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Modeling the Drivers of Agricultural Land Conversion Response to China's Rapidly Rural Urbanization: integrating remote sensing with socio-economic data

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Abstract: Agricultural land has changed remarkably response to the rapidly rural urbanization in China since the further market-oriented reform of early 1990s. Using accurate remote sensing images and socioeconomic data, this paper identified the temporal pattern of agricultural land conversion and estimated their driving forces during 1992-2010 in Yueqing City. Agricultural land change can be summarized to three trends: Firstly, the conversion between non-agricultural land and agricultural land was very remarkable, the non-agricultural land increased obviously from 1992 to 2010, in verse farmland decreased continuously; Secondly, the loss agricultural land mostly were the higher quality cropland. The expansion of settlements and industrial park was almost completely at the expense of fertilize farmland in flat area, but hillside and tideland were reclaimed for planting grain to keep the dynamic balance of total agricultural land amount. Thirdly, the changes of agricultural land distributed regularly and according to the distance to the No.104 national highway. In addition, the stepwise regression analysis indicated that both the booming of rural private enterprises and increasing of population was main driving force of agricultural land conversions. According to the results, we discussed the negative impact of fertile farmland shrink and gave some feasible advices in the end.

Keywords: agricultural land conversion; modeling socio-economic driving forces; rural urbanization; Yueqing City.

1. Introduction

Global Land Project (GLP) was initiated by IGBP and IHDP in September 2005. Its central objective is to retain the sustainable development of human and natural system and mitigate its frangibility in the globalization, by means of measuring, simulating and understanding the socio-environment coupled system, and interpreting both the changes of surface process and its social, economic and political results (GLP, 2005; Turner *et al.*, 2007). China is the most rapidly developing nation of the world and home to 1.3 billion people. Since the early 1980s, the unprecedented combination of economic and population growth has led to a dramatic land transformation across the nation (Chen, 1999; Lin, 2001; Liu *et al.*, 2005; Tian *et al.*, 2003). As a result of rapid urbanization, farmland conversion is dramatically frequent in China. In the eastern coast of China, the development process has been characterized by rural industrialization and urbanization. As a result, many coastal regions of China such as the Yangtze River Delta region, Pearl River Delta region and Beijing metropolitan areas experienced dramatic economic and spatial restructuring, which resulted in tremendous farmland conversion (Lin, 2001; Weng, 2002; Li and Yeh, 2004; Long *et al*., 2007a). Agricultural land conversions, while restricted by physical conditions, are mainly driven by socio-economic factors, which are tightly inter-related with human production activities.

In the late 1980s, some strict measures were adapted to control the conversion of agricultural land into non-agricultural use (Lin and Ho, 2005; Erik and Ding, 2008). The policies of "Dynamic balance of Total Farmland (*gengdi zongliang dongtai pingheng*)" and "Basic Farmland Protection Regulations" have relieved the rapid loss of farmland to some extent, but they did not have resulted in massive loss of fertilize farmland (Yang and Li, 2000). Actually, the absolute net change of farmland can not reflect the true relationship between farmland conversion and socio-economic development.

In this paper, through a detailed study of Yueqing, Zhejiang province, attempts to provide a better understanding of the agricultural land conversion and its driving forces response to rapid rural industrialization and urbanization. First, land use conversion over a period of rapid rural economic growth was described. Second, the

relationships between agricultural land conversion and socio-economic development are discussed. Thirdly, the characteristics of f agricultural land conversion and the mechanism of socio-economic driving forced were concluded. In the end, several key problem for land use management in rapid rural industrialization were discussed.

2. Study area

Yueqing City is located in the southeast of the Zhejiang province and faced to the East China Sea (Figure 1), with an area of coverage of 1251 km^2 and a population of 1389,300. The territory is composed of two main areas from south-east to north-west. The south-eastern area is occupied by plain and platform where is the bread basket of the city region, and the north-western area is a part of *Yandang Mountains* where suitable for fruit, citrus, tea, and edible fungi production.

