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Development of Groundwater Markets in China: A Glimpse into Progress to Date

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Summary. — The overall goal of the paper is to better understand the development of groundwater markets in northern China. Field survey shows that groundwater markets in northern China have emerged and are developing rapidly. Developing in a number of ways that make them appear somewhat similar to markets that are found in South Asia, groundwater markets in northern China also differ by the impersonality and case bases. The privatization of tubewells is one of the most important driving factors encouraging the development of groundwater markets. Increasing water and land scarcity are also major determinants that induce the development of groundwater markets.

Key words — groundwater markets, determinants, equitable, northern China, South Asia

1. INTRODUCTION

In recent years groundwater has begun to play an increasingly important role in irrigation in China, especially in northern China where *per capita* water availability is less than one-twentieth of the world average (Liu & He, 1996). Although surface water dominated China's irrigation development in the 1950s and 1960s, since the end of 1960s groundwater gradually has become the primary source of irrigation water. According to official statistics, during 1965–2003, the number of tubewells increased from 0.2 million to 4.7 million (Ministry of Water Resources & Nanjing Water Institute, 2004; Ministry of Water Resources, 2003). Nearly all of the tubewells (95%) are in northern China. Today, these tubewells provide about 68% of the total irrigation water in northern China (Wang, Huang, Blanke, Huang, & Rozelle, 2007).

The rise of groundwater in China not only fueled an expansion of sown area and rising production (Huang, Rozelle, Wang, & Huang, 2005), as the reliance on groundwater has increased, but also China's groundwater economy has become characterized by a growing water crisis (Wang *et al.*, 2007). Using data from a field survey conducted in six provinces in northern China, Wang, Huang, Huang,

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and Rozelle (2006) found that from 1995 to 2004, the water table is falling sharply in more than half of the regions in northern China. As a result, there has been a concomitant rise in the cost of sinking a tubewell. In parts of the North China Plain the shallow water table has been dropping at a rate of more than one meter per year (Ministry of Water Resources, 2002). The deep water table has fallen faster, declining at a rate of more than two meters per year in some areas (Wang, Huang, & Rozelle, 2005). The cost of sinking and operating a tubewell has at least doubled in many parts of northern China (Huang *et al.*, 2005).

During the 1990s with the falling of groundwater table, the ownership of tubewells also has begun to evolve. Before the rural reforms in the 1980s, most tubewells were owned and operated by the collective. For a variety of reasons, including the decline in the strength of the collective and the increased freedom of individuals to invest in their own farms, soon after the economic reforms began in the early 1980s the ownership of China's tubewell began to shift sharply from collective to private (Shah, Giordano, & Wang, 2004; Wang *et al.*, 2005). The number of private tubewells increased from almost nothing in the 1970s to nearly 40% by 1990. The shift to private tubewell ownership continued during the 1990s and beyond. For example, in 1995 collective ownership accounted for 58% of tubewells in the average groundwater using village in northern China (Wang *et al.*, 2007). By 2004, private tubewells rose to 70%.

While the rise of private tubewells has been shown to lead to more efficient use of water, higher levels of irrigated area and more complex cropping systems (Wang *et al.*, 2005, 2006), it has also made *access to irrigation water* an increasingly important issue. During the Socialist era (1950–70s) when local leaders were in charge of allocating groundwater in almost all villages, the equitable distribution of groundwater was not an issue. However, as tubewells have been installed and begun to be operated by private individuals, and as tubewells have begun to be sunk to deeper levels (making the real price of water rise), concern has arisen that not all farmers may have equal access to groundwater (Meinzen-Dick, 1996). It is possible that the farmers that have access to the capital are the ones that are more likely to sink and manage tubewells. It is also possible that because of this, these better endowed farmers have much better access to water than those without tubewells. If so, it is possible that part of the gains from increased efficiency that accrues from the rise of private tubewell ownership is being offset by rising inequities in the distribution of water and the associated gains.

The rise of private tubewells, however, does not have to lead to inequities if groundwater markets emerge and function well. While little has been written on groundwater markets in China, outside of China groundwater markets have long existed and recently have attracted the attention of researchers. For example, markets in groundwater have been found in many parts of South Asia. In 1975 a World Bank study in Pakistan reported that nearly 30% of tubewell owners sold part of their pumpage to other farmers (Shah, 2000). In the early 1990s Pant (1991) found that 86% of the households in eastern Uttar Pradesh purchased water for irrigation; in central and western Uttar Pradesh 65% of farm households purchased water. More recently studies in Pakistan by Strosser and Meinzen-Dick (1994) and Meinzen-Dick (1996) have found groundwater markets pervasive. While the analysis of many issues is complicated and the findings of many studies are controversial (meaning more study is needed on the management of groundwater markets), the South Asian experience has shown that groundwater markets in many places have provided opportunities for the farmers without tubewells to get access to water (Mukherji, 2004; Shah, 1993; Sharma & Sharma, 2004; Strosser & Meinzen-Dick, 1994).

Despite the observations by field workers regarding the similarities between the rise of groundwater markets in China and those of South Asia, almost no empirical studies have been done on the development of China's groundwater markets. In fact, searching of the literature has found that there is almost no reference in any work on groundwater markets in either Chinese or English. Despite the absence of research, policy makers and scholars have begun to raise a series of questions. How prevalent are groundwater markets in northern China? More specifically, what is the proportion of the tubewells that participate in selling water? How much of their water do they sell? What are the characteristics of groundwater markets in northern China? Who are the buyers? Finally, why is that we observe water markets in some villages but not in others? In other words, what are the determinants of groundwater markets in northern China and what are their effects on the equity of access to water?

The overall goal of this paper is to answer these questions to develop a better understanding of the development of groundwater markets in northern China. To do so, the paper focuses on getting the data right and providing a profile of groundwater markets and their determinants in northern China. To meet this goal, this paper has four specific objectives. First, the paper describes the evolution of groundwater markets in northern China. Second, the paper explores their characteristics. In doing so, this paper compares China's groundwater markets to those that have emerged in South Asia. Third, the paper measures the determinants of groundwater markets in northern China and tries to understand why they have emerged in some villages but not in others. Finally, the paper seeks to understand what types of farmers are selling water and what types of farmers are buying water in an effort to understand the equity implications of emerging groundwater markets. [1]

To pursue objectives, the paper is divided into six sections. The first section introduces the data. The second section uses the data to compare the characteristics of groundwater markets in northern China with those in South Asia. The third and fourth sections descriptively analyze the determinants of the development of groundwater markets and present the results of the multivariate analysis on the determinants of groundwater markets. The fifth section discusses whether or not groundwater markets are tending to help or hurt the poor. The final section concludes.

2. DATA

The analysis is based on two sets of data from northern China. [2] The first survey, called the China Water Institutions and Management survey (or CWIM), includes two rounds of data collection in 2001 and 2004. In the CWIM survey, enumerators collected data and information from 338 households, 110 tubewell owners, and 68 canal managers in 80 villages in three provinces (Hebei, Henan, and Ningxia Provinces). Since there is almost no irrigation by groundwater in the Ningxia Province sample, in this paper, we only use the data from Hebei and Henan provinces. Located in the North China Plain, the two provinces face serious water shortages and have the highest extent of groundwater irrigation (about 78% of irrigated area is from groundwater). Villages in Hebei were chosen from counties near the coast, near the mountains, and in the central region between the mountains and the coast. In Henan, villages were chosen from counties bordering the Yellow River and from counties in irrigation districts varying distances from the Yellow River. The most prominent feature of this survey is that the study team was able to collect information on water allocation and water sales from tubewell owners and managers—both those that sold water and those that did not.

