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Evolution of tubewell ownership and production in the North China Plain*

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The overall aim of the present paper is to better understand the evolution of tubewell ownership in the North China Plain, especially focusing on the factors that determine ownership and its effect on production. Based on a random sample of 30 villages in three counties in the Hai River Basin, our results show that collectively owned tubewells have been gradually privatised. The analyses demonstrate that increasing water and land scarcity and policy intervention (mainly fiscal and financial subsidies for tubewell investment) leads to the observed shifts in tubewell ownership patterns. The results also show that the privatisation of tubewells has affected cropping patterns in the North China Plain. When villages shift towards private tubewells, farmers move into more water-sensitive and high-value crops. Privatisation, however, has no negative effect on crop productivity in the present sample. Importantly, the evolution of tubewell ownership in the villages studied does not accelerate the fall of the groundwater table.

Key words: agricultural production, China, privatisation, subsidies, tubewell ownership, water scarcity.

1. Introduction

Water shortages are threatening China's resource base and agricultural production, especially in the North China Plain, one of the nation's main agricultural regions. Despite ranking fifth in total water resources among all the countries in the world, on a per capita basis China has only 25 per cent of the world average. Per capita water availability in north China is significantly lower than the national average (Ministry of Water Resources 2002). Between 1949 and 1998, total water use increased by 430 per cent, which is similar to the world average increase of 400 per cent (http://www.c-water.com.cn/news/luntan/guoyaichengshijieshuigaikuang1.htm [accessed on 23 February 2003]) but greater than the average for developing countries. Because China's water utilisation rates are already among the highest in the world, there is little scope for tapping additional sources (Ministry of Water Resources 2002;

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Rosegrant and Cai 2002). Water demand in industrial and urban sectors has risen so fast that the water available to the agricultural sector has declined.

Faced with increasing demands and limited surface water supplies, farming communities in the North China Plain began to turn to groundwater in the late 1960s. Under the directive of the central government, tubewells have developed quickly in China during the past several decades. By 1997, producers were extracting groundwater from 3.5 million tubewells and irrigating nearly 15 million hectares, mainly in the Hai River Basin and lower reaches of the Yellow River (Ministry of Water Resources 2000). Unfortunately, groundwater extraction has led to falling water tables and deteriorating water quality in north China.

Despite the growing water crisis, agricultural production in the North China Plain has not declined. Agricultural yields of wheat and maize rose by nearly 15–30 per cent during the 1990s (China National Bureau of Statistics 2002). Output grew by 20–35 per cent. Facing rising demand for new cash crops from domestic and export markets, farmers have also begun to shift from staple to cash crops, even though such crops often require more intensive use of water and more precise timing.

In examining the apparent contradiction between the looming water shortage and booming agricultural production, researchers have observed the rapid rise of private tubewell ownership and other new forms of tubewell management in north China. China's scholars have regarded the privatisation of tubewells as a measure that has improved groundwater management efficiency and increased agricultural productivity (Cai 1985; Dong and Zhang 1994; Chen *et al.* 1997). Nyberg and Rozelle (1999) and Nickum (1998) also point out the importance of expanding the role of private individuals in water management and investment. Although it is certainly a possibility that the shift of tubewell ownership and management responsibilities to private individuals has helped ease some of the key constraints that producers have faced in recent years, it is also possible that the privatisation of pumping services in an open–access environment (like that of groundwater in the North China Plain) could lead to an inefficiently rapid depletion of the region's water resources. Surprisingly, almost no research has systematically studied groundwater management issues in China.

The overall aim of our paper is to explain how the shift to private tubewell ownership in the North China Plain has helped supply the water for the region's agricultural sector. To meet the goal we have four objectives: (i) describe the evolution of tubewell ownership; (ii) examine the nature of the villages and households that live within them that have seen their tubewells privatised and measure the factors that influence privatisation; (iii) explore the impact of tubewell ownership change on agricultural production; and (iv) explore how changes in tubewell ownership affect the groundwater table.

2. Increasing water scarcity and groundwater depletion in the Hai River Basin

As one of the main economic and political centres of China, the economic region covering the Hai River Basin has grown rapidly over time. Covering the municipalities of Beijing and Tianjin, all of Hebei and small parts of Henan and Shandong provinces, the gross domestic product (GDP) of the basin has increased nearly 40-fold since the