Yeqing has been regarded as the origin place of the Wenzhou Model of China's economic development at the beginning of the reform and opening-up policy (Zhang and Li, 1990). The Wenzhou Model is famous for its domestic private investment in traditional manufacturing and bottom-up rural urbanization (Zhang and Li, 1990; Liu, 1992). Before the reform and opening up, Yueqing used to be one of the poorest regions in eastern China, it has a very limited amount of arable land at 0.52 mu (15 mu=1 hectare) per capita, about one-third of the national average. Meanwhile, Yueqing's proximity to Taiwan made it a likely war frontline in the planned economy era from 1949 to the late 1970s. Neither the central or provincial (Zhejiang) governments were inclined to spare their limited capital for Yueqing's infrastructural and industrial development (Tsai, 2002). With limited land resource, poor road access to major cities, and little supporting policy from the central government, it seemed to lack all the conditions necessary for economic growth. However, over the past three decades, Yueqing has been one of the most dynamic economical regions and one of the fastest urbanization cities all over China. To a large extent, it is representative of bottom-up rural urbanization all over the China. Therefore, it might provide some insights into the agricultural land-use change response to China's rapid urbanization through this case study.

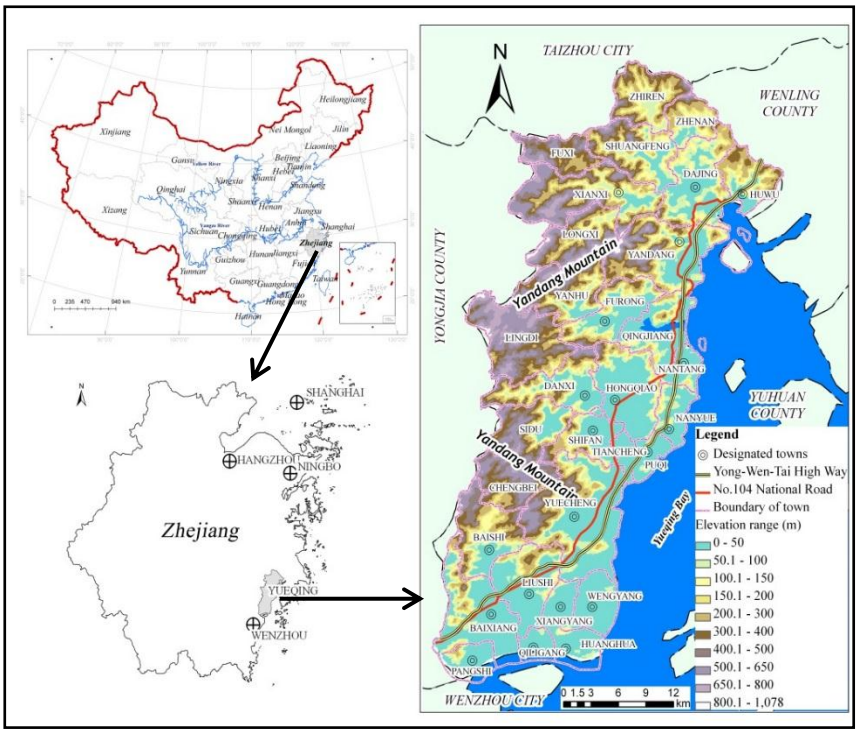


Figure 1. Study area: Yueqing, Zhejiang province, China

3. Materials and methods

3.1 Data source and pre-processing

Detailed spatial data of agricultural land conversion need to be produced for this study. We selected high-resolution remote sensing imagery as the basic data resource, and land use data, topographic maps, and socio-economic statistical data were also collected for further data processing.

