Innovation in Property Rights and Groundwater Irrigation Management: A Case Study of Tube-Well Ownership in Hebei, China

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Abstract

Traditionally, water problems have been treated mainly as engineering and technical problems. However, increasing evidence shows that water management and institutional arrangements are important measures for dealing with water-shortage problems. The purpose of this paper is to provide a better understanding of tube-well ownership innovation and groundwater-irrigation management in the Hebei Province of China. Econometric models for testing the determinants of tube-well ownership innovation are developed and estimated using several unique sets of data from 30 randomly selected villages within 3 counties of the Hebei Province. The results show that since 1980 collectively owned tube wells have been gradually replaced by a more market-oriented type of privately (or quasi-privately) owned tube wells. The major determinants of this innovation in tube-well ownership within the irrigation system are: increasing water shortage problems; stresses from local population growth combined with declining land endowment; the weakening of village or community economic power; improved human capital of the community; market development; and water finance and credit policies. Based on the findings of this study, a number of policy recommendations are made for future reform of the agricultural groundwater irrigation system in China. The authors propose that the government should encourage tube-well ownership innovation by effective water finance and credit policy instruments. Sustainable development of water resources, combined with rational water pricing should be promoted, so that tube-well ownership innovation should be emphasized by future water policies.

Background

Faced with increasingly competitive demands for water from a rapidly growing industrial sector, an expanding area under irrigation and a wealthier and growing population, global society has

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turned increasing attention towards the resolution of water-scarcity problems. Severe water shortages have also become major constraints to the sustainability of China's social and economic development. Although China ranks sixth in the world in total water-resources endowment, on a per capita basis it is among the poorest, having only one-fourth of the average world level (Liu and He 1996). Furthermore, its water resources are overwhelmingly concentrated in southern China, while northern China, an important agricultural region and the location for much of China's industrial production, has a far lower per capita water endowment. The national shares of population and cultivated area in Northern China were 52 percent and 70 percent, respectively, but only 24 percent of the nation's water resources were allocated to the region in 1998 (State Statistical Bureau 1999; Ministry of Water Resources 1998). Economic and social development in northern China have been due, partly, to easily exploitable groundwater (Ministry of Water Resources 1998).

Traditionally, water problems have been mainly treated as engineering and technical problems. However, increasing evidence shows that water management and its institutional arrangements are important measures for dealing with water-shortage problems (World Bank 1993; Johnson et al. 1995). Since the 1980s, many developing countries, along with some developed countries, have begun to transfer irrigation management responsibilities from the government to farmers' organization or other private organizations, in order to mitigate the financial burden of water projects, as well as to improve the efficiency of water use and supply (Vermillion 1997).

With rural reform and the implementation of production responsibility in China, agricultural-production management was transferred from the collective to farm households, which resulted in incompatibilities between collectively owned irrigation systems and privatized agricultural production. The increasingly serious aging and deterioration of rural water projects, due to incompatibilities between collective small-scale water project management and farm household agricultural-production management have become an important constraint to rural economic dvelopment (Chen and Yang 1998). To meet the goals of agricultural development, property rights innovation within small rural water projects has been initiated and developed since the early 1980s.

Different property rights regimes within irrigation systems have different impacts on water project management efficiency (Wang et al. 2000) and cropping patterns (Xiang and Huang 2000). In seeking to gain a clear understanding of property rights innovation within an irrigation system, two critical questions arise: how have the property rights of an irrigation system changed under innovation and what are the determinants of property rights innovation? How do we reform policies relevant to irrigation in order to promote rational property rights innovation within an irrigation system? Although understanding property rights innovation has important policy implications, almost no empirical study on this issue has been done in China.

Based on the water source, an irrigation system can be classified into either a surface-water irrigation system or a groundwater irrigation system (GWIS). Considering the increasingly important role of groundwater irrigation systems (mainly tube wells) in agricultural production (especially in northern China), the purpose of this paper is to understand ownership innovation within tube-well irrigation systems (or more simply referred to as tube wells), to understand the determinants and impact of innovation, and to provide empirical evidence for rational irrigation policy reform.

Tube-Well Ownership Innovation and Its Influential Factors

Literature Review and Data Sources

Among all the influential factors driving institutional innovation, relative price changes resulting from changes of natural-resources endowments and population increase are those emphasized by economists (North 1990; Demsetz 1969). Schultz (1968) found that the rise in the economic value of a human being is the main reason for institutional innovation. Government policies, the degree of democratic governance, the state of the rural financial market, the degree of agriculture commercialization, social mores, the regulation of inheritance and the legal constraints on property rights are all important factors of institutional innovation (White 1995). After synthesizing most research findings, Otsuka (1995) summed up five factors that influence tube-well ownership innovation: natural environment, population pressure, policy, commercialization and social environment. Some research such as that by Qiao et al. (1998) and Otsuka (1995) have all corroborated their empirical findings with theory, when they conducted their research on forestry and land property rights innovation.

