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GROUNDWATER MARKETS IN PAKISTAN: PARTICIPATION AND PRODUCTIVITY

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FOREWORD

Appropriate management of water resources is essential for agricultural production, food security, sustainable management of natural resources, and the reduction of malnutrition. This is true in any country, but especially so in arid and semiarid regions, where agriculture is heavily dependent on irrigation. Attention to water management is becoming increasingly important around the world as water scarcity, degradation of water quality, and competition between agriculture and growing industrial and municipal demands place pressure on this vital resource.

At the same time, conventional approaches to water management, which have relied on a heavy role for the state, are being called into question, and there is a search for alternatives. IFPRI is undertaking a multicountry research program called "Water Resource Allocation: Productivity and Environmental Impacts," which seeks to identify the appropriate role for government agencies, user groups, and markets in the allocation of water resources under a range of conditions. As part of that program, this research report examines the efficiency, equity, and environmental impacts of groundwater markets in Pakistan.

This study is also one of a wide-ranging series of studies in Pakistan undertaken jointly by IFPRI and the Government of Pakistan, with financial support from the U.S. Agency for International Development Mission in Pakistan. It uses part of a valuable longitudinal data set on 800 households in four districts of Pakistan that was collected between 1986 and 1993. That data set has been used in IFPRI studies of poverty, food security, agricultural production, credit, human capital accumulation, and nonfarm linkages, as well as in a variety of analyses by students and non-IFPRI researchers in Pakistan and other countries. Other IFPRI studies on Pakistan include *Sources of Income Inequality and Poverty in Rural Pakistan,* Research Report 102, *Poverty, Household Food Security, and Nutrition in Rural Pakistan,* Research Report 96, *Effects of Exchange Rate and Trade Policies on Agriculture in Pakistan,* Research Report 84, and *The Demand for Public Storage of Wheat in Pakistan,* Research Report 77.

Per Pinstrup-Andersen
Director General

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1

SUMMARY

Water markets provide one of the most promising institutional mechanisms for increasing access to irrigation from groundwater, particularly for tenants and small farmers in South Asia. This institution is particularly important in Pakistan, where agriculture is heavily dependent on irrigation, and increasingly dependent on groundwater for production. Because the public canal irrigation systems do not provide farmers with adequate water or enough control over irrigation deliveries, many are turning to groundwater from private tubewells as a sole or supplemental source of irrigation. However, tubewell ownership is limited to a relatively small proportion of farmers, who tend to be the larger and more affluent landowners. Sale and purchase of groundwater through informal water markets offers other farmers the opportunity to use groundwater.

From a policy standpoint, the government needs to have a better understanding of groundwater markets if it is to improve access to vital groundwater resources. This need includes information on how water markets operate, who participates, the nature of the transactions, and the impact of water markets on agricultural productivity and incomes. This research report reviews the emerging literature on groundwater markets, examines empirical evidence on their performance, and discusses policy options for the government to improve equity of access to groundwater resources.

The factors affecting private tubewell development and the emergence of groundwater markets are complex and interlinked, involving physical, economic, and social forces. This study examines the roles of the physical environment, surface water, groundwater, farm structure, rural development characteristics, and cropping patterns in affecting private tubewell density and water market activity, using district-level data. This is the first attempt to go beyond microlevel studies to identify determinants of groundwater market activity in Pakistan as a whole. While groundwater markets are found in all provinces, they are most prevalent in canal-irrigated areas of Punjab and in North-West Frontier Province (NWFP). Environmental problems of poor quality groundwater and falling water tables decrease the density of private tubewells, but poor quality groundwater increases the proportion of tubewell owners participating in groundwater sales. Tubewell water sales are more prevalent in areas with canal irrigation, and where tubewell owners have medium-sized, rather than large, landholdings.

To understand the dynamics of groundwater markets, the present study examines the operation of groundwater markets at the micro level, with particular emphasis on Faisalabad District in Punjab and Dir District in NWFP. Findings based on survey data of the International Food Policy Research Institute (IFPRI) indicate that, whereas large landowners are more likely to own tubewells and pumps, smaller landowners and tenants are more likely to rely on purchases from other farmers' tubewells for access to groundwater. The distance over which water can be transported provides a limit to groundwater market sales, but lined watercourses increase the distance over which tubewell water can be sold. Contractual arrangements for water include hourly

charges, the buyers providing the fuel plus a fee for wear and tear, and sharecropping for water. The price of water does not change over the course of a season to reflect its scarcity value, but buyers are frequently denied groundwater.

Unreliability of access to purchased tubewell water was a problem for more than half of the water buyers in the study areas. This analysis indicates that purchasers are more likely to have unreliable access to groundwater if they buy water from small-capacity, electric-powered tubewells, or if they are young and own little or no land. Thus, nonprice factors such as buyers' status act to ration access to limited groundwater resources.

All types of irrigation—canal, purchased groundwater, and own tubewell water—increase yields of wheat. Nevertheless, groundwater has a higher impact on yields than canal water, and water from farmers' own tubewells (which provides the farmers with the greatest degree of control) has a greater effect on yields than purchased groundwater. A similar pattern applies to effects on farm incomes. Analysis of gross margins for all crops on the farms shows that the irrigation surplus generated by water from farmers' own tubewells is much greater than that from purchased groundwater. This advantage of tubewell ownership is amplified if used together with canal irrigation.

By making groundwater available to farmers who do not own tubewells, water markets clearly increase the level of agricultural productivity in Pakistan. Thus, neither public tubewells nor ownership of tubewells by all farmers are required to ensure widespread use of groundwater in areas where water markets operate. Groundwater purchases offer farmers a greater degree of control over water supplies than is afforded by the surface irrigation systems, and this control is translated into greater incomes or "irrigation surplus." There remains, however, a gap between the productivity of purchased groundwater and that from farmers' own wells, which reflects the greater reliability of irrigation provided by tubewell ownership.

These results imply that water markets do improve the productivity of agriculture, particularly for small and medium farmers, but policies that expand tubewell ownership are likely to provide greater welfare gains than those which encourage groundwater sales from tubewells owned by a few farmers. At the same time, the total groundwater recharge available limits the number of tubewells that can be operated in a sustainable manner. This means that strategies are needed to improve the equity of access to groundwater resources. Promising options to achieve these goals include modifying the regulations on use of canal irrigation facilities, technology options for lower-capacity tubewells and more efficient conveyance structures, and shared tubewell ownership to expand the rights of small farmers to groundwater. Further research is needed on how groundwater markets work in less favorable environments, such as those with salinity, waterlogging, or falling water tables, and to identify policy interventions that are appropriate to each set of circumstances.

2

INTRODUCTION

Irrigation plays a key role in Pakistan's strategy for increasing agricultural productivity. Surface irrigation has allowed the extension of cultivation into areas and seasons that lack sufficient rainfall for agriculture, and it has raised yields above what is possible under rainfed cultivation. Groundwater irrigation is increasingly important in improving production, both on its own and in conjunction with surface irrigation.

Access to water in public irrigation systems (surface canals and public tubewells) is tied to ownership of land in the command area. This landownership entitles the farmer to a fixed turn of irrigation flow during a rotation cycle, to be used only on that land. The rigidity of such a system limits the productivity of surface irrigation and public tubewells, a limitation that is especially apparent in comparison with privately managed groundwater irrigation, where farmers have more control over the timing of water deliveries (Renfro and Sparling 1986).

Access to privately managed groundwater irrigation is dependent on investment in wells and pumping devices. To the extent that large and wealthy farmers are most likely to own tubewells and small or poor farmers are unable to make the necessary investment, the latter may be excluded from the benefits of highly productive groundwater resources. On the other hand, widespread private ownership leads to overinvestment in wells and pumpsets, particularly where holdings are small or fragmented. Institutional arrangements are needed to spread access to groundwater to other farmers and to increase agricultural productivity and equity of irrigation water resources.

Water markets, in which farmers buy and sell irrigation water, provide one of the most promising institutional mechanisms for increasing access to irrigation with private groundwater, for providing vertical drainage, and for increasing the efficiency of water use in irrigation systems. These markets are receiving increasing attention from both researchers and policymakers (Shah 1993b; Moench 1994; Rosegrant and Binswanger 1994; Rosegrant and Gazmuri Schleyer 1994; Kahnert and Levine 1993). The World Bank (1994,44) identifies "formalizing water markets and individual water property rights" as the first element of a broad strategy of reform for improving the overall irrigation system in Pakistan.

Although groundwater markets are not officially recognized, the sale of water from private tubewells is a growing form of water allocation. These informal groundwater markets do not represent the sale or trade of water rights (as discussed in Rosegrant and Binswanger 1994); rather, groundwater markets might be considered "spot markets." Nevertheless, they are important as an example of spontaneous water market development. The sale and purchase of public canal water supplies, though legally prohibited under the Canal and Drainage Act, is another type of private water market transaction that takes place in Pakistan. These are, however, much less common than tubewell water sales.[1]

This research report examines the nature and operation of groundwater markets in Pakistan. It deals with the extent of water market development, who participates, the nature of transactions, the reliability of purchased irrigation services, and the impact on productivity of irrigated agriculture and agricultural incomes. The final section suggests policy instruments for extending groundwater markets and improving their performance.

Sources of Irrigation in Pakistan

Irrigation provides crucial water for agricultural production on more than 80 percent of the gross cropped area in Pakistan. Most of this irrigation comes through public canal systems, which deliver surface water to approximately 70 percent of the irrigated area. The Indus Basin Irrigation System, the world's largest contiguous irrigation system (serving over 35 million acres), is the major source of canal water. But this system was designed more than a century ago, with the objective of spreading scarce water over as large an area as possible. As a result, planned cropping intensities were 50 to 75 percent—that is, only half the command area was to be irrigated in the *rabi* season (mid-October to mid-April), and up to a quarter in *kharif* (mid-April to mid-October). The rotational water delivery pattern, or *warabandi*, under canal irrigation is designed to spread the water between farmers in fixed proportion to their landholdings. The low water availability and rigid delivery pattern were not adapted to meet the demands of the more intensive agriculture that came in the wake of the Green Revolution and increasing population pressure in Pakistan. Moreover, allowances are not made for water losses in the channels. Problems with operation and maintenance of the canal systems mean that tail-end distributaries and watercourses do not receive enough canal water for the current cropping intensity, and delivery schedules are unreliable in many areas (Chaudhry and Young 1990a; Murray-Rust and Vander Velde 1994).

Although the development of dams and barrages has made possible some expansion of canal irrigation, available surface supplies are limited and cannot meet the demand for intensive irrigation in Pakistan's predominantly arid environment. Throughout the 1970s and 1980s groundwater irrigation has been the most rapidly growing source of irrigation: it now serves approximately 25 percent of the irrigated area and provides over 36 percent of the irrigation water available at the farmgate (Pakistan, Ministry of Food, Agriculture, and Livestock 1994). Groundwater has become a crucial input, both as a sole source of irrigation and used in conjunction with surface irrigation in canal irrigation commands.

From the mid-1950s to 1980 government policy on groundwater development focused on public tubewells, under the Salinity Control and Reclamation Program (SCARP). According to the World Bank (1984,i), "The Government of Pakistan opted for public control of an extensive groundwater pumpage program based on the

[1] Trading of canal irrigation turns is more common. This practice is more an informal adjustment of the canal rotation schedule than a market transaction (see Merrey 1986b).

rationale that this arrangement would enable the Government to meet multiple groundwater objectives in an efficient and equitable manner." These objectives included

- providing vertical drainage to control waterlogging and salinity problems, especially in saline groundwater areas;
- increasing cropping intensities and agricultural production;
- capitalizing on the economies of scale in pumping technology; and
- reducing inequity in access to groundwater, by serving farmers with all sizes of holdings, regardless of financial resources for investment.

In practice, institutional problems as well as technical difficulties resulted in disappointing performance of public tubewells. Because the systems were tied to the same rigid *warabandi* as public canal systems, they did not increase flexibility of irrigation. Rising operation and maintenance expenses for public tubewells, which consumed 60 percent more than the entire national budget for canal operation and maintenance in 1983/84 (Aklilu and Hussain 1992, 29), together with the poor performance of public tubewells in timeliness and reliability of irrigation supplies, led the government to devolve responsibility for groundwater irrigation development from the public to the private sector. (This was also a time when a general global trend favoring private sector involvement was emerging.)

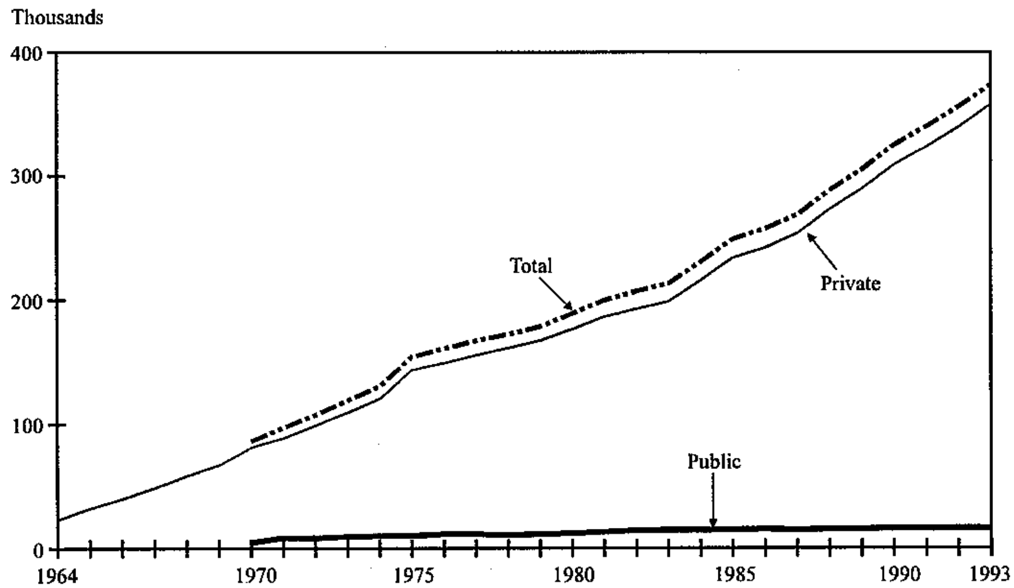
The first two policies adopted in Pakistan's Revised Action Plan for Irrigated Agriculture (WAPDA 1982, 16) were Recommendation 1, which stated that future development of usable groundwater should be entrusted to the private sector, and Recommendation 2, which said that present SCARP tubewells in the usable groundwater areas should be phased out and replaced by private tubewells.

How well can the objectives for public tubewells be met through private alternatives? Pakistan's experience suggests that private tubewell development can fulfill the objective of providing adequate vertical drainage, at least in areas of fresh groundwater (Chaudhry and Young 1990b). Figure 1 shows the dramatic growth in the number of private tubewells. This has been due not only to government programs to devolve tubewell ownership, but also to farmers investing in tubewells as a way of "opting out" of the inadequate and unreliable service provided by public canal or tubewell systems.[2] In 1992/93, there were 358,012 private tubewells supplying 72 percent of the groundwater and approximately 27 percent of total irrigation at the farmgate in Pakistan (Figure 2) (Pakistan, Ministry of Food, Agriculture, and Livestock 1994). Most of the tubewell development has taken place in Punjab, which has also had the most intensive agricultural development. As indicated in Figure 3, 89 percent of the private and 60 percent of the public tubewells of Pakistan were located in that province in 1992/93 (Pakistan, Ministry of Food, Agriculture, and Livestock 1994). Pumping of groundwater from private wells has provided more than adequate vertical drainage in many areas: in Punjab as a whole, withdrawals exceed groundwater recharge by an estimated 27 percent, raising serious questions about the sustainability of groundwater irrigation (NESPAK 1991).

The second objective of tubewell development, increasing cropping intensities and agricultural productivity, is better met through private than public ownership, primarily

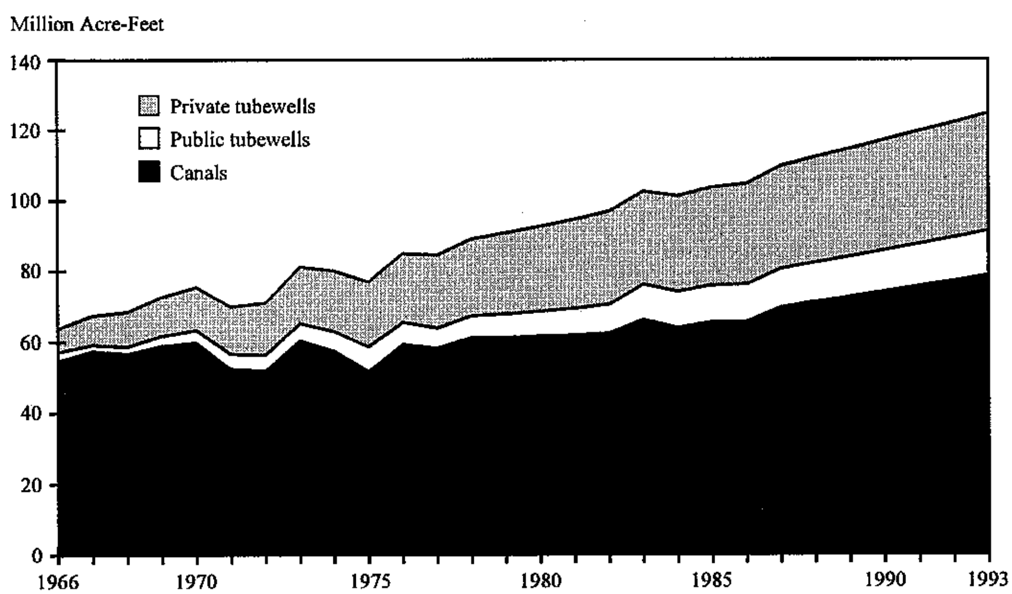
[2] Wood (1995) presents a clear analysis of a similar situation in Bihar, India.

Figure 1—Number of tubewells in Pakistan, 1964–93



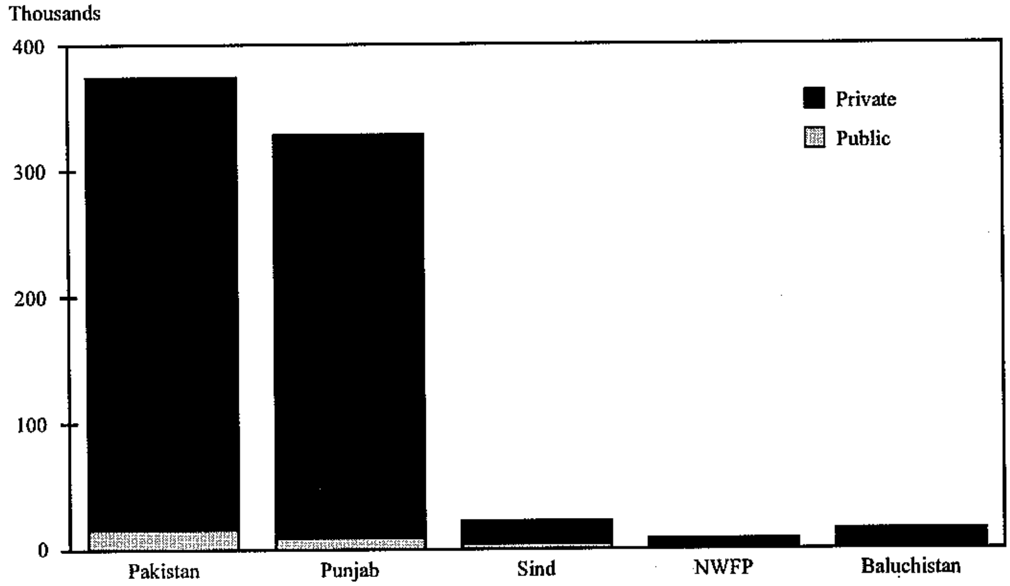
Sources: WAPDA 1993; Pakistan, Ministry of Food, Agriculture, and Cooperatives 1979 and Pakistan, Ministry of Food, Agriculture, and Livestock 1994.

Figure 2—Sources of water available at the farmgate, 1966–93



Sources: Pakistan, Ministry of Food, Agriculture, and Cooperatives 1979 and 1981; Pakistan, Finance Division 1994.

Figure 3—Number of public and private tubewells in Pakistan, by province, 1992/93



Source: Pakistan, Finance Division 1994.

because private tubewells are more reliable (Johnson 1989, 15; World Bank 1984, 29).[3] The record of public tubewells in increasing efficiency through technological economies of scale is also questionable. Because they provide water to a larger area than that controlled by single farmers, public tubewells can use larger pumps, which are, in theory at least, more efficient. The potential gains in technical efficiency derived from public tubewells using large-capacity pumps are offset, in practice, by frequent breakdowns and inadequate maintenance (see Kahnert and Levine 1993). Most private tubewells provide greater water use efficiency by more closely matching water deliveries to crop needs, instead of adhering to the rigid schedules of public tubewell deliveries.