Agricultural land use data

Four historical Landsat satellite images (TM data taken in October 1992, and ETM+ data in October 2010; (Path 118 (orbit), Row 40-41 (scene center)) were downloaded from the International Scientific Data Service Platform, and the Landsat ETM+ SLC-off image was processed with a self-adaptive local regression model for multi-temporal imagery. All of the images were clear and nearly free of clouds (total cloud cover less than 5%). In order to assist image interpretation, two land use maps

were collected from Land and Resources Department of Yueqing City. They were mapped by the two National Land Surveys, in 1990 and in 2008, respectively. The slope map was derived from ASTER Global Digital Elevation Model (ASTER GDEM) data which is acquired by a satellite-borne sensor "ASTER" to cover all the land on earth. It was downloaded from its official website. In September 2011, a field survey, including 90 sampling-points, was carried out by using a global positioning system to identify present land-use types and trace land-use histories. These points were evenly distributed in the study area, and at the same time land-use types and transportation accessibility were taken into consideration.

Twenty well distributed ground control points (GCPs) were selected for geometric correction of remote sensing imagery according to the Second Land Survey map. Two periods of images were geo-referenced to the Xi'an 1980 Coordinate System. The root mean square error (RMSE) was less than 1 pixel. A first order polynomial fit was applied and all the data were re-sampled to a spatial resolution of 30 m using nearest neighbor method. In order to improve the visual interpretability of images, a color composite (Landsat TM Bands 4, 5, and 3) was prepared and its contrast was stretched using the Gaussian distribution function. The 3 × 3 high pass filters were applied to the color composite to further enhance visual interpretation of linear features, e.g., rivers and vegetation features.

socio-economic data

In addition, a history time-series socioeconomic data were collected from the local governments and published statistical yearbooks (Yueqing County Statistical Bureau, 1993- 2011). They are used to analyze potential driving forces resulting in agricultural land conversion in the study area. The selection of data items took into consideration of the literature of China scholars (Xie and Costa, 1991; Ma and Xiang, 1998; Kirkby, 2000; Marton, 2000; Lin, 2001) and listed in Table 1. Data were compiled for townships (31 in total). Besides, with the recognition that many research questions cannot be addressed if analysis is based solely on official data, thorough field observations and unstructured interviews were conducted in field studies during Nov. 5-18, 2011. A wide range of people in Yueqing were interviewed, including government officials, enterprise managers, villagers, migrant workers, and town residents.

Table 1. List of the selected and socioeconomic variables

Abbreviation	Description	Unit	label
T-HH	Total households	INH[a]	x_1
T-POP	Total population	IND[b]	x_2
R-POP	Total population registered in rural area	IND	x_3
U-POP	Total population registered in urban area	IND	x_4
E-POP	Exotic Population	IND	x_5
PU	Percentage of population registered in urban area	%	x_6
R-INC	Rural per capita net income	Y[c]	x_7
GIO	Gross industrial output value	MY[d]	x_8
TVA	Total output value of agriculture	MY	x_9

[a]INH: the count of households; [b]IND: the individual count of population; [c]Y: Chinese Yuan; [d]MY: Million Chinese Yuan

3.2 Methods

Land Use Classification

In order to detail the land use/cover changes, it was classified i into 9 types: Farmland (FM), Forestland (FL), Garden plots (GP), Urban Settlements (US), Rural Settlements (RS), Water Body (WB), Industrial land (IL), Transportation land (TL), and unused land (UL). (see Table 2). The training areas were established according to more than 90 field-sampling points and the two National Land Use Surveys maps by the software Erdas 9.0. Then, the two images were interpreted by the method of supervised classification using Maximum Likelihood Classifier (MLC), visual interpretation involved the use of image characteristics such as texture, pattern, and color to translate image into land use. A 3 × 3 majority-neighborhood filter was used to adjust the classified images.

Land Use Change Matrix

A land use/cover change matrix reveals the internal variations of land use changes during the study period, showing the detailed information on cropland conversions. The transition matrix of land use/cover was conducted through the spatial overlay of the two-phase land use maps interpreted from Landsat data.