The second set of data, called the North China Water Resource Survey (or NCWRS), was also conducted in 2004. This survey of village leaders from 400 regionally representative villages in Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi, and Shanxi provinces used an extended version of the community-level village instrument of the CWIM survey. Using a stratified random sampling strategy for the purpose of generating a sample representative of northern China, counties in each of regionally representative sample provinces were sorted into one of four water scarcity categories: very scarce, somewhat scarce, normal, and mountainous/desert. [3] Two townships within each county and four villages within each township also were randomly selected. Although the information on water sales in the NCWRS is somewhat less rich than the CWIM survey (given that enumerators only surveyed village leaders and not tubewell owners and households directly) by using the NCWRS survey the study team was able to generate the representative point estimates of the prevalence of water markets across northern China.

The scopes of the two surveys were quite broad. Each of the survey questionnaires included more than 10 sections. Among the sections, there were those that focused on the village's resource base (both the scarcity of water and the amount of cultivated land), the evolution of the ownership of tubewells, the village's basic socio-economic conditions, and government policies and regulations. Private tubewells consist of two types of tubewells—individual and shareholding tubewells. If a tubewell belongs to a single individual or a family, it is called an individual tubewell. In many cases, however, a tubewell is owned by a group of individuals. Since in many of the groups, the individual members are assigned shares that indicate the investment stake that each member owns in the tubewell entity, the groups are often called shareholding groups and their tubewells are called shareholding tubewells.

In addition, there was a section that focused specifically on groundwater markets. Groundwater markets are defined as localized, community-level arrangements through which owners of tubewells sell pump irrigation services to other farmers of the village and neighboring villages (i.e., they sell water to other farmers from their wells for use on crops). This paper is only going to examine "private" water markets or the nature of groundwater markets that are being driven by individuals and groups of individuals that sink tubewells. In adopting such a definition, we are assuming that when village leaders (the collective) provide water to villagers, it is being done under *non-market* conditions and is not a groundwater market transaction.

For the section on groundwater markets, the study team designed many questions to elicit the nature of groundwater markets and measured their development. Enumerators asked village leaders if there were tubewell owners that sold water to farm households that did not own tubewells. The survey also tabulated the number of tubewells in a village from which water was sold by its owner. Detailed information was elicited on the water sales activities of each village's typical tubewell, including estimates of the total volume of water withdrawn, the volume water that was sold, and the information on how *water-buying households* paid for the water that they bought from the *water-selling farmers*. A series of questions were asked of the village leaders about government regulations governing the price of water sold from tubewells. Finally, several questions focused on asking water-selling households (or *tubewell owners*) if they sold water to farmers inside or outside of the village. [4]

Both surveys were designed in ways that allowed the construction of data with an intertemporal component. The surveys collected data on most of the variables for more than two years. For example, the CWIM survey covered four periods: 1990, 1995, 2001, and 2004. [5] The NCWRS survey covered 1995 and 2004. The CWIM survey was conducted in two rounds. The first round was carried out in 2001 which collected data and information on 1990, 1995, and 2001. The second round of the survey was conducted at the end of 2004 and collected data and information for 2004. In this sense the information from 2001 and 2004 is the true panel data. The NCWRS survey work was conducted in 2004 and collected data and information in 1995 and 2004.

3. GROUNDWATER MARKETS WITH CHINESE CHARACTERISTICS

This section measures the degree of the development of groundwater markets in terms of both breadth and depth as well as describes their characteristics. According to the definition of Shah (2000), "*Breadth* can be conceptually defined as the proportion of the farming community that is participating in water trade, as buyers or sellers or both; *depth* can be conceptually defined as the quantitative significance of water transactions in the economies of individual farm households of a community." In the rest of the paper the breadth of groundwater markets is measured by two indicators. One indicator is the share of villages that have any degree of groundwater market activity. The second indicator is the share of tubewells from which the tubewell owner is selling water to water-buying households. Depth is measured by the "share of the volume of water" sold to water-buying households that is pumped from tubewells that are selling water.

When using breadth indicators, groundwater markets have developed quickly in northern China. According to the NCWRS survey, in 1995 groundwater markets had emerged in only 9% of the sample villages (Table 1, column 1, row 1). However, by 2004 there were groundwater markets in 44% of the villages (column 2). During the same period the share of tubewells from which owners sold water also increased. In 1995 water was sold from only 5% of tubewells; by 2004, however, this number increased to 18% (row 2). In addition, when using indicators of the depth of groundwater markets, the CWIM survey shows that by 2004, groundwater market activities were dominating the tubewell pumping activities of those farmers-cum-tubewell owners that were selling water (row 3). [6]

Although there has been a lot more attention given to the study of groundwater markets in South Asia (because groundwater markets have traditionally been quite widespread), the data show that China is catching up quickly. For example, a number of studies suggest that groundwater markets have become quite pervasive in Pakistan (Meinzen-Dick, 1996; Strosser & Meinzen-Dick, 1994). These studies indicate that 30–60% of tubewell owners in Pakistan sell water. In India and other neighboring countries, Shah (2000) showed that when tubewell owners sold water, they sold from 40% to 70% of the volume of water they had pumped.

Table 1. *Development of breadth and depth of groundwater markets in China, 1995 and 2004*

	1995	2004
Breadth		
Share of villages having groundwater markets (%)	9	44
Share of tubewells selling water (%)	5	18
Depth		
Share of water sold (%) [conditional on tubewell owner selling water]	80	77

Data source: Data in row 1 and row 2 are from authors' survey of 68 randomly selected villages in four provinces (Hebei, Henan, Shanxi, and Shaanxi) of the NCWRS; Data in row 3 are from the authors' survey of 50 randomly selected tubewells in two provinces (Hebei and Henan) of CWIM. We do not use data from all of the sample villages of the two surveys since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.

Hence, while these numbers may not be exactly comparable, if assuming that the estimates are correct (i.e., water is being sold from 18% of tubewells in northern China; when water-selling households sell water, they are selling 77% of the water from their tubewells), the development of groundwater markets in northern China is approaching levels that are being observed elsewhere in the world.

(a) *Characteristics of groundwater markets in northern China*

Although groundwater markets in northern China have evolved more recently, there are at least three characteristics which appear to be shared by groundwater markets in northern China and South Asia. First, almost all groundwater markets in both places are *informal*. According to Shah (1993), a water market is informal when transactions between water-selling and water-buying households are done without legal sanction. In other words, farmers buy and sell water without a contract and their oral commitments cannot be adjudicated in a court of law. According to the data, there were zero written contracts covering water sales among agents in northern China; the same is true according to the literature from India.

Second, groundwater markets in both northern China and South Asia are almost always *localized*. According to Shah (1993), the localized nature of water markets is almost universal. In the survey data in China, water transactions also are mostly limited to water-selling and water-buying households that live and work in the same village. In fact, only 6% of water-selling tubewell owners (and a smaller share of the volume of water that they pump) sell water to farmers in other villages.

Third, groundwater markets in both northern China and South Asia are largely *unregulated*. In Shah (1993) the word unregulated means the government exercises no direct influence on the functioning of the market. Shah (1993) found little evidence of any intervention by any level of government in India. Based on the NCWRS survey data, there were only formal regulations on the books about any aspect of groundwater markets in less than 25% of villages (e.g., a price ceiling on the amount that a water-selling household can charge). Although somewhat higher than the case of India, during our field work and during interviews with tubewell owners, enumerators almost have never encountered a case in which the tubewell owner was constrained by a government regulation; village leaders and tubewell operators almost never were aware that there was any attempt by upper level officials to influence the functioning of water selling and buying. [7]

While there are a number of similarities, it appears as if the different environments within which groundwater markets have evolved in northern China and South Asia have produced several differences in the nature of groundwater markets. First, although field work in many villages has found evidence of impersonal markets, groundwater markets in parts of South Asia appear not to be fully *impersonalized*. For example, Shah (1993) stated that transactions between water-buying and water-selling households were *impersonal* in many cases. In India, this means that water-selling households in many villages do not distinguish among various buyers in terms of price at which they sell water and the quality of service provided. However, other studies find that groundwater markets can be personalized. For example, studies in Pakistan (Jacoby, Murgai, & Rehman, 2004), Bihar, India (Wood, 1995), and other regions in South Asia (Ballabh, Choudhary, Pandey, & Mishra, 2002; Pant, 2003) reported that sellers charged some buyers one price and other buyers another price. In other words, after observing what "kind of a person" a potential buyer is, the price of water was set.