The record of private tubewells in meeting the fourth objective, of providing access to groundwater to farmers of all sizes, is not as favorable. Private well ownership tends to be concentrated among larger or wealthier farmers because of their ability to mobilize the necessary resources, including personal finances, credit, and government connections for electricity supplies (Chambers, Saxena, and Shah 1989; Johnson 1989; Chaudhry 1990). In 1991, 88 percent of tubewells were owned by farmers with more than 12.5 acres, and 38 percent of all tubewells by farmers with more than 25 acres,[4] which seems "to point toward an adverse effect of private tubewells on income distribution within agriculture" (World Bank 1984, 35). As the government closes public tubewells, the extent to which private groundwater develop-

[3] For similar findings in Bangladesh, see Mandal 1993, and in India, see Pant 1993.

[4] Computed from data reported in NESPAK 1991.

ment will benefit a large number of farmers and meet stated equity objectives remains an important question (World Bank 1996).

Groundwater Markets

There is considerable interest throughout much of South Asia in water markets as a means of increasing access to and use of groundwater for irrigation (Kahnert and Levine 1993; Moench 1994). This interest arises not only from a recognition of the importance of groundwater resources for agricultural production, but also because, as Shah (1994, 3) points out,

> institutional vacuum is a major problem of the irrigation sector—and groundwater markets offer a good example of a spontaneous, popular institution which provides opportunities to study the behavior of communities and individuals in relation to natural resources.

Much of the literature on this subject is based on field studies conducted in India and Bangladesh. The present chapter of this study reviews the issues identified in the literature in order to set the stage for an empirical study of the performance of groundwater markets in Pakistan in subsequent chapters.

Although water sales from private wells are a longstanding practice, these informal arrangements have only recently been recognized and empirically examined (Chambers, Saxena, and Shah 1989, 100–101). There are numerous anecdotal reports and a growing number of studies of private water sales in Uttar Pradesh, Haryana, Punjab, Bihar, West Bengal, Orissa, Andhra Pradesh, and Tamil Nadu in India.[5]

In most cases in South Asia, water sellers are farmers who sell surplus water after meeting the needs of their own fields. Tubewell water sales have become a profitable enterprise for small farmers in Uttar Pradesh in India (Shankar 1992a) and even for the landless under the programs sponsored by several nongovernmental organizations (NGOs) in Bangladesh (Ahmed 1993; Wood and Palmer-Jones 1990). In Gujarat State in India, where groundwater markets are highly developed, individuals and even private water companies are investing in wells primarily to sell water to others (Shah 1985; Kolavalli and Chicoine 1989).

In Pakistan, groundwater markets are reported to operate in all provinces, but are most active in Punjab, where the greatest groundwater development has taken place. By 1975, more than 30 percent of tubewell owners in Pakistan reported selling water, but the fraction of water sold was very small (World Bank 1984, 35). A study by Pakistan's Water and Power Development Authority (WAPDA) in canal command areas of Punjab, Sind, and NWFP found water sales in 43 of 100 watercourses (WAPDA 1990; see also Bajwa and Ahmad 1991). Based on data from a survey of well owners throughout Pakistan, National Engineering Services-Pakistan (NESPAK), a parastatal engineering consulting firm, reported that 21 percent of well owners sold water (NESPAK 1991).

[5] See, for example, Shankar 1992a, 1992b; Pant 1991a, 1991b, 1993; Wood 1995; Kolavalli and Atheeq 1990; Kolavalli, Naik, and Kalro 1992; Kolavalli, Kalro, and Asopa 1989; Saleth 1991; Shah and Raju 1988; Barah et al. 1993; Palanisami 1994; and in Bangladesh, Mandal 1993.

The potential advantages of groundwater market development lie in improving utilization of tubewell capacity, increasing access to irrigation water supplies (especially among farmers with small or fragmented holdings), and lowering water tables in areas of waterlogging (Chambers, Saxena, and Shah 1989; Chaudhry and Young 1990b). By providing water to other farmers, tubewell owners can use a higher proportion of their well capacity than they would on their own holdings alone. The availability of hired tubewell services reduces the need for other farmers to install their own wells. Because groundwater markets increase the use of installed pumping capacity, they can improve the economic efficiency of private tubewell irrigation.

Groundwater markets make it possible for those without wells to use groundwater for irrigation. This improves equity of resources because it is generally the smaller farmers who do not own tubewells.[6] The opportunity to sell groundwater can make it profitable for farmers to invest in wells even if their own holdings are too small to use the full pumping capacity (Shankar 1992b). Dhawan (1991, 2) concludes that

> the thrust of empirical research on groundwater markets, both in India and Bangladesh, has been to underscore the superiority of the institution of groundwater markets over the public tubewell system in catering to the irrigation needs of small and marginal farmers.

Shah (1991) argues that the expansion of irrigation through groundwater markets has led to increases in cropping intensity and the demand for agricultural labor, which ultimately benefit the landless and those who rely on wage labor for household income. Increased employment opportunity is one of the biggest advantages for landless members of pump groups in Bangladesh (Wood and Palmer-Jones 1990).

Other researchers on groundwater markets have voiced concern about who appropriates the gains from irrigation (Pant 1991b; Janakarajan 1994). The prospect of exploitative "water lords" has been raised, especially where control over water through well ownership reinforces inequality based on land and other assets (Barah 1992; Barah et al. 1993). Although legal definitions of property rights to groundwater are ambiguous in much of South Asia (Saleth 1994), de facto ownership of the resource is accorded to the owners of the wells that lift the water. This, in turn, requires a considerable investment in wells and pumps, as well as ownership of at least some land above an aquifer.[7] Janakarajan (1994, 47) argues, based on studies in Tamil Nadu, India, that as a result of this

> unequal access to resources and the poor bargaining capacity and dependent status of water purchasers vis à vis water sellers . . . a few farmers emerge with power to exercise control over this precious resource and extract surplus.

Shah (1991) finds that well owners' extraction of monopoly rents from the sale of water is most likely to be problematic where the markets are not competitive. Since

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[6] In examining inequality of irrigation distribution, Gill and Sampath (1992) note the effects of water trading and sales, especially in *rabi* season, in promoting equity.

[7] In fieldwork by the International Irrigation Management Institute (IIMI), researchers saw some exceptions to this. Usufructory mortgagees or long-term leaseholders sometimes sank wells on land they did not own and took the pump with them when the loan was repaid or the lease expired (Edward Vander Velde, personal communication, February 1996).

water transactions are restricted by topography and the distance between source and field, market competition is more difficult to achieve. He suggests that the availability of groundwater resources and alternative irrigation supplies (especially canal water), a high density of wells, and the presence of lined conveyance structures can reduce the sellers' monopoly power and hence the price of water. Others (notably Palmer-Jones 1994) have argued that groundwater markets are contestable, especially where water tables are high.

> There may well be more to water pricing than these simple alternatives [monopoly or competitive markets]; questions of credit, transactions costs, and risk are involved, and there may well be other market imperfections which impinge on the terms and conditions of water sales (Palmer-Jones 1994, 26–27).

Kolavalli (1989) notes that transactions are not impersonal, but are part of multi-stranded linkages in which buyers may give preference to relatives or those with whom they have other relationships, either through lower water rates or priority for service. This can be a way of dealing with high transaction costs for water sellers, particularly where water is provided on credit (see also Bardhan 1984). Wood (1995, 5) explains the reasons for the relationships between buyer and seller in Bihar, India:

> Deals with clients are made within the existing transaction moralities in which trust does not equal faith in altruism but is guaranteed by the multiplex ties, often multi-periodic ties, which bind the client to the service provider (e.g. kin, debt, access to land, employment options and so on). . . . The general point to make is that much which is germane to our understanding of these relations is hidden from casual view.

Janakarajan (1993; 1994) similarly describes linkages between the markets for groundwater, land, and labor in Tamil Nadu, India. Pant (1991b, 277) observed that the relative social and economic position of buyers and sellers affects water rates in Orissa State, India, where small farmers selling water to large landowners charged less than nearby large farmers selling to small landowners.

Empirical research and anecdotal evidence indicate a variety of contract forms and a wide range of prices in groundwater markets. Buyers may pay for water by providing labor, fuel, or a share of the crop, though the tendency is to move toward a cash charge per hour of water supplied as groundwater markets develop (Chaudhry 1990; Shah 1991). Several studies of groundwater markets have dealt with the price of water (for example, Kolavalli and Atheeq 1990; Shah 1989). In Pakistan, Malik and Strosser (1993) modeled price as a function of discharge and source of power in one field site, while Strosser and Kuper (1994) used a model that includes these variables plus dummy variables for location and whether or not water was provided on credit (whether payment was collected at the time of water delivery or at the end of the season).

Although quality of irrigation service is acknowledged to be critical, analysis of the reliability of purchased private irrigation services and the impact of reliability on productivity has been missing from most studies of groundwater markets. Chambers, Saxena, and Shah (1989) cite farmers' preference for purchased irrigation water above canal supplies as evidence of quality of service, but they admit the difficulty of estimating adequacy, reliability, and other indicators. Freeman, Lowdermilk, and Early (1978) and Renfro (1982) studied water trading and sales in Pakistan as a means of increasing farmers' control over irrigation supplies. The former used yields as a proxy indicator of quality of irrigation services; the latter used data on water and cash input use, cropping intensity, and gross income per unit area. Both studies found that, while water purchases increased productivity over canal irrigation alone, they did not have as great an effect as tubewell ownership because tubewell ownership provided the highest degree of control.

Increases in productivity that result from greater control of water can be defined as "irrigation surplus." While in its most basic form irrigation surplus refers to increases due to the change from rainfed to irrigated production, the concept can be further refined to capture differences in productivity between sources of irrigation. According to Shah (1993b, 24),

> Different sources of irrigation vary widely in the quality of irrigation service they can provide and, consequently, in the size of the "irrigation surplus" that they generate. Studies comparing the performance of irrigated farming under various sources such as canals, tanks, public tubewells, private tubewells, etc. indicate that as the quality of irrigation service improves, cropping patterns shift in favor of more lucrative crops. All these result in increases in "gross irrigation surplus."

The extent of control over water supplies that groundwater markets provide to water purchasers, and the extent to which purchasers are able to capture the "irrigation surplus" from controlled supplies remain among the most important questions about the functioning of groundwater markets in South Asia. The present study addresses these issues in Chapter 6.

In addition to understanding how and how well water markets operate at the micro level, better understanding is needed of the conditions under which such markets operate. As Shah (1993a, 148) points out, "Not enough is known about the factors that facilitate or hinder the emergence of water markets." This information is especially important from a policy standpoint if governments seek to improve access to groundwater resources.

Prior empirical studies of water market development have not addressed the complete set of factors affecting such development for three reasons. First, the studies have not been guided by a comprehensive model that takes into account the interactions between the physical and social environments, conjunctive use of surface and groundwater, and agricultural production. Second, micro-level field studies often cannot capture variability in key parameters, particularly in agroecological zones and publicly provided infrastructure. Finally, it is difficult to obtain accurate data on all relevant factors impinging on private tubewell and water market development.

Shah (1991) provides a model of the process of water market development, based on evidence from different regions of India. Strosser and Meinzen-Dick (1994) provide a conceptual framework for examining the emergence of groundwater markets, along with a review of the available evidence from Pakistan on specific relationships within the model. Both of these reviews piece together findings of a range of micro-level studies. More comprehensive analysis of where groundwater markets have emerged and how they operate is needed to identify policy instruments to promote their development. The present study examines the factors associated with private tubewell investment and water market development at the district level in Chapter 3, then turns to a more detailed examination of the impact of tubewells, using micro-level data from two districts.

Data Sources

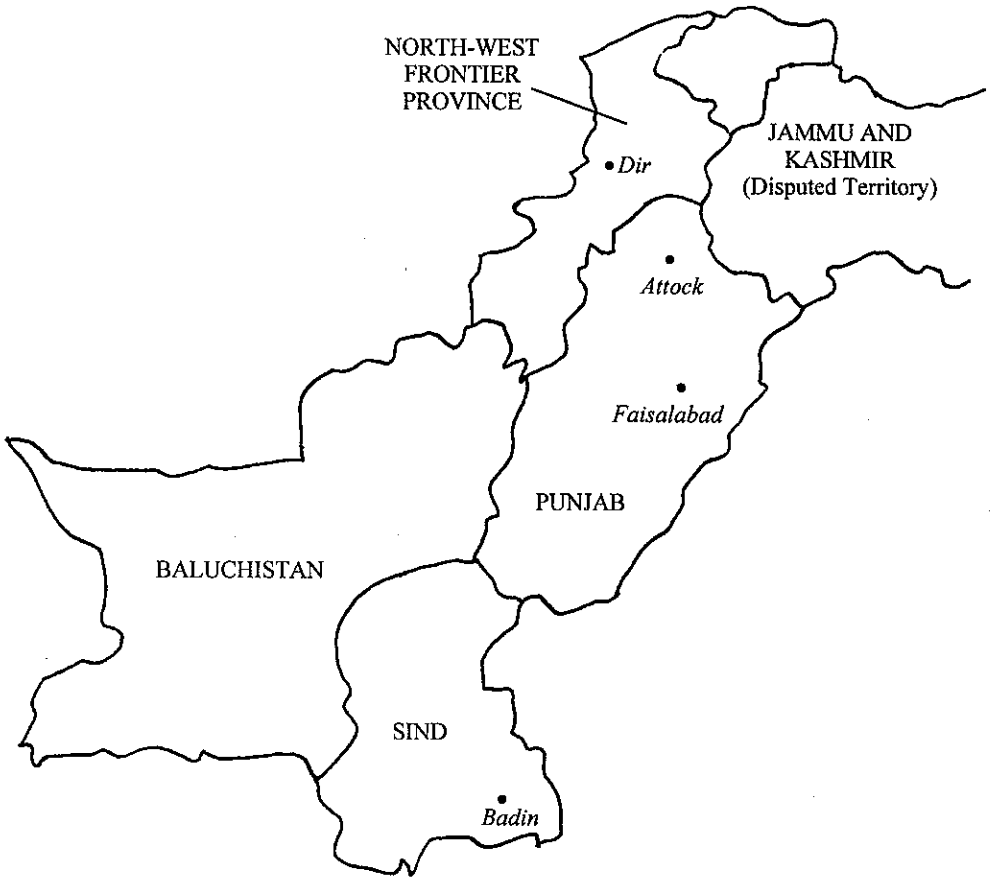
Data for the district-level analysis are drawn from published sources, particularly a study titled "Contribution of Private Tubewells in the Development of Water Potential," conducted by NESPAK (1991). In addition to assembling official statistics on the number of tubewells, surface and groundwater hydrology, water quality, energy use, and other parameters related to groundwater development, the NESPAK study conducted a survey of tubewell owners. The survey covered 5 percent of tubewell owners in most districts of Punjab, and 10 percent of tubewell owners in Rawalpindi and Sargodha Districts and in the remaining provinces. The present study combines the NESPAK data with official district-level development statistics on canal irrigated area, farm characteristics, rural development, and agricultural production.[8] Although the NESPAK data include Baluchistan, data on other variables were not available for this province, and it is therefore excluded from the analysis. However, this is not expected to distort the analysis because Baluchistan differs substantially from the other provinces. The predominantly desert landscape has little surface irrigation. Water tables are very low; hence Baluchistan accounts for only a small share of the groundwater resources, tubewells, and groundwater markets in the country.

After examining national patterns of tubewell development and groundwater market activity with aggregate data, this report turns to a more detailed analysis of the operation and effects of groundwater markets using micro data from selected areas. Household surveys on various aspects of agricultural production and rural poverty conducted by IFPRI in Faisalabad and Attock Districts of Punjab, Dir District of NWFP, and Badin District in Sind during 1990 to 1992 provide the basis for much of the micro analysis (Figure 4). While the latter three districts were selected to represent the poorest infrastructure development in each of their respective provinces, Faisalabad was included to represent a leading agricultural district (Alderman and Garcia 1993). Although the resulting sample is not representative of Pakistan as a whole, comparison of the IFPRI sample data and other nationally representative data sets (including the district-level statistics and the National Input-Output Survey collected by the University of Agriculture, Faisalabad) indicates that the broad trends identified from the micro-level data are likely to be applicable. However, because water markets were found only in Faisalabad and Dir districts in the IFPRI sample, the analysis of the productivity and income effects of water markets are based on these areas.

Data on household assets and agricultural production are available from 1986 to 1992, but the last full survey round, covering the 1990/91 agricultural year, provides the greatest detail on agricultural production and irrigation, and will therefore be used in this study. Plot-level measurements of soil characteristics from all farmers in the sample are also available from 1992. A resurvey of all tubewell owners and households participating in water markets, conducted in 1992, provides detail on these transactions and on the reliability of groundwater markets. The farm-level data on agricultural production and on the reliability of the irrigation service provide a basis

[8] Many development statistics are available in time series at the district level, but the NESPAK study is the only source of many key variables on the environment and activity of water markets. Because the NESPAK data cover one period only (1990), this study is limited to cross-sectional analysis.

Figure 4—Map of the provinces and survey districts included in the IFPRI panel study of Pakistan



Note: Survey districts are in italics.

for estimating the effects of groundwater markets in greater detail than previous studies. These data are used to examine determinants of participation in groundwater markets, effects of groundwater markets and other sources of irrigation on agricultural productivity and incomes, and factors affecting the reliability of such water markets.

Overview of the Study

The following chapters of this research report describe the functioning of groundwater markets in Pakistan, analyze the factors that influence their operation at the macro and micro levels, and assess their effects on agricultural productivity and incomes. The structure of the overall study is as follows: Chapter 3 sets out the framework for analyzing activity of groundwater markets developed by Strosser and Meinzen-Dick (1994) and applies this framework to analysis of district-level data to identify factors that affect the degree of tubewell development and groundwater market activity for the country as a whole. Chapter 4 presents a more detailed analysis of who participates in groundwater markets. It identifies the determinants of tubewell ownership and groundwater purchase at the micro level, using household survey data. Chapter 5 describes how groundwater markets operate, including the physical, social, and contractual relationships between participants. It further examines the reliability of access to groundwater that such markets afford. Chapter 6 deals with the impact of groundwater markets on productivity and incomes and compares the extent of irrigation surplus attributable to water from canals, purchased groundwater, and own tubewells. Chapter 7 concludes with a discussion of the implications of the study for policy and research.

3

FACTORS AFFECTING DEVELOPMENT OF GROUNDWATER MARKETS

Within Pakistan, water markets are most prevalent in the Punjab and NWFP, where groundwater irrigation is most developed. Although Punjab contains the highest number of well owners who sell water as well as the highest number of private wells, in NWFP a higher proportion of well owners are involved in groundwater markets. According to NESPAK (1991) data, 31.5 percent of sample well owners reported selling water in NWFP, compared with 20.9 percent in Punjab, 1.2 percent in Sind, and 3.7 percent in Baluchistan.

What accounts for the differences in water market activity? A host of influences can be identified, ranging from technical conditions to degree of agricultural intensification to various government policies. What is needed is a systematic way of identifying these factors and testing the magnitude of their effects.

This chapter uses a conceptual framework developed by Strosser and Meinzen-Dick (1994) for examining the development of groundwater irrigation and water markets. After discussing the overall structure and the components of the framework, district-level data are used to analyze the effects of the physical, social, and agroeconomic environments on the density of private tubewells and the activity of water markets.

Because the district-level analysis in this chapter covers a broader area, it can capture more of this variability than conventional studies from a few sites (although it sacrifices some of the accuracy of micro-level data by aggregating all farms in a district). This study goes beyond any previous work on groundwater markets in Pakistan, but further analysis of the interrelationships among factors would be desirable.