Will tube-well ownership innovation also adhere to theory? Will the innovation affect cropping patterns? In order to answer these question, we randomly selected 30 villages from three counties (Yuanshi County, Feixiang County, and Qinglong County) in the Hebei Province to conduct a field survey. Located in the Haihe river basin, Hebei is not only a water-scarce province, given that per capita water availability is only one-sixth of the national level, but is also an important agricultural production base for the country, where over 70 percent of irrigation water comes from groundwater. These three counties are all facing very serious water scarcity and have tube-well ownership as the predominant pattern of water use. The extent of tube-well ownership innovation and the cropping patterns that exist are very representative of those within Hebei, as well as within the whole of China itself. The field survey of these 30 villages covered four periods: the initial year of the production responsibility system (about 1983), 1990, 1997 and 1998.

Definition of Tube-Well Ownership

A tube-well irrigation system is defined as a system of water-extraction facilities used for supplying groundwater irrigation. An operational unit of the groundwater irrigation system comprises one complete set of water-extraction facilities, which include one tube well and other attached units such as pump(s), electricity supply and other necessary facilities. If the village collectively owns the tube well, we define it as collective ownership; otherwise, it is defined as non-collective ownership. Collective tube-well ownership is also further classified into the categories of pure-collective and quasi-collective ownership. If the collective owns all the facilities (including the tube well and its attached facilities), then we call it pure-collective ownership; if, except for the tube well, all the other facilities are owned by farmers or other organizations, such ownership is considered to be quasi-collective. For non-collective ownership of tube wells, there are also two patterns: one being private ownership and the other shareholding ownership. If all facilities belong to one owner, then it is defined as private ownership; otherwise it will be defined as shareholding ownership, which means that several shareholders will own the tube well at the same time.

Sample Description

Table 1 summarizes some general characteristics of the sample counties. Relatively large differences in per capita cultivated area, average groundwater table levels and shares of irrigated area existed in these counties; but they all present similar general development trends. Since the 1980s, per capita cultivated area has continuously declined and water resources have become increasingly scarce. Furthermore, as the groundwater table has dropped, the share of surface water used in irrigation has decreased. Groundwater has become the crucial source of irrigation water source. By 1998, the share of groundwater use had reached 100 percent, in both Yuanshi and Feixiang counties.

Survey data also indicate that since the 1980s, the share of sown cropping area under grain crops in the three counties has exhibited an increasing trend, the major grain crops being wheat and maize. Except for Qinglong County, the total shares of crop area sown with wheat and maize in the other two counties are very high (being generally higher than 80%), and had reached 55 percent in 1998. The share of sown area under cash crops in Qinglong County has increased constantly while that under cash crops in Yuanshi and Feixiang counties has declined (especially after the 1990s). No cotton has been planted in Qinglong County, whereas cotton is the main cash crop in the other two counties. The decline in the share of sown area under cotton is largely behind the decline of sown area under cash crops in Yuanshi and Feixiang counties (table 2).

Investment in Tube Wells

Tube wells were mainly financed by the local villages and townships, with government subsidies (to varying extents) up until implementation of the Household Production Responsibility System (HRS) that was initiated in the late 1970s. Farmers had always contributed family labor towards the construction of tube wells. Collective ownership dominated all forms of ownership throughout the groundwater irrigation system. With the implementation of HRS, there has been a declining role for the collective in the local economy, and a growing involvement of private individuals (farmers) in groundwater irrigation. The investment from collectives and the government has dropped considerably, while investment by farmers has increased significantly since the early 1980s. The shares of collective and government investment in groundwater irrigation declined from 21 percent and 12 percent, respectively, in 1983 to 5 percent and 3 percent, respectively, in 1998. Meanwhile, the share of farmers' investment had increased from 67 percent in 1983 to 92 percent in 1998 (table 3).

Characteristics of Tube-Well Ownership Innovation

The most significant change in the tube-well ownership regime within the irrigation systems in our study area, is the shift from collective to non-collective forms of ownership. In the early 1980s, the collectively owned groundwater irrigation system accounted for 83 percent of all groundwater irrigation (table 4). This was reduced to 31 percent in 1998. The share belonging to non-collectively owned irrigation systems increased from 17 percent to 69 percent, during the same period. Tube-well ownership innovation in the three counties has been uneven. Innovation in Feixiang County has been the quickest, since its share of non-collective tube-

Table 1. General situation in the sample site.

	Cultivated area (1,000 ha)	Share of irrigated area (%)	Per capita cultivated area (ha/person)	Share of surface water use in irrigation (%)	Share of non-collective tube-well ownership of GWIS (%)
Qinglong County					
1983	1.05	13	0.07	29	0
1990	0.98	15	0.06	31	4
Average in 1997-1998	0.93	42	0.06	6	69
Yuanshi County					
1983*	2.02	94	0.11	7	28
1990	1.92	95	0.10	15	48
Average in 1997-1998	1.81	95	0.08	0	63
Feixiang County					
1983	1.62	61	0.15	0	9
1990	1.53	69	0.13	1	54
Average in 1997-1998	1.50	83	0.12	0	80

Data source: Authors' field survey in 30 randomly selected villages from 3 selected counties of the Hebei Province.