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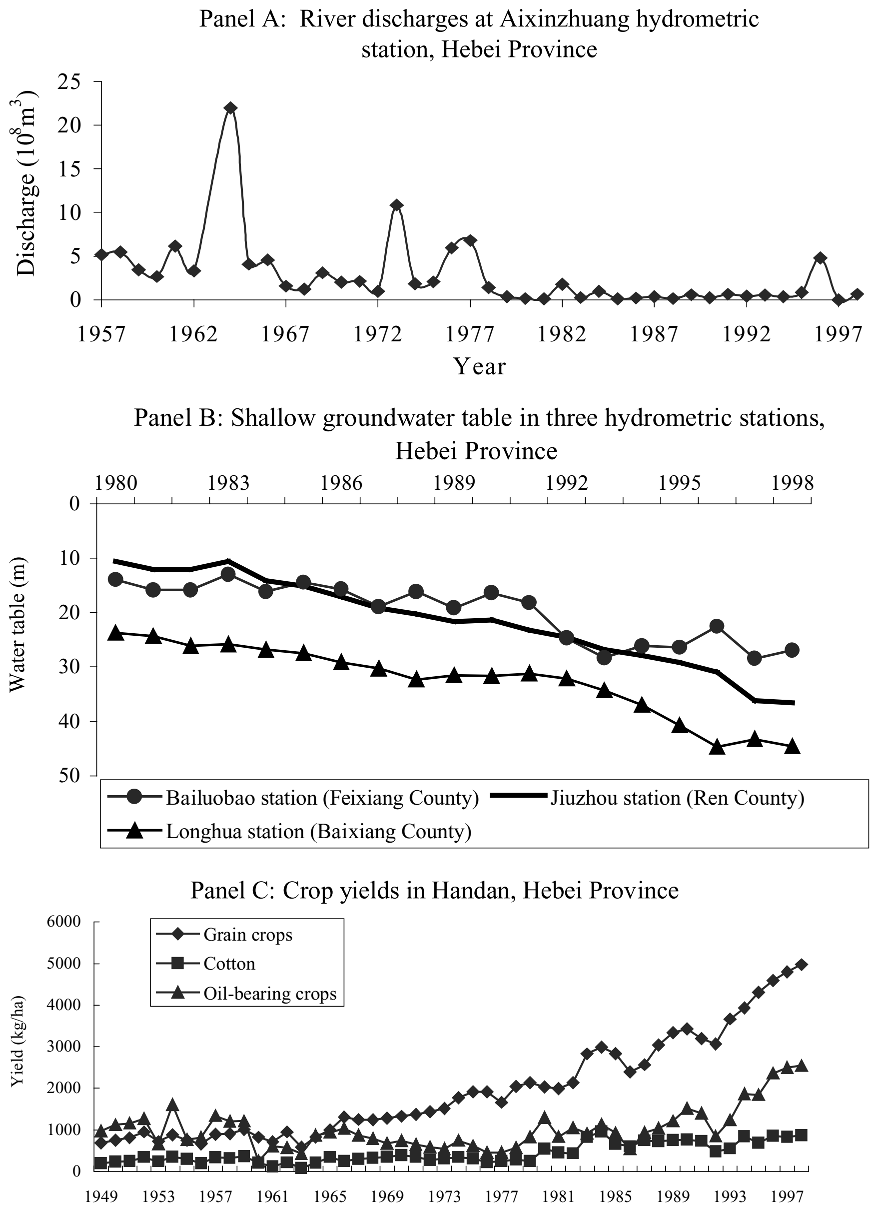

Figure 1 River discharge, groundwater table and crop yields in Hebei Province.

1950s (China National Bureau of Statistics 2002). Both rural and urban areas have contributed largely to the growth. Agricultural GDP has risen nearly 8-fold. Grain and cash crop yields in Handan Prefecture in Hebei Province have continuously increased during the past 50 years (Figure 1, Panel C). At the same time, industry grew by more than 60-fold.

Developing groundwater has been an important contribution to the growth of the agricultural economy in the Hai River Basin. Since the late 1960s, surface water

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availability in the basin has fallen. During this time, the basin changed from an open basin to a closed one. Since the 1990s, almost no water from the Hai River Basin is discharged into the sea. Withdrawals from the Fuyang River Basin, in the upper part of the Hai River Basin, almost completely depleted the main river (Figure 1, Panel A). There has been a steady fall of cultivated area serviced by surface water. During the same period, however, irrigated area has risen due to the exploitation of groundwater resources. Since 2001, nearly 70 per cent of the basin's water supply has come from groundwater resources (Ministry of Water Resources 2002).

Despite the importance of groundwater in stimulating the growth of the Hai River Basin's economy, serious environmental issues have arisen as a result of its extraction. Rising reliance on groundwater extraction has led to falling water tables. For example, in Feixiang County, a county located in the upstream part of the Fuyang River Basin, the shallow groundwater table fell by 0.6 m/year in the 1980s and 1.3 m/year in the 1990s (Figure 1, Panel B). Even greater rates of decline of the shallow groundwater table occurred in the middle and downstream parts of the basin. Excessive water withdrawals and falling water tables have caused land subsidence in some rural areas, cones of depression under some cities and deteriorating water quality near the coast (Hebei Hydrological Bureau and Water Environmental Monitoring Center 1999).

Although less well-publicised, the falling water table created another crisis in the groundwater sector when many of the tubewells and pumps became unusable. In almost any village that one visits in the Hai River Basin, retired cadres and older farmers can recount the number of wells that have become inoperable over the past two decades. The need for new investment for the replacement of tubewells came initially at a time in the early 1980s when decollectivisation and the fiscal reforms had left many villages without access to investment funds or command over labour to invest in tubewells.

The nature of the investment in tubewells and the purchase and operation of pumps in the Hai River Basin has shifted dramatically during the past 10–20 years. Although official data are scarce, according to two sets of data that we collected in another project in 2001 and 2002, private individuals sunk a large number of the new tubewells. In a sample of 32 villages in the Hai River Basin, we found that individuals purchased 80 per cent of the new pumps during the 1990s.

3. Data

The data for this study came from a survey that we conducted in 30 villages in three counties, Yuanshi County, Feixiang County and Qinglong County, in the Hebei Province in 1998. Located in the Hai River Basin, the three counties face serious water shortages. We do not have a random sample of villages for all of China. However, the Hai River Basin of Hebei Province is one of China's five main water basins. Within this region, we randomly selected counties and villages and, although relatively small, our sample is representative. All villages in the sample kept detailed records on community-level socioeconomic and water issues. We also held detailed interviews with village leaders and others who had been village residents for the entire sample period. Our field survey of the 30 villages covers four periods: the initial year of the Household Responsibility System (circa 1983), 1990, 1997 and 1998.