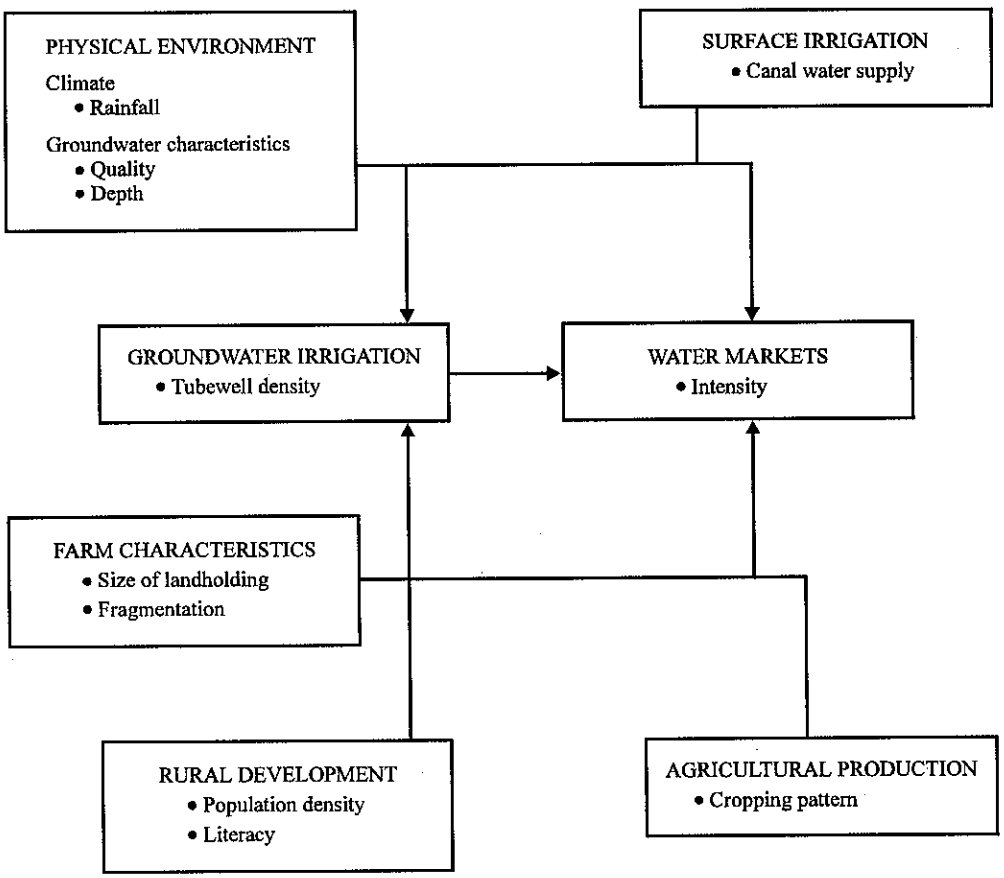
Conceptual Framework

The factors affecting private tubewell development and the emergence of groundwater markets are complex and interlinked, involving physical, economic, and social forces. Figure 5 presents the conceptual framework developed by Strosser and Meinzen-Dick (1994) for identifying relationships between groundwater markets and the environment in which they operate. The broad categories of physical environment, farm characteristics, surface irrigation, rural development, and agricultural production are used to identify and classify key factors affecting both groundwater supply through private tubewells and the activity of groundwater markets.

Physical Environment

The physical environment plays a key role in determining agronomic potential of an area and demand for irrigation. As Binswanger, Khandker, and Rosenzweig (1989, 5) point out,

Figure 5—Factors affecting groundwater irrigation and water markets



> Better agroclimatic opportunities such as better rainfall, a higher moisture holding capacity of the soil and a better irrigation potential . . . increase the economic return to private farm investments such as tractors, draft animals, or pumpsets.

Climate affects the need for irrigation to meet crop requirements. Although temperature, solar radiation, and wind all affect evapotranspiration, rainfall is often the single most important determinant of irrigation demand and is therefore used in this analysis.

Groundwater characteristics, particularly the water table depth and water quality, will affect both the costs and returns to use of groundwater for irrigation. Tubewell use may in turn affect groundwater characteristics, with extensive pumping lowering the water table and potentially altering the water quality. However, recharge from surface irrigation is a larger factor in determining groundwater characteristics in most areas of Pakistan.

Surface Irrigation

Studies of irrigation in Pakistan need to take into account the conjunctive nature of surface and groundwater irrigation. Although most canal systems are under government control while most tubewells are operated by farmers, the use of groundwater from private tubewells cannot be understood apart from the operation of the surface system. The availability of canal irrigation has an impact on groundwater irrigation in both a direct and indirect manner. Canal supplies provide a cheaper alternative to tubewells as a source of irrigation, thereby reducing demand for groundwater irrigation. At the same time, canal water increases supply by providing recharge to the water table, making more groundwater available for irrigation. In a more qualitative sense, unreliable canal deliveries can increase demand for tubewell water, while excessive canal supplies can cause waterlogging and reduce the agronomic potential of an area.

Farm Characteristics

Tubewells are lumpy investments. In the absence of highly effective credit markets, large farmers are therefore more likely to purchase tubewells because they can more readily mobilize the financial resources for tubewell investment. Large farmers are also likely to use more of the water on their own land than are small and medium farmers, and have less surplus water to sell. Thus, the percentage of tubewell owners is likely to be higher among farmers with large holdings, but groundwater markets may be more active where medium and small farmers predominate. Where farmers' holdings are fragmented, the proportion of a farm that can be served by a tubewell is reduced; fragmentation is therefore likely to have a negative effect on tubewell ownership but to increase the availability of and demand for tubewell water sales.

Rural Development

The literature on induced innovation suggests that both technology adoption and market development are associated with broader rural development trends (Boserup 1981; Hayami and Ruttan 1985). As population density increases, so do pressures for agricultural intensification, including irrigation development. Increases in education and literacy rates facilitate the adoption of new technology such as private tubewells, and demand for tubewell water. For example, more educated farmers are more likely to understand the advantages of and have the capacity to manage tubewell irrigation and are more able to carry out the administrative procedures necessary for getting a tubewell and pumpset.

Agricultural Production

The effects of groundwater irrigation and groundwater markets on agricultural production have been established in several studies (for example, Freeman, Lowdermilk, and Early 1978; Renfro 1982; WAPDA 1990), and are explored in greater detail in subsequent chapters of this study. However, agricultural production also has an impact on groundwater development and groundwater markets. Cropping patterns with crops that are highly water-consumptive and sensitive to moisture stress tend to increase demand for irrigation, including groundwater, while cultivation of profitable crops is needed to make tubewell investment and groundwater purchases profitable.

The effect of each of these sets of factors—the physical environment, surface irrigation, farm characteristics, rural development, and agricultural production—is likely to be different for the development of private tubewells and activity of groundwater markets. Moreover, the number and density of private tubewells will affect groundwater markets, though whether it will reduce the activity of groundwater markets because more farmers own tubewells, or increase the activity by making groundwater available over a larger area is an empirical question. The following sections of this chapter present estimation of two equations using district-level data. The first identifies the factors that have an impact on the density of private tubewells in a district. Tubewell density is then used, along with a number of other characteristics from the physical, social, and agroeconomic environment, in examining the factors that affect the proportion of tubewell owners who participate in groundwater markets.

Investment in Private Tubewells

Based on the foregoing discussion, a simple model is formulated to explain the density of private tubewells, in which[9]

$$TWDENSE = fn\ (RAIN, POORQGW, DEPTH_B, CANAL, FARMSIZE, FRAGMENT, POPDEN, LITERACY, RICEZONE, NWFP, SIND),$$

where

TWDENSE	=	tubewell density, defined as the number of private tubewells per thousand acres of cultivable area;
RAIN	=	average annual rainfall, in millimeters;
POORQGW	=	groundwater quality, defined as the proportion of area with water of poor quality;[10]
$DEPTH_B$	=	average groundwater depth before installation of tubewells, as reported by farmers in the NESPAK survey;
CANAL	=	area irrigated by canals as a percentage of potentially cultivable area in the district;
FARMSIZE	=	average farm size, in acres;
FRAGMENT	=	average number of fragments per farm;
POPDEN	=	rural population density per cultivable area;
LITERACY	=	rural male literacy rate;
RICEZONE	=	dummy variable for agroecological zones with predominant rice cultivation;
NWFP	=	dummy variable for North-West Frontier Province;
SIND	=	dummy variable for Sind Province.

[9] There are no compelling theoretical grounds to choose a particular structural form, so a straightforward linear specification is used.

[10] Using water quality standards adopted by NESPAK (1991), poor quality groundwater is defined as having an index of total dissolved salts (TDS) greater than 3,000 parts per million, a sodium absorption ratio (SAR) greater than 18, and residual sodium carbonate (RSC) greater than 5.

Because irrigation increases the cultivated area in a district, using cultivated area as the denominator for the dependent and several independent variables could cause endogeneity problems. To avoid such problems, this model uses total cultivable area (including net sown area, current fallow land, and land classified as cultivable waste) as the denominator for *TWDENSE, CANAL,* and *POPDEN.* Average rainfall is used instead of rainfall from particular years because groundwater development is a long-term phenomenon. While short-term fluctuations may have an effect on investment in tubewells, the total density of tubewells is more likely to be affected by average rainfall. Average reported depth before tubewell installation is used to indicate the water table conditions farmers faced when deciding whether to install tubewells. Selective migration and schooling could cause rural development variables such as population density and literacy to be endogenous in the long run, but given the relatively low proportion of the population in each district with private tubewells, this is unlikely to be a major factor (availability of canal irrigation is much more likely to influence overall rural development). The dummy for districts with strong traditions of rice cultivation[11] is included because rice is a very water-consumptive crop; so farmers in areas with a high proportion of rice are more likely to invest in tubewells. Other province-level effects are captured in the dummy variables with Punjab as the default.

Results of ordinary least squares (OLS) estimation for this equation are given in Table 1. Although the effect of rainfall (*RAIN*) on reducing the density of private tubewells is not significant, both variables relating to groundwater (*POORQGW* and $DEPTH_B$) have a significant negative effect in this model. The percentage of poor quality groundwater is consistent with the lower returns to groundwater irrigation when the water quality is poor. In the short run, saline groundwater use depresses yields, while in the long run, use of groundwater of poor quality has a negative effect on soil characteristics and the sustainability of agricultural production. Deeper water tables increase the costs of tubewell installation and pumping, and therefore they have a significant negative effect on tubewell density.

Surface water supplies provide a much cheaper alternative to groundwater and would therefore reduce farmers' investment in tubewells. However, other micro-level studies (Freeman, Lowdermilk, and Early 1978; Renfro 1982; Strosser and Kuper 1994) have shown that deficiencies in the canal irrigation system provide an impetus for groundwater use. The net effect at the district level is that greater availability of canal irrigation significantly reduces tubewell density. To capture the actual magnitude of the countervailing effects of canals on groundwater infrastructure would require more refined indicators than the simple percentage of cultivable area served by canals (such as total water deliveries and timeliness or reliability of canal supplies), which are not available at the district level.

The micro-level data analyzed in subsequent chapters of this study provide much better indicators of farm characteristics that affect groundwater use than are available

[11] Defined based on Pinckney's (1989) classification of a rice/wheat agroecological zone in Punjab and rice/other zone in Sind.

Table 1—District-level regression model for tubewell density

Independent Variable	Coefficient	Standard Error	t-Statistic	Variable Mean
RAIN	−0.013	0.013	−1.008	433.5
POORQGW	−1.024*	0.517	−1.981	17.3
DEPTH$_B$	−0.587*	0.329	−1.786	21.5
CANAL	−10.034*	5.405	−1.856	1.0
FARMSIZE	3.517*	2.086	1.686	3.8
FRAGMENT	−5.125	4.537	−1.130	2.8
POPDEN	2.802*	1.359	2.061	4.7
LITERACY	0.505	0.494	1.023	30.8
RICEZONE	18.724*	7.367	2.542	0.3
NWFP	−13.537	10.274	−1.318	0.1
SIND	−9.848	7.181	−1.371	0.2
Constant	31.304	23.256	1.346	
Adjusted R^2 = 0.49				
Number of observations = 30				

Source: Computed from data in NESPAK 1991; Pakistan, Ministry of Food, Agriculture, and Cooperatives 1991.

*Significant at the .10 level.

at the district level. For example, averaging farm sizes over all farms in the district is an insufficient proxy for the number of large farms, especially where landholdings are highly skewed. Nevertheless, in this model average farm size has a significant positive effect on tubewell density, as would be expected where large landowners are more likely to also own tubewells. The average number of fragments is negatively related to tubewell density, because if land is held in multiple parcels it is more difficult to irrigate the farm from one tubewell, but this effect is not significant.

Among rural development variables, population density has a significant positive effect on tubewell density, which is consistent with the induced innovation hypotheses. Literacy rates among rural males have a positive, but not significant, impact on tubewell density.

Most aspects of agricultural production cannot be included in this model because of problems with endogeneity. That is, the levels of output, yields, and input use are likely to be influenced by the presence of tubewells. While these factors may also, in turn, affect the adoption of tubewells, it is difficult to establish causality in a cross-sectional study. The dummy variable for rice zone is included because the sensitivity of rice to moisture stress is likely to create particular incentives for tubewell investment. This is borne out in the significant positive relationship of rice zone with tubewell density.

The dummy variables for NWFP and Sind capture residual effects, such as differences in the culture and policy environment between provinces. Although Punjab is the leader in tubewell installation, after controlling for the physical and socioeconomic environment, neither Sind nor NWFP was found to differ significantly from Punjab in patterns of tubewell density.

Intensity of Groundwater Markets

The density of private tubewells affects overall groundwater availability, but does not necessarily tell us about the activity of water markets. For understanding factors that affect intensity of water markets, the present study uses the proportion of tubewell owners who reported selling water as the dependent variable in a similar linear regression, as follows:[12]

$$TWSALES = fn\ (RAIN,\ POORQGW,\ DEPTH_A,\ CANAL,\ TWDENSE,\ TWDENSE_R,\ TOWN10\text{–}25,\ FRAGMENT,\ LITERACY,\ NWFP,\ SIND).$$

All variables are defined as in the first model, with the following additions:

TWSALES	=	percentage of tubewell owners selling water;
$DEPTH_A$	=	current depth of groundwater, after tubewell installation, in feet;
$TWDENSE_R$	=	residuals from the tubewell density equation above (as a test for endogeneity of tubewell density);
*TOWN*10–25	=	percentage of tubewell owners with landownership of 10 to 25 acres.

Of these variables, *RAIN, POORQGW,* $DEPTH_A$*, CANAL, TWDENSE, TOWN*10–25, and FRAGMENT are factors that affect the supply of groundwater available for sale. *RAIN, POORQGW, CANAL, FRAGMENT,* and *LITERACY* influence demand for groundwater purchases.[13]

Results of the model are given in Table 2. Instead of mean landownership for all farmers, this model uses the proportion of tubewell owners in the 10- to 25-acre landownership category. In modeling decisions about whether a tubewell owner sells water, what matters is not the average farm size of the population at large (used in the first model), but the farm sizes of tubewell owners (particularly once tubewell density is accounted for). The agricultural census and NESPAK data use the 10- to 25-acre size range to describe "medium-sized" farms. This category of tubewell owners is most likely to have surplus water available for sale, whereas large farmers with over 25 acres are more likely to use all the water on their own lands. Moreover, only a small proportion of farmers with fewer than 10 acres own tubewells.[14]

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[12] The model was also tested in a Tobit specification to deal with censoring of the dependent variable. However, the values for the Tobit parameters were not significantly different from the OLS estimates, and the OLS form is used because it requires fewer assumptions regarding the distribution of the error term.

[13] Nevertheless, this should not be interpreted as an equation that solves for the market-clearing quantity of water sold for two reasons: an adequate proxy for quantity of water sold is not available for the dependent variable, and the necessary assumption that the market clears does not hold. That is, demand may exceed supply at prevailing prices, as discussed below.

[14] This hypothesis is borne out at the micro level in the study by Strosser and Kuper (1994, 11). See also the analysis in the next chapter of this study.

Table 2—District-level regression model for tubewell water sales

Independent Variable	Coefficient	Standard Error	Z-Score	Variable Mean
RAIN	−0.046**	0.013	−3.707	433.500
POORQGW	0.964*	0.546	1.768	17.270
$DEPTH_A$	−0.041	0.197	−0.206	27.230
CANAL	10.109**	4.744	2.131	1.033
TWDENSE	0.110	0.281	0.393	13.850
$TWDENSE_R$	−0.0186	0.374	−0.050	0.000
TOWN10–25	0.331*	0.187	1.769	33.930
FRAGMENT	8.421	5.545	1.519	2.755
LITERACY	0.798	0.564	1.415	30.820
NWFP	26.458*	14.073	1.880	0.133
SIND	−25.272**	7.409	−3.411	0.233
Constant	−47.748*	27.380	−1.744	
Adjusted R^2 = 0.47				
Number of observations = 30				

Source: Computed from data in NESPAK 1991; Pakistan, Ministry of Food, Agriculture, and Cooperatives 1991.
*Significant at the .10 level.
**Significant at the .05 level.

Rural population density and rice zone are not included because they are expected to have less impact on water sales than on tubewell density.[15] Although rice cultivation increases demand for tubewells, it provides constraints to both the supply of and demand for groundwater sales. Tubewell owners who cultivate rice use more of the water themselves, and therefore have less surplus to sell. Moreover, the unreliability of water through groundwater markets (discussed below) makes farmers reluctant to rely on water purchases for this water-sensitive crop; they prefer owning their own tubewells.

Rainfall has a significant negative effect on groundwater sales, presumably because with higher rainfall there is less demand for groundwater. But in this model, poor quality groundwater has a significant positive effect on water sales, unlike the first model. If much of the area has poor-quality groundwater, farmers will seek to buy water from those with functioning tubewells (often in pockets of better-quality groundwater) rather than investing in their own tubewells, which are likely to have water quality problems. Depth of the water table did not have a significant effect on water sales.

Canal irrigation has a strong positive effect on groundwater sales, which can operate through both the supply and demand sides. In areas with canal irrigation there is more recharge, and tubewell owners are less likely to need all the available water

[15] In an alternative specification of the model, these variables were tested and found not to be significant. Exclusion of these variables from *TWSALES*, but not *TWDENSE*, also allows identification conditions to be met. Thus, although the models for tubewell density and water selling have six variables in common, each model has four variables that differ from the other model.

for their own crops; hence, more water is available for sale. On the demand side, inadequacies in canal deliveries create demand for supplemental groundwater. Furthermore, the watercourses used to supply canal water provide ready infrastructure for groundwater deliveries over a wider area, thereby facilitating groundwater market transfers (Strosser and Meinzen-Dick 1994). Tubewell density did not have a significant effect on the proportion of tubewell owners involved in water sales. The lack of a significant coefficient for the residuals of tubewell density from the first equation indicates that tubewell density is not endogenous in the model for water sales.

The proportion of tubewell owners who own 10 to 25 acres has a significant positive effect on the proportion of tubewell owners who sell water. These medium-sized farmers are more likely to have excess water available for sale than are large farmers, who can use more of their tubewell capacity on their own land. Neither degree of fragmentation nor rural literacy rates are shown to have a significant effect on groundwater market activity. Tubewell owners in NWFP are significantly more likely than those in Punjab to sell water, while those in Sind are significantly less likely. This may, in part, be due to differences in culture and commercial orientation between farmers in the different provinces.

Rainfall, groundwater quality, canal irrigation, and size of landholding of tubewell owners clearly affect the proportion of tubewell owners who sell groundwater. However, a more complete understanding of the degree of activity of groundwater markets would require addressing also the total amount and proportion of water that is sold (Strosser and Kuper 1994).

The present study is the first to identify determinants of groundwater market development at a national level in Pakistan. However, the available district-level data do not permit a full analysis of the operation of groundwater markets. A number of factors (notably rural electrification) are omitted because of unavailability of data. More important, it does not capture the dynamics of groundwater development and relationships between buyers and sellers. The NESPAK (1991) study provides an important baseline on the extent of private tubewell use, including groundwater market activity. Follow-up studies could provide valuable time series information on how this changes over time and the relationship to changes in the resource base, particularly groundwater quality and depth.

Using district-level statistics glosses over many complexities and micro-level variations in the operation of groundwater markets. In the following chapters micro-level data are analyzed to capture more of the details of the characteristics of groundwater market participants, and of the impact of that participation on agricultural production.

4

WHO PARTICIPATES IN GROUNDWATER MARKETS?

The pattern of water market activity identified in the district-level data, in which groundwater sales are most prevalent in Punjab and NWFP, is reflected also in the micro-level data that are used in the remainder of this study to examine how groundwater markets operate. In the IFPRI micro-level survey, groundwater markets were found only in Faisalabad District of Punjab and Dir District of NWFP, but not in Attock or Badin. Attock District of Punjab is a *barani* (rainfed) area, and no Attock farmers in the sample owned or used tubewells. The study villages in Badin District of Sind are largely underlain by saline groundwater aquifers, which pose a serious constraint to groundwater irrigation and water market development. Only one of the sample farmers from Badin owned a tubewell, and he did not sell water from it; none reported buying groundwater.

The IFPRI study areas in Faisalabad District lie within the command area of the Rakh, Jhang, and Gojra branches of the Lower Chenab Canal, where the terrain is relatively flat. Canals provide the sole source of irrigation to about 53 percent of the cultivated area in Faisalabad Division (including Faisalabad, Jhang, and Toba Tek Singh districts), with groundwater irrigating an additional 13 percent of the area and conjunctive use of surface and groundwater on 31 percent of the area (Punjab, Bureau of Statistics 1988). Groundwater use in the district is less than recharge, but there are some problems with groundwater salinity. Since annual rainfall is under 500 millimeters, cultivation is heavily dependent on irrigation. The major crops grown in Faisalabad are wheat, sugarcane, cotton, rice, and maize.