Table 2. Cropping pattern changes in three sample counties.

	Total sown area ('000 ha)	Share of sown area of grain crops (%)			Share of sown area of cash crops (%)		
		Sum	Wheat and maize	Others	Sum	Cotton	Others
Qinglong County							
About 1983	1.10	99	38	61	1	0	1
1990	1.08	98	41	57	2	0	2
Average in 1997-1998	1.13	95	55	40	5	0	5
Yuanshi County							
About 1983	3.47	87	84	3	13	7	6
1990	3.41	88	86	2	12	7	5
Average in 1997-1998	3.37	93	91	2	7	3	4
Feixiang County							
About 1983	2.38	73	66	8	27	23	4
1990	2.39	78	72	6	22	19	3
Average in 1997-1998	2.50	93	85	8	7	3	4

Note: Cash crops include cotton, oil-bearing crops, vegetables, etc.
Source: See table 1.

Table 3. Groundwater irrigation investment in the 30 sample villages in Feixiang, Yuanshi and Qinglong counties, Hebei Province.

Year	Total	Sources of groundwater irrigation investment (%)			
		State	Collective	Farmers	Others
1983	100	21	12	67	0
1990	100	10	11	69	11
1998	100	3	5	92	0

Source: Authors' surveys in randomly selected 30 villages from 3 selected counties of Hebei Province.

Table 4. Changing structure (%) of tube-well ownership, 1983-98.

Year	Collective vs. non-collective		Within collective		Within non-collective	
	Collective	Non-collective	Pure	Quasi	Shareholding	Private
1983	83	17	52	48	100	0
1990	56	44	24	76	99	1
1997	32	68	16	84	87	13
1998	31	69	18	82	86	14

Source: See table 1.

well ownership has increased by 71 percent from 1983 to 1998; the share of Qinglong County increased by 69 percent while that in Yuanshi County increased by 35 percent in the same period (table 1).

Within the collective tube-well ownership system, pure collectively owned irrigation schemes have been gradually replaced by quasi-collective ownership (table 4). The share of quasi-collective ownership accounted for only 48 percent of the GWIS under collective ownership in 1983. This share rose to 82 percent in 1998, and dominated the collectively owned irrigation system. On the other hand, the share of pure collective ownership within the collectively owned irrigation system declined from 52 percent to 18 percent during the same period (table 4).

The non-collectively owned groundwater irrigation systems were dominated by farmer-shareholding in the initial stage of tube-well ownership change, due to the credit constraints faced by individual farmers. But the individual privately owned irrigation system has been growing rapidly since the early 1990s, and increased from only 1 percent in 1990 to 14 percent in 1998 (table 4).

Factors Correlated with Innovation in Tube-Well Ownership

This section reviews factors that are correlated with changes in tube-well ownership institutions. The next section uses an econometric model to further explore determinants of innovation in tube-well ownership.

Water Scarcity

The groundwater table is an important indicator for water resource scarcity, given that decline in the groundwater table usually means increasing water scarcity. According to a group analysis of the share of non-collective property rights, general trends show that the share of collective tube-well ownership within the GWIS will decline, and the share of collective ownership rise, with the lowering of the groundwater table (table 5). It implies that increasing water scarcity will induce the innovation of tube-well ownership and this conforms to our expectations. Table 5 also shows that since the 1980s, the groundwater table has dropped annually and that the drop rate has accelerated during those years.

The share of surface water use indicates the degree of exploitation of groundwater. If the share of surface water use is low, then the share of groundwater use will be high; this means that the degree of groundwater exploitation is large, and also implies increasing water scarcity. Since the 1980s, the share of surface-water use has decreased from 12 percent of the total water use in the early 1980s to 2 percent in 1998. Agricultural development depends more and more on groundwater, which has become the main source of water for meeting local irrigation demand (table 5). With the ratio of surface water to total water use in decline, the possibility of non-collective tube-well ownership innovation within the GWIS will increase.

Table 5. Relationship between tube-well ownership innovation and water-resources scarcity.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Average groundwater table in the last year (meter)	Share of surface water use (%)	Year	Average share of non-collective tube-well ownership (%)	Average groundwater table in the last year (meter)	Share of surface water use (%)
0	0	42	16	1983	17	37	12
1-50	30	43	3	1990	44	42	16
51-99	77	40	1	1997	68	47	2
100	100	53	2	1998	69	48	2

Note: Groundwater table is defined as the distance between available water and the earth's surface; share of non-collective tube-well ownership is defined as the ratio of the number of non-collective tube wells to the total number of tube wells; share of surface water use is defined as the ratio of surface water use to the total irrigation water use. Sample distribution in the four groups is 53,16,25,26.

Source: See table 1.