In contrast, in the case of northern China groundwater markets are almost fully impersonal. Based on our survey of 30 village leaders, we found that within villages, only 7% of water-selling tubewell owners charge different prices for different types of buyers. In addition, in our survey of the tubewell owners, not one reported that they charged different prices for different types of buyers.

Second, the *patterns of payment* within groundwater markets in China and South Asia sometimes are different. In South Asia water-buying households often provide labor or offer a share of their crop's harvest in exchange for water (Shah, 2000). In northern China, however, water sold in groundwater markets is almost always paid for on a cash basis. Such differences may be primarily related to the different land tenure arrangements that dominate both countries. For example, in China the ownership of cultivated land belongs to village collectives. Since the early 1980s, with the implementation of household production responsibility in rural China, cultivated land was allocated relatively evenly to each farmer within a village. As such, it implies that each farmer has land use right though they have no land ownership. However, in South Asia, land ownership is private and many farmers have no land to be used for their production. These landless farmers have to rent land from land owners or provide their labor to land owners. Therefore, in the same way that they pay their rent with a share of the labor (i.e., through a sharecropping contract), water-buying households in South Asia also often provide labor or a share of their crop's harvest in exchange for water. In contrast, water-buying households in China do not exchange their labor for water in such a way and in all cases in our sample (100%) pay cash for water.

Another important difference between China and South Asia is the way in which electricity is priced. This, too, may have a major impact on the way groundwater markets work. For instance, in many Indian states, electricity is priced on a flat rate basis and this does not always reflect the scarcity value of water. In China, however, electricity meters are in place, electricity prices are mostly at market rates and the cost of pumping (and consequently the price of water) reflects mostly the scarcity value of water (because it reflects the depth from which the water is pumped). Also, in India rural electrification is poor and, hence, many farmers depend on diesel driven pumps and this may create a different configuration of groundwater

Table 2. *Characteristics of groundwater markets in poor and rich villages in China, 2004*

	Poor villages[a]	Rich villages[a]
Village characteristics		
Per capita income (yuan)	1008	2561
Groundwater markets		
Level of development (breadth/depth)		
Share of private tubewells selling water (%)	44	37
Share of water sold (%)	74	91
Policy interventions		
Share of villages having subsidy (%)	5	4
Share of villages receiving bank loans (%)	7	7
Share of villages requiring well-drilling permits (%)	66	70
Nature of groundwater markets		
Informal (share of villages not having contract for selling water, %)	100	100
Localized (share of water-selling tubewells selling water to farmers in the villages, %)	87	100
Unregulated (share of villages not having price ceilings, %)	80	74
Impersonal (share of water-selling tubewells owners that charge same prices for all types of buyers, %)	95	100
Patterns of payment (share of water-selling tubewells that pay in cash for selling water %)	100	100

Data sources: The authors' survey of 68 randomly selected villages in four provinces (Hebei, Henan, Shanxi, and Shaanxi) of the NCWRS and 13 randomly selected tubewells selling water in Hebei province of CWIM. We do not use data from all of the sample villages of the two surveys since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.

[a] Poor villages are those villages in which *per capita* income is less than 1625 yuan *per capita*; rich villages are those villages in which *per capita* income is more than 1625 yuan *per capita*.

markets than would appear when there are electric pumps.

There may be one final difference between China and India. Whereas, there are many institutional aspects of groundwater markets that differ between villages that are relatively poor and villages that are relatively rich in India, the same is not true in China. In fact, according to our data, most institutional features do not differ in a statistically significant way between villages that are relatively well-off in China and those that are relatively poor. We show this by dividing the sample into two groups—according to the village's *per capita* income. Our data show that income differs dramatically between rich and poor villages; average income in the richer villages was 250% higher than that in the poorer village (Table 2, row 1). Despite the large differences in income, there is almost no difference (statistically) in the development of groundwater markets, the nature of policy interventions, or the characteristics of groundwater markets between these two types of villages. For example, in the rich villages 37% of tubewells sell water. This share is almost same as that in the poor villages (in which 44% of tubewells sell water—row 2). Therefore, there is evidence that the development of groundwater markets in both rich and poor villages is more or less the same. In addition, the share of villages having bank loans or the share of village that are being affected by other policy interventions is also same in both poor and rich villages (rows 4–6). Finally, in both rich and poor villages, groundwater markets are unregulated, informal, localized and impersonal; payment for water (or the way in which transactions are settled) is also the same (rows 7–11).

4. GROUNDWATER MARKETS, TUBEWELL OWNERSHIP, AND RESOURCE SCARCITY

In the small number of international papers that have sought to understand the determinants of groundwater markets, a number of factors arise consistently and can be used as a basis for generating hypotheses that the paper can test using the survey data from northern China. For example, Shah (1993) descriptively showed that the availability of water resources, the scale of irrigation technology, and the extent of land fragmentation were correlated with the rise of groundwater markets. Strosser and Meinzen-Dick (1994) set up a theoretical framework that posits (among other factors) that the depth of the groundwater table and the population density of a community are important factors affecting groundwater markets. Shah (1993) and many others, such as Mukherji (2004), also indicated the importance of policy intervention in promoting or constraining the development of groundwater markets. Therefore, we would expect that if there were regulations, it would constrain the expansion of the number of tubewells. In the case of other policy intervention variables (e.g., the existence of bank loan and grant programs that are targeting those that invest in pumps and tubewells), when there are government grant and loan programs one would expect more tubewells and, as such, greater groundwater market activity. In other words, the observations of the researchers working on South Asia's groundwater markets suggest that groundwater markets are arising at least in part in response to the nature of the technology needed for sinking a well, the degree of resource scarcity—both for land and water and policy. If these observations and conjectures are picking up more general relationships, then based on the relationships a set of testable hypotheses can be generated: When the cost of sinking a well rises (either due to the falling groundwater table or the relative competitiveness of larger tubewells/pump sets) or when the attractiveness of sinking a well at a given cost declines (due to the fact that a farmer may have an increasingly small parcel of land that is not able to utilize the entire command area of a tubewell investment, or due to a policy intervention by the government), groundwater markets can be expected to emerge.

According to descriptive statistics based on the survey data from northern China, empirical evidence for the hypotheses is present. For example, the data indicate that the development of groundwater markets maybe related with water resource scarcity (Table 3). When the water table falls in the NCWRS sample villages over time (from 28 to 38 m—column 3), the share of tubewells from which water is being sold is higher (column 1). When dividing the villages in the sample by the share of tubewells from which water is sold into four groups, there is a positive correlation between the amount of groundwater market activity and the level of the groundwater table (columns 1 and 3, rows 3–6). [8] Likewise, when dividing the tubewells in the sample by the share of

Table 3. *Relationship between development (breadth) of groundwater markets and tubewell ownership/resource endowment in China, 1995 and 2004*

	Share of tubewells selling water (%)	Tubewell ownership	Water scarcity	Land scarcity
		Share of private tubewells (%)	Groundwater table (m)	*Per capita* arable land (ha)
Grouped by year[a]				
1995	5	50	28	0.12
2004	18	81	38	0.10
Grouped by share of tubewells selling water[b]				
0	0	68	28	0.11
0–30	12	46	45	0.12
30–90	57	70	48	0.11
90–100	100	100	48	0.09

Data source: The authors' survey in 68 randomly selected villages in four provinces (Hebei, Henan, Shanxi, and Shaanxi) of NCWRS. We do not use data from all of the sample villages of the NCWRS survey since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.
[a] The number of observations used for each row in rows 1 and 2 is 68.
[b] The number of observations used for each row in rows 3–6 is $n = 100$ (row 3); $n = 10$ (row 4); $n = 8$ (row 5); and $n = 18$ (row 6). Data are averages for two sample years.

water sold in three groups, there is also a positive relationship between the amount of groundwater market activity and the level of the groundwater table (Table 4, columns 1 and 4). One explanation of these trends is that when the groundwater table is lower, the cost of sinking a tubewell is higher, which could keep some farmers from investing in their own tubewells even though they have a high demand for irrigation services. Alternatively (although mainly in a relative sense), it could be that the lower the groundwater table, the larger is the size of the optimal tubewell/pump set. In villages with larger tubewells/pump sets, other factors (including land size) held constant, there is less of a need for all farmers to have their own tubewells.