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During our survey, enumerators identified two types of tubewell ownership: collective and private. If the village leadership council owns the tubewell, we define it as *collective*, otherwise the tubewell is defined as *private*. There are two types of private tubewells. If a tubewell belongs to a single individual or family, we call it an *individual tubewell*. Other private tubewells are owned by groups of individuals. Because in many of the groups the individual members are assigned shares that indicate the investment stake that each member has in the tubewell, the groups are often called *shareholding groups* and their tubewells are called *shareholding tubewells*. In executing our village questionnaire, enumerators asked village leaders to recall the total number of operating tubewells by ownership type in each of the survey's four target years.

The survey also collected information that we use to understand the determinants of tubewell ownership, including the scarcity of water and the amount of cultivated land per capita in the village. Water scarcity is defined as the depth of the water table in a tubewell after at least 3 months of non-use (typically in the fall season of each year). Water scarcity is also assumed to be correlated with the share of irrigated area supplied by groundwater. We also asked village leaders whether the government provided either fiscal subsidies or bank loans for aiding the collective or individual to invest in tubewells.

The survey collected other information that we use to develop several measures of the effects of ownership shifts on crop production. We recorded cropping patterns (the share of overall sown area accounted for by each crop) and crop yields to account for the productivity impacts. In our regressions that explain agricultural production, we control for the share of non-agricultural income in the average household's total income as well as each household's grain procurement quota. Descriptive statistics are shown in Appendix I.

4. Evolution of tubewell ownership

In a pattern similar to that found throughout the Hai River Basin, the sources of investment in and the pattern of ownership of tubewells in our sample areas have changed over time. Our data show that individuals already made two-thirds of new investments in 1983; the share of investments made by the state (21%) and collective (12%) was only approximately one-third (Table 1, row 1). Tubewell investment by the state and collective declined between 1983 and 1998 (columns 1 and 2). In its place, the share of investments made by individuals (or private investments) rose (column 3). At the same time that the sources of investment-funding for tubewells were shifting from

Table 1 Sources of tubewell investment in Hebei Province, 1983–1998

	Sources of tubewell investment (%)			
Year	State	Collective	Individual	Others
1983	21	12	67	0
1990	10	11	69	11
1998	3	5	92	0

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

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Table 2 Changes of tubewell number and shifts in tubewell ownership in Hebei Province, 1983–1998

Year	Collective versus private: Collective	Private
Share of tubewells (%)		
1983	93	7
1990	66	33
1997	38	62
1998	36	64
No. tubewells		
1983	474	36
1990	396	198
1997	376	614
1998	367	653

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

the collective to households, tubewell ownership in our study area was also evolving (Table 2).

Our interviews also revealed that the rise of privately financed investment means that the shift in tubewell ownership has mostly come from the establishment of new tubewells and has not been a result of the ownership change in collective tubewells (Table 2). Because of the fall of the groundwater table and lack of maintenance on pumps and engines, a number of collective tubewells became inoperable during the past two decades and the absolute number of collective tubewells fell (column 1, rows 5–8). During this time, the number of private wells increased rapidly (column 2, rows 5–8).

4.1 Tubewell ownership, resource scarcity and policy intervention

Scholars in recent years have analysed the determinants of institutional innovation both theoretically and empirically. For example, White (1995) finds that government policies, the degree of democratisation and financial market liberalisation play important roles in institutional change. Otsuka (1995) shows that in much of the empirical literature, environmental and population factors, government policies and other socioeconomic variables are the main determinants of institutional change. Tang (1991) and Uphoff (1986) have identified that three kinds of factors – physical and technical characteristics of the resource, characteristics of the group of users and attributes of institutional arrangements – influence water management organisation in particular.

Although little empirical work has focused specifically on groundwater, published literature has identified several factors that affect tubewell ownership. Based on a case study of tubewell ownership innovation in Pakistan, Meinzen-Dick (1996) concluded that the emergence of private tubewells is mainly a result of the changes of groundwater and surface water use, farm scale and population intensity. Shah (1993) showed how the emergence of institutions that encourage water sales in villages has levered the rise in private tubewell ownership. Barker and Molle (2002) point to the increased availability of reliable pumping technology and hint that this has been a factor in increasing the rise

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Table 3 Relationship between tubewell ownership and resource endowment and policy measures in Hebei Province, 1983–1998†

	Share of private tubewells (%)	Water scarcity: Groundwater table (m)	Water scarcity: Groundwater irrigation area (%)	Land scarcity: Per capita arable land (ha)	Policy intervention: Villages receiving investment subsidies for water projects (%)	Policy intervention: Villages receiving bank loans for water projects (%)	Village fiscal health: Per capita village real fiscal income (yuan)
Grouped by year‡							
1983	7	37	88	0.115	7	50	15
1990	33	42	84	0.100	23	53	12
1997	62	47	98	0.091	47	53	14
1998	64	48	98	0.089	47	53	16
Grouped by share of private§							
0	0	42	84	0.096	23	62	38
1–50	30	42	97	0.109	31	50	16
51–99	78	36	97	0.096	48	52	9
100	100	55	100	0.101	29	33	11

† Deflated by the general retail price index in 1978. ‡ The number of observations used for each row in rows 1–4 is 30. § The number of observations used for each row in rows 5–9 is $n = 53$ (row 5); $n = 16$ (row 6); $n = 27$ (row 7); and $n = 24$ (row 8). Data are averages for all sample years. Source: Authors' surveys in 30 randomly selected villages from three counties in Hebei Province.

of private tubewell ownership in South and South-East Asia. Despite the importance of groundwater in China's agriculture and its rapid evolution over time, almost no work has attempted to analyse the factors that have affected the choice of ownership in China.