Income

In our survey, we used per capita net income of farmers and per capita income of collectives to indicate the economic well-being of the local community. Survey findings indicate that, this the rise of per capita net income of farmers, the share of non-collective tube-well ownership has also shown a tendency to increase (table 6). However, we need to further understand the relationship between per capita net income of farmers and non-collective tube-well ownership innovation, since the per capita net income of farmers will be influenced by time variables.

Compared with the 4.41 percent annual growth rate of farmers' net income, collective per capita income has displayed a declining trend up to the mid-1990s, when per capita income of the collectives had begun to increase (table 6). With the decrease of per capita income of the collectives, however, the share of non-collective tube-well ownership has increased. This indicates that the decline of collective economic power may be one of the reasons behind tube-well ownership innovation.

Human Capital and Environmental Stresses

Human capital is a comprehensive indicator of a person's intellectual, mental and management ability. Among all the factors that comprise human capital, education level is the most important index. Therefore, we select the share of labor with middle-school-level and higher education as a representative indicator of human capital. Table 7 shows that there exists a positive correlation between tube-well ownership innovation and human capital improvement.

Per capita cultivated area indicates the degree of environmental stress. Large per capita cultivated area implies small environmental pressures, whereas a small cultivated area per capita will indicate that there are large environmental pressures. According to the grouped data in table 7, there does not exist an obvious correlation between tube-well ownership innovation and per capita cultivated area. However, table 7 also shows that since the 1980s, the per capita cultivated area in 30 villages has decreased and the share of non-collective tube-well ownership has shown an increasing trend. Therefore, further research needs to be conducted to ascertain if there are any relationships between tube-well ownership innovation and environmental pressures.

Policy Factors and Market Development

Tube-well ownership innovation has occurred and increased under specific policy environments. Two principal policies that are closely related to expenditures on the groundwater irrigation system are policies for financial subsidies and policies for credit. There are some differences in service objectives between these two policies. The village collectives can obtain financial subsidies for water-related expenditures, while farmers can also obtain them directly. However, for water-credit policy, village collectives have more opportunities to obtain credit than do farmers. Based on this, we expect that the water-finance policy will promote tube-well ownership innovation, whereas the water-credit policy will hinder tube-well ownership innovation.

Survey results show that since the 1980s, the share of villages that can obtain water credit has not changed much, being about 50 percent, whereas the share of villages that can obtain water-finance subsidies has increased annually, from 6 percent in 1998 to 47 percent in 1998 (table 8). Group analysis also indicates the complex relationship between tube-well

Table 6. Relationship between tube-well ownership innovation and economic power of local community.

Grouped in share or non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Per-capita net income of farmers (yuan/year)	Per-capita income of collective (yuan/year)	Year	Average share of non-collective tube-well ownership (%)	Per-capita net income of farmers (yuan/year)	Per-capita income of collective (yuan/year)
0	0	705	39	1983	17	498	40
1-50	30	811	23	1990	44	778	28
51-99	77	788	19	1997	68	901	36
100	100	914	21	1998	69	951	38

Note: Per-capita net income of farmers and per capita income of collective are calculated in real price of 1990.
Source: See table 1.

Table 7. Relationship between tube-well ownership innovation, human capital, and environmental stresses.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Share of middle school educated labor (%)	Per capita cultivated area (ha)	Year	Average share of non-collective tube-well ownership (%)	Share of middle-school educated labor (%)	Per capita cultivated area (ha)
0	0	39	0.10	1983	17	31	0.11
1-50	30	42	0.11	1990	44	44	0.09
51-99	77	51	0.10	1997	68	51	0.08
100	100	51	0.10	1998	69	51	0.08

Source: See table 1.

ownership innovation and both water-finance policy and water-credit policy. From the general development trend, the larger the number of villages that can obtain water finance subsidies, the greater the possibility of tube-well ownership innovation; and the fewer the number of villages that can get water credit, the greater the possibility of tube-well ownership innovation; which conforms to our expectations.

A higher degree of development and convenience of transport implies the existence of a more developed market, with a higher degree of commercialization and information content. Since the 1980s, the transportation conditions in these 30 villages have been improved gradually, so that 77 percent of villages had roads in 1998 (table 8). According to group analysis, based on the share of non-collective property rights, general development trends show that the share of non-collective tube-well ownership will increase with the improvement of transportation conditions. Therefore, market development may be one of the important factors that influence tube-well ownership innovation.

In summary, tube-well ownership innovation within the GWIS may be the outcome of factors that include: an increasing shortage of water; an increasing level of groundwater exploitation; a weakening of collective economic power; increasing environmental pressures within local communities; improvements in human capital; market development; and both water finance and credit policy.

Econometric Model of Tube-Well Ownership Innovation

In order to further explore the correlation between these phenomena, and to move beyond the simple single-factor analysis, we have constructed an econometric model of tube-well ownership innovation determinants to conduct a multi-factor analysis for tube-well ownership innovation.

