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Evolution of property rights in the groundwater irrigation system and food-water security in Haihe basin, China

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Abstract The evolution of property rights in groundwater irrigation systems (PRGIS) may affect not only crop structure, but also the potential output of water. Such an impact is especially obvious in Haihe basin where irrigation depends mostly on groundwater. Based on the policy dialogue model (PODIUMSIM) and an econometric model, the paper analyses this impact. The results show that, although the change of crops structure increases the quantity of consumed water, the peasants' economic income is greatly improved. Also, the evolution of PRGIS augments the available water through enhancing the efficiency of tubewell. Therefore, the evolution of PRGIS can improve food–water security in the Haihe basin.

Key words food-water security; groundwater irrigation system; PODIUMSIM; property rights evolution

INTRODUCTION

The Haihe basin is not only the political and economic centre in China, but it is also the main supply of agricultural commodities, which account for 10% of the total national output. Irrigated crops contribute to the greater part of output in Haihe basin, and irrigated agriculture is the dominant user of water in this region. Therefore groundwater is the main origin of water resources in such a semiarid region. However, its water resources per capita is only 305 m^3, which is the lowest compared to other basins in China (Yang & Zehnder, 2001; Xia Jun, 2007). Along with increasing water demand and proportion of groundwater withdrawal, the evolution of property rights in the groundwater irrigation system (PRGIS), which may affect irrigation efficiency, will significantly influence the food–water security in Haihe basin. In this paper we attempt to develop a numerical model for simulating the evolution of PRGIS and its impact on water-food security.

METHODOLOGY

Our analysis structure is shown in Fig. 1 and described below.

PRGIS simulation model

The PRGIS is the ownership of the tubewell and its related infrastructure. According to it, we divide the groundwater irrigation system (GIS) into collective and non-

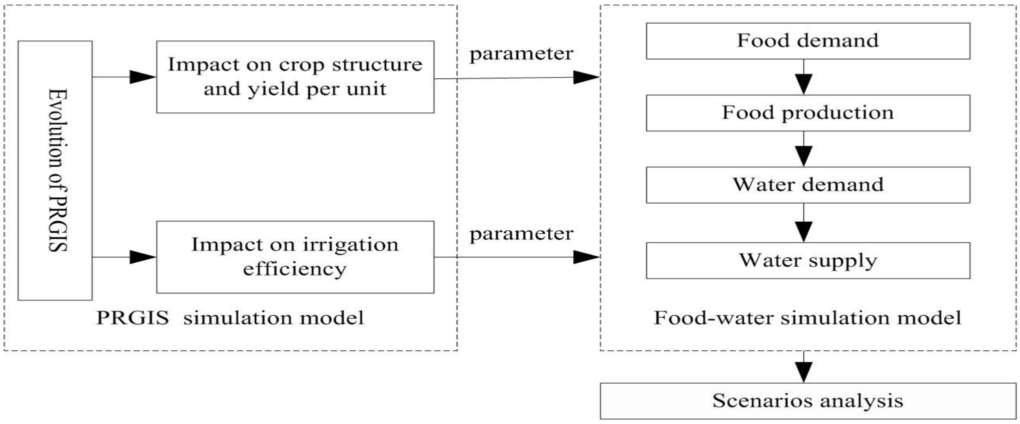

Fig. 1 Analysis structure of the impact of evolution of PRGIS on food-water security.

collective (Wang *et al.*, 2005). Different property right arrangements can cause different reward structures. Therefore, different PRGIS can have different incentive effects on the efficiency of water resources use. The enhancement of efficiency in water resources usage can drive the farmer to plant more economic crops, which are water sensible. Moreover, different property rights could cause different efficiency of water output, which would influence the potential water supply in the basin:

(a) Affect on crop structure. We chose the econometric model developed by Xiang & Huang (2000) as our analysis tool:

$$A_{ijt} = F[R_{jt}, W_{jt}, \ln(Q_{jt}), (P_G / P_I)_{jt-1}, (P_C / P_I)_{jt-1}, N_{jt}, D_k, T_t, e_{ijt}] \tag{1}$$

where i is commodity indices for specific crops (grain crops, cotton and economic crops), j is village index, k is county index, t is time index, A is the ratio of the i crops-sown area to all crops-sown area, R is the ratio of tubewells owned non-collectively. The property right is the endogenous variable, so we use the two stage least square method to estimate. Q is grain crops ordered by government per capita (kg capita^{-1}) which could measure the effect on crops structure caused by ordering policy. P_G, P_C and P_I are price index, cotton ordering price index, and fertilizer price index, respectively. The price of resources and input is shadow price, such as the ratio of irrigated surface water (W,%) and the opportunity cost of labour (N,%). We use the district pseudo variable D_k and year pseudo variable T_t to indicate the difference caused by different districts and years. e_{ijt} is the error term, which is supposed to obey the normal distribution.