Drawing on our data from the three study counties in the Hai River Basin, we find that several factors are associated with the shift of tubewell ownership from collective to private. Most strikingly, factor endowments – especially those of water and land – are correlated with ownership changes (Table 3). For example, in villages in which water is scarce, tubewell ownership has evolved quickly (column 1 vs column 2, rows 1–4). Although the patterns in the descriptive statistics do not prove causality, they are consistent with the idea that private tubewells may have emerged in response to north China's growing water and land scarcity.

Government programs to encourage investment by individual farmers and village leaders may also have influenced the pattern of tubewell ownership. Officials have implemented two main policies (fiscal subsidies and loans) that affect tubewell ownership decisions. Not all contenders in any given community, however, are eligible for these programs. Although the subsidy programs mainly support the investment efforts of individual farmers, banks typically target the special loans to village leaders. Because of the targeting rules of the two policies, we expect that in areas that have had relatively large fiscal subsidy programs, there should have been more of a shift towards private ownership. Likewise, in those areas with an active bank loan program, the access to

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Table 4 Relationship between tubewell ownership and cropping patterns and yields in Hebei Province, 1983–1998

	Share of private tubewells	Share of sown area (%)				Crop yield (kg/ha)	
		Wheat	Maize	Cotton	Other cash crops	Wheat	Maize
Grouped by year†							
1983	7	28	33	9	4	3489	3955
1990	33	30	34	8	5	4208	4802
1997	62	37	36	2	5	5256	5282
1998	64	39	37	2	4	5125	5659
Grouped by share of private tubewells‡							
0	0	29	33	5	4	4285	4557
1–50	30	35	35	8	4	4338	5006
51–99	78	35	35	2	6	5205	5539
100	100	42	39	7	5	4638	4970

† The number of observations used for each row in rows 1–4 is 30. ‡ The number of observations used for each row in rows 5–9 is $n = 53$ (row 5); $n = 16$ (row 6); $n = 27$ (row 7); and $n = 24$ (row 8). Data are averages for all sample years. Source: Authors' surveys in 30 randomly selected villages from three counties in Hebei Province.

special investment funds of the village leadership council may be keeping the collective active in maintaining or expanding their tubewells. Our descriptive data provide support (although not proof) for these hypotheses (Table 3, column 1 vs columns 5 and 6).

4.2 Tubewell ownership and production

Descriptive statistics from our data not only suggest that certain factors have systematically induced the rise of private tubewell ownership, but also indicate that changes in tubewell ownership have led to shifting cropping patterns (Table 4). Although there certainly are many other factors that affect cropping patterns, our data show that when the share of private tubewells increased from 7 to 64 per cent between 1983 and 1998, the share of sown area under wheat cultivation increased by 11 per cent (columns 1 and 2, rows 1–4). At the same time the area devoted to maize also rose, while the area in cotton fell (columns 3 and 4). There is also a weak correlation between private ownership and the share of areas under other cash crops (mainly horticulture crops) over time (column 1 vs column 5).

Although our data show a fairly strong relationship between tubewell ownership and cropping patterns, the relationship between ownership and yields is less clear. It is true that the descriptive data illustrate that yields increase over time as private tubewell ownership increases (Table 4, columns 6 and 7). There are, of course, many reasons (such as new technology) why yields may have risen. The correlation between tubewell ownership is less clear when examining the rates of increase of yields; yields increase less rapidly than that of private tubewell ownership (rows 1–4). The lack of correlation can also be found when analysing the relationship between yields and tubewell ownership across villages (rows 5–8).

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5. Determinants of tubewell ownership and impact analysis

Based on the above discussion and following similar work in other countries (e.g., the Philippines – Fujiie *et al.* 2002), we propose the following econometric model to analyse the determinants of tubewell ownership:

$$M_{jt} = \alpha + \beta W_{jt} + \gamma L_{jt} + \delta P_{jt} + \phi R_{jt} + \eta Z_{jt} + Dy_t + Dv_j + \varepsilon_{jt}. \quad (1)$$

In Equation (1), M_{jt} represents the share of private tubewells in village j in year t. The variables on the right-hand side of Equation (1) are those that explain differences in tubewell ownership decisions among villages and over time. The first two variables (W and L) represent resource endowments (water and land scarcity) and are included to measure if increasing resource scarcity helps induce changes in ownership. Specifically, the variable W_{jt}, represents the degree of water scarcity, measured as either the level of the groundwater table or the share of irrigated area serviced by groundwater only (implying water is scarce because there is no access to surface water). The variable L_{jt} represents the degree of land scarcity and is measured as arable land per capita. We also include a set of policy variables (policy interventions), P_{jt}, in order to assess the effects of policy on tubewell ownership patterns. Because we also use P_{jt} as instruments to identify tubewell ownership in the performance equations (see Equation 3), a fuller discussion follows.

In explaining tubewell ownership, we also control for a number of other factors. For example, the variable R_{jt} represents the village's ability to draw on its fiscal resources for investment and is measured as per capita village fiscal income. The rest of the control variables include: the share of agricultural labourers who received education to a level higher than primary school; a dummy variable ('one' if the village's road is paved and 'zero' if not); the average size of the village's farming operations (measured as cultivated land per household); and annual county rainfall. Unfortunately, our measure of rainfall only varies across counties, mainly because there are no observations or records at the village or farm level. Finally, we also use year (Dy_t) and village (Dv_j) dummy variables to control for unobserved year effects and unobserved village effects. We use two of these variables (access to paved roads and year dummy) as proxies to represent the influence of family income. The symbols α, β, γ, δ, ϕ and η are parameters to be estimated and ε_{jt} is the error term.