Specification of Econometric Model of Tube-Well Ownership Innovation Determinants

Based on the above discussion, we propose the following empirical model to analyze the determinants of tube-well ownership innovation:

1) $Private_{jt} = F(Wtable_{jt-1}, Wsource_{jt}, Land_{jt}, Income_{jt}, Revenue_{jt}, Edu_{jt}, Finance_{jt}, Credit_{jt}, Road_{jt}, Dv_j, Dy_t) + e_{jt}$

- In the above equation, j represents a village, t the year and e the random error vector.
- The share of non-collective tube-well ownership (Private, %) is treated as the dependent variable.
- Water-resource endowments are represented by two variables, average groundwater table in the last year (Wtable, meter) and the share of surface-water use in irrigation (Wsource, %).

Table 8. Relationship between tube-well ownership innovation and market development, water finance and credit policy.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Share of villages that received water finance subsidy (%)	Share of villages that received water credit (%)	Share of villages with road (%)	Year	Average share of non-collective property right (%)	Share of villages that received water finance subsidy (%)	Share of villages that received water credit (%)	Share of villages with road (%)
0	0	23	62	51	1983	17	6	50	47
1-50	30	31	50	81	1990	44	23	53	73
51-99	77	48	56	88	1997	68	47	53	77
100	100	31	31	77	1998	69	47	53	77

Source: See table 1.

- Both per capita real net income of farmer (income, yuan/year, in 1990) and per capita real income of village collective (revenue, yuan/year, in 1990) represent the local economic power.
- Local human capital is represented by the share of agricultural laborers who received a middle-school or higher education (Edu, %).
- Per capita cultivated area (cultivated area/person, ha) indicates the state of the existing environment (Land).
- We select two policy dummy variables for water-finance policy (Finance) and water-credit policy (Credit), so as to represent the presence of water-policy influence. If there are water-finance subsidies available, then Finance = 1; otherwise, Finance =0; if there is water credit, Credit = 1, otherwise, Credit = 0.
- A road dummy variable (Road) is selected to represent the state of market development; if Road = 1, it means that there is a road in the village; otherwise, it means no road exists in the village.
- In addition, we also introduce regional dummy variables and time dummy variables. Regional dummy variables (Dv_{it}) indicate the impact of constant differences among regions on tube-well ownership innovation while time dummy variables (Dy_{it}) control for the impact of all factors that will change with time, on tube-well ownership innovation.

Selection of Estimation Methods

Four periods in 30 villages of cross-section and time series are used for estimating equation (1), making the total sample size 120. First, we used ordinary least squares (OLS) to estimate the equation which included all village and time dummy variables. Second, similarly, we estimated equation (1) by OLS while no village and time dummy variables were included. Finally, we adopted a random-effects model estimated by the maximum likelihood approach. The random-effects model assumed that the differences in e_{it} for various regions and periods are random. At the same time, we transformed some variables into a logarithmic form, such as groundwater table level in the last year, per capita cultivated area, per capita real net income of farmers and per capita real income of villages. As a result, 12 models have been estimated.

Estimation Results

The estimation results, for the various models, are satisfactory and the R^2 varies between 0.46 and 0.83, while the F and Chi^2 tests are also statistically significant (table 9). The fact that the estimation results from the various models are almost the same implies that the estimated coefficients are stable. Most variable coefficients are statistically significant and the signs of the coefficients conform to our expectations. Most village coefficients are statistically significant at the 5 percent or 10 percent level, which implies that other village factors, except for those explicitly considered in the models, will have impacts on tube-well ownership innovation. The estimation results also show that the time-dummy variables are not statistically significant, which implies that the variations seem correlated to the specific factors included

Table 9. Estimates for econometric model of tube-well ownership innovation determinants.[a]

Dependent variables	Private (%)		
	OLS		
	Case 1	Case 2	Random effect model
Constant	-132.022	-404.156	-111.367
	(-0.69)[b]	(-4.55)***	(-1.99)**
Water-resources endowments			
Ln (Wtable)	4.817	66.031	13.246
	(1.39)	(3.33)***	(2.64)***
Wsource (%)	0.430	0.435	0.455
	(2.72)***	(3.07)***	(3.21)***
Environment			
Ln (Land)	-3.262	-83.075	-31.740
	(-0.27)	(-2.54)**	(-1.90)**
Local economy			
Ln (Income)	-9.370	-11.570	-11.740
	(-1.11)	(-0.91)	(-1.23)
Ln (Revenue)	-4.074	1.340	0.250
	(-1.82)*	(0.72)	(-0.13)
Human capital			
Edu (%)	1.979	0.038	1.595
	(5.54)	(0.07)	(4.06)***
Policy dummy variables			
Finance	9.359	13.479	13.873
	(1.25)	(2.06)**	(2.12)**
Credit	-27.680	-62.107	-30.018
	(-4.14)***	(-2.10)**	(-2.90)***
Market development dummy variables			
Road	13.383	21.947	19.037
	(1.84)**	(2.24)**	(2.29)**
29 village dummy variables[c]	-[d]		-
R^2	0.458	0.833	0.619
Adjusted R^2	0.413	0.755	-
F	10.31	10.63	-
Chi^2	-	-	137.77
Degree of freedom	110	81	110

a = Sample size is 120.