Likewise, the data provide similar support for the hypotheses when looking at the relationship between groundwater activity and land scarcity (Table 3, columns 1 and 4). During 1995–2004 the average size of land *per capita* for the sample villages fell from 0.12 to 0.10 ha (rows 1 and 2). Coupled with the observed rise in the share of tubewells that are selling water, the descriptive data are consistent with the idea that when farm size gets smaller, households have less of a need to invest in their own tubewells. As a result, this could be one reason behind the rise in groundwater markets. The same trends appear when grouping observations either by the share of tubewells from which water is sold (rows 3–6) or by the share of water sold (Table 4, columns 1 and 5).

Trips to the field and discussions with local officials and water users, as well as the survey data, also raise the prospect of one factor unique to China that may be behind the emergence of groundwater markets in the sample. According to the data, the private ownership

Table 4. *Relationship between development (depth) of groundwater markets and tubewell ownership/resource endowment in China, 2001*

	Share of water sold (%)	Tubewell ownership		Water scarcity	Land scarcity
		Share of individual tubewells (%)	Share of shareholding tubewells (%)	Groundwater table in 1995 (m)	*Per capita* arable land (ha)
Grouped by share of water sold[a]					
0	0	19	81	13.6	0.120
0–90	48	44	56	11.1	0.091
90–100	97	100	0	17.6	0.089

Data source: The authors' survey of 50 randomly selected tubewells in two provinces (Hebei and Henan) of CWIM. We do not use data from all of the sample villages of the CWIM survey since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.
[a] The number of observations used for each row in rows 1–3 is $n = 32$ (row 1); $n = 9$ (row 2); and $n = 9$ (row 3).

of tubewells is correlated strongly with the development of groundwater markets. Groundwater market activity is higher as the share of private wells has risen over time (from 50% to 81%—Table 3, columns 1 and 2, rows 1 and 2). Likewise, when observations are grouped according to the water sales activity of the tubewells, the share of private wells also rises sharply (from 68% to 100%—rows 3–6). Specifically, when the share of individual tubewells increases, the share of water sold is higher (Table 4, columns 1 and 2). Interviews with village leaders and tubewell owners and managers revealed that the main force driving this correlation appears to be the incentives that private tubewell owners face which encourage them to produce earnings from their tubewell investments. Hence, in studies of China, an additional testable hypothesis arises from descriptive statistics and observations in the field: Groundwater market activities rise as the share of private wells in a village increases.

5. DETERMINANTS OF GROUNDWATER MARKETS—MULTIVARIATE ANALYSIS

This section seeks to test more rigorously the determinants of groundwater markets. The paper is interested in identifying the factors that explain why some villages have groundwater markets and others do not; this analysis is needed because the findings will help us to better understand the forces that are creating the swell in groundwater market activity. This is important since it may help us predict as China's villages confront the rising economic and environmental pressures of the nation's development process (e.g., forces, such as the steady shift towards private ownership of productive assets, and increasing resource scarcity), whether or not institutions will emerge that will allow farm households to gain access to water, one of the most critical resources that they need for production. To analyze the determinants of groundwater markets, the first part of this section introduces the methodology. In the next part the results will be reported.

(a) *Methodology*

Based on the descriptive analysis above and work on groundwater markets in other countries, the following econometric model is proposed to analyze the determinants of the *breadth of groundwater markets*:

$$T_{jt} = \alpha + \beta O_{jt} + \gamma W_{jt} + \delta L_{jt} + \phi Z_{jt} + \varepsilon_{jt}. \qquad (1)$$

In Eqn. (1) T_{jt} represents the share of tubewells selling water in village j in year t. The variables on the right hand side of Eqn. (1) are those that explain differences in the breadth of groundwater markets (or the share of tubewells that sell water) among villages and over time. The first variable, O_{jt}, represents the change of tubewell ownership and is measured as the share of private tubewells in village j. The two variables, W_{jt} and L_{jt}, measure the resource endowments of the village (both its water and land resources) and are included to measure if increasing resource scarcity (or the cost of using the resource) helps induce the development of groundwater markets. Specifically, the water resources variable (W_{jt}) is measured as the level of the groundwater table. The degree of land scarcity (L_{jt}) is measured as cultivated land *per capita*.

In Eqn. (1) a set of control variables are included. The first set of control variables includes three policy variables which are included to assess the effects of policy on the development of groundwater markets. The first variable, *fiscal subsidies for tubewells*, is a dummy variable equal to one if there was a program of fiscal investment in the village that targeted tubewell construction (and zero otherwise). This government program, run by the local Bureau of Water Resources, is primarily targeted at individuals. A similar variable, *bank loans for tubewells*, is included to control for whether or not there was a loan program through China's banks that gives preferential access to low interest rate loans for investing in tubewells. Unlike the fiscal subsidy program, most bank loan programs target local villages and leaders; the loans are typically supposed to be used to be invested in collective wells. A final variable, *well-drilling regulations*, controls for the presence of local regulations that would, *ceteris paribus*, slow down the construction of tubewells. [9] Although there is no explicit government regulatory policy to encourage collective tubewells at the expense of private tubewells (or vice versa), without the support of government, it likely that such regulations, if present (and enforced), would have a greater effect on slowing down investment in private tubewells. The hypotheses are that any government program that encourages (discourages) private tubewells relative to collective wells will encourage (discourage) the development of groundwater markets.

In explaining the development of the breadth of groundwater markets, the adoption of irrigation water conveyance technologies in the village is included as a way to control for the cost and efficiency of delivering water from the tubewell to the field. This variable is measured as a dummy variable, equaling one if the village had adopted conveyance-inducing technology, such as surface (white dragons) or underground pipe networks. It is thought that if the conveyance of water is easier (and more efficient), water markets will emerge more readily. Finally, several other factors are also controlled for. For example, *village income per capita* is included as a control for the village's socio-economic conditions. The symbols α, β, γ, δ, and ϕ are parameters to be estimated and ε_{jt} is the error term.

To analyze the determinants of development of the *depth of groundwater markets*, the following econometric model has been specified:

$$M_j = \alpha + \beta O_j + \gamma W_j + \delta L_j + \phi Z_j + \varepsilon_j, \qquad (2)$$

where M_j represents the share of water sold for tubewell j. While the basic structure of Eqn. (2) is the same as Eqn. (1), because of the nature of the dependent variable (and differences in the sample—the breadth of water markets analysis uses village-level data; the depth of water markets analysis uses tubewell-level data), the specification is slightly modified. The first variable, O_j, represents the *ownership of tubewell j*; if the tubewell is owned by an individual (a single family), it equals to 1; otherwise, the tubewell is owned by a group of individuals and equals 0. Since the demand by the individual farm household for water from its own well is almost by definition less than the members of the shareholding group, a positive sign on the coefficient of the ownership variable would be expected (since there would be more of the excess capacity available for sale).

The relative scarcity of water and land also might be expected to affect the amount of water sold to other farmers. To control for water scarcity, the paper includes the variable W_j which is measured by the *depth of the groundwater table*. Since the cost of pumping (and, hence, the price at which water can be sold to farmers) is directly related to the depth of the well, a negative coefficient on the depth of the groundwater table variable would be expected. However, it is possible that the sign is positive if as the groundwater table falls (or is lower in level), it is more difficult for farmers to sink their own wells and so groundwater markets emerge to meet the demand. The analyst also needs to be concerned about the endogeneity of such a variable since the development of groundwater markets may influence the level of the groundwater table. Consequently, in the analysis the paper measures W_j as the groundwater table of the village in 1995, a time before the sample and a period before the takeoff of groundwater markets.