Because we are concerned that tubewell ownership may be endogenous in the impact analysis (i.e., in the second part of our paper that uses multivariate analysis to measure the effect of tubewell ownership on sown area decisions and yields), we need to include variables that will be able to identify the effect of tubewell ownership on agriculture decisions. To do so, in Equation (1) we include the vector, P_{jt}, which is made up of two policy intervention variables. The first variable equals 'one' if the village received financial subsidies for investing in tubewells from county officials in the water bureau, and 'zero' if not. The second policy variable equals 'one' if the village received targeted bank loans for tubewell investment and 'zero' otherwise. We believe that the formulaic way in which upper level officials allocate the grants and loans allow us to use these

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policy variables as instruments. Officials used a predetermined formula as a basis on which they distributed the investment funds and loans. Assuming this was so, investment grants and targeted bank loans should have affected tubewell ownership, but would have had no independent effect on sown area decisions or yields.

Because the ownership of tubewells may also affect water scarcity, we need to control for the potential endogeneity that could affect the estimated coefficient on the water scarcity variable in Equation (1). To do so, we also adopt an instrumental variable approach and specify the following equation that will be used to generate a predicted water scarcity variable:

$$W_{jt} = \alpha + \beta M_{jt} + \gamma IV_{jt} + Dy_t + Dv_j + \varepsilon_{jt}. \tag{2}$$

In Equation (2) the water table, W_{jt}, is specified as a function of tubewell ownership, M_{jt}, a single instrumental variable (IV) and year and village indicator variables (Dy_t and Dj). Besides being needed for our econometric estimation, the results of Equation (2) should be of interest to policy-makers as it will be useful in assessing whether or not tubewell ownership reform accelerates the drawdown of the water table. To accomplish its main purpose of identifying the effect of water scarcity on tubewell ownership in Equation (1), we use the level of the groundwater table in 1983 as our instrumental variable. We assume that the instrumental variable can at least in part explain the level of the water table during the study period, but has no direct or independent influence on tubewell ownership (except through its effect on water scarcity).

To analyse the impact of tubewell ownership on cropping patterns and yields, we specify the equation:

$$y_{jt} = \alpha + \beta \hat{M}_{jt} + \gamma \hat{W}_{jt} + \delta L_{jt} + \varphi Z'_{jt} + Dy_t + Dv_i + \varepsilon_{jt}, \tag{3}$$

where y_{jt} measures one of two types of performance indicators: either the share of crop area sown to one of the region's major crops (wheat, maize, cotton and other cash crops) or the yields of major food grain crops (wheat and maize). The variables on the right side of Equation (3) are those that explain the performance indicators. Using the identification strategy discussed above, we include the prediction of the tubewell ownership variable ($\hat{M}_{jt}$) from Equation (1). The definitions of the variables $\hat{M}_{jt}$ and L_{jt} are similar to those used in the specification of Equation (1), except that we use the prediction of the water scarcity variable from Equation (2). We also include R_{jt} (the village's fiscal income) and the vector of variables, Z'_{jt}, to control for other factors that might affect cropping patterns, yields and/or income, including year and village effects. In addition to the variables holding the effect of education and roads constant, Z' also includes measures of per capita grain procurement quota, the share of non-agricultural income and annual rainfall at county level. Equation (3) represents a supply function – the decision of the farmer to allocate land to a particular crop or to supply a particular yield – so it does not include inputs. Output prices are not represented because, during most of the reform era, prices within a village in a location such as the Hai River Basin almost certainly did not vary among households within the village.

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6. Results

Because of our concerns with the endogeneity of certain variables when estimating the determinants of tubewell ownership and its impact on agricultural production, we use a three-stage least squares (3SLS) estimation approach. Using this approach we simultaneously estimate a system of eight equations (Table 5). (We have tried Tobit models for the regressions (1) and (3)–(6). The results, both coefficients and marginal effects, vary little from those produced by the ordinary least squares (OLS) regression estimates.) The first two regressions in columns 1 and 2 of Table 5 present the results of the equations that allow us to examine the determinants of tubewell ownership and water scarcity and correspond to Equations (1) and (2). The other six regressions estimate the impact of tubewell ownership on performance as specified in Equation (3). To examine the robustness of the determinants of tubewell ownership results, we include the results of four single-equation estimations that account for various specifications and several alternative estimation approaches in Appendix II.

6.1 Determinants of tubewell ownership

In estimating the set of equations in Table 5, we need to account for the endogeneity of tubewell ownership. There are several estimators that could be used to estimate the equation: pooled OLS; random effects (RE) or fixed effects (FE). We report the results for the determinants of tubewell ownership for all three estimation approaches in Appendix II. We selected the fixed effects approach and applied it by including village dummy variables. This choice was based on: a Breusch–Pagan Lagrangian multiplier test statistic (the chi-squared statistic is 29.25, implying that either an RE or FE is preferred over a pooled OLS) and a Hausman test ($\chi^2 = 15.74$, suggesting that the FE model is better than the RE model).

Our econometric estimation performs well for the determinants of tubewell ownership equations (Table 5 and Appendix II). The goodness of fit measure, adjusted R^2, ranges from 0.58 to 0.74 and is sufficiently high for this type of analyses. Most of the coefficients of the control variables also have the expected signs and a number of the coefficients are statistically significant. For example, the coefficient of the variable measuring the village's fiscal income level is negative and significant (Table 5, column 1, row 6 and Appendix II, row 6). The coefficient on the road variable is also significant and positive.