b = Numbers in brackets represent t statistic test (case 1 and case 2) or Z statistic test (Random effects model); *, ** and *** represent statistic significance at 10%, 5% and 1% levels, respectively.

c: In order to save space, coefficients of village dummy variables have not been listed. Estimating results show that most coefficients of independent variables are statistically significant.

d: "-"indicates that the variable has not been included in the model or there is no estimating of them.

in the model and not just a correlation with general trends over time. In order to save space, we have not listed the estimation results of time dummies. In this paper we have reported only three estimation models.

Based on the estimation results of the econometric model, the following section will summarize major factors that induce tube-well ownership innovation.

Increasing water scarcity is one of the most important factors that induce non-collective tube-well ownership innovation. The estimation results of the econometric model show that the coefficient on the groundwater table level, in most models, is statistically significant at the 1 percent level and that the coefficient sign is positive (table 9). Therefore, ceteris paribus, the lower the level of the groundwater table, the higher the water-resources scarcity, and the greater the possibility of transformation towards non-collective tube-well ownership in GWIS from collective property rights. Table 9 shows that the coefficient of the groundwater table level variable is 4.8, which indicates that if the groundwater table level drops by 1 percent, then the share of non-collective tube-well ownership in GWIS will rise by almost 5 percent (4.8%).

Increasing groundwater exploitation will result in development of non-collective tube-well ownership. The coefficient on the share of surface water use is statistically significant at the 1 percent level and is of negative sign, in all the various models (table 9). The estimation results imply that, ceteris paribus, the greater the degree of groundwater exploitation, the greater the possibility of tube-well ownership innovation. Table 9 shows that if the share of surface-water use in irrigation declines by 1 percent, then the share of non-collective tube-well ownership of GWIS will increase by about 0.44 percent.

Both the groundwater table level and the share of surface-water use in irrigation are important indicators of water-resources scarcity. Our estimation results show that increasing water scarcity is an important factor in determining the degree of tube-well ownership innovation of GWIS, which supports the theoretical assumptions of institutional innovation induced by natural-resources scarcity.

Deterioration of the resource environment will induce non-collective tube-well ownership innovation of GWIS. The estimation results show that the coefficients for per capita cultivated area are all statistically significant at the 5 percent level and their signs are negative (table 9). That is, ceteris paribus, the smaller the per capita level of cultivated area, the greater the deterioration of the resource environment, and the greater the possibilities for tube-well ownership innovation of GWIS.

Weakening of village collective or community power will lead to non-collective tube-well ownership innovation of GWIS. The coefficients on the per capita real income of collectives are statistically significant at both the 5 percent and 1 percent levels, and the signs are negative. These results indicate that, ceteris paribus, the weakening of the economic power of the collectives will induce non-collective property innovation of GWIS. Table 9 indicates that the coefficient of per capita income of the collective is 11.44, which means that if the per capita income of the collective decreases by 1 percent, the share of non-collective tube-well ownership within the GWIS will increase by 11.44 percent.

However, tube-well ownership innovation of GWIS is not responsive to increases in the per capita real net income of farmers. Our estimation shows that the coefficient on the per capita real net income of farmers is not statistically significant and that, furthermore, if we drop the variable from the model, there is not much of an effect on the model estimation results. Due to limited space, we have not listed these model results. This result implies that an improvement in farmers' income has little effect on non-collective tube-well ownership innovation.

Therefore, as far as the effect of local-community economic strength goes, it is mainly collective economic power that has an important impact on tube-well ownership innovation of GWIS, while farmers' income has little effect on it. One possible explanation of this is that an individual farmer's income does not exert enough of an effect to influence tube-well ownership innovation. The above analysis also shows that the sharing of tube-well ownership is the predominant pattern within the GWIS. Sharing tube-well ownership within the GWIS not only allows farmers to share investment risk, but also serves to reduce the investment cost for every shareholder. Therefore, the sharing of tube-well ownership within the GWIS is a rational economic choice, given the farmers' current economic status.

Improvement of human capital within the local community can obviously induce non-collective tube-well ownership innovation of GWIS. Coinciding with our expectations, most of the coefficients on human capital are statistically significant at the 1 percent level and have a positive sign (table 9). It indicates that, all other variables remaining constant, the higher the educational level of agricultural laborers, the greater the possibility for the innovation of tube-well ownership. Table 9 shows that the coefficient of human capital is 1.979, and implies that if the share of agricultural labor receiving middle-school or higher education increases by 1 percent, then the share of non-collective tube-well ownership within the GWIS will increase by about 2 percent (1.979%).