In the same spirit, the paper includes a variable L_j to control for the degree of land scarcity (which is measured as cultivated land *per capita* in the village in which tubewell j is located). The hypothesis here is that when land *per capita* is lower, the benefits of investing in one's own well fall and increase the demand for water markets.

In Eqn. (2), as in Eqn. (1), a set of three policy variables and a set of control variables also are included. The first variable equals one if the tubewell owner (or the shareholding group) received a fiscally subsidized rebate after investing in the well (and was zero if it was fully self-financed). The second policy variable equals one if the tubewell owner received a bank loan as part of the investment financing package of the well (and zero if not). Finally, a third policy variable equals one if the tubewell owner was issued a well-drilling permission certificate before the well was drilled, and zero otherwise. It would be expected that any policy that facilitates (discourages) the investment in tubewells would increase (decrease) the size and depth of the well and provide individuals with more (less) excess capacity from which they are able to sell water. The definitions (and expected signs) of the other control variables (*village income per capita*; dummy of adopting water delivery pipes) are the same as those in Eqn. (1).

(b) *Results*

When estimating the determinants of the development of the breadth and depth of groundwater markets, a Tobit model is used. [10] This estimation strategy is needed since the dependent variables in both Eqns. (1) and (2) are in "share" form (i.e., between 0 and 1). There are also a number of villages (tubewells) in which the value of the dependent variable is zero. Using ordinary least squares approach (OLS) might generate a biased set of estimated parameters.

In addition, we can also address several potential statistical problems that might arise in the estimation of Eqns. (1) and (2). [11] Specifically, two possible multicollinearity problems come from using either the three policy intervention variables and/or the conveyance technology variable along with the actual share of private tubewells in the same regression (Eqn. (1)). There are two ways to assess whether or not this is a problem. First, we use regression diagnostics to generate a condition number for the full model. Since the condition number is only 39, we can conclude that there is no evidence of multicollinearity in a statistical sense. We can also assess the impact of "including the variables" by re-estimating Eqn. (1), but without including the policy intervention variables (Table 5, column 2). As can be seen (comparing the results of all of the other variables in columns 1 and 2), the results vary little. The same is true when we re-estimate the equation without using conveyance technology (Table 5, column 3) or without including conveyance technology and the policy intervention variables (Table 5, column 4—that is, there are few changes to the coefficients of interest). We adopt the same strategy for assessing the robustness of the results of Eqn. (2). While we can report that there is little change to the coefficients, due to space constraints, we do not include the detailed findings in a paper. Therefore, we believe that any potential multicollinearity problem in Eqns. (1) and (2) is not serious.

(i) *Determinants of the breadth of groundwater markets*

In estimating Eqn. (1) with the survey data, the econometric estimation performs well (Table 5, column 1). Most of the coefficients of the control variables have the expected signs and a number of the coefficients are statistically significant. For example, the coefficient of well-drilling permit regulation variable is positive and statistically significant (column 1, row 8). Even if we drop these policy intervention variables (column 2) or if we drop the conservation technology variable (column 3), econometric estimation still performs well and there are few differences among the estimation results.

More importantly, when examining the variables of interest, research results show that the change of tubewell ownership from collective to non-collective induces the development of groundwater markets. The coefficient on the share of non-collective tubewells variable is positive and significant (Table 5, row 1, columns 1–4). All other things held constant, when the share of the non-collective tubewells in a village increases, the share of tubewells selling water increases. If the share of non-collective tubewells increases by 10%, the share of tubewells selling water will increase by nearly 3% (column 4). Although the paper cannot infer causality, this result shows the correlation between privatization and the rise of groundwater markets. One explanation of this is that in villages with more privately owned tubewells, there is more of an incentive to sell water. Another explanation of this relationship is that in villages with a higher percent of private tubewells, it may be that there is less service provided by the operators of the collective tubewells (for any number of reasons). Therefore, in these villages, for farmers to gain access to water, it would be necessary for farmers to access water from sales from private tubewells.

Resource scarcity is also associated with the emergence of groundwater markets. Although it could have been that deeper water tables mean higher water prices and less demands, in fact, the coefficient on the depth to groundwater table is positive and significant (Table 5, row 3, columns 1–4). When the groundwater table drops by 1 m, the share of tubewells selling water will increase by about 1% (column 4). Hence, the alternative interpretation is consistent with the findings: in areas in which the groundwater table is deep, farmers' demand for water from groundwater markets is higher (relative to providing water from one's own well). In simplest terms, if these results are indicative of underlying causal relations, the findings are evidence of the hypothesis that in villages with scarce water resources, groundwater markets develop more quickly.

Research results also show that land pressure has increased the breadth of groundwater markets. The coefficient on the *per capita* arable land variable is negative and statistically significant (Table 5, row 5, columns 1–4). If *per capita* cultivated land in the villages falls by 0.1 ha, the share of tubewells selling water will increase by 10% (column 4). In other words, the results imply that with the decrease of *per capita* land resources, the share of tubewells selling water has increased. To understand the influence of household size on the breath of groundwater markets, the cultivated land *per capita* has also been replaced by the cultivated land per household (farm size) (Appendix Table, column 1, row 3). The results of the new analysis show that the coefficient of this variable is also significant in the regression analysis (as was the original coefficient) of determinants of breadth of

Table 5. *Regression analysis of the determinants of development (breadth and depth) of groundwater markets in China (using Tobit estimator)*

	Dependent variable: share of tubewells selling water				Share of water sold
	(1)	(2)	(3)	(4)	
Tubewell ownership					
Share of private tubewells	0.183	0.286	0.180	0.286	
	(3.86)***	(7.70)***	(3.83)***	(7.40)***	
Dummy of individual tubewell					0.389
					(4.33)***
Water and land scarcity					
Log of groundwater table	0.003	0.006	0.003	0.006	
	(3.82)***	(5.06)***	(3.81)***	(4.96)***	
Log of groundwater table in 1995					0.008
					(2.01)**
Log of *per capita* cultivated land	−0.900	−1.036	−0.909	−1.036	−4.745
	(2.39)**	(3.21)***	(2.40)**	(3.10)***	(3.50)***
Policy interventions					
Dummy of fiscal subsidies for tubewell investment	0.051		0.041		−0.121
	(0.46)		(0.38)		(1.58)
Dummy of bank loans for tubewell investment	0.065		0.066		0.484
	(0.59)		(0.60)		(3.02)***
Dummy of well-drilling permission regulation	0.116		0.117		0.045
	(3.09)***		(3.08)***		(0.46)
Other control variables					
Dummy of adopting water delivery pipes	−0.025	0.008			−0.093
	(0.64)	(0.23)			(0.94)
Per capita net income of farmers	−0.000	−0.000	−0.000	−0.000	0.000
	(0.18)	(0.88)	(0.24)	(0.85)	(1.94)*
Constant	−4.257	−3.853	−4.204	−3.918	−2.943
	(3.68)***	(4.74)***	(3.66)***	(4.76)***	(3.34)***
Observations	136	136	136	136	50
Chi-square	35.19	96.41	35.30	94.29	46.37

Coefficients are marginal effects; absolute value of z or t statistics in parentheses.
Data source: Data in the model "Share of tubewells selling water" come from the authors' survey in 68 randomly selected villages in four provinces (Hebei, Henan, Shanxi, and Shaanxi) in two years (1995 and 2004) of CNWRS. Data in the model "Share of water sold" come from the authors' survey in 50 randomly selected tubewells in two provinces (Hebei and Henan) of CWIM. We do not use data from all of the sample villages of the two surveys since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

groundwater markets (i.e., the equation that used "share of tubewells selling water" as the dependent variable—Appendix Table, column 1, row 3). These results imply that when the average holding of land in a village is small, there is more of a tendency for village's tubewell owners to sell water. [12]

(ii) *Determinants of the depth of groundwater markets*

The econometric estimation also performs well when estimating the depth of groundwater markets (Table 5, column 5). The Chi-square is 46, higher than that above explaining the breadth of groundwater markets (column 1, row 13). Similarly, most of the coefficients of the control variables have the expected signs and a number of the coefficients are statistically significant. For example, the coefficient on the variable of farmer *per capita* net income is significant (row 10). This means that farmers in villages with higher *per capita* income sell more.