(b) Affect on potential water output. Under different PRGIS, the water output of unit fixed asset is also different. Accordingly, we chose the increasing ratio of water output of unit fixed asset to measure the increasing of potential water resources caused by evolution of PRGIS. The formula is as follows:

$$GWR = \left(\frac{CRW \times BCR + \mathrm{P}RW \times BPR}{CRW \times PCR + PRW \times PPR} - 1\right) \times 100\% \tag{2}$$

where GWR is the increasing ratio of water output of unit fixed asset; CRW is water output of unit fixed asset in collective GIS, PRW is water output of unit fixed asset in non-collective GIS; *BCR* is the ratio of collective GIS in base year; *BPR* is the ratio of non-collective GIS in base year; *PCR* is the ratio of collective GIS in project year; *PPR* is the ratio of non-collective GIS in project year.

Food–water simulation model

We chose the policy dialogue model (PODIUMSIM), which was developed by IWMI (International Water Management Institution) as a food–water simulation model. The model is designed to provide a user-friendly interface for policy makers, scientists and others to interact in developing alternative water scenarios using a consistent framework of data and analysis (de Fraiture *et al.*, 2001; IWMI, 2005). IWMI have applied this model in China (IWMI, 2003), and we name it as PODIUMSIM-China (2003). The model contains four modules: the first module estimates food requirements of the basin; the second computes the projected food production which was converted into equivalent water demand making allowances for water use efficiency and recycling in the third module; the final section calculates the expected domestic and industrial water use based on income growth projections. The total water requirements for food production and domestic and industrial use are summed and compared with the base year (2000) actual water diversions.

RESULTS AND DISCUSSION

Scenarios setting

This paper takes 2000 as the base year and 2010 as the project year, forecasting and analysing the different results of food–water security in different property right evolution scenarios. According to investigations, we set the starting value that non-collective GIS accounts for 64% of the total. In scenario 1, we assume this proportion is invariable. In scenario 2 and 3, we assume this proportion rises to 84% and 94%, respectively.

Results on crops structure

Through simulating parameters we can obtain the results that the property right coefficients are –0.082, 0.039, 0.042 in the grain crops equation, the economic crops equations, and the cotton equation, respectively. These results indicate that when the proportion of tubewells obtained by the non-collective increases 10%, the proportion of grain crop sown area reduces by 0.82%, the proportion of economic crops sown area increases 0.43%, and the cotton sown area increases 0.39%. The *t*-test values are –3.63, 1.83, 3.54, and the significance level are all above 1%, which means the development of tubewells obtained by non-collective influences the crops structure adjustment that remarkably happened among the grain crops and economic crops. In different scenarios we obtain various changes in the crops sown area (see Table 1).

Table 1 effect on crop structure and water supply.

	Scenarios	Scope of change	Final percentage	Change of crop sown area (%)			*GWR* (%)
	(%)	(%)	(%)	Grain	Cotton	Economic crops	
Proportion of GIS obtained by non-collective)	Scenario 1	0	64	0	0	0	0
	Scenario 2	20	84	1.64	0.78	0.86	7
	Scenario 3	30	94	2.46	1.17	1.29	10

Results on potential water output

Through sampling investigations in 1998, we found that the water output of the unit fixed asset was 35 m^3 $Yuan^{-1}$ in the collective property right system and 49 m^3 $Yuan^{-1}$ in the non-collective property right system, and we supposed this value to be invariable in 2000. Based on formula (2) we calculate the increasing rates of water output of unit fixed asset which are 0, 7%, and 10% in different scenarios (see Table1). In addition, this sampling investigation also uncovers that the evolution of PRGIS certainly has no influence on the water output of unit variable asset and the water output of unit labour cost. This indicated that the fixed asset investment in GIS and property right reform are key factors which affect the potential groundwater output.

Results on food–water security

In various scenarios, we take the change ratio of different crops sown area as the controllable exogenous variables, and input these variables into the food supply module of the PODIUMSIM-China model. Then effective irrigated area of different crops can be determined under various scenarios in 2010 (see Table 2).