Water-finance policy has promoted non-collective tube-well ownership innovation, but water-credit policy has hindered tube-well ownership innovation. In concordace with our expectations, the signs of the water-finance policy coefficients are all positive and statistically significant at the 5 percent level (table 9). The estimation results indicate that, ceteris paribus, the water-finance policy, with subsidies available to both villages and farmers, has had an important positive effect on tube-well ownership innovation.

Estimation results of the impacts of the water-credit policy also conform to our expectations. The coefficients on the water-credit policy are statistically significant, and their negative sign indicates that water credit, which is available to villages but not to farmers, has had a negative effect on tube-well ownership innovation.

Market development has an obvious positive correlation with non-collective tube-well ownership innovation. In agreement with our theoretical expectations, most of the coefficients on the road dummy variables are statistically significant at the 5 percent level and have a positive sign (table 9). Keeping other factors constant, the higher the development of the level of transportation, the greater the development of the markets, which implies even greater possibilities for non-collective tube-well ownership innovation.

Table 10. Relationship between tube-well ownership innovation and market development, water finance and credit policy.

By share of non-collective property right (%)	Sum	Wheat and maize	Others	Sum	Cotton	Others
0-0.99	90	74	16	10	7	3
1-89.9	89	79	11	11	6	5
90-100	88	80	8	12	7	5

Source: See table 1.

Table 11. Estimates for econometric model of cropping-pattern determinants.

Independent	$Area_G$		$Area_C$		$Area_o$	
variables	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Constant	82.530	99.377	7.448	-10.100	10.022	10.723
	(25.19)***	(13.14)***	(2.39)**	(-1.41)	(5.69)***	(2.64)***
Private	-0.078	-0.082	0.033	0.039	0.045	0.043
	(-3.42)***	(-3.63)***	(1.54)	(1.83)*	(3.63)***	(3.54)***
Ln (Quota)	3.029	2.964	-0.730	-0.649	-2.299	-2.315
	(4.07)***	(3.99)***	(-1.03)	(-0.92)	(-5.75)***	(-5.82)***
Wsource	0.031	0.028	-0.023	-0.019	-0.008	-0.009
	(0.92)	(0.83)	(-0.72)	(-0.59)	(-0.44)	(-0.50)
$Price_G/Price_f$	—	2.604	—	-3.336	—	0.732
	—	(0.15)	—	(-0.20)	—	(0.08)
$Price_C/Price_f$	—	-5.430	—	5.713	—	-0.283
	—	(-2.90)***	—	(3.21)***	—	(-0.28)
Nincome	0.108	0.095	-0.054	-0.037	-0.054	-0.058
	(1.81)*	(1.65)*	(-0.96)	(-0.67)	(-1.69)	(-1.88)*
Adjusted R^2	0.43	0.43	0.40	0.40	0.29	0.23
F	10.86	12.26	9.66	10.83	5.41	6.06

Note: *, **, ***, represent statistical significance at 10 percent, 5 percent and 1 percent, respectively. Estimation results of county and year dummy are omitted.

Impact of Tube-Well Ownership on Cropping Patterns

Our sample data indicate that there is a positive relationship between non-collective tube-well ownership and the share of cash-crop areas. When the share of non-collective tube-well ownership increases from less than .1 percent to more than 90 percent, the share of grain-crop areas declines from 90 percent to 88 percent, while the share of cash-crop areas increases from 10 percent to 12 percent (table 10). Therefore, the greater the share of non-collective property rights within a GWIS, the greater the share of area under cash-crop cultivation and the lower the share under grain crops. However, cropping patterns are also correlated with other factors, such as grain-procurement policy, relative price of input and output, relative price of grain and cash crops, farmer income and labor-opportunity cost.

In order to control other factor influence, we specified the following model to explore the relationship between tube-well ownership innovation and cropping patterns:

(2) $Area_{ijt} = F(Private_{jt}, Wsource_{jt}, Quota_{jt}, (Price_g/Price_f)_{jt-1}, (Price_c/Price_i)_{jt-1}, Nincome_{jt}, Dc_j, Dy_t) + e_{it}$

- In the above equation, i represents each crop (including grain crops, cotton and other cash crops), j, the village and t, the time period.
- Areait represents the share of cultivated area of crop i of the total crop area in period t and village j, such that AreaGjt is for grain crops, AreaCjt is for cotton and Areaojt is for other cash crops.
- Private represents the share of non-collective property right of GWIS predicted from equation (1).
- The variable Quota represents the per capita grain procurement quota (kg/person), which will measure the effect of the government grain purchase policy on cropping patterns.
- $Price_G$, $Price_C$, and $Price_f$, represent the market price of grain crops, the purchase price of cotton and the price index of fertilizer input, respectively. Since cropping pattern is mainly influenced by the price expectation instead of the price of the current year, here we use last year's price to indicate the price expectation.
- The prices of natural resources and opportunity cost of agricultural labor are usually measured by shadow prices, so we select the share of surface-water use in irrigation to reflect water-resources scarcity (Wsource,%) and the share of nonagricultural income (Nincome,%) to capture the opportunity cost of agricultural labor.
- In order to explain the impact of differences between regions and years on the cropping pattern, we select county dummy variables Dc_j, and dummy variables for the year Dy_t.