The average farm size of sample farmers in Faisalabad was 9 acres, which supported an average family size of 7.75 persons (Table 3). Most farm households owned at least some of their own land, but 18 percent were tenants. The gross margins from cultivation averaged Rs 22,655 per household,[16] but income sources were diversified: 53 percent of households received more income from nonfarm sources, averaging Rs 17,341 per household. Wheat yields averaged 1,482 kilograms per acre, which is below the 1990/91 national average of 1,841 kilograms, but higher than the sample farmers' yields in Dir (898 kilograms per acre).

Dir District has relatively hilly terrain. With higher annual rainfall (averaging 1,364 millimeters), the area is less dependent on irrigation. The main sources of irrigation are small-scale surface systems with some tubewells. The major crops are wheat, tomatoes, onions, and maize. The average farm size of 5.24 acres in the survey was smaller than that in Faisalabad, and a third of the families were tenant farmers. Family sizes were larger (10.53 persons), however. The gross margin from farming,

[16] Sample households not involved in cultivation have been excluded from the analysis in this study.

Table 3—Characteristics of sample farms in Faisalabad and Dir districts

Item	Whole Farm	Per Acre
Faisalabad		
Average farm size (acres)	9.00 (2.91)	. . .
Average household size	7.75 (2.91)	2.48 (3.99)
Average wheat output (kilograms)	5,200 (5,852)	1,482 (911)
Average farm revenue (Rs)	44,181 (57,949)	3,154 (2,021)
Average variable cost (Rs)	21,526 (22,648)	1,717 (865)
Average gross margin (Rs)	22,655 (38,060)	1,437 (1,500)
Household average nonfarm income (Rs)	17,341 (21,686)	8,644 (16,767)
Dir		
Average farm size (acres)	5.24 (7.27)	. . .
Average household size	10.53 (5.67)	4.44 (3.86)
Average wheat output (kilograms)	1,187 (931)	898 (668)
Average farm revenue (Rs)	16,333 (21,902)	2,658 (2,793)
Average variable cost (Rs)	9,523 (11,135)	1,479 (1,321)
Average gross margin (Rs)	6,810 (14,568)	1,179 (1,827)
Household average nonfarm income (Rs)	19,334 (25,364)	8,464 (13,741)

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92.
Note: Numbers in parentheses are standard deviations.

which averaged Rs 6,810 per household, was consequently smaller than in Faisalabad, and families depended more heavily on nonfarm income.

Three types of tubewell technology are found in the study areas: electric and diesel-powered pumpsets and power takeoff (PTO) tubewells, which are connected to tractors to drive their water lifts. Electric tubewells are generally the most expensive to install but cheapest to operate in terms of energy costs. PTO tubewells, by contrast, are cheapest to install because they do not require dedicated pumpsets. However, these lifts are less efficient, and both energy and maintenance costs are higher than with electric or diesel-powered pumpsets.

Table 4—Farmer participation in groundwater market in Faisalabad and Dir districts, 1992

District	Tubewell Owner	Tubewell Water Seller	Tubewell Water Buyer	Total Sample Size
		(number of sample farmers)		
Faisalabad	22 (22.2)	5 (5.1)	49 (49.5)	99
Dir	7 (7.9)	4 (4.5)	8 (9.0)	89
Total	29 (15.4)	9 (4.8)	57 (30.3)	188

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are the percentage of sample farmers.

Two farmers in the areas covered by the IFPRI survey reported purchasing canal water, compared with 74 purchasers and 10 sellers of tubewell water. This is similar to the findings of a WAPDA (1990) study of water trading and sales practices in 100 watercourses, which reported two to three times as many farmers involved in sale of water from private tubewells as in sale of their turns from public (canal and tubewell) sources.

The extent of water market participation among IFPRI sample farmers in Faisalabad and Dir districts is indicated in Table 4. Nearly half of the sample farmers in Faisalabad District purchased tubewell water, more than twice the number who owned tubewells. Of the 22 sample farmers who owned tubewells in Faisalabad, only 5 reported selling tubewell water. In Dir, where groundwater irrigation is less prevalent, 9 percent of all sample farmers purchased water, approximately the same proportion that owned tubewells, but twice the number that sold tubewell water.[17]

Water markets are most pervasive in Faisalabad, where groundwater purchasers or sellers were found in all six study locales (Table 5). Within the villages, participation rates ranged from 0 to 17 percent of farmers selling water, and 0 to 82 percent of farmers purchasing water. Although all study locales in Faisalabad fall within the command area of public canal irrigation systems, the watercourses in Jaranwala receive almost no surface water. Therefore, 75 percent of the sample farmers in Jaranwala have invested in wells, often jointly with other farmers, giving it a significantly higher proportion of well owners than other locations.

Only 5 of 11 study villages in Dir had any groundwater use among sample farmers, and water markets were reported in only 3 of the 5 villages (Table 6). The

[17] The high ratio of water buyers to water sellers is not unusual, as each seller frequently has multiple clients. Using complete enumeration of sales and purchases from wells, Janakarajan (1994) reports 49 sellers to 210 buyers in South India. In the present study, the random sample is likely to miss some sellers (as happened in Saddoana and Khalisabad villages in Faisalabad and Batan and Khanpur villages in Dir; see Tables 5 and 6), because few farmers own tubewells and even fewer sell water.

Table 5—Water market participation among sample farmers in Faisalabad District, by village, 1992

Village	Tubewell Owner	Tubewell Water Seller	Tubewell Water Buyer	Total Sample Size
	(number of sample farmers)			
Gojra	1 (9.1)	0 (0.0)	7 (63.6)	11
Jaranwala	15 (75.0)	3 (15.0)	5 (25.0)	20
Khalisabad	4 (18.2)	0 (0.0)	18 (81.8)	22
Saddoana	0 (0.0)	0 (0.0)	15 (71.4)	21
Singpura Chak	1 (16.7)	1 (16.7)	4 (66.7)	6
Sumundri	1 (5.3)	1 (5.3)	0 (0.0)	19
Total	22 (22.2)	5 (5.1)	49 (49.5)	99

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are the percentage of sample farmers.

Table 6—Water market participation among sample farmers in Dir District, by village, 1992

Village	Tubewell Owner	Tubewell Water Seller	Tubewell Water Buyer	Total Sample Size
	(number of sample farmers)			
Batan	0 (0.0)	0 (0.0)	3 (25.0)	12
Kamangara	1 (20.0)	0 (0.0)	0 (0.0)	5
Katigram	5 (27.8)	4 (22.2)	1 (5.6)	18
Khanpur	0 (0.0)	0 (0.0)	4 (21.1)	19
Shah Alam Baba	1 (14.3)	0 (0.0)	0 (0.0)	7
Six other villages	0 (0.0)	0 (0.0)	0 (0.0)	28
Total	7 (7.9)	4 (4.5)	8 (9.0)	89

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are the percentage of sample farmers.

Table 7—Type of irrigation and access to tubewell water by agroecological zone

Source of Irrigation	Punjab Zones: Rice/ Wheat	Mixed	Cotton/ Wheat	Low Intensity	*Barani*	Sind Zones: Cotton/ Wheat	Rice/ Other	NWFP Zone Except D. I. Khan	Total
	(percent of sample farmers)								
Unirrigated	0.7	0.0	1.0	0.0	48.0	0.0	0.0	51.4	6.2
Public irrigation sources only	26.5	17.3	27.4	30.4	0.0	85.0	97.1	42.8	37.9
Purchased tubewell water only	9.6	0.6	4.1	6.2	16.0	2.1	0.0	3.6	5.2
Canal and purchased tubewell water	4.7	21.2	31.3	23.8	0.0	0.7	0.7	1.4	14.0
Own tubewell water only	31.4	7.7	7.8	5.7	36.0	0.7	0.0	0.7	12.3
Canal and own tubewell water	27.0	53.2	28.4	33.9	0.0	11.4	2.1	0.0	24.3
Total sample size	407	156	387	227	50	140	140	138	1,645

Source: National Input Output Survey data, Agricultural University of Faisalabad, 1991/92.
[a]D. I. Khan District of NWFP is included in Punjab's low-intensity zone.

groundwater market is most active in Katigram, where more than one-fourth of the farmers own tubewells and nearly all well owners sell water.

The pattern of groundwater market participation found in the IFPRI survey is also consistent with findings from the National Input Output Survey of Major Crops, which interviewed 1,700 farmers distributed across all agroecological zones in Pakistan, with the exception of Baluchistan.[18] The largest share of farmers relying on purchased groundwater was in the cotton/wheat zone of Punjab (Bahawalnagar, Bahawalpur, Multan/Vehari, R.Y. Khan, and Sahiwal districts), where more than a third of all farmers buy tubewell water (Table 7).[19] The low-intensity Punjab zone was second, with 30 percent, and the mixed cropping zone of Punjab, which includes Faisalabad District, had the third highest proportion of tubewell water buyers, with 21.8 percent. Although 16 percent of farmers in the *barani* zone of Punjab, which includes Attock, purchased groundwater and 36 percent owned tubewells, tubewell use is concentrated in Jhelum District and is very low in Attock District itself (Punjab, Bureau of Statistics 1988, 53). Less than 3 percent of farmers use any groundwater in either of the zones in Sind. Of 138 farmers interviewed for the National Input Output Survey in the NWFP zone, only 5 percent reported purchasing water from tubewells.

[18] For details on the classification of agroecological zones, see Pinckney 1989.

[19] Tubewell water buyers include those who purchased tubewell water only, as well as those who had canal water but also purchased tubewell water.

Tubewell Owners

What are the characteristics of tubewell owners and water purchasers? The pattern of tubewell owners' having larger landholdings found in much of Pakistan—indeed, in much of South Asia—also holds true in the study areas. In Table 8, which presents average landholding size and other characteristics of tubewell owners, water purchasers, and nonusers of groundwater, farmers who own tubewells also own significantly more land than either groundwater purchasers or nonusers of groundwater, though their operational holding sizes are not significantly larger than water buyers. A comparable pattern in which larger landowners own wells and smaller landowners purchase tubewell water, based on the National Input Output Survey data from the Punjab mixed cropping zone, is shown in Table 9. Much of the difference in holding sizes is made up by water buyers renting in land. Nearly one-third of water buyers and nonusers of groundwater are landless tenants, whereas all tubewell owners own at least some land. The proportion of landowners who rented in additional land ranged from 13 to 16 percent among all categories of farmers. Water buyers are from significantly younger households than those of tubewell owners, indicating that they may not be as well established. This may arise because, when land is divided among sons, the eldest may keep the tubewell and others purchase from him or other nearby farmers.

The combined effect of these factors can be examined using a logistic regression (logit) model for tubewell ownership among sample farmers in Faisalabad and Dir districts, in which

Table 8—Average characteristics of sample tubewell owners and water buyers

Characteristic	Tubewell Owner	Tubewell Water Buyer	Nonuser of Groundwater	Total Sample
Land owned (acres)	8.21 (5.85)	3.46 (6.56)	4.64 (7.89)	4.83 (7.43)
Operational holding (acres)	7.72 (5.47)	6.04 (5.16)	5.93 (7.66)	6.20 (6.83)
Percent of landless tenants	0 (0)	33 (48)	31 (46)	27 (45)
Percent of owner-tenants[a]	13 (34)	13 (34)	16 (37)	15 (36)
Age of household head (years)	59.50 (13.31)	50.13 (14.25)	56.51 (13.44)	55.29 (13.93)
Sample size	24	45	108	177

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are standard deviations.
[a] Owner-tenants are farmers who rented in land in addition to land they owned.

Table 9—Participation in tubewell water market in Punjab mixed cropping zone, by size of landownership

	Total Landownership						
	Less Than 1 Acre	1–5 Acres	6–12 Acres	13–25 Acres	26–50 Acres	More Than 50 Acres	Total
Tubewell owner	0 (0.0)	15 (44.1)	17 (48.6)	33 (91.7)	12 (70.6)	12 (85.7)	89 (65.0)
Tubewell water buyer	1 (100.0)	11 (32.4)	9 (25.7)	2 (5.6)	4 (23.5)	1 (7.1)	28 (20.4)
Total sample size	1	34	35	36	17	14	137

Source: National Input Output Survey data, Agricultural University of Faisalabad, 1991/92.
Note: Numbers in parentheses are percentage of farmers in each size category who own a tubewell or purchase tubewell water.

$$TWOWN = fn\ (LANDOWN,\ AGE,\ NOCANAL,\ DIR),$$

where

TWOWN = probability of tubewell ownership;
LANDOWN = size of landownership, in acres;
AGE = age of head of household, in years;
NOCANAL = dummy variable for Jaranwala Village in Faisalabad District, which receives no canal water;
DIR = dummy variable for Dir District.

The logit technique allows examination of the effects of a number of variables on the underlying probability of a dichotomous dependent variable, such as the probability of owning a tubewell. It can be thought of as regressing the likelihood of tubewell ownership on a set of independent variables.

The dummy variable for Jaranwala is a proxy indicator for availability of alternative canal water supply and groundwater recharge, while the dummy for Dir District captures the effects of higher rainfall and hilly terrain. Other indicators of water supply, such as position of farm relative to canal systems and discharge in the watercourse, might refine the model, but are difficult to quantify and measure. Similarly, water table depth is not available at the farm level. Household wealth or income are not included in the model because they may be endogenous, with tubewell ownership contributing to wealth or income. Factors such as cropping pattern, which influences demand for tubewell water, are not included because no indicator is available for farmers' desired cropping pattern, and availability of tubewell water has a stronger influence on cropping pattern than actual cropping pattern has on availability of tubewell water.[20] Education (defined as maximum years of schooling of any

[20] Rice is not a major crop in either of the sample areas, so proportion of land under rice is not included in this model.

Table 10—Logistic regression model for tubewell ownership

Independent Variable	Coefficient	t-Ratio	Wald Statistic
LANDOWN	0.117**	3.90	14.83
AGE	0.055**	2.39	5.97
NOCANAL	4.277**	5.25	27.62
DIR	0.335	0.48	0.23
Constant	−6.749**	−4.21	17.73

Model chi-square = 62.5** with 4 degrees of freedom
Number of observations = 182

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.

Notes: Predicted versus observed results for tubewell ownership are as follows:

	Predicted: *NOT OWNER*	Predicted: *OWNER*	Percent Correct
Observed			
NOT OWNER	148	7	95.5
OWNER	14	13	48.2
			Overall 88.5

*Significant at the .10 level.
**Significant at the .05 level.

male over 16 years) and literacy were included in an earlier estimation of the model but found to be nonsignificant. Such variables were not included in the final model because of multicollinearity between education and landownership.[21]

Results of the final model are given in Table 10. Although aggregated farm characteristics were not shown to significantly affect tubewell density in the district-level model, the characteristics of farms have a strong effect at the household level. Landownership has a significant positive effect on well ownership, implying that households owning more land are more likely to own wells. The age of head of household has a significant positive effect on well ownership, perhaps because farmers invest in tubewells as the household is able to accumulate funds for tubewell purchase. The dummy variable for no canal water has a large and significant coefficient. As noted above, the lack of alternative surface irrigation supplies has pushed these farmers to purchase tubewells, and joint investment has enabled even small farmers in Jaranwala Village to own at least a partial share of a well. The pattern of well ownership in Dir District, however, is not significantly different from that in Faisalabad District. This model correctly predicts well ownership status in 88.5 percent of all cases.

Although a small holding is not an insurmountable obstacle to well ownership (as demonstrated by a high proportion of joint well owners with small holdings in

[21] Similarly, the number of adult males in the household was found to be nonsignificant, and it was dropped from the final model because of potential multicollinearity. Multicollinearity between education and landownership may reflect the high correlation between human and physical capital in economies with imperfect credit markets.

Table 11—Water buyers' reasons for not owning tubewells

Reason	Faisalabad District	Dir District	Total
Too expensive	40 (54.1)	14 (93.3)	54 (60.7)
Holding too small	11 (14.9)	0 (0.0)	11 (12.4)
Not landowner	12 (16.2)	0 (0.0)	12 (13.5)
Land not near canal (insufficient recharge)	1 (1.4)	0 (0.0)	1 (1.1)
Poor groundwater quality	6 (8.2)	1 (6.6)	7 (7.8)
Total number of water buyers[a]	74[a]	15	89

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are percentage of water buyers.
[a]Includes those who own tubewells and purchase supplemental water.

Jaranwala), it is a constraint to widespread tubewell ownership. Tenants, especially those with no land of their own, are at a disadvantage in tubewell ownership because they do not have secure enough rights to land on which to install a tubewell and are likely to face credit constraints for tubewell investment (Malik, Broca, and Gill forthcoming). In the survey on water markets, over 60 percent of groundwater buyers cited the expense of purchasing a tubewell as a reason for not owning a well, but 25 percent cited a lack of landownership or too small a holding as a reason for not investing in a well (Table 11). Groundwater quality problems also prevent farmers from installing their own wells. Groundwater markets meet the need for water among those who have too little land, cannot afford tubewells, or find the investment not worthwhile, and those who have problems with the quality of groundwater on their own land.

Tubewell Water Purchasers

A logistic regression model, similar to that for tubewell ownership, was calculated to identify factors that predict who purchased tubewell water during the *rabi* and *kharif* seasons of 1991/92:[22]

$$TWBUY = fn\ (LANDOWN,\ AGE,\ SEASON,\ NOCANAL,\ DIR),$$

[22] Because of the small number of tubewell owners in the sample, it is not possible to develop a model to predict which tubewell owners sell water.

where all variables are defined as in the model for tubewell ownership, and

$TWBUY$ = probability of tubewell water purchase;
$SEASON$ = dummy variable for the *rabi* season.

The variable for season is added to see if there is a significant difference between *rabi* and *kharif* irrigation purchases. Whereas tubewell ownership is not likely to change between seasons, farmers may decide whether to purchase or sell water each season. As in the model for tubewell ownership, cropping patterns are not included because they are determined largely by the availability of water. The location of fields relative to the canal system and to tubewells whose owners are willing to sell water is likely to affect water purchases along with groundwater quality, but these factors are not included because the data are unavailable.[23]

Whereas the size of landownership and the age of household head have a strong positive effect on tubewell ownership in the model, these variables have a significant negative effect on water purchases (Table 12).[24] Thus younger households with less land are more likely to purchase groundwater than older households owning substantial amounts of land. Tenant farmers are likely to be dependent on other households' tubewells, as well as other households' land. Farmers in Dir are significantly less likely to purchase groundwater than those in Faisalabad, in part because of the higher rainfall and lower availability of tubewells in Dir.[25] Farmers in Jaranwala, who lack canal water, are also significantly less likely to purchase water. In this village, joint ownership, rather than groundwater markets, provides small farmers with access to groundwater. Because alternative sources of irrigation are not available, farmers in that village seek to assure themselves of access to groundwater by investing in wells rather than depending on groundwater purchases. The season does not have a significant effect on water purchases: 30 percent of farmers reported purchasing irrigation in *kharif*, compared with 25 percent in *rabi*.

Landownership and age are indicators of overall status among farm households. Farmers do not invest in tubewells for prestige, but higher status can enable them to mobilize the resources needed for tubewell investment, including financial resources and government assistance (such as electricity connections). Therefore, it is not

[23] Tubewell ownership was not included in the model because of the high multicollinearity between landownership and tubewell ownership. Similarly, operational holding size was not included because it is highly correlated with landownership. An alternative specification of the model, with operational holding instead of landownership, did not show a significant effect of holding size on water purchases.

[24] In a logit model for groundwater purchasing, using cross-sectional survey data from five states in India, Saleth (1991) also found a significant negative effect of farm size on likelihood of purchasing in three of five states. The other two states are characterized by small, fragmented holdings and higher-than-average rainfall. Thus the need for supplemental groundwater was less, and the larger farmers in those states were as likely to purchase groundwater as small farmers.

[25] The effect of number and density of tubewells in a village was tested in an alternative specification of the model. Tubewell density has a significant positive effect on the likelihood of water purchases, both in addition to the dummy variables for Dir and Jaranwala, and without the dummy variables included. The variable for tubewell density is not included in the final model because there are multicollinearity problems when it is included along with the dummy variables for location, and tubewell density does not explain as much as the two dummy variables, which capture rainfall and terrain effects as well.

Table 12—Logistic regression model for groundwater purchase

Independent Variable	Coefficient	t-Ratio	Wald Statistic
LANDOWN	−0.039**	−2.28	5.22
AGE	−0.031**	−3.30	10.87
SEASON	−0.355	−1.24	1.54
NOCANAL	−1.398**	−3.38	11.46
DIR	−3.262**	−8.15	66.50
Constant	2.250**	3.98	15.82

Model chi-square = 118.4** with 5 degrees of freedom
Number of observations = 352

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.
Notes: Predicted versus observed results for groundwater purchase are as follows:

	Predicted		
	NOT BUYING	*BUYING*	Percent Correct
Observed			
NOT BUYING	221	31	87.7
BUYING	36	64	64.0
			Overall 81.0

*Significant at the .10 level.
**Significant at the .05 level.

surprising that higher-status households are more likely to own wells, and lower-status households are more likely to rely on tubewell water purchases.[26]

But it is not only low-status households who purchase water: 7 of 28 tubewell owners in the IFPRI sample also buy groundwater. Water purchases may provide a backup when a farmer's own well is not functioning, or purchases may be used to irrigate land that cannot be served by a farmer's well. In several cases, farmers preferred buying water to operating their own wells because purchasing water from electric-powered wells was cheaper than using their own PTO tubewells.

