation by the year 2014, and about 90% of this investment is targeted for STW. However, the current rate of installation of STWs is too slow to meet this target by 2014.

Despite the importance of GW in Nepal, very few studies (Kayastha; Koirala; Upadhyay) have been conducted to assess the economics of GW use and to identify constraints that have so far limited the expansion of GW use in Nepal. The objectives in this study were

to analyze those aspects of GW use in Nepal through the use of farm-level data.

The article is organized as follows. Methodology and data used are presented in the first section. A descriptive analysis of the production system and the characteristics of STW are subsequently provided. This is followed by an assessment of the productivity effect of STWs. Factors that condition the ownership of STWs are then identified using econometric tools. Implications for the expansion of GW use are discussed in the final section.

Analytical Framework

To have access to GW, it is not essential for farmers to own the STW. They can also obtain water by purchasing from farmers who have STWs.³ Thus, a farmer may be an owner of a STW, a nonowner but a water purchaser, or someone who does not use GW at all. The latter category of farmers may use other sources of irrigation (such as a canal) or grow crops under rainfed conditions. The distinction between an owner and a nonowner of STW is important because the owner has the first access to water. Water is normally sold only after the owners of STWs have satisfied their need for water (Pant; Singh). Whenever water needs for crops are high because of drought or a break in the rains, owners normally irrigate their crop first, before selling the remaining water. In this sense, the water market is a “residual” market. Relative to the owners, water purchasers are, hence, likely to face a less-reliable supply of water. This implies that the owners are likely to realize greater benefits from irrigation. Thus, the ownership of an STW is an important variable to consider. The term “ownership” is used synonymously in this article with “adoption” of STWs.

For estimating the economic impact of STW ownership, various performance indicators need to be compared against a benchmark level. Here, two types of benchmarks are used:

² DTWs are used to extract water from lower depths (more than 40 m). Their discharge ranges from 25 L per second up to 100 L per second.

³ Farms of water buyers are adjacent to those of water sellers in the majority of cases. Earthen channels are mostly used for water transfers; use of polyvinyl chloride (PVC) plastic pipes is limited.

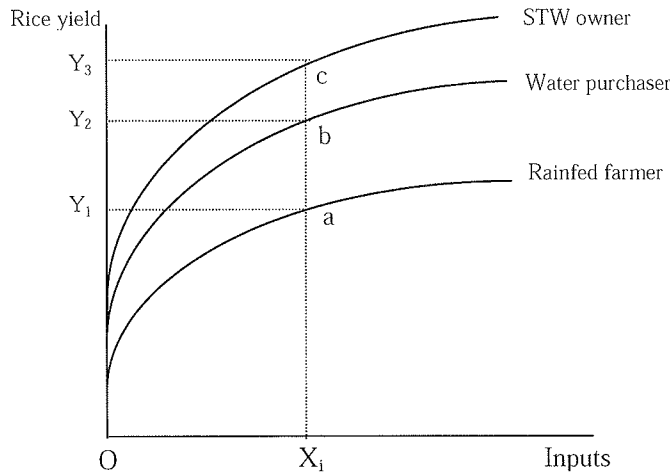


Figure 1. Hypothesized Effect of Shallow Tubewell Irrigation on Rice Production

one based on water purchasers and the other based on rainfed farmers. A comparison of economic benefits obtained by STW owners and water purchasers provides an estimate of the differential effect of ownership. A comparison of economic benefits of owners of STW and rainfed farmers provides an estimate of the economic value of assured irrigation.

The economic impact of ownership of STWs is estimated in two ways. First, the effect of STW ownership on the productivity of rice is estimated using a production function. This production function is compared with the production function for purchasers of water from an STW and also with that of rainfed farmers. The effect of STWs on crop productivity can be measured as a shift in the intercept or in the slope coefficients of the input variables (Figure 1). A significant difference in the intercept or slope coefficients for the owners of a STW, relative to purchasers of water from a STW (or relative to rainfed farmers, as the case may be) would lead to the rejection of the null hypothesis that crop productivity does not vary across these farmer categories. Second, net returns from investments in STWs are compared with net returns obtained by water purchasers and rain-fed farmers. Net returns are defined as gross returns minus the paid-out costs, which include the cost of STWs. Because STW is a piece of durable equipment, its annual contribution to production is estimated as the sum of depre-

ciation and the opportunity cost of capital invested as well as the operation and maintenance costs.