When examining our variables of interest, our results show that increasing water scarcity affects the evolution of tubewell ownership. Regardless of the specification of the water scarcity variable (Appendix II, column 1 or 2) and regardless of the econometric estimator (Appendix II, columns 1, 3 and 4 or Table 5, column 1), the coefficient on the groundwater table level variable is positive and significant. All other things held constant, when the groundwater table falls and water becomes scarce, tubewell ownership shifts from collective to private.

Land pressure from increasing population growth is another significant factor determining the evolution of tubewell ownership. Per capita arable land is negative and

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Table 5 Regression analysis using Three–Stage Least–Squares of the determinants of tubewell ownership and its impact on cropping pattern and yield

	(1) Dependent variable (stage 1): share of private tubewells	(2) Dependent variable (stage 1): log of groundwater table	Dependent variable (stage 2): share of sown area				Dependent variable (stage 2): crop yield per hectare	
			(3) Wheat	(4) Maize	(5) Cotton	(6) Other cash crops	(7) Wheat	(8) Maize
Tubewell ownership								
Share of private tubewells (predicted from column 1)		0.105 (1.10)	0.231 (1.75)*	0.157 (1.17)	−0.446 (1.80)*	0.138 (1.72)*	−1020.6 (0.37)	−2367.2 (1.04)
Water and land scarcity								
Log of groundwater table (predicted from column 2)	1.727 (2.53)**		−0.079 (0.15)	0.183 (0.34)	1.281 (1.34)	−0.913 (3.35)***	31 630.9 (3.29)***	14 463.0 (1.66)*
Per capita arable land	−9.847 (2.14)**		2.660 (1.27)	0.751 (0.35)	−3.076 (0.82)	1.796 (1.67)*	−35 639.7 (0.94)	−47 489.3 (1.38)
Policy interventions								
Dummy of fiscal subsidies for tubewell investment	0.133 (2.18)**							
Dummy of bank loans for tubewell investment	−0.208 (0.80)							
Other control variables								
Per capita village fiscal income	−0.001 (1.95)*		0.000 (0.45)	0.000 (1.00)	−0.000 (0.45)	−0.000 (0.39)	8.671 (2.05)**	5.974 (1.56)
Share of labour force with at least primary schooling	0.102 (0.14)		−0.016 (0.04)	0.051 (0.12)	−0.484 (0.64)	0.265 (1.24)	−9729.2 (1.29)	−1795.9 (0.26)

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Table 5 Continued...

	(1) Dependent variable (stage 1): share of private tubewells	(2) Dependent variable (stage 1): log of groundwater table	Dependent variable (stage 2): share of sown area				Dependent variable (stage 2): crop yield per hectare	
			(3) Wheat	(4) Maize	(5) Cotton	(6) Other cash crops	(7) Wheat	(8) Maize
Dummy for paved road	0.203		−0.018	−0.018	0.057	−0.040	1710.1	687.5
	(1.89)*		(0.31)	(0.30)	(0.53)	(1.31)	(1.59)	(0.70)
Size of farming operations	−0.004		−0.020	0.009	0.027	−0.003	482.7	454.4
	(0.07)		(0.98)	(0.45)	(0.74)	(0.26)	(1.33)	(1.38)
Log of grain procurement quota per capita			0.004	0.005	0.003	−0.015	324.0	151.4
			(0.38)	(0.42)	(0.14)	(2.74)***	(1.65)*	(0.85)
Share of non-agricultural income			−0.001	−0.000	0.002	−0.000	25.212	5.267
			(0.84)	(0.42)	(1.09)	(0.82)	(1.26)	(0.30)
Log of groundwater table in 1983		1.039						
		(38.60)***						
Rainfall – county average	0.000	−0.000	0.000	0.000	0.000	−0.000	5.855	2.929
	(0.67)	(0.68)	(1.21)	(0.88)	(0.45)	(1.23)	(2.43)**	(1.64)
Year dummies†								
Dummy of 1990	−0.252	0.166	−0.012	−0.043	−0.125	0.151	−5678.7	−1891.6
	(1.52)	(3.70)***	(0.11)	(0.41)	(0.65)	(2.63)***	(2.81)***	(1.08)
Dummy of 1997	−0.218	0.199	0.029	−0.027	−0.174	0.186	−5368.3	−1629.5
	(0.98)	(3.16)***	(0.25)	(0.22)	(0.81)	(2.81)***	(2.32)**	(0.83)
Dummy of 1998	−0.342	0.266	0.039	−0.046	−0.259	0.247	−8343.2	−2508.0
	(1.33)	(4.38)***	(0.24)	(0.28)	(0.90)	(2.90)***	(2.78)***	(0.95)
Constant	−4.779	0.000	0.403	−0.640	−4.250	3.223	−114569.5	−48281.1
	(1.87)*	(.)	(0.22)	(0.35)	(1.31)	(3.49)***	(3.52)***	(1.63)
Observations	105	105	105	105	105	105	105	105
Chi-squared	517	115939	783	395	85	117	108	162

* Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent. † Village dummies were included, but are not reported to save space. Absolute values of *z*–statistics are in parentheses.

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statistically significant in all of the models (Table 5, column 1, row 3 and Appendix II, row 3). The results are consistent with the hypothesis that in villages with scarce land resources, individual villagers are more willing to invest in tubewells to improve the productivity of their scarce factors.