In addition, similar to the regression results on the determinants of the development of the breadth of groundwater markets, the development of the depth of groundwater markets is also significantly associated with tubewell ownership and water and land scarcity. For example, the coefficient on the dummy variable for individual tubewell ownership is positive and significant (Table 5, row 2). This means that compared with shareholding tubewells, individual tubewells sell a higher share of their water. In addition, the coefficient on the groundwater table is also positive and significant (Table 5, row 4). Hence, in areas in which the groundwater table is deep, farmers' demand for water from groundwater markets is higher. In simplest terms, if these results are also indicative of underlying causal relations, the findings are evidence of the hypothesis that in villages with scarce water resources, groundwater markets develop more quickly.

Research results also show that land pressure has intensified the depth of groundwater markets. The coefficient on the *per capita* arable land variables is significant (Table 5, row 5). Therefore, it appears that agricultural land is scarcer (making it less desirable for an individual farmer to sink his/her own tubewell), the average tubewell operator sells a greater share of water from his/her tubewell.

6. DO GROUNDWATER MARKETS HELP THE POOR?

Based on the above analysis, the research results show that groundwater markets in northern China have developed in terms of both their breadth and depth. Household data further indicate the importance of groundwater markets for irrigation in northern China. Results show that more than 70% of the sample households depend on groundwater for irrigation (Table 6, rows 1 and 2). However, among all of the households using groundwater, only 34% of them own tubewells. In contrast, 20% of households have to depend on groundwater markets to gain access to water for irrigation (rows 3 and 4). Although a fairly large number of households still access groundwater from collective tubewells, as the strength of the collective diminishes, it is clear that the role of groundwater markets will become increasingly important in the coming years.

As groundwater markets become increasingly important, it is important to understand if groundwater markets are helping or hurting the poor and/or increasing or reducing inequality in rural China. If groundwater markets emerge and function well, the rise of private tubewells does not have to lead to inequities (although it may—the final answer is an empirical one). Elsewhere in the world, research has shown that groundwater markets can be equity enhancing. For example, in Pakistan Meinzen-Dick (1996) demonstrated in their case study area that groundwater markets improved equity of groundwater use by making water available to small landowners or tenants and younger households—those farmers who were least likely to own tubewells.

Table 6. *Participation in groundwater markets by farm households in China, 2004*

	2004
Total households	173
Number of household using groundwater	128
Share of households having tubewells themselves to irrigate (%)	34
Share of households getting groundwater irrigation through groundwater markets (%)	20

Data source: The authors' survey data from 46 randomly selected villages in two provinces (Hebei and Henan) of CWIM. We do not use data from all of the sample villages of the CWIM survey since the information in the table is conditioned on villages that use groundwater to irrigate and that have private tubewells.

Our field surveys in northern China have provided the similar evidence as that in Pakistan and other countries. According to the survey data, groundwater markets have provided the groundwater access opportunity to poor farmers and reduced potential income gaps by enhancing the access to groundwater. Specifically, households in the sample that buy water from groundwater markets are poorer than water-selling households. For example, the *per capita* income from cropping of water-buying households is only 61% of that of water-selling households; *per capita* total income of water-buying households is also lower than that of water-selling households (Table 7, rows 1 and 2). Such results may imply that, although poor farmers do not have enough money to sink tubewells, they can buy water from markets. If this is the case, groundwater markets almost certainly are helping the poor.

The data also indicate that groundwater markets benefit weak farmers that are small, less education, and older. Households that buy water have smaller holdings of cultivate land than water-selling households. For example, the *per capita* land area of water-buying house-

Table 7. *Characteristics of water-selling and water-buying households in China, 2004*

	Water-selling households	Water-buying households
Per capita cropping income (yuan)	1609	988
Per capita total income (yuan)	2891	2634
Per capita cultivated land area (ha)	0.15	0.13
Education level of household head (year)	6.3	5.5
Age of household head (year)	47.6	50.0

The sample sizes of water-selling households and water-buying households are 36 and 25.
Data source: Authors' survey in 46 randomly selected villages in two provinces (Hebei and Henan) of CWIM. We do not use data from all of the sample villages of the CWIM survey since the information in the table is conditioned on villages that use groundwater to irrigate and have private tubewells.

holds is 0.13 ha while the land area of water-selling households is slightly larger, 0.15 ha (Table 7, row 3). Such a finding implies that households with small holdings of land, who are not able to or choose to not sink a tubewell (and cannot utilize the entire command area of a tubewell investment), are able to buy water through groundwater markets. In addition, research finds that less educated and older farmers also depend more on groundwater markets to gain access to groundwater (rows 4 and 5). [13]

Whether groundwater markets benefit the poor or not may also be related with the structure of the markets (i.e., whether they are monopolistic or competitive). The poor should be able to benefit more when markets are competitive than when water buyers face a single seller. However, analysts do not always agree on how to measure market structure. In other researches outside of China, researchers indicate that due to physical and topographical conditions, groundwater markets may be fragmented and could be monopolistic (Bagachi, 1995; Campbell, 1995; Dhawan, 1988; Jacoby *et al.*, 2004; Kahnert & Levine, 1994; Pant, 1991; Shah, 1993). In another work, economists attempt to measure the degree of competition. For example, to do so, following the work of Lerner (1970), Shah (1993) hypothesized that the ratio of water price to total variable cost can be used as a fairly good indicator of the level for monopoly profits (see Lerner (1970) for the proof of this proposition). In applying this to the case of India, Shah and Ballabh (1997) found that the ratio was high, about 2.5–3.0 in Mazaffarpur. Based on this, Shah and Ballabh (1997) concluded that groundwater markets were not very competitive. Other researchers do not agree with the approach of Lerner (1970) and Shah (1993). For example, both Fujita and Hossain (1995) and Palmer-Jones (2001) also found fairly high ratios (water price to total variable cost) in their studies (averages 2.6). However, unlike Shah and Ballabh (1997), they interpreted the results to mean that, far from being monopolistic, water markets were competitive; the high ratio merely reflects the entrepreneur's risk premium. In other words, based on their observations, water markets were competitive and they are able to explain the high ratio with an alternative explanation.

To examine the structure of groundwater markets in China, we follow the lead of other researchers from South Asia. First, following the approach of Shah (1993), we calculate the ratio of water price to total variable cost. According to our data, the ratio is 2.2, ranging from 1.2 to 3.3. More than 70% of tubewells have the ratios which were lower than 2.5. This average level is lower than the findings of Shah and Ballabh (1997) in India (range is from 2.5 to 3.0) and Fujita and Hossain (1995), Palmer-Jones (2001). Hence, if the low ratio of water price to total variable cost does, in fact, measure competition, from this angle there is evidence that groundwater markets in China are relatively competitive.