A Cobb-Douglas production function as specified in Equation (1) was used to model the productivity effects.

$$(1) \quad \ln Y_j = \alpha + \sum_{i=1}^{10} \beta_i \ln X_{ij} + \sum_{k=1}^2 \beta_k X_{kj} + \varepsilon_j$$

where X_i is the continuous, independent variable; X_k is the dummy independent variable; α and β are the parameters to be estimated; and ε is the disturbance term. The dependent variable Y_j is the whole farm yield of rice for the j th household. The continuous independent variables are defined as X_{1j} , labor (person day/ha); X_{2j} , chemical fertilizer in terms of nitrogen, phosphorus, and potassium (NPK; kg/ha); X_{3j} , farm-yard manure (kg/ha); X_{4j} , rice seed (kg/ha); X_{5j} , cost of plant protection (U.S.\$/ha); X_{6j} , farm power measured in terms of tractor-hours (h/ha); X_{7j} , rice area under modern varieties (MV; %); X_{8j} , farm size (ha); X_{9j} , STW water use measured as the hours of STW irrigation use (h/ha); and X_{10j} , area under a rainfed condition (%). The dummy independent variables are defined as X_{1j} , dummy for tenure status (1 for owner *cum* tenant, 0 otherwise); and X_{2j} , dummy for study region (1 for western region, 0 otherwise).

The specific farm decision being modeled here is whether or not to "own" a STW. This

is a discrete binary choice facing a farm household.⁴ Following the adoption literature (Feder, Just, and Zilberman; Foltz; Isham), a probit model was used to diagnose the factors that condition the ownership of STWs. Theoretically, let y^* be the unobserved, underlying stimulus index of tubewell ownership, and y be the observed choice. Thus, the probit model is defined as

$$(2) \quad y^* = x'\beta + u$$

$$y = \begin{cases} 1, & \text{if } y^* > 0 \\ 0, & \text{otherwise} \end{cases}$$

where x is a vector of exogenous or predetermined variables; β is a vector of parameters; and $u \sim IN(0, \sigma^2)$. The probit model assumes that the ownership is a function of a latent variable, and ownership is observed only when the latent variable exceeds the individual-specific threshold value. The latent variable is assumed to be a function of farm and household characteristics. The explanatory variables specified in the model are the same as those presented in Table 6. The marginal effects for any continuous variable, x_i , is estimated as

$$(3) \quad \frac{\partial \hat{p}(y = 1 | x)}{\partial x_i} = \phi(x'\beta) \beta_i$$

where $\phi(x'\beta)$ is the standard normal density. For any dummy variable x_k , the partial marginal effect of changing x_k from zero to one, holding all other variables fixed, is defined as

$$(4) \quad \Phi\left(\sum_{j \neq k} x_j \beta_j + \beta_k\right) - \Phi\left(\sum_{j \neq k} x_j \beta_j\right)$$

where $\Phi(x'\beta)$ is the standard normal cumulative distribution function.

The installation of tubewells requires a large initial investment, and large farmers may be in a better financial position to make such investments. In addition to being able to

spread the cost over a larger area, large farmers may also be better positioned to make more gains because of their better ability to invest in complementary inputs such as fertilizers. Thus, the effect of farm size on tubewell ownership is expected to be positive. Farm size is taken here as an exogenous variable because the adoption of a tubewell is too recent in the study area to have influenced the farm size through the capital accumulation process.

For a given farm size, farmers with highly fragmented holdings are less likely to invest in a STW because a single device cannot service a fragmented holding. Moving pumps around frequently may also cause early breakdowns, and that entails more cost. Such farmers are, hence, likely to rely more on the water market for irrigation than on owning their own pumps. Education, age, gender of the household head, and caste of the household are some other potential explanatory variables. Education and age reflect the possible effect of human capital, whereas gender and caste reflect the social variables that may work to the disadvantage of female-headed households and households belonging to a lower caste.

STWs can be operated using either electricity or diesel. However, the cost of operation is substantially lower for electric-powered STWs (Shah). Thus, access to electricity is expected to make the ownership of STWs more likely. For large investments such as STWs, access to institutional credit is also likely to be an important variable.

During the farm survey, STW owners were found to have a proportionately larger area under modern rice varieties and under vegetables. Farmers mentioned that they were motivated to install STWs to be able to expand the area under modern varieties (MV) of rice and vegetables. This indicates that the "planned" area of MV of rice and vegetables could have affected the decision to invest in STWs. "Planned area," is, however, unobservable in *ex post* surveys, such as the one conducted in this study. Actual area may be substituted for the planned area under the assumption that the ownership of STWs permitted farmers to expand the actual area until it was equal to the

⁴ For farmers who decide not to own a STW, another decision variable that could be considered is the purchase of water. However, given the objective of this study, that decision was not modeled in the article.