Based on the coefficients of both the results from the water and land scarcity variables, our findings can be interpreted as support for the induced innovation hypothesis, a hypothesis that has been found to be true in many studies outside of water management. Changes of natural resource endowments will induce institutional innovation towards organisational forms that will help conserve the scarce resource. As water and land have become scarce in the North China Plain, local actors have begun searching for ways to organise tubewell enterprises to facilitate new investment. In the evidence presented in Wang *et al.* (2002), it is shown that private tubewell operators are also more efficient, at least in pumping more water at a lower cost.

Although the robustness of the coefficients on the water scarcity variable in the tubewell ownership equation suggests that endogeneity may not be a major statistical problem, examining the water scarcity equation demonstrates the statistical validity of our instrumentation strategy (Table 5, column 2). The depth of the water table in 1983, apart from rainfall and the ownership of tubewells in the village, has high explanatory power in determining the depth of the water table in later years. In addition, the χ^2 test used in the second part of the exclusion restriction test shows that the instrumental variables have no independent explanatory power in the tubewell ownership equation. In other words, the Hausman–Wu exclusion restriction test demonstrates that our instrument is valid.[1]

The coefficient on the tubewell ownership variable in the water scarcity equation is also of interest in its own right (Table 5, column 2, row 11). Our results suggest that the groundwater table is not lower in villages with more private tubewell ownership. Because our results show that private operators have no excessive, negative impact on the water table, the finding should allay fears that the shift to private ownership will lead to an acceleration of the fall in the groundwater table. However, it should be cautioned that our findings do not eliminate the need to further study the causes of the deterioration of China's groundwater resources. It is possible that private operators are, in fact, pumping in a way that is leading to a fall in the groundwater table; our results only demonstrate that converting a tubewell from collective to private operators does not lead to a more rapid fall.

[1] To test if the set of identifying instruments are exogenous, a Lagrange multiplier test can be used (Hausman–Wu exclusion restriction test). This test is divided into four steps: (i) run Equation (2) and save the predicted water table levels; (ii) run Equation (1) where water table is the predicted value from step 1, and save the residuals; (iii) regress residuals from Equation (1) on the instrumental variable – the level of the water table in 1983; (iv) calculate the test statistic, $n \times R^2$, where n is the number of observations, and R^2 is the measure of goodness-of-fit in the third step regression. It is distributed as a chi-square. In our study, the test statistics is 0.001 and we cannot reject the null that there is no correlation between the exogenous instruments and the disturbance term from tubewell ownerhsip Equation (1). This means that we have a set of instruments that are statistically valid.

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In addition to pressures provided by scarce resource endowments, the policy programs of water officials have also influenced tubewell ownership patterns, although different programs have had different impacts (Table 5). The coefficient of the fiscal subsidy variable is positive and significant, suggesting that fiscal subsidies for tubewell investment have promoted the ownership of tubewells by private individuals. In contrast, the coefficient of bank loan is negative (column 1, rows 4 and 5), indicating that targeted loans from banks have encouraged the expansion of the collective ownership of tubewells. Both of these shifts are as expected.

6.2 Ownership impacts on sown area decisions and yields

Our results also show that the evolution of tubewell ownership has led to systematic adjustments in the cropping patterns of our sample farmers in the North China Plain (Table 5, columns 3–6). The coefficients on the tubewell ownership variable (share of private tubewells) in the wheat and other cash crop equations are positive and significant (columns 3, 4 and 6, row 1). In contrast, the coefficient is negative and significant in the cotton equation (column 5). When the share of private tubewells in a village rises, farmers in our sample increase wheat area in the dry (winter) season and shift–sown area from cotton and other grain crops to other cash crops (mainly horticulture crops). Given the greater need for reliable irrigation in the dry season (where crops without irrigation cannot be grown) and given the greater demand by horticultural producers for timely water deliveries, our results from the sown area equations might be interpreted as meaning that the shift to private tubewell ownership has facilitated the expansion of high-value crops that have special water needs. If private tubewell ownership performs more efficiently (as found in Wang *et al.* 2002) and if they are able to respond more to producer demands, the shift to private tubewell ownership may enhance the evolution of agriculture in the North China Plain.

In contrast, our results show that there is no significant relationship between tubewell ownership and crop yields (Table 5, columns 7 and 8). The coefficient of tubewell ownership variable is not significant in either the wheat or maize yield equation. It indicates that despite increasing water scarcity, caused by changes in tubewell ownership, agricultural productivity will not be adversely influenced.

In some ways our findings are different from and in other ways they are consistent with those found in other nations, such as India. During the 1980s, the Indian government recognised that public tubewells were not functioning well. In response, they began to reform tubewell management by turning over public tubewells to farmer organisations (Kolavalli and Raju 1994; Shah *et al.* 1994). In contrast to the rapid implementation of the policy in China, many believe that the privatisation program has not been very successful as a result of policy design and implementation issues. However, in areas that have implemented the privatisation program well, research results show that private tubewells perform more efficiently (Shah *et al.* 1994). Private tubewells in India provide more reliable water and extend accessibility by selling water to poorer farmers (Shah 1993). In India, like in China, sown area has been affected

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when privatisation is done well. Unlike India, however, yields have not been affected for most crops in our sample region.

7. Conclusion

In the present paper, we have sought to understand the evolution of tubewell ownership in the North China Plain and its effect on production and groundwater levels. The results show that since the early 1980s collective ownership of tubewells has largely been replaced by private ownership. At present private tubewell ownership has become the dominant form of ownership in many regions. Most private tubewells are still owned jointly by several individuals as shareholding tubewells.

Changes of natural resource endowment have been shown to lead to changes in the commonly observed forms of institutions, consistent with the induced innovation hypothesis (as commonly found in other developing economies). With falls in groundwater table and reduced deliveries of surface water resources, water has become scarce in the North China Plain.