The two land-use grid maps were mainly used to detect the internal variations of land-use change from 1992 to 2010. For each pair of grid datasets, a change matrix A_{ij} was constructed. Then, B_{ij} and C_{ij} were calculated based on matrix A_{ij} accounting for inner change of all land-use types. Where row *i* is the land-use types of 2006, and column *j* is the land-use type of 1992. B_{ij} is the percentage of land-use type

j that converted to *i*, C_{ij} is the percentage of land-use type *j* that came from *i*.

$$B_{ij} = A_{ij} \times 100 / \sum_{i=1}^{10} A_{ij} \quad (1)$$

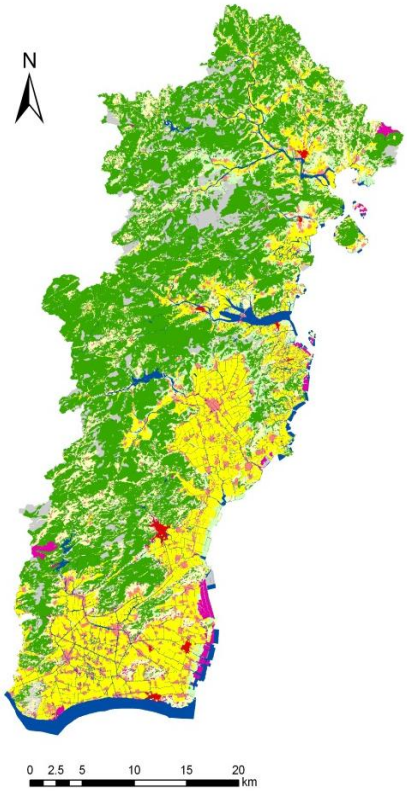
$$C_{ij} = A_{ij} \times 100 / \sum_{j=1}^{10} A_{ij} \quad (2)$$

4. Results

4.1 Agricultural Land changes in Yueqing

Land use has changed significantly over the period from 1992 to 2010 in Yueqing City (Table 2, Figure 2, Figure 3). From 1992 to 2010, farmland decreased by 22.2%. In contrast, urban settlements, rural settlements, industrial land and transportation land increased by 503.4%, 23.4%, 51.9%, and 424.7%. To a large extent, land-use change from 1992 to 2010 in Yueqing County was characterized by a replacement of agricultural land with urban settlement, rural settlements, and industrial land.

Exchanges of land use were analyzed from two aspects during the period of 1992 to 2010. One was how many percentages of the later land-use type came from the former ones, the other was how many percentages of the former land-use type changed into the later ones. The expansions of urban settlements are at the expense of occupying great amounts of farmland and rural settlement, 43.8 % and 33.6% of urban settlements came from farmland and rural settlement respectively. Rural settlements increases are at the expense of occupying lots of farmland, 29.1% of rural settlements came from farmland and 72.3%% of transportation land came from farmland.



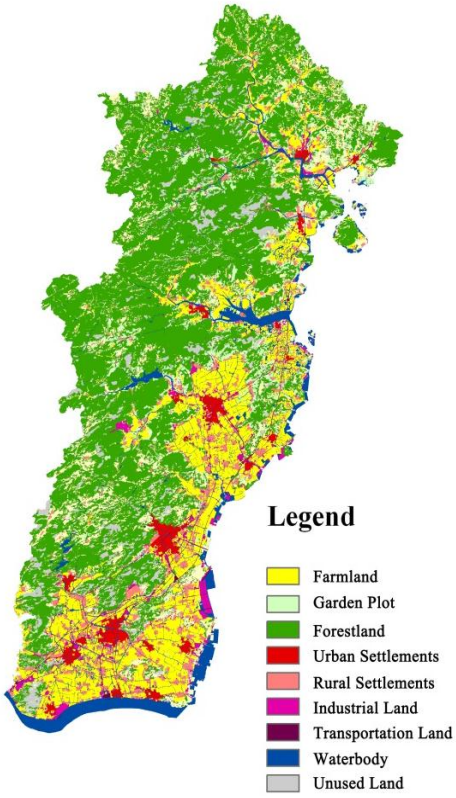


Figure 2. Land use map of Yueqing in 1992 Figure 3. Land use map of Yueqing in 2010