planned area. However, it may also be argued that the observed area under MV of rice and vegetables are endogenous variables, and their values are determined simultaneously with the decision to acquire STWs. The estimation of the probit function in this case would require a simultaneous equation model consisting of one dichotomous variable and two continuous, endogenous variables. To get around the econometric difficulties involved, a simplified instrumental variable approach was employed (Chun and Oh; Newey). This involved estimating separate equations for the area under MV of rice (AMVR) and the area under vegetables (AVEG) first and substituting the predicted values of these variables as instruments into the probit equation. The models for AMVR and AVEG were specified as follows:

$$(5) \quad AMVR = f(EDU, AGE, TRNG, FSZ, CRDT, EXT, CST, TNC, STE)$$

$$(6) \quad AVEG = f(EDU, AGE, FSZ, CRDT, EXT, CST, SCATL, ACES, TNC, STE)$$

where *EDU* is the education of household head (yr); *AGE* is the age of household head (yr); *TRNG* is training of household head in farming (days); *FSZ* is farm size (ha); *CRDT* is a dummy for access to formal credit for agriculture (1, easily available; 0, otherwise); *EXT* is a dummy for extension contact (1, if extension agent visits weekly or fortnightly; 0, otherwise); *CST* is caste of household (1, if upper caste; 0, otherwise); *TNC* is a dummy for tenure status (1, for owner *cum* tenant; 0, otherwise); *STE* is a dummy for study region (1, for western region; 0, otherwise); *SCATL* is a dummy for a stray cattle problem (1, if farm has a stray cattle problem; 0, otherwise); and *ACES* is a dummy for access to road and market (1, if farm has easy access; 0, otherwise). The estimated equations are presented in Appendix 2.

Data Source

The study is based on primary data collected by the senior author from two Districts in the Terai of Nepal-Sarlahi in the Eastern region,

and Banke in the Western region. Four village development committees (VDCs) in each District were selected randomly for the detailed household survey. The purposively stratified sampling design was used to select the farmers. Farmers were first divided into two strata, namely STW owners and nonowners. STW owners were defined as those who have installed at least one tubewell for irrigation, and nonowners were those who do not own an STW. STW-nonowner farmers were further classified into water purchasers and rainfed farmers (nonpurchasers). Water purchasers are those farmers who do not own the tubewell but have access to groundwater through water markets. The sampling units were selected randomly from these three different strata for the household survey.

The sample size consisted of 324 farmer-respondents comprising 162 STW owners, 129 water purchasers, and 33 rainfed farmers. Farm-level data on input use as well as cost and returns of rice production, STW characteristics, operation of GW markets, and farmers' perceptions regarding advantages of STW ownership were collected from these respondents for the crop year 1997–1998 using semi-structured interview schedules. Focus-group discussions were conducted to collect the qualitative information. In addition, secondary information was collected from different government agencies to supplement the primary data.

Characteristics of Production System and Shallow Tubewell

Socioeconomic Characteristics

The basic characteristics of the production systems in these two locations are summarized in Table 1. Rice, wheat, and maize are the dominant cereal crops in both sites. Cotton, pulses, and vegetables are important cash crops in the western region; jute, tobacco, sugarcane, and vegetables are dominant in the eastern region. The average farm size is relatively higher in the western region as compared with eastern region, but the percentage of irrigated area and household income is

Table 1. General Characteristics of Production System in the Study Area

Features	Banke (West)	Sarlahi (East)
Average annual rainfall (mm)	1,250	1,600
Farm size per household (ha)	1.37	1.14
Farming household (%)	68	78
Average number of parcels (no./household)	3.7	3.6
Irrigated area (% of total cultivated area)	21	43
Average parcel size (ha)	0.37	0.32
Average household gross income (U.S.\$/yr)	229	358
Marginal and small farms ^a (%)	81	63
Medium farms (%)	11	21
Large farms (%)	8	16
Major crops	Rice, wheat, maize, pulses, oilseeds, cotton, and vegetables	Rice, wheat, maize, oilseeds, sugarcane, jute, tobacco, and vegetables

^a Farm households were classified into four groups according to their landholding: marginal (≤ 1.02 ha), small (1.03–2.71 ha), medium (2.72–5.42 ha), and large (> 5.42 ha).

higher in the eastern region. The sample from the western region had proportionately more marginal and small farmers as compared with the eastern region.