Results of these models indicate that, whereas private tubewells are likely to be owned by large farmers, water markets improve equity of groundwater use by making water available to small landowners or tenants and younger households—those farmers who are least likely to own tubewells. In Faisalabad, where groundwater markets are most active, they provide the only access to groundwater for approximately half of the farmers who own less than 12.5 acres.

[26]Describing a similar phenomenon in Bihar, India, Wood (1995,70) found that wealthier households used social connections to get pumpsets and fuel. He notes that "poorer farming households [are] dependent upon access to the pumpsets of the rich. Such dependent access represents a degraded or conditional opt-out solution for poorer families, and is consistent with relations of dependency between families in the village."

5

OPERATION OF GROUNDWATER MARKETS

Although there is considerable debate on the extent of monopoly power exercised in groundwater markets (as discussed in Chapter 2), most would agree that groundwater markets are not perfectly competitive markets in which buyers are free to choose among a number of sellers. Water rights are not well defined, and transaction costs are far from being zero. Because buyer and seller are not anonymous, but face each other as neighbors every day, more is involved in transactions than a simple sale of water. Shah (1991) argues that as groundwater markets develop, they become depersonalized and move toward fixed cash prices. The evidence on the extent to which this has taken place in the IFPRI study areas is mixed. This chapter examines the operation of water markets in terms of the physical and social relations between buyer and seller, the types of contracts, and the reliability of access that groundwater markets afford to buyers.

Physical Relationships between Buyer and Seller

One of the first constraints to competition in groundwater markets is that in many areas there are not a large number of water sellers who can serve a particular plot of land. Under conditions prevailing in most of Pakistan, tubewell irrigation water is not a commodity that can be transported far from the source to the area of application. Conveyance losses between the tubewell and the field restrict purchasers to buying from tubewells located in close proximity of their fields (and restricts sellers to those within a limited radius of the well). The distance over which it is feasible and economically viable to transmit water depends on the soils, topography, and type of channel used to convey the water. In the IFPRI survey, the average distance between the tubewell and purchasers' fields was 600 meters in Faisalabad District and 180 meters in Dir, which has more undulating topography. Use of lined watercourses or field channels, which have lower transmission losses than unlined channels, increases the distance over which water can be transported. Ten of the 13 cases in which the distance between source and fields was over 1,000 meters used lined watercourses (including one case in which water traveled down 3 kilometers of lined watercourse between the well and field).

Lined watercourses and pipes ensure that water purchasers receive more of the water they pay for from the tubewell and permit sales to a wider potential number of fields from each tubewell. Underground pipes can even, to some extent, overcome topographic limitations to water sales, by enabling water to reach fields at a higher level than the tubewell. Lined conveyance structures thus go hand in hand with the development of more competitive groundwater markets. They allow purchasers to obtain water within a wider radius of their fields, thereby increasing the number of potential suppliers. Shah and Raju (1988) report that as competitive groundwater markets developed in Gujarat State, India, tubewell water sellers who wanted to maintain clients installed lined conveyances to ensure that water could reach as many buyers as possible with low losses.

Despite these advantages for groundwater markets, there has been little private investment in lining or pipes in the IFPRI sample areas. Four farmers reported using lined field channels to convey purchased tubewell water part of the way (though in two cases the field channels were only lined for the first 20 meters from the tubewell, which is done primarily to absorb the energy of the tubewell water being pumped into the channel). Three sellers used underground pipes, which have the lowest conveyance losses. *Pukka* (lined) watercourses are used more frequently than lined field channels or pipes because watercourse lining results from government and collective farmer investment, while lining field channels or installing pipes requires considerable private investment.

Farmers use watercourses for tubewell water despite the Canal and Drainage Act provision that all who do so are assessed the water rate for canal irrigation use. A NESPAK (1991) study suggests that this law restricts the sale of tubewell water; it recommends allowing farmers to use watercourses for tubewell water without charge to encourage groundwater markets and the mixing of marginal-quality tubewell water with fresh canal water supplies. The Canal and Drainage Act further restricts transporting tubewell water by prohibiting farmers from carrying water across public watercourses. It may be worth lifting this restriction, provided the pipes or other structures used to carry the tubewell water do not block or erode the watercourse.

Renfro's (1982) study notes a positive association between private tubewells and collective activity among farmers, particularly with regard to watercourse lining.[27] Renfro and Sparling (1986, 206) suggest the reason for this is that "farmers with cooperative neighbors are more likely to invest in tubewells, and the presence of private tubewells gives farmers new reasons to cooperate with each other." However, this explanation omits the role of watercourse condition in reducing transmission losses of high-value groundwater. An alternative explanation is that, with tubewell use in general and groundwater market sales in particular, farmers recognize the value of canal lining and have greater incentive to reduce water losses through watercourse lining and cleaning.[28] Watercourse rehabilitation conserves canal water; but by reducing transmission losses of tubewell water, lining can also encourage the development of competitive groundwater markets.

Social Relationships Between Buyer and Seller

Physical proximity is not the only relevant relationship that influences the development of competitive groundwater markets. Social relationships between buyer and seller also restrict the sale and purchase of groundwater if tubewell owners are only willing to sell to close relatives or those with whom they have other ties.

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[27] Under the On-Farm Water Management projects implemented by the Government of Pakistan with USAID and World Bank assistance, farmers are required to organize into water users' associations in order to receive government assistance for watercourse improvement (see Byrnes 1992).

[28] It may also be that both watercourse lining and water markets are the product of a more cooperative social structure. Strosser and Kuper (1994) report that in their study area of Punjab, there were more water sales among the "settler" community, which has a reputation for being more cooperative, than among the community of "locals," with larger holdings cultivated by external labor and less of an orientation toward cooperation.

A major reason for sales among kin is that relatives often have the closest landholdings, due to inheritance patterns. Selling water to relatives also provides a means of controlling transaction costs and ensuring fee repayment. However, transaction costs can also be higher with relatives, either because of quarrels or difficulty in collecting payments (Merrey 1986a). Sale to tenants and clients reduces transaction costs and risk, because patterns of interaction are already established, and payment for water is guaranteed by other ties (Wood 1995).

Sales do not appear to be limited to relatives in the IFPRI study areas. Only 22 percent of groundwater market transactions in Faisalabad District were between close relatives. Approximately one-third (37 percent) of transactions were between members of the same *biradari*,[29] which represents a broader social grouping. Sale of tubewell water between kin is even more rare in Dir, where only 2 percent of transactions were between close relatives or *biradari* members. There, groundwater market transactions were more likely to follow patron-client ties, with 37 percent of sales reported between landlord and sharecropper (compared with less than 1 percent in Faisalabad District).

The fact that sales to relatives and clients are not more pervasive seems to indicate that the "depersonalization" that Shah (1991) hypothesizes as groundwater markets develop has taken place in the study areas. Kinship relationships neither restrict access to groundwater nor have a significant effect on the reliability of deliveries, as discussed later. However, because sales are restricted to nearby landholdings, buyer and seller will have some form of social tie as neighbors. There is also some interlinkage between land and water markets, especially in Dir. These factors are likely to affect the price of water, as noted below.

Nature of Groundwater Market Contracts

A flat charge per hour of pumping is the most common form of groundwater market contract in both Faisalabad and Dir districts (Table 13). This type of arrangement occurs under all types of tubewells. Water from diesel pumpsets in Jaranwala (Faisalabad District) is commonly sold under an arrangement whereby the buyer supplies the diesel and motor oil for the pump and pays an additional fee of Rs 4 to 6 per hour to the well owner to cover the wear and tear on the engine. Sharecropping contracts for water are used under both diesel and electric tubewells in Dir.

Prices under the hourly charge system range from Rs 14 to 80 per hour, depending on the pump type, capacity, and location (for mean values, see Table 14). The higher price of water from PTO tubewells reflects the higher cost of operating this type of pump. The average price of water under the hourly charge system is approximately the same for diesel and electric tubewells, although the former are usually more expensive to operate. The mean hourly cost of water to the purchasers from diesel tubewells is slightly higher under the buyer-brings-fuel system than under the flat hourly charge. Water sellers with diesel pumps are apparently only recovering their own operation

[29] *Biradari* are "brotherhoods" or named local coresident groups based on a combination of patrilineal descent and marriage (Merrey 1986b).

Table 13—Water market contracts, by type of pump

District/Type of Contract	Type of Pump: Electric	Diesel	Power Takeoff	Total
Faisalabad District				
Flat charge per hour	44	9	19	72
Buyer brings fuel	0	18	0	18
Share of crop	0	0	0	0
Total	44	27	19	90
Dir District				
Flat charge per hour	0	13	0	13
Buyer brings fuel	0	0	0	0
Share of crop	6	2	0	8
Total	6	15	0	21

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Table includes number of sellers' and buyers' responses about type of contract.

and maintenance costs under either type of contract.[30] The sellers' transaction costs in acquiring the fuel and operating or supervising the operation of the pump are presumably higher under the hourly charge contracts, but there may be reluctance to let some purchasers operate the pumps themselves under the buyer-brings-fuel system. Among IFPRI sample villages, the buyer-brings-fuel contract was only found in Jaranwala, where there is also a high incidence of joint ownership of wells. With jointly owned wells, having the buyer bring the fuel reduces the need for the shareholders to share the costs or income from the sale. However, this type of contract is also reported in other areas with conjunctive canal and tubewell irrigation, such as southern Punjab.

All water transactions under hourly charge contracts in Dir are found in Khanpur. The price is Rs 40 to 80 per hour, which is higher, on average, than in Faisalabad. Several factors could account for the higher price in Khanpur: the well from which most farmers purchase is large-capacity, powered by a 113-horsepower truck engine, and therefore expensive to operate.[31] Irrigation water is also more scarce in Dir than in Faisalabad, where canal water is readily available and groundwater tables are generally higher. A final consideration may be that land and water markets are linked in Khanpur, where most water purchasers buy water from their landlord, whereas only one case of this was found in Faisalabad.

A larger sample of water sellers and purchasers under different ecological and socioeconomic conditions would be necessary to estimate the effect of these factors on

[30] Unfortunately, much of the information on price of purchased tubewell water comes from water buyers, rather than from the sellers. There are thus not enough data on tubewell operations costs and water delivery rates to determine the profit margin for water sales or the exact price per unit water pumped.

[31] The price per horsepower is lower in Dir than Faisalabad, but this may be misleading because the relationship between horsepower and water delivery is not linear, particularly when comparing the pumpset powered by a truck engine with lower-horsepower engines designed for tubewells.

Table 14—Average cost of tubewell water, by type of pump and contract

District/Contract	Type of Pump Electric	Diesel	Power Takeoff
Faisalabad			
Flat charge (Rs/hour)	27.82 (7.77)	29.44 (8.08)	43.95 (7.56)
Buyer brings fuel (Rs/hour)	. . .	32.06 (5.39)	. . .
Dir			
Flat charge (Rs/hour)	. . .	49.23 (17.54)	. . .
Share of crop (percent)	23.15 (2.31)	25.00 (0.00)	. . .

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1991/92.
Notes: Costs computed from sellers' and buyers' responses. Numbers in parentheses are standard deviations. Leaders (. . .) indicate not applicable.

the cost of private tubewell water.[32] However, it is notable that under both the hourly charge and buyer-brings-fuel contracts, the price of water does not vary over the course of a season to reflect changes in its scarcity and value. It does not appear that the prices reported under either system represent a large profit to the tubewell owner.[33]

Why do farmers not adjust water prices to capture the scarcity value of water? It may be that tubewell owners are not seen as owners of the water, and hence the transaction is regarded more as the rental of tubewell equipment (akin to tractor rental), rather than sale of water (see Saleth 1994). However, in interviews farmers did not conceptually distinguish between the two, and Shah (1994) suggests that this is mostly an academic distinction. Wood (1995) explains that a fixed price reduces transaction costs, and it avoids perceptions that a seller is profiting from the misfortunes and water needs of the buyer (who is often a neighbor, or relative, or both). Sales may not be limited to close kin, but they are limited to close neighbors, and there are repeated interactions between buyer and seller over the course of many years—not only on water transactions but in many other ways. Maximizing profits from water sales could lose goodwill and cost the seller more in the long run. However, in Pakistan, as in Bihar, "the notional existence of such a general price does not translate into economic entitlement for those prepared to pay the price. Such families can be,

[32] Analysis by Malik and Strosser (1993) and Strosser and Kuper (1994) shows that within a local area, tubewell discharge, energy source, location on watercourse, and time of payment are important determinants of groundwater price. Unfortunately, the present study has discharge data available only if the well owner was in the sample, but not for the larger number of water buyers. The small sample size and segmentation of owners into different contract types precludes modeling price of water in the IFPRI sample areas.

[33] Strosser and Kuper (1994) report that the buyer-brings-fuel sales in their study areas do not include a charge for wear and tear on the engine. In such situations, sellers do not even recover their maintenance and depreciation costs.

and often are, denied the use of a pumpset" (Wood 1995, 29). The extent to which households dependent on purchased groundwater are denied access to that resource and the implications for productivity are explored in the next section.

The fact that water is priced close to the cost of lifting has several important implications. First, concerns over water sellers' appropriating the value of groundwater do not seem justified, particularly in the Faisalabad area. It also means, however, that there is not much profit to be made from water sales; therefore, small farmers are not likely to be able to use profits from water sales to cover the costs of tubewell investment.

Sharecropping contracts for tubewell water are only applied to tomato, onion, and some maize cultivation in Dir. The standard rate is 25 percent of the crop. Three water sellers reported giving a different rate to their tenants: 20 percent as the share for the water (in addition to the share for the land), or 50 percent for the land and water combined. The use of sharecropping contracts for provision of water in Dir may reflect the greater prevalence of sharecropping for land in that area than in Faisalabad. Sharecropping for water is also reported for rice and berseem crops in other regions.[34] The extent of crop share contracts for water may be underestimated where the land and water markets are interlinked. While tubewell irrigation can then be considered as one of the inputs that the landlord provides (such as fertilizer or plowing services), to do so masks the importance of timing and reliability of irrigation service in the overall production process.

It is noteworthy that sharecropping for tubewell water is practiced under the cultivation of crops such as tomatoes, onions, or rice, which are sensitive to moisture stress at critical periods. In sharecropping contracts, the water seller has a stake in the outcome of the crop, and a share in the losses if the water supply does not meet crop needs. Therefore, the seller has an incentive to supply tubewell water in an adequate and timely manner. This is not as critical for crops less susceptible to the timing of irrigation, or where alternative sources of irrigation are readily available. Chaudhry (1990) and Shah (1991) have suggested that, as groundwater markets develop, there is a tendency to move toward cash contracts. If, however, sharecropping for water offers a greater incentive for sellers to provide reliable irrigation service, this type of contract may remain for water-sensitive crops. Further empirical research on the provision of tubewell water in different agroecological zones and for different crops is necessary to establish the factors affecting the choice of contract and quality of irrigation service, but Aggarwal's (1996, 17) analysis of data from Gujarat, India, "strongly supports the hypothesis that crops in which output is highly sensitive to the timing of irrigations are more likely to be under cropsharing contracts."

Reliability of Irrigation Service

The productivity of irrigated agriculture is not determined solely by the amount of irrigation water supplied. The timeliness and reliability of water supplies are also critical. Timing waterings to meet crop evapotranspirative demand has a direct impact on yield, while the confidence farmers have in their water supply can affect their crop

[34] Personal communication, Muhammad Jameel Khan, March 1992. Also see Chaudhry 1990.

choice, level of fertilizer and labor use, and the application of other inputs. Given the high investment of labor and other inputs required for production of many irrigated crops, Wood (1995, 30) points out that "it is disastrous to start such a season without a guaranteed supply of water to complete the season."

Few studies of groundwater markets have addressed the timeliness and reliability of purchased irrigation services, especially because they are difficult to quantify and measure.[35] However, availability of water throughout the season, especially at critical times, provides one indicator of irrigation service.

Because tubewell water is not tied to a fixed *warabandi* rotation schedule, it is easier to match tubewell irrigations to crop needs, in order to provide more frequent irrigations during periods of peak demand, if necessary. Tubewell water is also available throughout the year, except during periods of mechanical breakdown. In the IFPRI sample, tubewell owners reported that pump or engine failures made groundwater unavailable for an average of two weeks per season in Faisalabad, and one week per season in Dir. This compares favorably with the reported unavailability of canal water for an average of four weeks per season in Faisalabad and five weeks per season in Dir.

Although the reliability of irrigation service under private tubewells is generally higher than under public sources such as canals and government tubewells, it is likely to be lower for water purchasers than for farmers with their own wells because tubewell owners sell surplus water after meeting the needs of their own crops. Thus, the deficits created by shortages of groundwater or energy supplies are not shared equally between owner and purchaser, but rather reduce groundwater availability to purchasers first. Such groundwater shortages compound groundwater unavailability due to mechanical failure of pumps, the latter affecting both owners and purchasers.

Tubewell water sellers and purchasers in the IFPRI sample were asked whether water was always available when requested, as an indicator of reliability. Farmers responded that water is most likely to be unavailable for sale or purchase during periods of electricity shortage,[36] and during periods of peak water demand. Not surprisingly, water buyers were more likely to identify problems with water availability than were the water sellers (Table 15). Over a fourth of Faisalabad water buyers reported that they were unable to purchase water to meet crop needs during times of electricity shortage, although no sellers reported being unable to sell because of electricity shortage. Times of peak water demand are more problematic: nearly a fourth of all sellers and over half of all buyers reported that purchased tubewell water was not always available when needed during such periods.

What influences the reliability of purchased irrigation water? [37] Three factors can be hypothesized to have an effect: type of tubewell, characteristics of the buyer, and the relationship between seller and buyer.

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[35] For an empirical measure of the timeliness of surface and groundwater irrigation and the effects of timeliness on productivity in Bihar, India, see Meinzen-Dick 1995.

[36] Although load shedding officially ended in 1991, power outages are common at times of high demand for groundwater, especially during canal closure periods in *rabi* and high evapotranspiration periods in *kharif* (Murray-Rust and Vander Velde 1994, 230).

[37] It may be argued that if particular farmers know they cannot purchase water at certain times, their supply is still reliable. In practice, farmers do not know with certainty whether they will or will not be able to get water at a given time; hence, it is unreliable.

Table 15—Reported unavailability of purchased tubewell water

Period When Purchased Tubewell Water May Be Unavailable	Faisalabad		Dir		Total	
	Sellers Reporting	Buyers Reporting	Sellers Reporting	Buyers Reporting	Sellers Reporting	Buyers Reporting
Electricity load shedding	0 (0.0)	22 (26.5)	0 (0.0)	0 (0.0)	0 (0.0)	22 (22.4)
Peak demand seasons	1 (14.3)	54 (65.1)	2 (33.3)	1 (6.6)	3 (23.1)	55 (56.1)
Total sample size	7	83	6	15	13	98

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are percentage of sample reporting.

Electric tubewells are more susceptible to power outages and are therefore likely to be less reliable. Larger-capacity tubewells and those that draw water from deeper levels are hypothesized to be more reliable. Buyers with higher social status, indicated by landownership and age, are also hypothesized to have more reliable access to purchased tubewell water. If social ties influence reliability of water markets, farmers who buy water from close relatives or their landlords would be expected to receive more reliable irrigation service.

The following logistic regression model has been used to test these hypotheses, using buyers' reported availability of tubewell water whenever needed as an indicator of reliability:

RELIABLE = fn (ELECTRIC, DIAMETER, DEPTH, LANDOWN, AGE, RELATIVE, LANDLORD, JARANWALA, DIR),

where

RELIABLE = groundwater always available for sale or purchase when needed;
ELECTRIC = dummy variable for electric powered tubewell;
DIAMETER = diameter of tubewell, in inches;
DEPTH = depth of tubewell, in feet;
LANDOWN = land owned by water buyer, in acres;
AGE = age of head of water-buying household, in years;
RELATIVE = dummy variable for buying from a close relative;
LANDLORD = dummy variable for buying from a landlord;
JARANWALA = dummy variable for Jaranwala Village in Faisalabad District;
DIR = dummy variable for Dir District.