In addition, we also examine the data on water prices and compare within village averages of price variations with between village variations. Since groundwater markets are localized and most transactions are among farmers in the same villages. Therefore, if markets are competitive, we would expect that most price variation should come from between villages, not from within villages. In fact, we find that the variation in the price of water is mainly due to regional differences among villages, not from within villages. [14] For example, in one village the price of water from one tubewell is more than 3.4 times that from one tubewell in another village. However, within any of our villages, the highest difference among the price observations is only 50%. In 75% of villages, water price differences among tubewells selling water within villages are much smaller. These results are also consistent with the findings of other researchers that believe water markets in their study areas are competitive. For example, after controlling for the influence of other factors, Kajisa and Sakurai (2003) found that the variation of water price mainly comes from regional differences which lead them to the conclusion that groundwater markets are not monopolistic. [15]

Besides analyzing prices directly, we also examine other types of data to provide evidence that supports the finding of the non-monopolistic nature of groundwater markets. First, we look at profits from selling water. When using our data, we are able to estimate both the fixed and variable costs that are associated with pumping and selling water. Accordingly, our results demonstrate that (even when we do not consider the value of family labor that is used to pump and sell water) profits are generally small.

Second, we also look at the number of well operators that are selling water and water delivery conditions. Shah (2000) suggested that when wells are sunk in a fairly dense manner, and when there are lined conveyance structures in a village, there is less of a probability that a single seller will have monopoly power and that the price of water will be relatively more competitive. Using this approach with our survey data, we find that in almost all villages, there are many tubewell operators selling water, not only just one. On average, in each village, there are 18 tubewells (and 13 private ones) and more than 70% of the private tubewells are selling water. Furthermore, the adoption rate of surface pipe (or hoses) in groundwater irrigation regions of northern China (i.e., the use of efficiency-enhancing conveyance technologies) is common. Our survey found that more than 70% of tubewell owners are using surface pipes to deliver water. The adoption of surface pipes greatly increased the ability of farmers to choose tubewells from which they want to buy water. Therefore, based on these analyses, it seems that groundwater markets in northern China almost certainly are not monopolistic.

7. CONCLUDING REMARKS

This paper has sought to understand the development of groundwater markets in northern China and examine the factors that determine the development of groundwater markets. Using our two data sets, research results provide strong evidence that groundwater markets in northern China have developed in terms of both their breadth (the share of villages in which there is groundwater market activity) and depth (the share of water which the average water-selling tubewell owner sells to others on a market basis). Interestingly, although fewer people have worked on groundwater markets in China, even compared to countries, such as India and Pakistan, which have better documented groundwater markets, groundwater markets in northern China clearly have emerged and are almost equal in pervasiveness.

Our findings also demonstrate that while there are many similarities, there are also differences. Groundwater markets in northern China have many characteristics similar to those in South Asia; they are informal, localized, and mostly unregulated. At the same time, however, China's markets appear to be less personalized and transaction in China is done more on a cash basis.

While the multivariate analysis is carried out mostly to understand descriptively the correlates of groundwater markets, there are a number of robust findings that support the hypotheses of interest. The form of ownership appears to be strongly correlated with the emergence of groundwater markets. Groundwater markets also appear in more villages and tubewell owners sell a higher share of the water from their wells when the groundwater table is deep (i.e., water is scarce) and land is scarce. All of these are suggestive that when the factors that affect supply and demand for groundwater are in place, there is a tendency for markets to emerge. Policy has also played a role in China.

While much of the results are suggestive that groundwater markets are largely self-organizing and unregulated, there also does appear to be a role for the state. The findings show that when the government makes it easier for individuals and shareholding groups to get access to capital and are not subject to local regulations, there is a greater level of groundwater market activity. Since our research results also show that groundwater markets at the very least are not regressive and may, in some cases, be progressive, it may be that government-sponsored investment and banking programs that allow individuals access to grants and loans to sink tubewell will further promote groundwater markets with Chinese characteristics.

Finally, the research results indicate that groundwater markets in northern China do help the poor. Households that buy water from groundwater markets are poorer than water-selling households. Such a finding implies that groundwater markets have provided greater access to groundwater to poor farmers and possibly help reduce income inequalities in rural China.

While it is beyond the scope of the paper to measure the impact of the emergence of groundwater markets on the groundwater table it is possible that groundwater markets, to the extent that they encourage the greater use of groundwater, could accelerate the fall of the groundwater table. If this is so, the question remains whether groundwater markets should be encouraged. What are the options? If groundwater markets were suppressed, given our results, it could actually hurt the poor. So what should happen? To avoid hurting the environment (if it was being hurt), instead of directly trying to suppress groundwater markets, alternative policies that would control the drawdown of the water table (e.g., water pricing policies) should be promoted. In addition, efforts to allow groundwater markets to emerge could help spread the benefits that come with greater access to irrigation.

The analysis in this paper also has implications that go beyond the water literature. First, the emergence of markets does not have to hurt the poor. In fact, it is possible that they are propoor. According to our analysis, in the case of China's groundwater markets, the poor have benefited. Poor households have been involved with both the supply and demand sides of the market. This is somewhat different from what has been the case in other parts of the world where groundwater markets have emerged.

So why might this be the case? One thought is that markets work well and are competitive and expand the opportunities for access to resources for the poor (and rich) when they are composed of agents that all have access to minimum amount of resources—both land and capital—and the market environment is relatively unregulated. In the case of China, all households in each village have land and the government has instituted programs that have offered loans and grants to those that want to sink a well. In addition, given the initial investment by the government in water (in the pre- and early reform era), the incomes of most farmers were already high enough to allow some farmers to gain access to enough capital for investment (and so had access to sufficient liquidity) that they were able to afford to buy water when it was provided in a competitive market environment. Therefore, when groundwater markets emerge in such an environment, buyers and sellers can both benefit, and overall access to water can raise production and the welfare of all participants. Such a case, however, may not occur in places in which resources—such as land and capital—are less equitably distributed.

NOTES

1. Due to limitations on the nature of the data, and the length of this paper, we are not examining the impacts of the rise of groundwater markets. While it is an extremely important topic to measure the effects of groundwater markets on cropping patterns, crop productivity and the water table, it is really beyond the scope of this paper. In addition, in the past there had been another work done on groundwater markets and a paper by Mukherji (2004) provided an excellent review of the literature that does not need replicating here. According to Mukherji, there were a number of papers that have looked at the groundwater markets from an institutional point of view (Dubash, 2000, 2002; Kajisa, 1999; Palmer-Jones, 1994). In this paper, however, we take a neo-classical economists approach as having a number of other economists (e.g., Shah, 1985, 1989, 1991, 1993).

2. In our studies northern China is defined to include the following regions: northern China (*huabei*), Northeast China (*dongbei*), and Northwest China (*xibei*).

3. Since water resource endowments in mountainous or desert regions are complex and we do not have detailed secondary data to sort these areas into the other three categories, we decided to classify mountainous and desert regions into an independent category. During the course of sample selection, it should be noted that we did not select any desert sample counties. By design, we chose only a limited number of counties that are classified as mountainous (10%).

4. There is a potential asymmetry when trying to match water-selling and water-buying households with households that own tubewells and those that do not own tubewells (henceforth, *non-tubewell owners*). While a non-tubewell owner can only be a water-buying household and cannot be a water-selling household, a tubewell owner can be both a water-selling household and a water-buying household (e.g., in the case when he/she is cultivating a plot that is in a location that cannot be supplied by his/her own tubewell).

5. In China, nearly all villages have trained accountants that maintain written records about many aspects of the village life, including information on demographics, the economic structure of the village, income, land, etc. In addition (and importantly), most villages in the sample kept detailed, community-level records about village water issues. We also held detailed interviews with multiple stakeholders in the village—leaders, tubewell owners, and farmers—who had been village residents for the entire sample period (during 1995–2004). Given the importance of water, villagers had little trouble remembering their "well histories." In other words, we were able to rely on both leader/wellowner/farmer recall and accountant records to enumerate the number of wells and pumps in past years.

6. We also note that the share of water sold reduced from 80% in 1995 to 77% in 2004 (Table 1, row 3). This is either possibly due to the increase in the number of wells selling water or the reduction in the demand of water with the increase in number of tubewells in the region. According to our data, either of these two interpretations is all plausible. During 1995–2004, both the number of wells selling water and the total number of wells have increased. In the 68 sample villages that are in the NCWRS, the number of wells selling water increased from 75 in 1995 to 342 in 2004; at the same time, the total number of wells also increased from 1472 to 1967.