The socioeconomic characteristics of STW owners and nonowners are summarized in Table 2. Irrigation from an owned STW accounted for 70% of the cultivated area of STW

Table 2. Socioeconomic Characteristics of Shallow Tubewell Owners and Nonowners^a

Variable	STW Owner	STW Nonowner	
		Water Purchaser	Rainfed Farmer
Family size (no.)	11.7	8.6	9.4
Education of household head (yr)	5	3	1
Age of household head (yr)	51	47	46
Farm size (ha)	4.6	1.5	1.2
No. of land parcels (no./ha)	1.1	2.8	3.0
Rice yield (t/ha)	3.93	3.08	2.10
Cropping intensity (%)	232	214	193
Labor (person days/ha)	164	170	156
Chemical fertilizer (NPK) (kg/ha)	72	46	17
Cultivated area of rice under MV (%)	87	59	31
Cultivated area under vegetables (%)	11	9	4
STW water use (h/ha)	64	46	0
Source of irrigation (%area)			
Canal Irrigation	5	6	1
Own STW	70	0	0
Purchased water from STW	18	67	0
Rain-fed	7	27	99
Household category (%)			
Marginal	0	32	61
Small	35	58	39
Medium	41	9	0
Large	24	1	0

^a STW is shallow tubewell; NPK is nitrogen, phosphorus, and potassium; MV is modern varieties.

Table 3. General Characteristics of Shallow Tubewells (STWs)

Description	Figure
Modal size of pumpsets (hp)	8
Modal size of boring (cm)	10
Average irrigated area of 8-hp STW (ha)	2.4
Installation cost of diesel 8-hp STW (U.S.\$) ^a	585
Installation cost of 1.5-hp electric STW (U.S.\$)	365
Frequency of diesel-operated STW (%)	91
Life of diesel STW (yr)	19
Life of electric STW (yr)	14
Number of hours of STW use (h/yr)	624
Depth of boring (m)	15

^a 1 U.S.\$ = 75.10 Nepalese rupees.

owners. For nonowners but purchasers of STW water, 67% of the area was irrigated from purchased water. Thus, STW was the major source of irrigation for both owners and nonowners of STW. Nonowners of STWs and nonpurchaser farmers irrigated a very small area from canal water and grew rice mostly under rainfed conditions. Generally, STW owners grew modern varieties of rice in a proportionately larger area, applied more fertilizers, had a higher cropping intensity, and obtained a higher yield of rice than other categories of farmers.

The average farm size of STW owners was found to be higher (4.6 ha) than that of water purchasers (1.5 ha) and nonpurchasers (1.2 ha). Among STW owners, a majority (65%) of the farmers were found to be operating medium or large farms. Ninety percent of water purchasers and all nonpurchasers were found to be operating small and marginal farms. The ownership of STWs was, hence, skewed toward large farms, whereas small and marginal farmers were the majority of purchasers.

STW Characteristics

Although farmers were using different sizes of STWs, the 8-hp diesel-operated tubewell with a discharge rate of 12–15 L per second was found to be the most common (Table 3). It has the potential of irrigating 5 hectares if oper-

ated at full capacity. However, the average area irrigated from an 8-hp diesel STW was found to be 2.4 hectares during the wet season (June–October) and almost negligible during the dry season (November–May). Limited use of STW during the dry season is mainly because of a smaller cropped area and higher extraction cost associated with a lower water table. Farmers prefer electric STWs because of the small capital outlay required; the electric tubewell costs U.S.\$365, whereas the diesel tubewells cost U.S.\$585. In addition, electric tubewells have low operation and maintenance costs, and their size is more suited to small landholdings. Most commonly used electric tubewells had the capacity in the range of 1–1.5 hp, whereas the capacity of diesel tubewells was normally in the range of 5–10 hp. However, the limited availability of electricity in rural areas has constrained adoption of the electric STW. As a result, diesel tubewells were found to be more common, with 91% of the tubewells being diesel-operated. Only about 5% of households owned two STWs.

Features of Water Market

About 20% of STW owners and 80% of nonowners bought water, whereas 65% of STW owners sold water. A flat charge per hour of pumping was the most dominant system of water pricing, although the practice of charging on the basis of area irrigated or in the form of a share of harvested crop was also found occasionally. Where land is highly fragmented, farmers who sold water at one location also bought water at another location.

The average cost of GW extraction was estimated to be \$0.74 h⁻¹ and ranged between \$0.40–0.88 h⁻¹ depending on the factors associated with GW extraction.⁵ The variable

⁵ The per-hour fuel cost is estimated based on the average fuel consumption of 1.27 liter h⁻¹ and a fuel price of U.S.\$ 0.25 per liter. Annual repair and maintenance and lubricant cost was divided by the annual operation hours to get the per-hour cost. Because STWs were operated mostly by household members, the per-hour labor cost was computed as the opportunity cost of family labor. The capital cost of the pump

Table 4. Extraction Cost of Groundwater through Shallow Tubewell (STW)

Cost Items	Imputed Cost (U.S.\$/h)
Fuel cost	0.32
Repair and maintenance cost	0.03
Lubricant cost	0.01
Labor cost	0.21
Total variable cost	0.57
Fixed cost	0.17
Total cost of STW water	0.74

cost accounted for over 77% of the total cost (Table 4). The average selling price of water was found to be \$0.97 h⁻¹ with a range of \$0.73–1.17 h⁻¹. A comparison of extraction cost and the selling price of water indicates that water price is 33% higher than the cost of extraction. This indicates that there is an element of monopoly in the water market. This finding is consistent with the results of other studies on water markets in Nepal (KC; Koirala, Upadhyay). During the field survey, farm-

ers also indicated that the water price is basically set by the seller.