The model performs well and the adjusted R^2 range of 0.23 to 0.43, is high enough for the estimation (table 11). Most variables in equation (2) are statistically significant and the signs are consistent with our expectations. For example, our results show that the per capita grain procurement quota has a positive relationship with grain-crop areas; the higher the price ratio between cotton and fertilizer, the larger the areas of cotton and the smaller the areas of grain crops.

More importantly, our results show the significant impacts of innovation of tube-well ownership on cropping patterns (table 11). The coefficient on the variable for the share of non-collective property rights within the GWIS is statistically significant at the 1 percent level, and has a positive correlation with the share of sown area of grain crops, while having a negative correlation with the share of sown area under cash crops. So, ceteris paribus, the innovation of non-collective property rights will have an influence on the cropping pattern changes of grain and cash crops.

In the grain-crops model, the coefficient of non-collective property rights is 0.082, which means that when the share of non-collective property rights within the GWIS increases by 10 percent (i.e., the average value increases from 42% to 52%), then the share of sown area of grain crops will be reduced by 0.82 percent (0.082×10=0.82) (table 11). Similarly, the share of sown area of cotton and other cash crops will increase by 0.39 and 0.43 percent, respectively.

Therefore, the development of non-collective property rights within a GWIS can be seen to play an important role in causing cropping pattern changes, especially that of increasing the cultivated area of high-valued crops. With tube-well ownership transferring from collective to non-collective, the reliability and timing of water supply have been enhanced inducing farmers to have more incentive to plant high-value crops. Due to the relatively higher marginal income from cash crops than from grain crops, farmers can earn more money with the adjustment of the cropping patterns.

Discussion and Recommendations

Based on a case study of groundwater irrigation systems, this paper analyzes the internal relationship between tube-well ownership innovation and its inducement factors, and the impacts of tube-well ownership innovation on cropping patterns. Research results show that tube-well ownership innovation within the groundwater irrigation system agrees with theoretical assumptions, and is induced by the following factors: increasing scarcity of water resources and groundwater exploitation, a declining resource environment, a weakening of local community economic strength (mainly that of the collective), improvements in human capital, water-finance policy, water-credit policy, and market development. Tube-well ownership will continue to change with changes in these factors.

Changes in these factors occur gradually and slowly, and different forms of property rights will result in different benefits for society and water-resources use. Transferring tube-well ownership from collective to non-collective can promote the cash-crop development. This implies that if policy can rationally induce tube-well ownership innovation, then tube-well ownership innovation will promote sustainable water-resources development and create greater welfare for society.

Based on the above discussion, several policy recommendations are put forward, as follows:

Actively induce tube-well ownership innovation. It is difficult to effect changes to the continuing trend of increasing scarcity of water resources and worsening environment; but if tube-well ownership innovation within a GWIS is to remain heavily dependent on a deteriorating resource and environmental base, then we cannot expect it to occur quickly. At the same time, we do not expect tube-well ownership innovation to occur at the expense of resource and environmental sustainability. Therefore, the government should implement effective policy measures in order to encourage and induce tube-well ownership innovation.

Adjust water-finance and water-credit policies. To make the policy direction clear, the government should apply effective and rational water-finance and water-credit policies to induce tube-well ownership innovation. On the one hand, the government should extend water-finance subsidies for the development of non-collective tube-well ownership within the GWIS and, on the other, it should put more emphasis on developing rural credit markets, and improving credit access to farmers so as to improve their investment ability.

Accelerate the development of human capital. The government should increase investment in farmers' education, improve their knowledge and management ability, develop their market awareness and strengthen human-capital development, in order to accelerate tube-well ownership innovation and improve water-use efficiency.

Promoting integrated river-basin management, especivially addressing groundwater issues. Within the administrative jurisdictions of the river basin, water supply and demand, too many authorities having different interests control and manage groundwater and surface water resulting in various conflicts in balancing water use in the region. Faced with increasing water shortage and groundwater depletion especially in North China, it is urgent to realize the integrated water management between water supply and water demand, and between groundwater and surface-water resources in the river basin.

With tube-well ownership being transferred from collective to non-collective, groundwater management is more distinct than before. If there is no rational and intergrated macro water policies to guide individual behaviors, it is possible that groundwater exploitation will be accelerated. Although farmers can get benefits from the ownership change in the short term, in the long term, with the further depletion of groundwater resources and if groundwater is not utilized and planned in a sustainable way, finally farmers will deplete all the available groundwater resources, and their production and environment will be greatly destroyed. Therefore, how to take rational and effective measures (such as groundwater resources fee, withdrawal permit system, etc.) to promote the sustainable water and socioeconomic development has to be emphasized by the policymakers and reseachers.

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