Diameter of tubewell is a proxy for tubewell capacity, because discharge data are not available for the wells from which sample farmers purchase. Dummy variables for

Table 16—Logistic regression model for reliability of purchased groundwater

Independent Variable	Coefficient	t-Ratio	Wald Statistic
ELECTRIC	−2.189**	−2.934	8.617
DIAMETER	1.267**	2.368	5.587
DEPTH	−0.026	−1.245	1.553
LANDOWN	0.072**	1.986	3.949
AGE	0.045*	1.844	3.398
RELATIVE	0.855	0.866	0.750
LANDLORD	10.613	0.435	0.189
JARANWALA	0.668	0.726	0.527
DIR	4.209**	2.397	5.745
Constant	−5.929*	−1.838	3.378

Model chi-square = 58.2** with 9 degrees of freedom
Number of observations = 96

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.

Notes: Predicted versus observed results for reliability of purchased tubewell water are as follows:

	Predicted: *NOT RELIABLE*	Predicted: *RELIABLE*	Percent Correct
Observed			
NOT RELIABLE	49	6	89.1
RELIABLE	9	32	78.5
			Overall 84.4

*Significant at the .10 level.
**Significant at the .05 level.

Jaranwala and for Dir District are included to control for agroecological differences between these areas and the rest of the sample (most notably the differential availability of canal irrigation).

Results of the logit model are given in Table 16. As predicted, electric tubewells are significantly less reliable than those with diesel or PTO lifts.[38] Larger-diameter tubewells are significantly more reliable than smaller ones, but deeper tubewells do not provide more reliable irrigation for purchasers—indeed, the coefficient is negative, though not significant. Deeper tubewells may be located in groundwater-scarce areas and therefore provide less reliable supplies to purchasers.

The amount of land owned has a significant and positive effect on reliability, suggesting that water sellers are less likely to deny requests for water from larger landowners than from small landowners or landless tenant cultivators. This is due to the influence of landownership, not the size of farm operated. An alternate specification of the model with operational holding, rather than land owned, showed no

[38] In an alternative specification of the model, the difference between diesel and tractor tubewells was tested and found not significant.

significant coefficient for size of holding.[39] The age of purchasers' head of household, another indicator of status, has a positive effect on reliability. The model does not show kinship or landlord-tenant relationships between water buyer and seller as having a significant effect on reliability of access to groundwater. The village of Jaranwala does not differ significantly from other areas in reliability of purchased tubewell water, but buyers in Dir District reported significantly more reliable access to groundwater. This is somewhat surprising because irrigation is less available in Dir than in the canal-irrigated areas of Faisalabad, and therefore one would expect the demand for groundwater to be higher there. However, rainfall is higher in Dir, reducing the need for irrigation.

Although buyers' reported problems with unavailability of purchased groundwater is an imperfect indicator of reliability, this model points to important sources of problems in groundwater markets. Purchasers are more likely to receive insufficient groundwater if they buy from small-capacity, electric-powered tubewells; if they are young and own little or no land; or if they live in Faisalabad District. Improving the reliability of electric power or switching to diesel pumps are the most readily identifiable interventions to improve reliability of groundwater markets (as well as reliability of water for well owners). Both of these options are, however, expensive. Identifying the factors that lead to lower reliability in Faisalabad than in Dir requires further study.

Although landownership and age have strong influences on reliability, they do not appear to point to policy interventions that can improve reliability. Improving the reliability of irrigation by increasing the landownership and age of water-purchasing households is not feasible or even desirable. However, it may be possible to raise the status of purchasers *relative to* water sellers by encouraging medium-sized farmers to purchase tubewells. This study does not have data on both the sellers' and buyers' characteristics for each relationship, but it is possible that farmers with less land will provide more reliable service, both because there is less of a status gap between them and the purchasers and because tubewell owners with medium-sized holdings will not need as much water to meet irrigation needs on their own fields, and thus have surplus water available for sale (as suggested by the district-level analysis above).

Price and Nonprice Factors in Groundwater Allocation

Because groundwater markets operate with repeated interactions between a local set of groundwater buyers and sellers who are connected by more than a single transaction, it is not only the price of water that determines the allocation of this resource. Physical parameters, such as location of wells, fields, and conveyance infrastructure, set limits on potential buyers and sellers. Socioeconomic factors, such as personal relations between buyer and seller and the choice of crop, strongly influence the type of contract and price of water.

Even once the (informal) contract is set, a number of nonprice factors affect access to the resource. In times of scarcity, prices do not rise, but a form of informal rationing

[39] Both ownership and operational holding size could not be included because of multicollinearity problems.

takes place, depending on the status of the buyer (as indicated by landownership and age). Weitzman (1977, 517) argues that rationing is more effective than price mechanisms "as needs for the deficit commodity are more uniform or as there is greater income inequality." Certainly the widespread need for supplemental groundwater and the inequality of incomes apply in rural Pakistan. But the implicit rationing, as currently practiced, reinforces both inequity (because scarcity is shared unequally between well owners and buyers, and even among buyers, based on their status) and uncertainty (because purchasers cannot rely on ability to purchase) in access to the critical resource.

Why is reliability of groundwater sales a matter for concern? If, as Shah (1993b) suggests, the value of irrigation surplus is related to the degree of water control, water purchasers may not be receiving the full benefit of groundwater irrigation. Aggarwal (1996, 3) points out that "because the productivity of many high-yielding crop varieties is very sensitive to the timeliness of irrigation supply, who has ownership over the well and hence the residual rights of control matters not only for equity but also efficiency reasons." The following chapter examines the evidence on this through comparison of the contribution of different sources of irrigation to wheat yields and overall farm income in the IFPRI study areas.

6

IMPACT ON AGRICULTURAL PRODUCTIVITY AND INCOMES

Irrigation offers the potential to increase agricultural productivity by increasing the total availability of water for crop growth. It also gives farmers greater flexibility and control in the amount and timing of water application and provides insurance against disasters. With better water control, agricultural productivity is likely to increase because of three factors: (1) as the risks of production decline with improved water control, farmers may use more inputs; (2) crop yields may increase; and (3) farmers may switch to more profitable but water-sensitive crops. Shah (1993b) argues that the "irrigation surplus" is therefore directly related to the quality of irrigation service.

Not all sources of irrigation are equal in meeting the needs of crops. In Pakistan, canal water is generally cheaper and of higher quality than water from private tubewells.[40] The major advantage of groundwater from private sources lies in the greater quantity and the degree of control that farmers can exercise over the timing of irrigation. Canal deliveries are often not available for the whole year, thereby curtailing the intensity of irrigated cultivation. Even when canal supplies are available, they are often not sufficient for intensive irrigated agriculture. Murray-Rust and Vander Velde (1994) argue that the volume of water supplied by tubewells is critical to the cropping patterns adopted in much of Pakistan. Furthermore, the *warabandi* system, which provides a fixed schedule of canal deliveries, does not allow farmers the flexibility to adapt applications to meet optimal crop water requirements. The potential to improve the timing of water deliveries is one of the great attractions of private tubewell irrigation.

This chapter examines the impact of water markets on agricultural productivity and farm incomes by comparing the effects of canal water, purchased groundwater, and water from farmers' own tubewells on yields and gross margins in the IFPRI sample areas. Previous studies have shown clear productivity gains to farmers purchasing groundwater over those using only public canal or public tubewell supplies, but the gains were much less than those obtained by tubewell owners. The wheat and cotton yield increases of tubewell water purchasers (compared with those with canal water only) were half as great as the yield increases for tubewell owners in Freeman,

[40] Farmers are charged for canal water on the basis of acres of crops, not volume of water consumed. However, cost per acre-foot ranges from Rs 12 for sugarcane to Rs 40 for oilseeds (Chaudhry, Majid, and Chaudhry 1993). This is less than a tenth of the cost of tubewell water, which ranges from Rs 176 to 437 per acre foot of water pumped (NESPAK 1991, 4–21). Canal water has very low salinity, but much of the groundwater is saline. NESPAK (1991, Annex Table 1.2.2) reports that area underlain by good quality groundwater ranges from 82 percent of the area in NWFP to 64 percent in Punjab and only 58 percent in Sind (with some districts as low as 31 percent).

Table 17—Average yields of major crops by water source in Freeman, Lowdermilk, and Early's 1978 study

Crop	Canal Only	Public Tubewell	Purchased from Tubewell	Own Tubewell
		(kilograms/acre)		
Wheat	672	747	784	896
Rice	522	709	784	859
Cotton	261	299	373	485

Source: Freeman, Lowdermilk, and Early 1978.
Note: All tubewell water is in addition to canal supplies.

Lowdermilk, and Early's (1978) study. For rice the gap was narrower: water purchasers obtained 78 percent of the yield increases of tubewell owners (Table 17).[41]

A study of private tubewells by WAPDA (1980, cited in World Bank 1984) found that overall cropping intensity and the proportion of area under water-consumptive crops was higher for tubewell owners than for water purchasers. There was also a yield gap between water purchasers and tubewell owners for sugarcane, rice, wheat, and vegetables (Table 18). Part of the difference in yields may be due to lower applications of irrigation water and complementary inputs such as fertilizer and insecticides by tubewell water purchasers than by owners (even though tubewell water purchasers used more inputs and had higher yields than nonusers for almost all crops).

Renfro (1982) found that the cropping intensities, the proportion of area under water-consumptive crops, and the gross income per acre achieved by tubewell water purchasers more closely approximated that of farmers who only received canal water than that of tubewell owners, even though their cash and labor inputs were virtually as high as those of tubewell owners (Table 19). A more recent evaluation of the SCARP Transition Pilot Project in Punjab found convergence between well owners and water purchasers on wheat and, to a lesser extent, rice yields. But an overall productivity gap remains: well owners had higher fodder yields, which enabled them to free more land for high-value vegetables. Furthermore, well owners' returns per acre of vegetables were 79 percent higher than for those water buyers who grew vegetables (World Bank 1996).

In part, water buyers may have lower cropping intensities and yields than tubewell owners because buyers choose to use less water due to the cost of purchased tubewell water. However, the price of water for tubewell water buyers in the IFPRI sample was not much greater than the cost to tubewell owners (except for owners of electric pumpsets with fixed electricity charges, who face a very low marginal cost and therefore have an incentive to pump as much water as can be used). Whether tubewell water buyers use less groundwater based on an input allocation decision or supply

[41] A WAPDA (1990) study also assesses the effects of productivity of purchased water. However, the yield differentials are based on farmers' assessments of what their yields would be with and without privately purchased water and are thus not as reliable as comparisons of actual yields of farmers with and without purchased water.

Table 18—Input use and yields for tubewell users and nonusers in WAPDA study

Item	Unit	Type	Sugar-cane	Rice	Gardens	Vege-table	Cotton	Wheat	Pulses	Oil-seeds	Others	Total
Cropping pattern	Percent acres	O	8	21	4	3	8	60	15	8	18	157
		P	5	16	2	2	8	36	13	13	19	136
		Nu	3	7	1	1	7.5	50	16	11	15	113
Per acre use of												
Nitrogen	50 kilogram bag	O	1.5	1.5	0.5	0.9	0.5	1.0	...	0.2	0.5	...
		P	1.0	1.3	0.5	0.5	0.5	0.75	...	0.1	0.4	...
		Nu	1.0	1.0	0.4	0.5	0.2	0.5	...	...	0.2	...
Phosphorus	50 kilogram bag	O	0.25	0.5	0.2	1.0	0.25	0.75	0.1	...	0.2	...
		P	0.2	0.5	0.2	0.5	0.1	0.6	...	...	...	...
		Nu	0.2	0.4	0.1	...	0.1	0.2	0.2	...	0.1	...
Seed rate	Maunds or Rs	O	67	0.13	130	300	0.15	0.9	0.6	0.1	50	...
		P	71	0.12	150	300	0.14	0.8	0.6	0.1	50	...
		Nu	53	0.13	150	300	0.11	0.9	0.7	0.1	50	...
Insecticide	Rs	O	14	11.0	50	...	25	1.0	...	...	...	...
		P	18	10.5	50	...	13	...	...	...	...	...
		Nu	7	11.2	50	...	17	...	...	...	...	...
Canal water	Acre-feet	O	1.5	1.5	2.0	1.5	0.9	0.6	0.2	0.1	0.4	...
		P/Nu	1.2	1.2	1.5	1.2	0.7	0.4	0.2	0.1	0.3	...
Tubewell delta	Acre-feet	O	2.0	2.0	1.1	0.7	0.3	0.5	...	...	0.5	...
		P	1.0	1.5	1.0	0.6	...	0.3	...	...	0.3	...
Yield/acre	Maunds or Rs	O	595.0	32.1	23.6	2,450.0	1,680.0	9.3	26.3	9.3	9.1	600.0
		P	485.0	29.3	22.9	2,573.0	1,595.0	8.5	21.7	10.4	8.9	600.0
		Nu	315.0	21.4	18.7	2,138.0	1,030.0	9.2	18.5	10.8	9.7	600.0

Source: WAPDA 1980.
Notes: O = tubewell owner, P = tubewell water purchaser, and Nu = nonuser of tubewell water. Leaders (. . .) indicate not applicable.

Table 19—Input use and agricultural productivity in Renfro's 1982 study

Item	Canal Water Only	Tubewell Water Buyers	Tubewell Owners	Average for Total Sample
Gross crop income	3,018	3,475	4,659	3,297
(Rs/acre)	(1,081)*	(1,632)*	(2,029)	(1,453)
Canal water use/acre	26.3	26.2	25.2	26.0
(acre minutes)	(9.5)	(5.6)	(6.7)	(9.2)
Tubewell water use/acre	0.0	14.2	31.4	7.9
(acre minutes)	(0.0)*	(13.3)*	(21.9)	(14.9)
Cash input expenditure	309	385	388	344
(Rs/acre)	(156)	(158)	(86)	(198)
Labor use	73.8	76.2	75.5	74.0
(man-days/acre)	(37.8)	(35.4)	(46.4)	(37.3)
Cropping intensity	160	168	184	164
(percent)	(25)	(28)	(23)	(26)
Percent of water-consumptive	35	36	45	36
crops	(17)	(22)	(20)	(19)
Sample size	69	50	10	129

Source: Renfro 1982.
Note: Numbers in parentheses are standard deviations.
*Difference between categories is significant at the .05 level.

constraints is unclear. As discussed above, there are numerous occasions when tubewell water is not available to water buyers at any cost, despite their demand for it. The lower reliability of purchased tubewell water compared with owned tubewell water is likely to be a major contributor to any yield or income gap between tubewell owners and water purchasers. Renfro (1982, 83) concludes that, in comparison with water purchasers, "actual sampled tubewell owners can exert more control over water supplies with favorable impacts on productivity."

The differences in cropping pattern between tubewell owners, water purchasers, and nonusers of tubewell water are not as clear in the IFPRI sample villages as in the WAPDA (1980) and Renfro (1982) studies. Table 20 examines the cropping patterns in Faisalabad and Dir districts by source of irrigation. In Faisalabad, all categories of farmers cultivated approximately 85 to 93 percent of their land in *kharif,* and differences among the categories were not significant. In the drier *rabi* season, tubewell owners and water buyers both cultivated an average of 80 percent of their holdings, which was significantly higher than nonusers of groundwater, who averaged less than 60 percent. Dir farmers cultivated less than 80 percent of their holdings, on average, in *kharif.* In *rabi,* tubewell owners and nonusers of groundwater grew crops on approximately 85 percent of their land, while groundwater purchasers had only 62 percent under cultivation. However, these differences were not significant.

Simple differences in cropping patterns, yields, and incomes from cultivation are inadequate indicators of the degree of irrigation surplus afforded by different types of water control. The present study provides a more complete examination of the effects

Table 20—Cropping pattern by access to tubewell water, Faisalabad and Dir districts

Item	Tubewell Owner	Tubewell Water Buyer	Nonuser of Groundwater	Average for Total Sample
		(percent of sample farm area)		
Faisalabad				
Kharif crops	93.00 (37.6)	84.5 (24.0)	88.6 (37.9)	87.6 (31.6)
Rabi crops	81.1 (38.7)	79.4 (28.9)	58.5 (32.7)	73.7 (33.5)
Cropping intensity	174.1 (64.0)	163.9 (40.1)	147.2 (58.9)	161.4 (52.3)
Sample size	21	45	27	93
Dir				
Kharif crops	73.3 (34.8)	76.0 (38.1)	79.6 (40.3)	79.2 (39.7)
Rabi crops	84.4 (20.1)	62.0 (18.0)	86.6 (32.6)	73.7 (33.5)
Cropping intensity	157.8 (49.3)	138.1 (41.1)	166.3 (61.2)	164.7 (59.9)
Sample size	4	4	86	94

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.
Note: Numbers in parentheses are standard deviations.

of groundwater markets on agricultural productivity, using IFPRI survey data from 1991/92 in Faisalabad and Dir districts. It first analyzes the effect of each water application using a production function for wheat, the major irrigated crop. It then turns to an examination of the overall effect on farm incomes, using a reduced form equation to model the effects of tubewell ownership, groundwater purchase, and canal irrigation on gross margins.

Contribution to Wheat Yields

In order to examine the impact of different sources of irrigation on yields, a production function was estimated using plot-level data for the 1990/91 agricultural year. Due to limited degrees of freedom for other crops in the sample, this equation was estimated for wheat only, a staple crop grown by nearly all farmers in both Faisalabad and Dir. In this model,

YWHEAT = fn (SEED, FERTILIZE, LABOR, BASEpH, SOILK, SOILP, SALINITY, CANALIRR, PURTWIRR, OWNTWIRR), where

YWHEAT	=	yield of wheat, in kilograms per acre;
SEED	=	seeding rate, in kilograms per acre;
FERTILIZE	=	fertilizer inputs (elemental nitrogen plus phosphorus) in kilograms per acre;
LABOR	=	labor input, in person-days per acre;
BASEpH	=	degree of alkalinity, or adjusted pH;
SOILK	=	soil potassium, in parts per million per acre;
SOILP	=	soil phosphorus, in parts per million per acre;
SALINITY	=	soil salinity dummy;
CANALIRR	=	number of canal irrigation applications;
PURTWIRR	=	number of purchased groundwater irrigation applications;
OWNTWIRR	=	number of irrigation applications from own tubewell.

Soil pH has been transformed to degree of alkalinity, a variable computed by subtracting 7 from the original pH value.[42] Salinity is represented by a dummy variable indicating if measured electrical conductivity levels are greater than or equal to 4 millimhos (a unit of electrical conductance) per centimeter, the threshold level for average crop tolerance of salinity.[43]

Unlike conventional production functions, this analysis separates out the irrigation applications by source. It further distinguishes between groundwater applied from own tubewells and those applications purchased from other farmers. Because canal water is generally of higher quality, canal applications should make a greater contribution than groundwater, while applications from both groundwater sources should have approximately the same impact, unless there are differences in the degree of control and timeliness of irrigation applications from different sources.[44]

Table 21 shows the results of this estimation, using a linear yield function.[45] The seeding rate and amount of nitrogen and phosphorus fertilizer have a strong positive effect on wheat yields.[46] Total labor inputs, including family, exchange, permanent

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[42] Original pH on sample plots ranged from 7.0 (neutral) to 8.5 (alkaline).

[43] The dummy variable for Dir was not included because of multicollinearity with soil parameters and number of irrigation applications.

[44] Data are not available on the exact amount of water applied per irrigation, but this is assumed to be comparable between sources. If there are differences, the volume of canal applications is likely to be greater than that of tubewell applications, which would also tend to give a higher yield impact for surface water.

[45] Alternative functional forms, such as Cobb-Douglas and log-linear, were tested but did not fit the data as well as linear regression. The large number of cases with values of 0 for one or more of the independent variables, notably the irrigation inputs, may account for the poor fit of the Cobb-Douglas equation. Quadratic and interaction terms were tested but found not significant and are therefore not included in the model.

[46] A single variable for the sum of nitrogen and phosphorus fertilizer is used because the levels of these two inputs are multicollinear. If N and P are included as separate variables in the model, both have significant coefficients of approximately the same magnitude as the total fertilizer coefficient (4.4) in the final model.

Table 21—Effect of irrigation applications on plot-level wheat yields in Faisalabad and Dir districts

Independent Variable	Coefficient	Standard Error	t-Statistic	Variable Mean
SEED	3.60**	1.82	1.98	40.93
FERTILIZE	4.67**	0.73	6.09	47.12
LABOR	1.89*	1.12	1.68	27.86
BASEpH	253.54**	69.20	3.66	0.62
SOILK	1.25**	0.38	3.32	128.14
SOILP	−4.50	4.82	0.93	10.07
SALINITY	−44.61	68.99	0.65	0.13
CANALIRR	31.14**	9.00	3.46	2.53
PURTWIRR	44.58**	16.66	2.68	0.62
OWNTWIRR	48.31**	18.45	2.62	0.50
Constant	−63.16	112.20	0.56	
Adjusted R^2 = 0.31**				
Number of observations = 263				

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.
*Significant at the .10 level.
**Significant at the .05 level.

hired, and casual hired labor, are also associated with higher yields. Both the level of potassium in the soil and degree of soil alkalinity significantly increase yields. Higher pH values influence yields because slightly alkaline soils (those with a pH above 7.0) are characterized by greater nitrogen, phosphorus, and potassium availability. The coefficients for other soil characteristics—phosphorus content and salinity—are not significant.