Economic Impact of STW Ownership

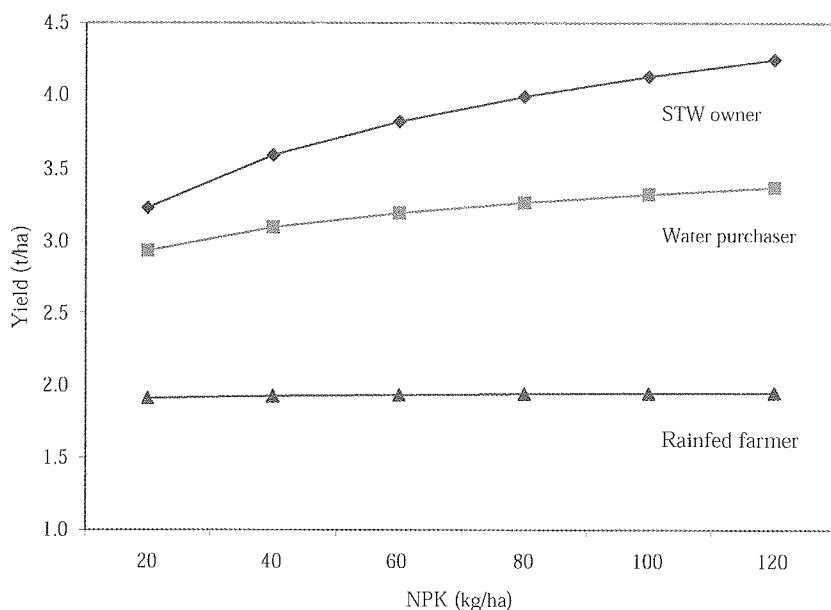
Advantages of STW Ownership

The nature of the benefits of STWs was elicited from STW owners, who were asked to list important benefits they perceived. Increased crop productivity and farm income (27%); regular and off-season vegetable production and crop diversification (19%); timely crop planting and irrigation (16%); assured irrigation and drought security (12%); adoption of improved variety of crops (10%); and higher cropping intensity (9%) were some of the major advantages of STW ownership reported by farmers. The cropping intensity of STW owners (232%) was significantly higher than that of water purchasers (214%) and nonpurchasers (Table 2). Irrigation from STWs helped raise the cropping intensity and yield for both owners of STW and water purchasers.

Productivity Effect of STW

The average rice yields of STW owners, water purchasers, and rain-fed farmers were esti-

was computed based on the annual depreciation cost and opportunity cost of capital invested in the STW. The hourly fixed cost was obtained by dividing the total annual fixed cost by hours of STW use per year.

**Figure 2.** Estimated Rice Yield Response to Chemical Fertilizer by Farmer Category

mated to be 3.9, 3.1, and 2.1 t ha⁻¹, respectively (Table 2). Thus, the average yield of STW owners was 25% and 86% higher than that of the water purchasers and rainfed farmers, respectively. Farmers considered a high degree of control and availability of dependable quantity and quality of irrigation water to be the main reasons for higher yields among STW owners. These differences in yields are the joint manifestations of the availability of irrigation, differences in input use, biophysical characteristics of the farm, and the overall crop management. *F*-tests of the estimated production functions (Appendix 1) rejected the null hypotheses that the production functions for STW owners, water purchasers, and rainfed farmers were the same (Gujarati). The yield response functions with respect to fertilizer (NPK) at the geometric means of independent variables for the three farmer categories are plotted in Figure 2. The marginal productivity of fertilizers is highest for the STW owners and the lowest for rainfed farmers. This result supports the hypothesis about the productivity effect of STW ownership. The result provides support to the hypothesis of a lower productivity of purchased water, possibly because of the "residual" nature of the market.