Table 2. the internal matrix of Land use changes of Yueqing City during 1992 - 2010 (ha, %)

1992 2010		FM	GP	FL	US	RS	IL	TL	WB	UL	Total
FM	*A*	27741.7	1068.8	1399.7	6.4	181.2	136.1	0.4	423.9	306.6	31264.6
	B	134.0	14.7	2.6	1.5	3.2	7.9	2.6	5.9	3.6	
	C	173.0	8.0	11.8	0.0	1.2	1.0	0.0	2.5	2.4	
GP	*A*	1760.7	3819.7	984.4	0.1	74.0	19.4	0.5	69.9	228.3	6957.0
	B	10.2	52.5	1.8	0.0	1.3	1.1	3.4	1.0	2.7	
	C	25.3	54.9	14.1	0.0	1.1	0.3	0.0	1.0	3.3	
FL	*A*	3518.2	1456.2	49073.1	0.6	174.0	540.3	0.2	150.8	4656.0	59569.4
	B	21.5	20.0	90.8	0.1	3.0	31.3	1.2	2.1	54.3	
	C	5.9	2.4	82.4	0.0	0.3	0.9	0.0	0.3	7.8	
US	*A*	1149.1	49.7	9.5	393.6	881.6	45.9	2.0	74.0	18.7	2624.0
	B	4.9	0.7	0.0	90.5	15.4	2.7	14.8	1.0	0.2	
	C	43.8	1.9	0.4	15.0	33.6	1.7	0.1	2.8	0.7	
RS	*A*	2053.1	254.0	191.9	19.9	4228.2	93.3	1.1	156.8	58.2	7056.5
	B	9.7	3.5	0.4	4.6	73.9	5.4	7.7	2.2	0.7	
	C	29.1	3.6	2.7	0.3	59.9	1.3	0.0	2.2	0.8	
IL	*A*	1509.4	238.9	227.5	1.0	37.1	454.6	1.2	91.9	60.0	2621.5
	B	7.0	3.3	0.4	0.2	0.6	26.3	8.7	1.3	0.7	
	C	57.6	9.1	8.7	0.0	1.4	17.3	0.0	3.5	2.3	
TL	*A*	545.3	53.1	25.8	4.3	55.6	21.1	6.9	30.0	12.5	754.7
	B	2.4	0.7	0.0	1.0	1.0	1.2	50.4	0.4	0.1	
	C	72.3	7.0	3.4	0.6	7.4	2.8	0.9	4.0	1.7	
WB	*A*	1011.5	235.3	146.3	8.9	79.9	338.9	1.5	6197.8	202.9	8222.9
	B	4.8	3.2	0.3	2.0	1.4	19.6	11.2	85.8	2.4	
	C	12.3	2.9	1.8	0.1	1.0	4.1	0.0	75.4	2.5	
UL	*A*	879.3	106.8	1963.5	0.0	7.1	76.3	0.0	26.0	3038.0	6097.0
	B	5.6	1.5	3.6	0.0	0.1	4.4	0.0	0.4	35.4	
	C	14.4	1.8	32.2	0.0	0.1	1.3	0.0	0.4	49.8	
Total		40168.2	7282.5	54021.6	434.9	5718.7	1725.9	13.7	7221.0	8581.1	125167.6