The lack of a significant effect of electrical conductivity on wheat yields is important because in areas of tubewell irrigation, secondary soil salinity induced by large amounts of groundwater use is a potential concern (Murray-Rust and Vander Velde 1994). Present levels of salinity, which average 0.8 millimhos per centimeter in Dir and 3.2 millimhos per centimeter in the Faisalabad study area, do not appear problematic for wheat, but higher levels may reduce productivity.

After controlling for fertilizer input and soil fertility, all three types of irrigation inputs had a significant positive effect on wheat yields. But the magnitude of the coefficients indicates that irrigation applications from own tubewells have the highest impact on yield (48.31 kilograms per application), followed by purchased groundwater (44.58 kilograms), and canal applications (31.14 kilograms).

A major reason for the productivity gap between tubewell owners and water purchasers lies in the orientation of tubewell owners toward their own farms. Those who sell water generally do so only if there is surplus water and pumping time after meeting the needs of their own land (Strosser and Meinzen-Dick 1994). In an area with well-developed groundwater markets in Gujarat, India, Shah (1985) found tubewell owners who operated their wells primarily as commercial enterprises and gave purchasers' claims for water at least equal weighting with those of their own land. However, although this study is frequently cited, such behavior is much less frequently observed in South Asia, particularly in Pakistan. What is more common is that pumpset owners "are concerned, then, to meet their own irrigation requirements before 'being persuaded' to rent out surplus capacity to others" (Wood 1995, 26). Thus, in times when water or electricity is scarce, tubewell owners use their wells for their own land, and those dependent on purchased groundwater are cut off.[47]

The number of applications is an imperfect indicator of irrigation, because it does not control for the volume of water used per application (though the area of crop irrigated is controlled for), nor for timing of applications. The volume of water per application is usually lower for tubewell than for canal applications and therefore would not explain the higher productivity of groundwater irrigation. However, farmers have relatively little control over timing under *warabandi* rotations of canal systems. Tubewell water can be adjusted to the crop needs and growing cycle, and therefore it has more impact on production.

The relationships identified in this production function may differ under other agroecological conditions, such as in areas with significant salinity problems. These results show that irrigation, and especially tubewell irrigation, has a strong effect on yields among sample farmers in Faisalabad and Dir districts. At the same time, they point to a productivity gap between the effect of water from one's own tubewell, over which farmers have considerable control, and purchased tubewell water, over which farmers have less control. The following section examines the overall effect of differences between sources of irrigation on agricultural income from all crops in both *kharif* and *rabi* seasons.

Estimates of Irrigation Surplus

While the preceding analysis provides evidence of the yield-increasing aspect of the irrigation surplus (controlling for other variable inputs), it is limited to a single crop and does not capture the intensification of input use or cropping patterns. In particular, it does not capture the effects of decisions to diversify into higher-value crops that require greater water control. The present section goes beyond this to look at economic returns to production of all crops. It therefore provides a more complete picture of the irrigation surplus attributable to different sources, including the effects of controlled irrigation on increasing input levels as well as of changes in cropping pattern in increasing returns to agriculture.

Examining the contribution of different sources of irrigation to gross margins provides an estimate of the irrigation surplus derived from greater control of water. The gross margin is computed by deducting all cash input costs (including the costs of irrigation) from gross crop revenues. This indicates the returns to land, family labor, and own capital.[48] The present analysis uses a reduced form equation to model

[47] In their field sites in Punjab, Pakistan, Strosser and Kuper (1994, 16) note that "most of the farmers report that when situations with water shortage arise, they first fulfill their own irrigation needs and then sell water to potential purchasers. Tubewell owners are, first of all, farmers and then water sellers."

[48] Rental payments for land have not been deducted from the gross margins, to ensure comparability between landowners and tenants.

differences in household gross margins as a function of season, household characteristics and assets, soil parameters, and source of irrigation. Unlike the structural form that models decisions regarding cropping pattern and input use and traces their effect on gross margins, the reduced form expresses gross margins as a function only of the set of exogenous variables, that is, characteristics that are fixed at the start of the season, such as household assets, irrigation, and physical conditions.[49]

In this analysis, household gross margins are regressed on explanatory variables as follows:

MARGIN = fn (SEASON, HHSIZE, TENURE, SALINITY, LANDSIZE, TRACTOR, DIR, CANALONLY, BUYTONLY, OWNTONLY, CANALBUYT, CANALOWNT),

where

MARGIN	= gross margin for the household in each season;
SEASON	= season (0 = *kharif*, 1 = *rabi*);
HHSIZE	= household size per acre of operational holding, as an indicator of household labor availability;
TENURE	= tenure status as tenant or owner-cum-tenant, to control for any inefficiency due to tenancy (dummy variable);
SALINITY	= soil salinity greater than 4 millimhos per centimeter, the critical level for wheat responses to salinity (dummy variable);
LANDSIZE	= operational holding size, in acres;
TRACTOR	= tractor ownership (dummy variable);
DIR	= Dir District, NWFP (dummy variable, default is Faisalabad District in Punjab);
CANALONLY	= use of canal irrigation only (dummy variable);
BUYTONLY	= use of purchased tubewell water only (dummy variable);
OWNTONLY	= use of own tubewell water only (dummy variable);
CANALBUYT	= conjunctive use of canal and purchased tubewell water (dummy variable);
CANALOWNT	= conjunctive use of canal and own tubewell water (dummy variable).

[49] The analysis is done at the household rather than the crop level because certain costs, notably energy costs for tubewells, could not be allocated among crops without more complete data on hours of pump operation by plot and crop. Price variables are not included because of insufficient variability within the sample.

Table 22—Regression model for household gross margins per season

Independent Variable	Coefficient	Standard Error	t-Statistic	Variable Mean
SEASON	−1,813.61*	1,109.41	−1.64	0.49
HHSIZE	7.10	154.12	0.05	3.48
TENURE	−336.54	1,194.66	−0.28	0.45
SALINITY	−3,483.46**	1,793.54	−1.94	0.14
LANDSIZE	653.69**	90.36	7.23	6.82
TRACTOR	9,946.28**	2,515.10	3.96	0.07
DIR	−288.82	1,580.61	−0.11	0.47
CANALONLY	2,315.23	1,603.18	1.44	0.41
BUYTONLY	2,277.10	3,761.10	0.61	0.03
OWNTONLY	4,959.79**	2,476.14	2.00	0.10
CANALBUYT	6,190.24**	2,206.98	2.81	0.23
CANALOWNT	13,853.20**	3,704.35	3.74	0.04
Constant	−191.56	2,282.84	−0.08	

Adjusted $R^2 = 0.37$
Number of observations = 329

Source: Data from Pakistan household survey, International Food Policy Research Institute, 1991/92, and Pakistan water markets survey, International Food Policy Research Institute, 1992.
*Significant at the .10 level.
**Significant at the .05 level.

Separate dummy variables are used for each source of irrigation or combination of sources, with unirrigated farms as the base.[50] Conjunctive use of surface and groundwater plays a critical role in Pakistan's irrigation, with canals providing an important source of recharge for tubewells, and tubewells providing additional water and vertical drainage critical to reducing waterlogging in some areas. Those farmers using tubewell irrigation in conjunction with canal water have greater recharge and water availability than those who use groundwater outside the command of surface systems. While each water application from surface or groundwater could be considered additive in the preceding production function analysis, farmers' decisionmaking on cropping patterns and input use and the returns they receive from those decisions are more likely to take into account the total water availability from all sources. Thus, the benefits derived from each source of irrigation are likely to be affected by whether it is the sole source of irrigation or used conjunctively with other sources.

Results of this model are presented in Table 22. The negative coefficient for season indicates that gross margins are higher in *kharif* than in *rabi,* in part because of

[50] There was one farm using a combination of canal water, purchased tubewell, and own tubewell water, which was included with those using canal plus own tubewell; the two farms using purchased and own tubewell water without canal water were included with those having own tubewells. This saved having to create separate dummy variables for the few cases using both sources of groundwater. Moreover, ownership of a tubewell gives these farmers a security of access to groundwater that purchasers do not have, and so they are likely to behave more like other tubewell owners than like the majority of groundwater purchasers who are dependent on others' tubewells.

the higher water availability and cropping intensity in that season. Neither household size nor the dummy variable for Dir District have a significant impact on gross margins. Tenancy has a nonsignificant negative effect on gross margins. This is consistent with findings of Hayami and Otsuka (1993) that, although share tenancy is inefficient as long as information is not perfect, the accumulated empirical evidence from South and Southeast Asia indicates that it is not significantly inefficient.

Although soil salinity does not have a significant impact on yields of wheat alone, it does reduce total income from cultivation. This may be due to depressed yields on saline fields and to farmers' switch to less profitable, but salinity-tolerant, crops. High-value vegetable crops, in particular, are very sensitive to salinity.

The coefficient for operational holding size indicates a gross margin of approximately Rs 650 per acre, after other factors are controlled for. Tractor ownership has a substantial effect (nearly Rs 10,000) on household gross margins. Like tubewell ownership, tractor ownership gives farmers greater control over the timing of agricultural operations, which in turn increases returns to cultivation.

The magnitude and significance of the coefficients for source of irrigation exhibit a clear pattern. Both canal irrigation alone and purchased tubewell water alone have coefficients of about Rs 2,300, though neither is significant. This is not to say that canal irrigation does not increase gross margins over rainfed cultivation. However, the variability in gross margins among those sample farmers using only canal sources is too high for the coefficient to be significant. The few farmers dependent on purchased tubewell water alone, without canal sources, also face highly variable returns from production.

Although the number of tubewell owners is even smaller (17 cases with canal irrigation, 35 cases without), the magnitude of the effect of own tubewell water alone is twice as great as that for canal or purchased tubewells only—approximately Rs 5,000. Access to purchased tubewell water in conjunction with canal irrigation has a stronger effect (Rs 6,190) than own tubewell water only, but the effect of own tubewell water plus canal access was more than twice as great as any other type of irrigation (Rs 13,853). This indicates particularly high returns to tubewell owners in areas with conjunctive use. The canals provide both surface water supplies and groundwater recharge, while the control of a tubewell allows farmers to make up for deficiencies in the canal supplies. Water purchasers, who have less control over tubewell applications, are not able to reap as substantial a benefit from the conjunctive use of groundwater.

These findings are consistent with those of the wheat production function analysis, in which the contributions of own tubewell applications were greater than those of purchased tubewell water or canal water alone. They support the idea that tubewell ownership gives farmers a greater degree of control over water than depending on either canal water alone or purchased tubewell water.

The gap in gross margins between tubewell owners and water purchasers is not likely to be due to a higher price paid by water purchasers than by tubewell owners. As noted above, the data from the IFPRI sample does not indicate that water sellers are selling water for much above their own operating costs. The majority of purchases were from wells with diesel pumps. For these, either the buyer brought the fuel and paid a nominal fee (Rs 4–6 per hour) toward the wear and tear on the engine, or a flat hourly fee was charged, which was approximately the same as the operating costs.

The cost of purchased irrigation from electric pumps may be higher than the average cost of operation for tubewell owners, but this was still less than the owners' costs of operation for diesel tubewells. Differences in the costs of pumping or purchasing water are not likely to account for the differences in gross margins between tubewell owners and water purchasers. There remains a gap between the returns of tubewell owners and those dependent on water purchase.

Capital Investments in Tubewells

While this analysis shows that tubewell owners have higher gross margins than those who only purchase groundwater, gross margins reflect returns to land, family labor, and own capital. Returns to land are explicitly accounted for in the model. Family labor availability is taken into account through the variable for household size. The portion of own capital invested in tractors is likewise accounted for (and shown to have a substantial impact on gross margins).

However, tubewell owners have made a substantial capital investment in their wells and pumpsets, and should be expected to receive some return on that capital. The extent of irrigation surplus that tubewell ownership provides by virtue of control over groundwater resources can be estimated by examining the costs of the tubewells and the expected returns on such an investment (Table 23).

Using survey responses on the year and cost of tubewell installation together with pumpset purchase and the price index of manufactured goods for Pakistan, the mean 1991 value of the tubewell investment was calculated for diesel and electric tubewells.

Table 23—Capital costs of sample tubewell owners

Item	Type of Tubewell: Electric	Type of Tubewell: Diesel	Sample Average[a]
Present value of investment[b] (Rs)	57,502 (22,277)	32,660 (6,468)	41,976 (18,891)
Annual capital cost[c] (Rs)	8,186 (3,171)	4,649 (921)	5,975 (2,689)
Annual repair costs (Rs)	667 (256)	895 (406)	810 (374)
Total annual cost (Rs)	8,852 (2,992)	5,544 (765)	6,785 (2,508)
Share of tubewell owned (percent)	80 (28)	25 (28)	46 (39)
Annual cost share (Rs)	6,912 (3,427)	1,426 (1,737)	3,100 (3,653)
Number of sample tubewells	6	10	16

Source: Data from Pakistan water markets survey, International Food Policy Research Institute, 1992.
Notes: Numbers in parentheses are standard deviations.
[a]Excludes power takeoff tubewells.
[b]Uses the price index of manufactured goods to compute value in 1991.
[c]Assumes 20-year depreciation and 13 percent annual interest rate.

Table 24—Costs and returns to tubewell ownership versus water purchase

Item	Type of Tubewell[a] Electric	Diesel
Mean total annual cost (Rs)	8,852	5,544
Mean annual cost share (Rs)	6,912	1,426
Groundwater only		
Difference in gross margin		
Per season	2,683	2,683
Per year	5,365	5,365
Ratio of gross margin difference to		
Total annual cost	0.61	0.97
Annual cost share	0.78	3.76
Canal plus groundwater		
Difference in gross margin		
Per season	7,663	7,663
Per year	15,326	15,326
Ratio of gross margin difference to		
Total annual cost	1.73	2.76
Annual cost share	2.22	10.75

Sources: Tables 21 and 22.
[a]Excludes power takeoff tubewells.

PTO tubewells were not included in this analysis because data were not available on hours of tractor operation used for tubewell operation as opposed to plowing or other activities. The annual cost of tubewell capital investment was computed assuming a 20-year depreciation cycle and 13 percent annual interest rate. The annual cost of capital plus annual repair costs gives a mean annual cost of tubewell investment of Rs 8,852 for electric and Rs 5,544 for diesel-powered tubewells. PTO tubewells are less costly because they do not require purchase and repair of a separate engine (though operating costs are generally higher than for dedicated diesel or electric pumpsets). However, most sample farmers are not sole owners of tubewells but joint owners with other farmers. Therefore, they share the capital and repair costs. When farmers' shares of tubewells are taken into account, annual costs to sample farmers average Rs 6,912 for electric tubewells and Rs 1,426 for diesel tubewells.

The costs for diesel tubewells in particular compare favorably with the increase in gross margins that tubewell ownership affords (Table 24). Without canal water, the return attributable to tubewell ownership is 40 percent less than the total costs for electric tubewells in the sample, and almost equal to the total annual costs for diesel tubewells.[51] With conjunctive use, returns are 2.76 times the cost of diesel tubewells, and 1.73 times as great as the cost of electric tubewell investment.

[51] Seasonal difference in gross margin for those without canal water is computed as the difference between coefficients for *OWNTONLY* and *BUYTONLY* (4,960 – 2,277 = 2,683); the difference for those with conjunctive use is the difference between coefficients for *CANALOWNT* and *CANALBUYT* (13,853 – 6,190 = 7,663). Seasonal differences are multiplied by two to get annual differences.

The costs for electric tubewells are more than four times as high as those for diesel tubewells, because of the higher investment cost and the higher proportion of sole owners among electric tubewell owners. However, the share of annual costs for both electric and diesel tubewells is considerably less than the incremental gross margin that can be attributed to tubewell ownership.

This means the water control provided by tubewell ownership results in an irrigation surplus that is much greater than the costs farmers bear for tubewell investment. Groundwater purchasers would therefore be better off if they could own tubewells, rather than purchasing groundwater.

Why do farmers rely on water purchases instead of purchasing tubewells, which would give them more reliable access to groundwater? For many, not owning land is the greatest constraint to tubewell ownership. Pure tenants cannot purchase tubewells because they do not own land on which to install the tubewell. Farmers with small holdings are often unable to afford a tubewell unless they can cooperate with others to make a joint tubewell investment. For many farmers, lack of credit or other financial resources is a constraint to making such a substantial capital investment. Finally, physical constraints such as impervious, deep, or saline aquifers limit options for many.

By making groundwater available to farmers who do not own tubewells, water markets clearly increase the level of agricultural productivity in Pakistan. Furthermore, groundwater purchases offer farmers a greater degree of control over water supplies than is afforded by the surface irrigation systems, and this control translates into greater incomes or "irrigation surplus." There remains, however, a gap between the productivity of purchased groundwater and that from farmers' own wells, which reflects the greater reliability of irrigation provided by tubewell ownership. The implications of these findings for policies to improve the productivity and equity of groundwater use in Pakistan are discussed in the final chapter of this report.

7

CONCLUSIONS, POLICY IMPLICATIONS, AND FUTURE RESEARCH

Water markets are largely autonomous, indigenous institutions that function—and are likely to continue functioning—without a great deal of official intervention. What type of attention, if any, should the government, researchers, and other agencies pay to water markets? This final chapter highlights policy instruments and remaining research questions pertaining to water market development.

Water markets clearly play an important role in expanding access to critical groundwater resources in Pakistan. Because access to such groundwater is not tied to rigid *warabandi* schedules and the unreliability of canal irrigation supplies, water markets also increase farmers' control over irrigation. The analysis in this study shows that such control contributes to a greater "irrigation surplus" for farmers purchasing groundwater than for those dependent on surface irrigation alone.

Understanding the role water markets play in mediating access to and control over groundwater resources can assist tubewell development programs in serving a larger number of farmers. This study indicates that water markets improve the equity of groundwater use by increasing the access of small farmers, tenants, and younger households who are least likely to own tubewells. Thus, neither public tubewells nor ownership of tubewells by all farmers are required to ensure widespread use of groundwater in areas where water markets operate.

Despite the advantages of water markets, this study also shows that the degree of water control afforded to groundwater purchasers is not as great as that of tubewell owners. Tubewell owners treat water sales as a residual category, to be met after serving the needs of their own fields. Groundwater sales are generally not a commercial enterprise, in which sellers have an interest in meeting the needs of their clientele. In view of the high returns to tubewell ownership demonstrated in the analysis of gross margins, giving priority to their own fields is a rational strategy for tubewell owners. But the result is that water purchasers cannot rely on getting as much water as they need, when they need it. Purchased tubewell water is therefore not as productive as water from own tubewells. The outcome is seen in the difference in degree of irrigation surplus between tubewell owners and water purchasers: in terms of both wheat yields and gross margins for all cultivation, water from farmers' own tubewells gives a higher return than that purchased from others. This is an economically inefficient outcome, because the marginal value product of water is less for owners than for purchasers whenever there is excess demand at prevailing prices. This implies that, while water markets do improve the productivity of agriculture, policies that expand participation in tubewell ownership are likely to provide greater welfare gains to farmers than those that encourage groundwater sales from tubewells owned by a few farmers.

At the same time, overall constraints to renewable groundwater supplies place limits on the number of tubewells that can be installed and operated in a sustainable manner. A growing number of areas are already experiencing net groundwater withdrawals and falling water tables. In Punjab as a whole, pumpage exceeds recharge by more than 25 percent (NESPAK 1991). This means that providing a tubewell for every farm is not a viable solution in the long run. Therefore, strategies are required to improve the equity of access to groundwater resources through efficient operation of groundwater markets, shared tubewell ownership, and other means to expand the rights of small farmers to groundwater.

Policy Options

The appropriate objectives and policy instruments for dealing with the development of both private tubewells and groundwater markets depend on the local environment, particularly the extent of recharge and groundwater quality (see Strosser and Meinzen-Dick 1994). Where groundwater supplies are abundant and of good quality (as evidenced by stable or rising water tables with low electrical conductivity), promoting private tubewell ownership is appropriate. Because tubewell owners generally receive more reliable service and have higher returns than water purchasers, making tubewell ownership available to as many farmers as possible is advantageous if there are no groundwater constraints. However, because water tables are falling or of poor quality in many areas, stimulating further tubewell density is not sustainable. In such situations, promoting private groundwater markets can improve equity by spreading available water to as many farmers as possible, but further study is needed to assess the impact of groundwater markets on the water table.

There are no policies that can manipulate those aspects of the physical environment that influence current patterns of private tubewell and water market development. Nevertheless, knowledge of these physical determinants sheds light on the areas in which such groundwater use is occurring. The district-level analysis in this study reveals that tubewell density is already less in areas with salinity problems and lower water tables but groundwater markets are more active in those areas. Monitoring and regulation of tubewell density is required to prevent further environmental degradation. Nevertheless, it is difficult to balance groundwater extraction with recharge, as policies such as restrictions on the number of tubewells are difficult to implement and favor the early investors who tend to be large farmers.