7. In the villages that claimed that there was a formal regulated ceiling on the price of water, typically, the regulation was said to have been set by the price bureau. When such an announcement was made, in many cases the regulation was mainly targeted at all water users in the county (including—often especially—at water uses in industry and municipal water districts). Because of this in some villages even though leaders said that there was a regulation "on the books," it did not always mean that the rule was "implemented" in practice in the village.

8. We want to emphasize that in this part of the section of the paper, we are only examining correlations with our descriptive data. We are not suggesting causality. The most that we can say with descriptive statistics is that we are showing data trends that are consistent with the hypotheses. We include a multivariate analysis in the next section.

9. In our study areas well-drilling regulations are the rules and directives produced by local officials that seek to influence the behavior of farmers before they drill new wells. When these are enforced, a farmer is supposed to apply for a permit for drilling a new well from the local government. The permit often says where and at what depth the well is to be drilled. Once it is granted, the farmer is legally allowed to sink a new well. Although there are such regulations in many, if not most, regions of China, these regulations are rarely implemented effectively. During our survey, we asked village leaders if farmers in their villages officially are *supposed* to apply for such permits before sinking new tubewells in their villages. If the answer was "Yes," the variable *well-drilling permit* is coded as "1," otherwise it is coded as "0."

10. The Tobit model was developed by Tobin (1958) to treat data sets when the dependent variable was characterized as being censored. The Tobit model, in the form of $y = f(X) = \text{Max}(0, Xb + U)$, is a hybrid of the Probit model and the linear regression model (McDonald & Moffitt, 1980). The use of Tobit model has two advantages. First, it overcomes the information loss which would occur if a Probit model was used with censored data that was translated into binary data. Second, it overcomes the violation of the OLS assumptions that would occur if an OLS estimator was used with censored data. Recent social science research has shown a growth in applying Tobit model (Gunderson, 1974; Helms & Jacobs, 2002; Langbein, 1986).

11. Besides multicollinearity problems, we might also be concerned about the potential endogeneity problems in Eqns. (1) and (2). It is possible that the estimated parameters of our variables of interest are biased since the share of tubewells selling water may be determined simultaneously with the share of private tubewells. It could also be that the estimated coefficient is affected by unobserved heterogeneity. In such a situation, the estimate of the coefficient on the share of private tubewells variable could be biased. To control for any of this endogeneity, we use a fixed effects model (Appendix Table, column 2). The results of the fixed effects model show that most coefficients (especially the coefficients of interest) do not change much (compared with the findings in column 4, Table 5; and column 2, Appendix Table). We take the same strategy for assessing the robustness of the results of Eqn. (2). While we can report that there is little change to the coefficients, due to space constraints, we do not include the findings in a paper. Therefore, we believe that any potential endogeneity problem in Eqns. (1) and (2) is not serious.

12. What are the implications of these results? They do not mean necessarily that only small households are buying water. In China, one of the effects of the nature of the nation's initial de-collectivization movement was that there was not much difference in the size of the land that was allocated to farmers *within the village*. Therefore, what we are seeing are inter-village differences. As a result, this means that the villages that have mostly small households have more sales; as opposed to villages with mostly large households. This feature of China makes it

different from other countries—especially those in South Asia.

13. We also conducted statistical tests (t-tests) to understand whether or not the differences between water-selling and water-buying households are significant statistically. Results show that none of them are significant. The t statistics for *per capita* land area is 1.18, education level of the household head is 0.52, and the age of the household head is 1.17. However, this result does not in itself prove causality. If these characteristics influence the decision of buying or selling water, we need to do further multivariate analysis.

14. The shares of total expenditures that are accounted for by water are also relatively homogeneous within villages. Whether a household purchased water from a tubewell operator or whether he/she supplied water from his/her own well, our results show that within the same village there are only narrow differences.

15. According to our survey in the villages that have collective tubewells and private tubewells selling water, we found that water price of collective tubewell is almost same to private groundwater markets. On average, the difference between the price of water being sold from collective tubewells and that being sold from private tubewells is less than 15%. In addition, we have also not found a significant level of difference between the price of water being sold by private tubewell owners and that being sold by the owners of shareholding tubewells.

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APPENDIX A

Regression analysis of the determinants of development breadth of groundwater markets

	Share of tubewells selling water		
	Tobit	Fixed effect	Tobit
Tubewell ownership			
Share of private tubewells	0.275 (3.86)***	0.654 (7.95)***	0.189 (4.09)***
Water and land scarcity			
Log of groundwater table	0.006 (3.49)***	0.008 (2.06)**	0.003 (3.52)***
Log of cultivated land per household	−0.377 (2.44)**		
Log of *per capita* cultivated land		−0.827 (0.75)	−0.927 (2.37)**

Appendix A—*continued*

	Share of tubewells selling water		
	Tobit	Fixed effect	Tobit
Policy interventions			
Dummy of fiscal subsidies for tubewell investment			0.033
			(0.32)
Dummy of bank loans for tubewell investment			0.063
			(0.57)
Dummy of well-drilling permission regulation			0.116
			(3.04)***
Other control variables			
Dummy of adopting water delivery pipes			−0.009
			(0.24)
Per capita net income of farmers	−0.000	−0.000	−0.000
	(0.20)	(0.27)	(0.10)
Well density			−1.255
			(0.72)
Share of sown area for grain crops			0.152
			(1.47)
Constant	−7.302	−0.739	−4.691
	(2.96)***	(1.59)	(3.85)***
Observations	136	136	136
Chi-square	22.78		40.28
R^2		0.73	

Coefficients are marginal effect, absolute value of z statistics in parentheses.
Data source: Data in the model "Share of tubewells selling water" come from authors' survey in 68 randomly selected villages in four provinces (Hebei, Henan, Shanxi, and Shaanxi) in two years (1995 and 2004) of NCWRS. We do not use data from all of the sample villages of the NCWRC survey since the information in the table is conditioned on a village that uses groundwater to irrigate and has private tubewells.
* Significant at 10%.
** Significant at the 5% level.
*** Significant at the 1% level.

APPENDIX B. A CASE STUDY

To illustrate how the broader institutional framework affect the emergence and development of groundwater markets in northern China, during the survey in Hebei province enumerators visited one village in one of the sample counties and conducted additional interviews. In this village groundwater is the only source of water for irrigation. In 1983, there were eight collective tubewells. These collective tubewells were able to provide irrigation to about 30% of cultivated land. Things changed, however, after 1983. In the early 1980s, reformers in the province de-collectivized agriculture and land was contracted to each household in the village. The land was distributed equally to all of the farmers (about 4.5 mu or 0.3 ha per household). These rural reforms provided greater incentives for farmers to exert effort, which led to increased agricultural productivity and higher incomes (Lin, 1992). However, in such villages access to water was still one of the main constraints to even greater productivity increases. More importantly, the water table in the village was falling during the early and mid-1980s. By 1985, the level of water had dropped so far that a number of the collective tubewells could not be operated. To maintain the original level of irrigation services, some farmers began to dig their own tubewells. Farmers at this time would have preferred the village to re-sink the well, but in this village the leadership had access to few funds and so there was no alternative but to sink the wells themselves. Generally, each tubewell in the village was able to irrigate about 50 mu (or 3.3 ha). This means that each tubewell could supply irrigation to about 10 households. Since some farmers either lacked the financial resources or were too busy to invest in their own tubewells, they began to buy water from their neighbors who had tubewells. Under such an environment, groundwater markets have emerged gradually. Later in the early 1990s, government loan programs helped farmers to finance tubewell construction. By 2004 the number of wells had grown to 27, and 89% of them were private. Due to the development of private tubewells and groundwater markets, by 2004 more than 60% of land in the village could be irrigated, a level much higher than during the early 1980s.