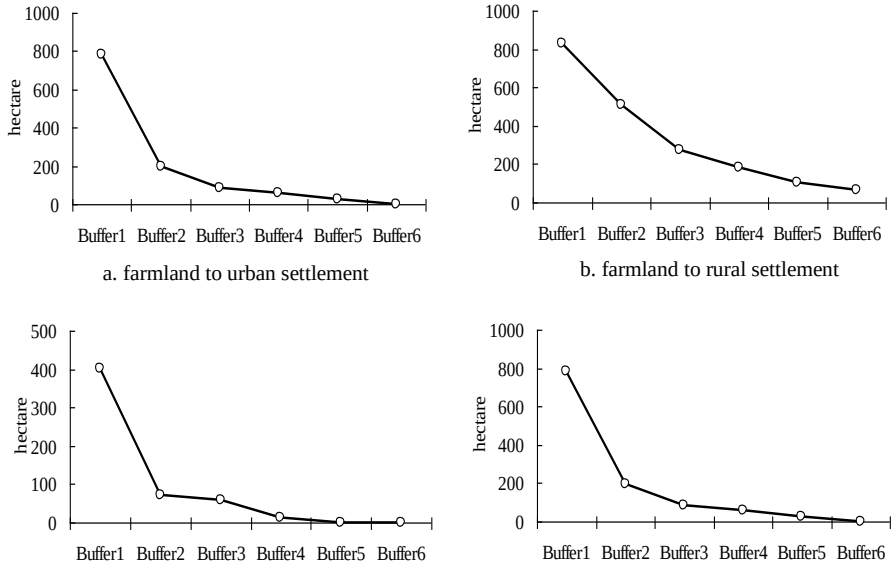
Note: *FM-Farmland; GP-Garden Plots; FL-Fores land; IL-Industrial Land; TL – Transportation Land WB-Waterbody; UL- Unused Land

4.2 Spatial distribution characteristics of land use conversions

The road system in rural China is the key factor to promote rural industrialization

and agricultural economy (Rozelle and Jiang, 1995). There are few investments to infrastructure by the state and local government in Yueqing until the end of 1980s, because it is close to Taiwan. Since the No. 104 national highway was finished in 1992, it has been the lifeline of rural development in Yueqing County. The road shaped a banded spatial pattern of urban and rural expansion. six buffers were built along the No. 104 national highway at intervals of one kilometer to exanimate the spatial characteristics of rural land use change. The changes of land-use in these buffered belts were reported in Figure 4.

The No. 104 national highway played a primordial role in rural socio-economic development and its power of influence diminished outwards. For example, the increase of urban settlement, rural settlement, construction land and transportation land were highest within the 1 km buffer; respectively, the decrease of paddy field and dry field were highest. Besides, the main types of land use conversion were calculated over 6 buffered belts that include farmland to urban settlement (FMUS), farm land to rural settlement (FMRS), farm land to transportation land (FMCL), and rural settlement to urban settlement (RSUS), the trend of land use conversions were depicted in Figure 4.



a. farmland to urban settlement

b. farmland to rural settlement

c. farm and to construction land

d. rural settlement to urban settlement

Figure 4. Main land use conversions along the buffered belts from No. 104 national highway

4.3 Modeling socio-economic driving forces of agricultural land conversion

Using socioeconomic data of 31 towns from statistical yearbooks and land use conversion data derived from land-use maps, the interactions between land-use conversions and socioeconomic driving forces were examined. The quantitative changes between 1992 and 2010 for the socioeconomic variables were computed, and four main land-use conversion types were counted for all towns that including FMUS (farmland to urban settlement), FMRS (farmland to rural settlement), FMCL (farmland to construction land), FLFM (forest land to farmland) and ULFM (unused land to farmland). The regression analyses were conducted between the farmland conversion and socioeconomic variables (Table 3).

Table 3. Regression final model of dependent variables

Dependent variables	Final regression model	Adjusted R^2
FMUS	$y_1 = 0.305x_5 + 1.752x_6 - 4358.819x_4 + 495.778$	0.965
FMCL	$y_2 = 0.039x_8 + 0.791x_5 + 1.780x_2 + 431.808$	0.911
FMRS	$y_3 = 0.034x_8 + 4.022x_7 + 604.522$	0.869
FLFM	$y_4 = 0.949x_9 + 700.593$	0.371
ULFM	$y_5 = 0.418x_4 + 107.178$	0.425