Fiscal and financial policies have also played important roles in the evolution of tubewell ownership. Because fiscal subsidy programs have been designed to directly extend funding to individual farmers for tubewell investment, these fiscal measures have promoted the emergence of private tubewells. In contrast, targeted bank loan policies that have mainly provided bank loans to village leadership councils for tubewell investment have slowed down the privatisation of tubewells.

Our findings also demonstrate that the privatisation of tubewells has promoted the adjustment of cropping patterns while having no adverse impact on crop yield. Such results are consistent with the hypothesis that when tubewell ownership shifts from collective to private (as shown in this paper) and water is more efficiently managed (shown in Wang *et al.* 2002), producers are able to cultivate relatively high-valued crops, which in some cases demand greater attention of tubewell owners. Specifically, our results show that after privatisation, farmers have expanded the sown area of water-sensitive and high-value crops, such as wheat and non-cotton cash crops (which are mainly horticulture crops). It is perhaps because of the rising demand for horticulture crops that some private individuals have become interested in investing in tubewells. When combined with the rising efficiency of groundwater services that are associated with private tubewells, we may have discovered at least part of the reason why agricultural production has increased when facing increasing water scarcity. Institutions have evolved that have conserved scarce resources while allowing producers to continue to produce.

Finally, our research indicates that, in contrast to the concerns of some observers, the privatisation of tubewells per se has not accelerated the fall in the groundwater table. Although this result does not imply that we should be unconcerned about the rapid fall in the groundwater table, we need to examine other possible causes than tubewell privatisation.

Given our results, we believe that policy-makers should continue to support the privatisation of tubewells in the North China Plains. Although measures should be taken to address the falling groundwater table, going back to collective tubewell ownership

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is not the answer. Other policies, such as pricing and regulatory measures, may need to be used to combat the deterioration of China's groundwater. In fact, given the increased pressure to move into higher valued crops, despite increasing resource scarcity, it seems that the shift to private tubewells will continue. Given their greater efficiency, encouragement of this trend may be warranted. Although the cost-effectiveness of China's fiscal policies has not been shown, they have been successful in promoting the privatisation of China's tubewells.

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Appendix I

Descriptive statistics for major variables

Variables	Mean	Standard deviation
Share of private tubewells	0.42	0.43
Groundwater table	43	49
Share of groundwater irrigation area	0.92	0.23
Village nominal fiscal income per capita (yuan)	39	70
Arable land per capita (ha)	0.10	0.04
Share of labour force with at least primary schooling	0.44	0.11
Share of villages receiving fiscal subsidies for tubewell investment	0.31	0.46
Share of villages receiving bank loans for tubewell investment	0.53	0.50
Share of villages having paved roads	0.68	0.47
Share of grain area	0.90	0.10
Share of cotton area	0.05	0.09
Share of other cash crops	0.04	0.05
Share of wheat area	0.34	0.18
Share of maize area	0.35	0.10
Share of other grain crops	0.22	0.26
Wheat yields (kg/ha)	4604	1361
Maize yields (kg/ha)	4918	1415
The size of farming operations (ha)	0.04	0.18
Population (no.)	1615	869
Cultivated land (ha)	147	76
Household (no.)	401	222

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

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Appendix II

Regression analysis of the determinants of tubewell ownership

	Share of private tubewells			
	OLS	OLS	Random effect	Fixed effect
Water and land scarcity				
Log of groundwater table	0.091		0.135	0.408
	(2.51)**		(2.62)***	(2.22)**
Share of groundwater irrigation area		0.393		
		(2.69)***		
Per capita arable land	−0.502	−0.238	−2.611	−9.217
	(0.16)	(0.08)	(0.66)	(1.62)
Policy interventions				
Dummy of fiscal subsidies for tubewell investment	0.074	0.043	0.115	0.115
	(0.94)	(0.57)	(1.71)*	(1.65)*
Dummy of bank loans for tubewell investment	−0.214	−0.237	−0.233	−0.303
	(3.18)***	(3.44)***	(2.31)**	(1.07)
Other control variables				
Per capita village fiscal income	−0.002	−0.002	−0.002	−0.001
	(4.53)***	(4.12)***	(3.45)***	(2.15)**
Share of labour force with at least primary schooling	1.530	1.391	0.878	−0.211
	(3.36)***	(3.08)***	(1.51)	(0.27)
Dummy of paved road	0.205	0.135	0.191	0.159
	(2.98)***	(2.05)**	(2.36)**	(1.52)
Size of farming operations	−0.010	0.016	−0.006	−0.026
	(0.20)	(0.33)	(0.10)	(0.36)
Rainfall – county average	−0.000	−0.000	−0.000	−0.000
	(1.30)	(1.32)	(1.12)	(0.19)
Year dummies†				
Dummy of 1990	0.034	0.141	0.061	−0.002
	(0.29)	(1.30)	(0.54)	(0.02)
Dummy of 1997	0.135	0.226	0.199	0.161
	(0.92)	(1.64)	(1.28)	(0.76)
Dummy of 1998	0.223	0.316	0.262	0.160
	(1.57)	(2.42)**	(1.69)*	(0.74)
Constant	−0.300	−0.533	−0.049	0.399
	(1.44)	(2.34)**	(0.19)	(0.62)
Observations	120	120	120	120
Adjusted R^2	0.47	0.47	0.63	0.67

* Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent. † Village dummies were included, but are not reported to save space. Absolute values of *t*–statistics are in parentheses. OLS, ordinary least–squares regression.

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