As we take the basin as the analysis unit, we may suppose that the basin can get the food needed through interregional trade. Therefore, the situation of the basin's

Table 2 Crops' effective irrigation area of different scenarios in Haihe basin**.**

		2000		2010		2010		2010	
				Scenario 1		Scenario 2		Scenario3	
Species	Crops	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
		(M Ha)	(M Ha)	(M Ha)	(M Ha)	(M Ha)	(M Ha)	(M Ha)	(M Ha)
Grain	Rice	0.23	0.00	0.22	0.00	0.22	0.00	0.22	0.00
	Wheat	0.04	2.62	0.04	2.67	0.04	2.64	0.03	2.59
	Maize	2.05	0.00	2.16	0.00	2.14	0.00	2.09	0.00
	cereals	0.24	0.10	0.24	0.10	0.24	0.10	0.24	0.10
Economic crops	Pulses	0.12	0.00	0.12	0.00	0.13	0.00	0.13	0.00
	Oil crops	0.07	0.66	0.08	0.72	0.08	0.73	0.08	0.73
	Vegetables	0.70	0.55	0.75	0.60	0.76	0.60	0.76	0.60
	Tubers	0.28	0.00	0.30	0.00	0.30	0.00	0.30	0.00
	Fruits	0.37	0.00	0.43	0.00	0.00	0.00	0.00	0.00
cotton	cotton	0.31	0.00	0.33	0.00	0.33	0.00	0.33	0.00

Origin of data, PODIUMSIM-China (2003).

Table 3 Crop supply–needs a balance of different scenarios in the Haihe basin.

		Requirement (BUS$)	Production (BUS$)	Surplus/Deficit (BUS$)	Degree of food security (%)
2000	Grain crops	8.3	6.3	–2.1	25
	Other crops	34.4	39.9	5.5	15
	All crops	42.7	46.2	3.4	7
Scenario 1	Grain crops	9.0	7.0	–2.0	22
	Other crops	38.1	47.8	9.7	25
	All crops	47.1	54.8	7.8	16
Scenario 2	Grain crops	9.0	7.0	–2.0	22
	Other crops	38.1	48.2	10.2	27
	All crops	47.1	55.2	8.1	17
Scenario 3	Grain crops	9.0	6.9	–2.1	23
	Other crops	38.1	48.2	10.2	27
	All crops	47.1	55.1	8.0	17

Origin of data, PODIUMSIM-China (2003).

Table 4 Water supply-needs balance of different scenarios in the Haihe basin.

	2000	Scenario 1	Scenario 2	Scenario 3
Total net water resource (km^3)	33.9	33.9	35.3	35.9
Total diversions (km^3)	42.3	44.8	44.8	45.0
Depletion (km^3)	28.9	31.1	31.2	31.3
Total evaporation (km^3)	26.5	28.6	28.7	28.8
Beneficial evaporation (km^3)	21.8	24.1	24.1	24.2
Degree of development (%)	96	103	99	97

Origin of data, PODIUMSIM-China (2003).

food–water security can be weighed by the degree of dependence on outside food supply, and the ability to gain funds through export economic crops (see Table 3).

With continual reduction in the cropping area of grain, the gross output value of grain crops is always about 7 billion US dollars. The food requirement which is met from outside is about 22%, while the degree of exports of economic crops accounting for local requirement is about 26%. That is, although the degree of dependence on outside food supply is high, the export of economic crops can offer the funds that buy grain crops from outside. As to the whole picture of the food–water security in Haihe basin, the change of crops structure is advantageous to it.

The net groundwater resources have been enhanced in the Haihe basin by the increasing ratio of non-collective GIS. Moreover, in terms of Wang's research (Wang, 2005), the evolution of PRGIS does not lead to decreasing groundwater level. If we augment the fixed asset investment in GIS, which will be used for technique reformation, the deficiency of water resources will be reduced in the Haihe basin.

From Table 4, we can also see that the evolution of PRGIS has changed the structure of crops in the Haihe basin. Water sensitive crops, which can earn more income, have been planted. The water sensitive crops consume more water, and the total evaporation has increased, which is caused by the enhancement of beneficial evaporation in the whole basin.

Finally, if there is no reform of property rights, the development of water resources will be 103% in the Haihe basin, which means that this region can not self-satisfy the water requirement without the South to North Water Diversion Project. In contrast the development of water resources will be 99% and 97% when the reform of property rights is brought into effect.

CONCLUSIONS

(a) In regard to basin, although the evolution of PRGIS will enhance the degree of dependence on outside food supply, the increase of economic crops export can earn more money to exchange for food. Therefore, the evolution of PRGIS can improve food security in the basin.
(b) The evolution of PRGIS will enhance the water requirement in the whole basin. The reason is that more water sensitive crops have been planted, and the depletion of the whole basin has enhanced accordingly.
(c) The evolution of PRGIS has caused not only the increase of water depletion, but also the increase of net available water resources in the basin. However, the development of water resources has decreased. The coefficient of water security has been raised in the basin.
(d) The evolution of PRGIS can enhance not only the coefficient of food security, but also the coefficient of water security in the basin. Therefore, the government should construct a better political environment to encourage the evolution of PRGIS.

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