The final regression model indicated that the FMUS conversion was mainly related to the changes of three factors: E-POP (exotic population), U-POP (population registered in urban area), and PU (urbanization). The three parameters together explained 96.5% of the FLUS conversion. The regression analysis confirms that increasing of E-POP and rapid growth of U-POP gave the direct impact on the farmland to urban settlement land. The highest contributor was the increasing of exotic population (E-POP) (Table 5). Since Deng Xiaoping made remarks during his inspection tour of southern China in 1992, a market-oriented employment mechanism has been building up, many exotic people settled in the town or suburb in Yueqing. For example, there were 66 863 exotic population of Liushi Town in 2010, which was 39.3% of total population. The second contributor was the growth of population registered in urban area (U-POP). Remarkable growth of E-POP and U-POP demanded that large amounts of farmland be converted to urban land for settlement

industrial, commercial and infrastructure construction. Yueqing was undergoing rapid rural urbanization. However, its relationship with the FMUS conversion was reversed (Table 6). The interpretation was that the capacity of urban settlement was higher than that of rural settlement; hence, the improvement of urbanization level contributed to slow the conversion of FMUS.

The FMCL conversion was mainly related to the changes of four factors GIO (Gross industrial output value), E-POP (exotic population), T-POP (total population), and TVA (Total output value of agriculture). Together these parameters explained 91.1% of the FMCL conversion. At the beginning of 1990s, some large area economic development zones (jingji kaifa qu) were built, a part of private household enterprises moved out of rural settlements by reason of enlarging production scale, which settled in economic development zones, and lots of exotic population worked in these areas. As it shown in table 6, the largest contributor was the increasing of GIO, rural industrialization caused farmland converting to construction land. On one hand, rural industrialization attracted a lot of exotic population from central and western regions of China; on the other hand, enlarging production scale contributed to enlarging workshop place through occupying farmland. For instance, the build-up part of Zhejiang Provincial Yueqing Economic Development Zone covered 6.05km^2 with more than 160 enterprises, and two thirds of labors came from outside .

The conversion of FMRS can be explained 87.7% by the increasing of GIO and growth of R-INC. Rural private enterprises were widely regarded as the primary form of rural industrialization for Wenzhou Model. As Lin and Ho (2003) pointed out, the expansion of construction land was largely a result of rural industrialization in China. Numerous factories such as buttons, ball pen and electric accessory can be easily found in the residential backyards of the villagers in rural Yueqing. The increasing of rural income levels spured peasants to extend their dwelling space. Usually, peasants in China want to build another new multifunctional, more comfortable or spacious house if they become affluent, although they did not really need. Peasants preferred to build their houses closing to roads and other available infrastructure. Besides, another universal phenomenon was found during interviews with town officials and village cadres across Yueqing, it was pointed out that many private businessmen managed enterprise all over China, but they built luxury and spacious dwelling in their

hometown, for example, there were two brothers in Daixia village Hongqiao town, each of them spent more than 400 000 Yuan (RMB) on building new rural villa, but they only lived few days during the holiday of Chinese New Year Festivities.

FLFM and ULFM contributed to balance the farmland loss by urbanization and industrialization. The conversion of FLFM mostly distributed in the mountain and hill area of western Yueqing, it can be explained 37.1% by the increasing of TVA. There were many under development villages in the western Yueqing, they were far away from urban area, central towns and arterial road. Agricultural production was the principal source of peasants' income in this area; therefore, peasants were willing to cultivate land on slope to plant crops, vegetables and other cash corps. The conversion of ULFM mostly distributed along the coastline in the eastern Yueqing, it can be explained 42.5% by the growth of U-POP. To guarantee the goal of the dynamic balance of the total farmland, the government was planning to reclaim unused land such as tideland, marshlands, and barren land.

Discussion

China's rapid industrial growth has received wide attentions in the literature (Allen et al., 2005). As the most dynamic private economics in China, Yueqing provides a good case for us to examine the agricultural land conversion and its driving forces behind China's fast rural industrialization. Then, several lessons can be drawn from the results of our research.