Impact of STW Adoption

Per-hectare costs and returns of rice production for STW owners, water purchasers, and nonpurchasers are shown in Table 5. The net return to STW owners was estimated to be more than three times that of water purchasers. The net return obtained by water purchasers was estimated to be nearly four times than that of farmers using the rainfed method of farming. The net benefit obtained by STW owners exceeds that of the rainfed farmers and water purchasers by \$69/ha and \$50/ha, respectively. This is the estimated benefit from rice production only and does not include additional gains that are likely to be obtained through crop intensification and diversification. Thus, STW owners and water purchasers were able to obtain higher net returns compared with rainfed rice farmers.

Factors Determining Tubewell Ownership

Estimates of the probit regression for tubewell ownership are presented in Table 6. The likelihood-ratio value was found to be significant at the 1% level, implying that the independent variables, taken together, significantly explained the farmers' decisions to own STWs. Indeed, independent variables in the model explained 75% of the variation in the tubewell ownership decision. The farm size, land fragmentation, education and age of the farmer, caste, area under MV of rice, area under vegetables, access to credit, and access to electricity significantly influenced the farmer's tubewell ownership decision. The results suggest that a farmer who has a larger and less-fragmented farm, is upper caste, has a higher level of education, is younger, has more area under MV of rice and vegetables, has easy access to credit, and has access to electricity is more likely to own an STW. The results also show that STW ownership is not scale-neutral. The result is consistent with the findings of other similar studies (Clay; Koirala; Shah). The effects of other explanatory variables were as expected.

To evaluate the effect of each explanatory variable on the probability of tubewell ownership, partial derivatives of probabilities (marginal effects) were estimated at the sample mean of independent variables.⁶ An increase in farm size by 1 ha will increase the probability of tubewell ownership by 38%, *ceteris paribus*. Farmers with access to credit are 34% more likely to adopt STWs than those without access to credit. Among the significant variables, farm size showed the highest partial effect, followed by the farmer's credit, caste, land fragmentation, access to electricity, education, area under vegetables, age of decision makers, and area under MV of rice. Thus, credit and electricity are the important policy

⁶ Marginal effects are the partial derivatives of probabilities with respect to the vector of characteristics. The marginal effects for dummy variables are analyzed as discrete or relative changes when the respective dummy takes its two different values 0 and 1, respectively.

Table 5. Costs and Returns (U.S.\$/ha) in Rice Production by Farm Category

Characteristics	STW Owner (<i>n</i> = 162)	STW Nonowner	
		Water Purchaser (<i>n</i> = 129)	Rain-fed Farmer (<i>n</i> = 33)
Total costs (<i>a</i>)	284.03	260.99	193.56
Variable (<i>b</i>)	261.68	250.19	185.99
Fixed	22.35	10.80	7.57
Gross returns (<i>c</i>)	358.82	285.36	199.79
Main product	344.74	270.18	184.21
Byproduct	14.08	15.18	15.58
Gross margins (<i>c</i> - <i>b</i>)	97.14	35.17	13.80
Net returns (<i>c</i> - <i>a</i>)	74.79	24.37	6.23
Incremental net returns ^a			
Relative to water purchaser	50.42		
Relative to rainfed farmers	68.56		

^a Subtracting the net return of respective group from shallow tubewell (STW) owner derives incremental net return.

variables that can be manipulated to increase the adoption of STWs.

Discussion and Policy Implications

Lack of adequate irrigation facilities and heavy dependence on rainfall remain major causes of low agricultural production and productivity growth in Nepal (Kayastha; WI). Similar to the situation in neighboring countries, such as India, Bangladesh, and Pakistan, GW irrigation has a high potential for generating agricultural growth and reducing poverty in Nepal. Despite its high potential and priority assigned by the government (APP), GW irrigation accounts for only 19% of irrigated area (Bhandari). Nepal is somewhat lagging behind in the "pump race" in south Asia and can gain substantially through the use of its plentiful GW reserve.

The empirical section of this study showed that STW irrigation has significant positive effects on yield, input productivity, and farm incomes. Water markets that are in their infancy in Nepal can also play a significant role in spreading these benefits widely among smallholders whose farm size may be too small for the ownership of pumps to be economically viable.

The slow rate of growth in GW use in Nepal relative to that in the neighboring countries is due to both demand and supply factors. The

demand factors include small farm size, high degree of land fragmentation, poor access to credit, and generally a low capacity for investment. The supply factors include inadequate public sector support, limited rural electrification, the high cost of diesel fuel, and a limited involvement of the private sector in promoting, supplying, and maintaining the tubewells and related equipment. The promotion of GW irrigation will, hence, require interventions that address both these sets of constraints.