How can access to groundwater be expanded beyond the largest farmers who are currently most likely to own such valuable farm capital? Targeting medium-sized farmers for tubewell ownership and modifying regulations and energy policy are the main policy instruments for improving access through water markets. However, the use of smaller-capacity tubewell technology and joint ownership of tubewells by a number of farmers are promising alternative strategies to increase small farmers' control over groundwater, provided they are implemented without the rent-seeking and favoritism that has often characterized such programs.

Stimulating Water Markets

The district-level analysis indicates that the most direct policy instrument for encouraging water market development is *targeting medium-sized farmers* (those with 10 to 25 acres) for tubewell ownership. On the one hand, large farmers tend to use a high proportion of the groundwater pumped on their own land, leaving little surplus for sale. On the other hand, small farmers are less likely to be able to afford the investment in a tubewell. Those small farmers who can make the initial investment do not use much of the capacity on their own fields; thus, unless they are able to share the investment cost and well capacity with other farmers or obtain considerable rents from water sales, their returns on the investment are much lower than those of larger farmers who use more of their wells' capacity (World Bank 1996). So long as groundwater sales are priced close to the pumping cost, small farmers cannot recoup their investment with the profits from water sales.

Under conditions presently prevailing in Pakistan, farmers with 10 to 25 acres can probably afford a tubewell, and they are more likely than larger farmers to have surplus water available for sale. Strosser and Kuper's (1994) finding that medium-sized farmers are the most active participants in water markets bears this out. Furthermore, the findings of the microlevel analysis in the IFPRI study areas indicate that relative size of holding of buyers and sellers affects the reliability of water sales. Medium-sized farmers are more likely than large farmers to be concerned with providing reliable irrigation services to others. Thus, in areas with sufficient groundwater to sustain further exploitation, directing credit and technical assistance for tubewell installation toward medium farmers will foster the development of groundwater markets and improve the equity of access to valuable groundwater resources. (Assisting groups of small farmers to invest would be even more beneficial, as discussed below.)

The government can also support the development of water markets by *modifying regulations* on the use of surface water and groundwater, as well as on the use of irrigation infrastructure. In particular, provisions of the Canal and Drainage Act should be re-examined to remove unnecessary restrictions on the use of watercourses for tubewell water. As long as conveying groundwater through watercourses does not interfere with the schedule of canal deliveries or lead to deterioration of the infrastructure, farmers should be free to do so. Although many aspects of the legislation regarding irrigation are not followed in practice (Byrnes 1992), the rights of the farmers to use facilities should be clarified. Not only do such restrictions inhibit the development of water markets, but they are inconsistent with the objectives of the On-Farm Water Management Program to give farmers a sense of ownership of the watercourses. If farmers are to be responsible for the facilities, they should have the right to decide how they are used, for groundwater as well as surface water.

Electricity connections, power supply, and pricing are another set of policy instruments to influence the number of private tubewells and the activity and reliability of groundwater markets. Electric-powered pumps generally have lower operation and maintenance costs than diesel pumpsets and PTO lifts. A flat rate power tariff structure is available for tubewells in Pakistan, under which the tubewell owner pays a monthly fee per horsepower of the motor regardless of the quantity of electricity consumed. This has been recommended as a powerful tool to stimulate water markets because it reduces the marginal cost of pumping to virtually zero, and therefore creates an incentive to sell as much water as possible (Shah 1993b). However, this does not appear to be the appropriate solution for stimulating water markets in Pakistan. There is a danger that the flat rate tarriff will stimulate overpumping of groundwater, particularly in the growing areas in which the water table is being depleted. This is a matter of special concern because Strosser and Kuper (1994) report that electric tubewell owners may sell water to more farmers, but they sell a lower proportion of the water they pump than do owners of diesel tubewells. The low marginal cost of pumping is therefore not being translated into more equitable access to groundwater resources.

The analysis in this study indicates that reliability is a more serious obstacle to groundwater markets than price of water. A major drawback to electric-powered tubewells is their susceptibility to fluctuations in power supply. If power is not available for much of the time, it does not matter if the marginal cost of energy is nearly zero. What is more relevant to tubewell owners' decisions to sell water is the opportunity cost of the water that could be pumped and applied to their own fields. Results of the gross margin analysis in this study indicate that the value of that water on tubewell owners' fields is high. As long as tubewell owners only sell surplus water above their own needs, rather than selling water as an enterprise in itself, shortages of tubewell water due to load shedding will be disproportionately borne by the purchasers rather than by well owners. Rationing and uncertainty of power supply translates into rationing and uncertainty of groundwater available for sale. As noted above, purchasers from electric tubewells report more problems than those who buy from diesel tubewells. Diesel may be relatively more expensive, but under present conditions it is a more reliable source of energy than electricity. Thus, extending electricity grids and making it easier for farmers to obtain connections for tubewells can assist in development of water markets, but only if the power supply is also reliable. Further study is needed to determine which factors, besides improved electricity supplies, can increase the reliability of groundwater irrigation services, particularly for small farmers.

Tubewell technology affects tubewell owners' willingness to sell water, as well as small farmers' likelihood of tubewell ownership. Large-capacity pumps can deliver water to a wider area, but smaller pumps with lower investment and operations costs may be preferable for small farmers. Smaller-capacity tubewells with 5 to 10 horsepower engines, delivering flows of less than a cusec (cubic foot per second), are widely used in India and Bangladesh, while tubewells in the Indus Basin of Pakistan typically have 10 to 20 horsepower engines delivering approximately 1 cusec. The historical experience of Pakistan with large-capacity public tubewells may have conditioned farmers to expect larger discharges from tubewells. There are technological advantages of the larger tubewells, as well: they can tap water from deeper water tables and are generally more efficient in terms of capital and operational cost per unit of water delivered. Moreover, the 1 cusec flows are easier to handle and have lower transmission losses between pump and fields. However, for small farmers in Pakistan, smaller tubewells that they can more easily afford to purchase may provide higher returns than relying on larger-capacity tubewells from other farmers.

PTO tubewells currently offer a means of tapping groundwater with less initial capital investment than for tubewells with diesel or electric pumpsets. They can also be moved from borehole to borehole, which further reduces the capital investment required per well. However, PTO tubewells require the use of a tractor to operate, which is also beyond the reach of many small and medium farmers, and entails competition for the use of the tractor in the field versus at the tubewell. Moreover, PTO tubewells are more expensive to operate than those with dedicated pumpsets. This results in low utilization rates (Malik and Strosser 1993). They are thus treated as an intermediate step until a farmer can afford a dedicated pumpset.

Technical assistance programs to identify optimal technology and siting of tubewells can reduce the risk of investing. This is especially important in areas of marginal or poor quality of groundwater, in which identifying any pockets of fresh groundwater and avoiding areas of saline water would improve the returns on tubewell investment and the sustainability of production. Advice on siting of tubewells could also include layout of water delivery channels to permit water sales to as many farmers as possible, while minimizing interference with the canal water distribution system. Such technical assistance is one means of adjusting groundwater development according to aquifer conditions, as suggested above.

Credit is often proposed as an instrument to expand ownership of capital items to small farmers, but this is unlikely to have a strong effect for tubewells in Pakistan. Credit is currently available to small and medium farmers (though not to landless tenants). The Agricultural Development Bank requires ownership of only 3 acres in a consolidated area to receive credit for tubewells, and it has a lower equity contribution requirement for smaller farmers than for larger farmers. However, Malik (1993) found that institutional credit (with its lower interest rates) does not reach many small farmers. He recommends simplifying application forms and procedures for receiving credit to make it more likely that small farmers and those with less education will benefit. The extent to which lack of education limits groundwater development is not clear. At the district level, literacy rates contribute to tubewell density. But household-level analysis in this study indicates that education per se does not increase the likelihood of tubewell ownership. Thus, alternative approaches are also needed.

Many of the credit and subsidy programs to encourage private tubewell development have focused on wells and pumping equipment. The contribution of *delivery channels and pipes* to the development of groundwater irrigation in general, and water markets in particular, has been largely overlooked. Lining conveyance systems to reduce water losses extends the effective command area of tubewells. At present there is little private investment in lined conveyance systems or pipes for tubewell water in Pakistan, but *pukka* (lined) watercourses are important. In the IFPRI sample, lined watercourses in canal command areas allowed water to be conveyed over distances of 1 to 3 kilometers from the tubewell to the purchaser's plot. Even where lining is not cost-effective, keeping earthen watercourses desilted and free of weeds will reduce water losses. The watercourse rehabilitation and lining done under the On-Farm Water Management Program and related projects can, therefore, not only contribute to canal irrigation performance, but also provide infrastructure to assist the development of water markets. If reducing losses of canal water is not sufficient incentive for farmers to cooperate in lining or maintaining watercourses, the savings of relatively more expensive (and high-value) tubewell water can provide a stronger motivation where water markets operate.

Dealing with Overexploitation of Groundwater

Much of Pakistan's policy toward groundwater, dating back to the early SCARP programs, has been based on the need to lower water tables to control waterlogging and salinity. While waterlogging is still a serious problem in many areas, an acceleration of groundwater use has led to falling water tables in many areas, especially in the Punjab, where pumpage exceeds recharge by 8.45 million acre-feet, or 27 percent (NESPAK 1991, 2–24). Thus, overexploitation of groundwater resources is a matter for increased attention.

Under present conditions, it is unlikely that groundwater markets contribute greatly to the depletion of water tables. The fraction of water sold is relatively small, compared with the water used on tubewell owners' farms. Furthermore, the micro-level evidence suggests that sales are cut off when water becomes scarce. Thus, limiting the operation of groundwater markets in areas of falling water tables does not seem to be the appropriate response, as it would deny access to the smaller farmers. Limiting consumption by tubewell owners on their own farms would be a higher priority for the sustainability of groundwater irrigation, as well as for the continued operation of water markets.

Nevertheless, falling water tables due to the private use of groundwater—by tubewell owners or water purchasers—does pose a serious externality problem that affects not only neighboring farmers, but also domestic water supply. Overexploitation not only reduces the availability of the resource and raises pumping costs for all, but may contribute to salinization of groundwater. This calls for a regulatory role for the state. Unfortunately, controlling groundwater use is very difficult, in part because of the difficulty in identifying clear property rights to the resource and in monitoring withdrawals by many individual well owners.

At a minimum there is a pressing need for clear information on available recharge, water quality, current exploitation levels, and remaining potential. The NESPAK (1991) study has made a valuable contribution in collecting many of these technical statistics, but the data need to be regularly updated and made available to farmers at the local (subdistrict) level. Such information is a public good that can help farmers and government officials make appropriate decisions on sustainable groundwater use.

Joint Tubewell Ownership

Shared ownership of tubewells by groups of farmers provides a potential social, rather than technological, means of increasing groundwater access among small farmers, and even tenants. There is a longstanding tradition of shares in wells in Pakistan, dating to the precolonial period. British settlement reports recorded "the existence of (shares) in the resources of the village, including those, such as water, that had helped to facilitate settlement, . . . And such shares were prominent also in rights of access to the water from wells" (Gilmartin 1995). In the present study, a majority of tubewell owners were not sole owners, but owned shares in a tubewell with up to 11 other farmers.

Small farmers who cannot afford the full investment in a tubewell may nonetheless be able to purchase one jointly with neighbors. Moreover, jointly owned wells are not incompatible with water markets (as seen in the village of Jaranwala). Water can be made available to nonowners, though usually at a different cost than to owners. Shared ownership can improve the chances of locating wells so that they tap good quality groundwater and serve the maximum number of farmers (by locating near the head of a watercourse, for example).

The great advantage of joint tubewell ownership is that it gives the smaller farmers a stronger right to groundwater. Thus, ownership of groundwater resources is shared more equitably than it is when a few large farmers become de facto owners of the resources. This is likely to be more important as groundwater resources become more scarce. As noted earlier, purchasers are frequently denied access to others' wells when water is scarce, especially if they are from smaller farms or households with less status. The importance of ownership rights in giving farmers a claim on water when supplies are scarce is seen in Jaranwala. In that area, where alternative water supplies are unavailable, farmers prefer owning at least a stake in a tubewell to depending on purchases from someone else.

Moreover, group tubewells are economically more efficient. The rapid expansion of private tubewells has led to overinvestment and surplus pumping capacity in many areas (World Bank 1996). By serving more farmers, group-owned wells use a higher proportion of their capacity than individual farmers' tubewells—an estimated 32 percent more in a study by Malik and Strosser (1993, 12–13). This increase in capacity utilization leads to substantial savings in capital investment.[52]

The major disadvantage of joint tubewell ownership lies in the social transaction costs, which are higher than for sole ownership. Farmers must negotiate with each other in making the initial purchase and deciding where to locate the tubewell. Then agreements must be reached on how to share the water, expenses, and maintenance responsibility on an ongoing basis. Aggarwal's (1995) study of group wells in Andhra Pradesh, India, found that for existing group wells, everyday allocation of water could be managed by simple rules of thumb, but mobilizing resources for maintenance and expansion was more difficult. If such investment is difficult for existing groups, the obstacles to organizing for the initial investment would be even greater. This could be especially problematic in areas without established traditions of cooperation, as in many areas of Pakistan (see Byrnes 1992; Merrey 1979).

Furthermore, the arrangements may restrict a farmer's degree of control over tubewell use. Strosser and Kuper (1994) found that, while sole owners of tubewells in their study area had a higher cropping intensity and larger areas under the main crops (wheat and cotton) than other farmers, tubewell water purchasers and tubewell shareholders had similar cropping intensities and areas under wheat and cotton, suggesting that tubewell water purchasers and tubewell shareholders face irrigation services of similar quality. Examination of gross margins from agricultural production in the present study indicates that even shareholders in tubewells do receive higher returns than water purchasers. Further research with a larger sample of sole and joint tubewell owners is needed to determine how much water control each type of farmer is able to exercise and the consequent effects on productivity and incomes.

While the transaction costs for farmers to organize shared tubewell ownership may seem high, these can also be viewed as an investment in social capital. Coward (1986, 227) argues that the creation and ownership of irrigation property—including water and structures—form the basis for relationships among the irrigators, which "become the social basis for collective action by irrigators in performing various irrigation tasks." For example, Ali and Mirza (1994) argue that joint tubewell ownership can provide an economic interest to strengthen group activity under water users' associations (WUAs) for surface irrigation. Similarly, small groups of well owners can provide a focal point for extension advice. For small farmers, cooperation for tubewell ownership can pay off in access to critical groundwater resources, but it can also create new incentives for cooperation, and in the long run, transaction costs may decrease.

[52] This higher-capacity utilization does not necessarily accelerate groundwater depletion because the water that is pumped serves more than an individual farmer.

The shared ownership of groundwater implied by joint tubewells is likely to become increasingly important for equitable allocation of the resource as it becomes more scarce. Ali and Mirza (1994) cite examples of such tubewell groups on watercourses that have set up *warabandi* schedules for use of tubewell water. These schedules may even make provisions for load shedding, breakdowns, or other contingencies. For government agencies, dealing with or monitoring groundwater use by thousands of individual well owners is much more difficult than dealing with a smaller number of well groups (who may also monitor each others' water use). Thus, tubewell groups could become a valuable local institution for groundwater management.

Promoting joint tubewell ownership among small farmers requires more than simple policies such as preferential access to credit or technical assistance for groups of farmers (though these may help). What is required is attention to ways to facilitate cooperation, both for initial investment and for ongoing operation. Studies of the history of formal and informal joint tubewell groups would be valuable in this regard. This should include information on how they came together, what arrangements have been reached for sharing of water and expenses, disputes that have arisen, and mechanisms for conflict management. For example, the PATA project in NWFP used community organizers to help farmers establish group wells, and the rights of all members were recorded on official stamp paper and registered with the *tahsildar* (Revenue Department officer). The full procedures for developing such systems have also been documented (PATA Project 1994).

If joint tubewells are seen as building social capital for water management, the On-Farm Water Management and other programs for WUA development can also assist farmers in forming or maintaining joint tubewell groups. Evidence of optimal group size, landholding distribution, and mechanisms for reducing social transaction costs can assist in promoting joint tubewells to increase access to and control over vital groundwater resources.

In view of these advantages of joint tubewell ownership, the plans to promote community tubewells under the Privatization of Groundwater Development Project (under development) should be viewed as an important investment. Public assistance such as community organizers to identify and foster community groups and indirect public investment (such as loans and technical assistance) for construction of community tubewells is welcomed so long as the farmers own and control the wells (World Bank 1996).

Canal Irrigation

Water markets are not the only—or even the major—type of institution affecting the efficiency and equity of irrigation in Pakistan. The Indus Basin canal irrigation system remains the most important source of water in Pakistan. It contributes to production through direct surface irrigation and is the primary source of recharge for public and private groundwater irrigation. Furthermore, the district-level analysis in this study indicates that canal irrigation stimulates the activity of groundwater markets.

Groundwater markets cannot be understood without considering the physical and institutional framework of canal irrigation. These canals offer farmers cheaper water of higher quality than groundwater, and they provide the source of most groundwater recharge. At the same time, shortages and unreliability of canal water have also created much of the demand for groundwater. Improvements in canal operation may, therefore, seem to reduce the need for groundwater markets. However, given the large and growing demands for water in Pakistan and the limited availability of surface water, groundwater markets are unlikely to decline. Increases in irrigated production require conjuntive use of surface and groundwater.

Thus, a final policy implication of this study relates to the potential to increase returns to canal irrigation. The analysis of wheat production functions and farm-level gross margins shows that supplemental groundwater from private sources has a greater impact on agricultural productivity than irrigation from public canals. The productivity gap between canal and tubewell irrigation is not due to inherent water quality (which is generally better from surface than from groundwater sources), but to the greater degree of control which farmers exercise over water from own tubewells or water purchases. Measures to increase the reliability of surface water deliveries and responsiveness to farmers' needs are likely to increase the irrigation surplus attributable to canal irrigation and reduce the productivity gap between public canal and private tubewell sources.[53]

Groundwater market development can go hand in hand with institutional change in canal irrigation. This is especially true of watercourse-level efforts to distribute water or develop and maintain tertiary infrastructure such as watercourses. Patterns of groundwater sale or exchanges may also provide the basis for localized markets for surface water if current restrictions on canal water sales are lifted. Institutions that support cooperation among farmers—whether for canal or groundwater use—contribute to the overall productivity of irrigated agriculture.

Research Needs

Because of their importance in expanding access to and use of groundwater irrigation, it is important to improve our understanding of water markets and their linkages to crop choice, agricultural productivity, and resource sustainability. Results of this and other studies demonstrate that purchased irrigation makes a significant contribution to productivity, but also indicate a productivity gap between own and purchased groundwater. The greater control of irrigation afforded by tubewell ownership is likely to be a major factor in this, but further study is needed to identify ways of improving the reliability of access to critical groundwater resources through water markets.

Because of the small sample of tubewell owners, this study was not able to determine the factors affecting which tubewell owners sell water. Possible factors influencing the decision to sell include the size and location of tubewell owners' landholdings and their cropping patterns, as well as tubewell technology and energy costs. Further research on this topic, as well as on the nature of the specific transactions occurring between buyers and sellers, would be useful in stimulating water markets. Examination of the reliability of access under different types of water market contracts and agroeconomic conditions can help identify incentives for water sellers to improve the reliability—and hence, the productivity—of groundwater markets.

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[53] That the present study did not find the marked differences in cropping patterns reported by Freeman, Lowdermilk, and Early (1978) or Renfro (1982) may reflect improvements in watercourse conditions, along with greater overall availability of private well water.

More detailed comparisons of the operations and productivity of water markets and joint tubewell ownership are needed to identify ways to improve equity of access to groundwater. These should address the role of explicit and implicit water rights under water markets and joint ownership. Study of the arrangements between buyers and sellers or co-owners could make an important theoretical and practical contribution by examining the transaction costs, degree of water control, and irrigation surplus achieved under different conditions. This would help address questions of what benefits small farmers the most, what existing social networks or other institutions facilitate access to groundwater, and what the state or other agencies can do to promote these informal institutions.

Much of the empirical work on water markets in Pakistan to date has been in relatively favorable conditions: fresh groundwater areas and areas where recharge equals or exceeds groundwater withdrawals. The incentive and managerial problems of getting farmers to pump and purchase groundwater where it is so saline that it has to be mixed with canal flows are considerable and may require continued state intervention through public tubewells. Where waterlogging (but not salinity) is a problem, developing water markets can help to control rising water tables. In areas where groundwater is in scarce supply, water markets can improve the equity of access to the resource, but they can also encourage its overexploitation and thus need to be monitored and, if possible, regulated. If tubewell owners reserve first use of groundwater to meet their own crop needs before selling water to others, groundwater scarcity is likely to exacerbate problems of unreliability for water purchasers. Research is needed on how water markets work in these less favorable environments and to identify policy interventions that are appropriate under each set of circumstances.

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