This study examines the temporal and spatial pattern of land use change as a consequence of rural industrialization. Using accurate spatial data from two land survey and history statistic data of 31 towns, the study clearly identifies a temporal pattern of land use change during 1992-2010 based on GIS. Land-use change in Yueqing can be characterized by three major trends: First, the non-agricultural land (urban and rural settlements, construction land, and transportation land) increased substantially from 1992 to 2010, thus causing farmland to decrease continuously, land use conversion between non-agricultural land and farmland were very remarkable. Secondly, the conversion of farmland in Yueqing was a very serious issue. On one hand, expansion of urban and rural settlements, and construction land was almost completely at the expense of farmland, on the other hand, lots of fertilize farmland

lost, but hillside and tideland were reclaimed for planting grain. Thirdly, there are clear spatial patterns of land use change geographically, which are crafted by the No.104 national highway built in 1992. The buffer analysis indicated that the distance is the nearer to highway road, the integrated degree is higher.

Our study has also highlighted the driving forces of farmland conversions through method of regression step by step. E-POP (exotic population), U-POP (population registered in urban area), and PU (urbanization) were the main driving forces of farmland to urban settlement; GIO (Gross industrial output value), E-POP (exotic population), T-POP (total population) have driven farmland to construction land dramatically; the conversion of FMRS can be explained 87.7% by the increase of GIO and growth of R-INC; TVA and U-POP can respectively explain forest land and unused land to farmland. In general, both the increase of rural private enterprises including GIO and R-INC growth and population development including population structure change for E-POP and U-POP increase are main driving forces of farmland conversions.

The rapid industrialization and urbanization in Yueqing stimulated the demand of farmland converting to non-agricultural land, which led the expansion of rural settlements and local environmental pollution; however, there were such few areas of farmland that they cannot suppose this unsustainable developing model. Many private household enterprises scattered in rural area, accordingly, which resulted in the low efficiency of land production and the disorder expansion of urban. For an instance, we investigated a private household enterprise in Beibaixiang Town that occupied 0.31 ha land and employed 4 workers; accordingly, the efficiency of land use was much lower than urban areas. In the long run, the government should combine the rural industrialization and current urbanization process, and encourage private household enterprises to move to industrial centralization region. The countermeasures that established a scientific land utilization ethics and economical, intensive use of land, the model of the urban and rural integration reform measures and so on were put forward from the angle of saving, intensive use and sustainable development.

Rural economic development is very inequality in Yueqing. There were 9 less developed towns located in the hill region which the net income per peasant was less than 4 000 Yuan (RMB); however, there were some developed towns which the net

income per peasant has exceeded 10 000 Yuan (RMB) such as Liushi, Hongqiao and Beibaixiang. There was 12.7% of total population, but only 1.5% of total gross industrial output value and 7.5% of total output value of agriculture in the less developed towns. Developed towns have occupied lots farmland in the past three decades, and the farmland already reduced to the limit by 0.017ha per capita in Yueqing County. The state had no choice but to adapt the strictest farmland protection system against the increasing threat of food safety. There is few surplus of farmland for the less developed towns to develop industries; moreover, to guarantee the goal of the dynamic balance of the total farmland, some hillside areas were reclaimed for planting grains that was easy to soil erosion. In interviews with town officials and village cadres of Lingdi and Yandang Town, two less developed towns, they pointed out that the shortage of land for industrial and housing development were the biggest obstacle of rural development. Therefore, the government of Yueqing County should work out a feasible development plan for less developed region, which emphasized at least four point as follow: (1) to take advantage of its ecological resources and topographical benefits to develop specialty products and industries; (2) to increase budgetary funds and loans for poverty alleviation, balance the development of different rural region; (3) to provide much more employment opportunities in the developed towns, and give priority to underdeveloped rural labors ; and (4) to implement ecological emigration plan, encourage peasants to emigrate from remote hill villages to developed region.

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