A major area of intervention is through suitable credit policy and design of credit schemes. The conventional approaches based on subsidized credit tend to be the normal response of the public sector. However, such approaches tend to be less effective in addressing the credit needs of small farmers because of high transaction costs and are inefficient due to the distortions in the credit market they generate (APO; Diagne and Zeller). New institutional innovations that use the micro-credit approach for providing institutional credit for potential investments in small tubewells or in group tubewells could be more effective in this regard. This approach has not been tried in Nepal and deserves the consideration of policy makers. Similarly, operational policy designs that bring farmers, bankers, and private sector together along similar lines as in

Table 6. Estimated Coefficients and Marginal Effects from Probit Function for STW Ownership^a

Variable	MLE		Marginal Effects	
	Coefficient	SE	Coefficient	SE
Constant	-6.535***	1.503	—	—
Farm size	0.989***	0.145	0.377	0.058
Land fragmentation	-0.325***	0.125	-0.124	0.047
Education of household head	0.178***	0.064	0.068	0.024
Age of household head	0.036**	0.015	0.014	0.006
Area under MV of rice	0.021**	0.010	0.008	0.004
Area under vegetables	0.126***	0.038	0.048	0.015
Access to credit (dummy) ^b	0.899***	0.307	0.338	0.112
Access to electricity (dummy) ^c	0.311**	0.157	0.112	0.056
Gender of household head (dummy) ^d	0.917	0.780	0.282	0.167
Caste of household (dummy) ^e	0.672**	0.300	0.249	0.107
Study region (dummy) ^f	-0.030	0.304	-0.011	0.116
Likelihood ratio for chi-square		336.83***		
Goodness of fit (pseudo- R^2)		0.75		
Number of observations		324		

^a STW is shallow tubewell; MLE is maximum likelihood estimation; SE is standard error; MV is modern varieties.

^b 1, if the farmer perceives that credit is easily available; 0, otherwise.

^c 1, if farmer has access to electricity; 0, otherwise.

^d 1, if household head is male; 0, otherwise.

^e 1, if the farmer belongs to the upper caste; 0, otherwise.

^f 1, if the farm is located in the Western region; 0, otherwise.

* Indicates 1% level of significance.

** Indicates 5% level of significance.

*** Indicates 10% level of significance.

eastern Uttar Pradesh could make credit more widely available by reducing the transaction costs (Pant). In eastern Uttar Pradesh, the emergence of private pump-set dealers as intermediaries played an important role in improving farmers' access to institutional credit.

Another area of intervention refers to the promotion of more efficient tubewell and water conveyance technologies. Although electric tubewells have a lower cost per unit of water supplied, limited rural electrification currently precludes their widespread use. Investments in rural electrification are desirable, not just for promoting pumps, but as instruments of rural development policy in general. Although Nepal has a large hydroelectric potential, a massive expansion of rural electrification is unlikely to occur in the short to medium run. Accordingly, promotion of alternative low-cost pumping technologies, such as treadle pumps and other low-lift mechanical devices, could make water available cheaply, especially

in areas with shallow GW table. Testing, adaptation, and promotion of such technologies would complement other measures for improving the access to GW. Similarly, technical assistance in terms of locating the aquifer and providing information on suitable pumping and water conveyance technologies could play a catalytic role because the private sector currently is not able to provide these services efficiently.

Another potential area of intervention that could be linked with the credit scheme is to promote group ownership of tubewells. Group ownership can get around the problem of funding constraints that limit private ownership. In addition, capacity use of such pumps can be expected to be high. Group ownership can similarly provide incentive for proper care and maintenance, which often plagues public tubewells. However, the success of group ownership schemes will depend critically upon the size of the group, the degree of social ho-

mogeneity of its members, and the institutional arrangements through which the group is collectively responsible to the credit provider (Agrawal; Heyer, Stewart, and Thorp; Olson; Ostrom; Ostrom, Walker, and Gardner). Rather than a general strategy for promoting tubewells, group-based schemes may, therefore, be more applicable in particular circumstances.

The water market provides an alternative for group-ownership. The internal mechanism for managing group-ownership is substituted by market forces when buyers and sellers engage in market-based exchanges. There is a potential for increasing the use of GW through interventions that reduce the price of water. Policy towards development of water markets could be an important strategy toward overcoming the constraints on private investment in GW that arise from fragmentation of landholding. The water market in Nepal is in its infancy because there are very few sellers, and the water market is basically residual. There is an element of monopoly in water pricing, and the reliability of the water supply is low. These critical problems are likely to be overcome through strategies that promote more widespread use of GW. Again the public sector can assist in this process through the provision of information on pumping and conveyance technologies and through the supply of credit and public sponsorship of boring schemes along lines similar to what was done in eastern Uttar Pradesh during the 1980s (Pant).

Other general policy interventions that can encourage the use of GW include consolidation of landholdings and changes in tax and inheritance laws to prevent extreme fragmentation of landholdings. These longer-term measures will also result in an overall efficiency gain in farming, irrespective of their effect on GW use.

GW offers a precious opportunity for alleviating the misery of the poor, but it also poses many intimidating challenges in preserving the resource. Although GW resource is presently underused in Nepal, many alarming environmental and economic problems, such as the lowering of the water table, increased pumping cost, and land subsidence,

could arise. Unplanned GW exploitation can wreak havoc on fragile ecologies (Dhawan; Shah et al.). Hence, GW development in Nepal should be well planned so that the sustainability of this important source of irrigation is not compromised. This requires an assessment of the GW stock and sustainable rate of withdrawal and the implementation of regulatory mechanisms such as registration of users by permit or license and enforcing minimum spacing between wells. Moreover, policies toward augmenting GW recharge, through rainwater harvesting and watershed management activities, promoting water-saving crop technologies, providing incentives for water conservation and artificial recharge, and planning and management of GW at the basin level, are essential for its sustainable use.

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Appendix 1. Cobb-Douglas Production Function for Rice by Farm Category^a

Variable ^b	STW Nonowner					
	STW Owner		Water Purchaser		Rain-fed Farmer	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
Constant	-1.936***	0.254	-1.702***	0.476	-0.247	0.775
ln(labor)	0.226***	0.055	0.253**	0.099	0.303**	0.133
ln(NPK)	0.154***	0.011	0.078***	0.007	0.011***	0.002
ln(FYM)	0.024**	0.012	0.062***	0.014	0.062**	0.025
ln(seed)	0.009	0.043	0.086	0.073	0.137	0.148
ln(plant protection)	0.040***	0.011	0.002**	0.001	0.004***	0.001
ln(farm power)	0.084***	0.026	0.027	0.039	0.042**	0.019
ln(MV rice area)	0.070***	0.008	0.034***	0.001	0.007**	0.003
ln(farm size)	-0.003	0.005	-0.001	0.008	-0.008	0.015
ln(STW water use)	0.171***	0.020	0.076***	0.013	—	—
ln(rain-fed area)	—	—	—	—	-0.329***	0.045
Tenure status (dummy)	0.012	0.008	-0.013	0.010	0.031	0.019
Study region (dummy)	-0.023***	0.006	-0.023**	0.010	-0.315***	0.024
Adjusted R^2	0.94		0.94		0.95	
F -value	247.7***		150.8***		87.4***	
No. of observation	160		129		33	

^a STW is shallow tubewell; Coeff. is estimated coefficients; SE is standard error; ln is natural logarithm; NPK is nitrogen, phosphorus, and potassium; FYM is farm yard manure; MV is modern varieties.

^b The dependent variable is ln (yield) of rice (t/ha) for the whole farm.

*** Indicates 1% level of significance.

** Indicates 5% level of significance.

* Indicates 10% level of significance.

Appendix 2. Estimated Coefficients of Percentage Area Under Modern Varieties of Rice and Percentage Area Under Vegetables^a

Variable	Estimates for Area Under MV of Rice		Estimates for Area Under Vegetables	
	Coeff.	SE	Coeff.	SE
Constant	23.47***	10.30	3.93*	2.06
Farm size	0.08	0.61	0.23**	0.12
Education of household head	2.37***	0.58	0.23**	0.11
Age of household head	0.39**	0.18	0.04	0.03
Training of household head on farming	0.34	0.32	—	—
Access to credit (dummy) ^b	16.96***	4.21	0.59	0.79
Visit of extension agent (dummy) ^c	3.75	3.84	1.88***	0.76
Caste of household (dummy) ^d	11.52***	4.07	-1.20	0.82
Tenure status (dummy) ^e	1.86	5.46	-2.12**	1.04
Study site (dummy) ^f	6.32	4.07	4.77***	1.08
Problem of stray cattle (dummy) ^g	—	—	-6.51***	1.07
Access to road and market (dummy) ^h	—	—	4.51***	0.96
F-value	9.22***	—	14.51***	—

^a MV is modern varieties; SE is standard error.^b 1, if the farmer perceives that credit is easily available; 0, otherwise.^c 1, if extension agent visits weekly or fortnightly; 0, otherwise.^d 1, if the farmer belongs to the upper caste; 0, otherwise.^e 1, if the farmer is owner *cum* tenant; 0, otherwise.^f 1, if the farm is located in the Western region; 0, otherwise.^g 1, if the farmer has a stray cattle problem; 0, otherwise.^h 1, if access to the road and market is easy; 0, otherwise.

*** Indicates the 1% significance level.

** Indicates the 5% significance level.

* Indicates the 10% significance level.

