

Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China

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Abstract

This research examines the impact of the farmland protection policy institutionalized for China's paddy field conversion in the mid-1990s. This paper demonstrates an integrated research method for studying land use-cover changes from the perspective of the interactions between policy changes and socioeconomic factors. The integrated method deploys remote sensing to obtain accurate measures of paddy field changes and applies multiple regression analysis to explore the interactions between paddy field change and socioeconomic factors. It constructs a policy-determined categorical regression analysis to investigate whether the policy change impacts paddy field conversion and how the policy interacts with other socioeconomic factors in affecting paddy field losses. A geographic information system is deployed to interpret the spatial patterns of the interactions. The case study in Wuxian City (Jiangsu Province) concludes that there is a distinct policy shift between 1990–1995 and 1995–2000. The policy of regulating farmland losses practiced in the mid-1990s has a significant role of slowing down paddy field conversion. But the success has been partial and was largely compromised in the rural areas due to the compounding forces of policies to promote rapid economic growth and better living standards. Moreover, continued rural to urban migration, rural economic development and rapid urban expansion represent the primary forces that lead to the conversion of paddy fields into non-agricultural uses.

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1. Introduction

Land is an important and finite resource for most human activities such as settlement, agriculture, forestry, animal husbandry, industry, transportation and recreation. It has been tightly coupled with economic growth (Richards, 1990). One of the six possible forces driving land-use and land-cover changes is population increase and its level of affluence, technology, political

economy, political structure, and attitudes and values (Turner and Meyer, 1991; Stern et al., 1992). Population increase arises a sequence of immediate life sustaining needs such as residence space, food and fiber (Engelman and LeRoy, 1995; Döös, 2002; Uusivuori et al., 2002). However, due to the finite amount of available land, fast economic development and population growth lead to deforestation and loss of arable land and biodiversity (Turner, 1989; Hobbs et al., 1991; Fearnside, 2001; Gardner, 2001), and reduction of environmental services (Lambin et al., 2001; Peterson et al., 2001).

Recent institutional changes, marketization, and globalization have combined to bring about rapid economic growth in contemporary China (Zhou and Ma, 2000; Logan, 2002; Ma, 2002; Pannell, 2002). The

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latest Chinese national population census conducted in 2000—the fifth of this kind ever conducted since 1949—revealed an accelerated process of urbanization characterized, not only by its sheer scale, but also by the rapidity of changes that has no parallel anywhere else in the world. The census disclosed that China housed the world's largest population of 1.265 billion people, of which 455.94 million, or 36%, lived in cities and towns (China State Council, 2001). China has more people living in cities and towns than any other country in the world. The census also identified clearly a pattern of accelerated urbanization for the nation in recent decades. The share of urban population rose from 20% in 1982 to 36% in 2000, a net gain of 16% in less than two decades. This stood in sharp contrast with the pre-reform era when the share of urban population showed a marginal increase from 10.6% to 17.9% over the thirty years from 1949–78 (Ma and Cui, 1987; Chan, 1994; Zhang and Zhao, 1998). The existing 455.94 million of urban population has yet to claim its dominance in the nation. Chinese authorities anticipated that the nation would have half of its population living in cities and towns by 2015. This would involve an increase of at least another 250 million urban people in the next decade and a half. Given China's enormous population size and its growing interaction with the world economy, there are good reasons to believe that the processes of accelerated urbanization unfolding there will have far-reaching economic, social, and environmental implications, not only for the largest developing nation, but also for the globalizing world.

One of immediate consequences of rapid urbanization and population growth is the loss of agriculture land. Exactly how much land China uses for agriculture is unclear. Before the Census of Agriculture, which reported farm household data before 1996, official statistics showed the amount of cultivated land in China was below 100 million hectares and falling, from 95.67 million hectares in 1990 to 94.97 million hectares in 1995. The 1997 Census of Agriculture, however, revealed that cultivated area was 130.04 million hectares in 1996 (Lohmar, 2001). China lost 2.53 million hectares of arable land in 2003, according to statistics provided by the Ministry of Land and Resources (Xinhua, 2004). China's arable land has been reduced to about 123 million hectares in 2003 since 1996, or 12.8% of its total land area. Though there are no systematic data about China's arable land, reports on continued and rapid loss of arable land to urban expansion and economic development have been consistent in recent years (Li, 1997; Lohmar, 2001; Xinhua, 2004). China's agricultural economy faces a scarcity of land.

More alarmingly, above 90% of the population and 80% of the arable land are concentrated in the eastern part of China (Gale, 2002). Fertile and productive arable land is in particular located in the eastern plains

and river basins (Dutt and Xie, 1992). Paddy fields, due to rich water and climate resources and fertile soils, are the main form of arable land in these regions. For instance, the south coastal and south central regions (the Yangtze River Basin and the Pearl River Basin) produce 87% of the rice in China (Gale, 2002). The high concentration of population and hot economic development compete or threaten the fertile paddy fields in these regions. This is a critical issue for Chinese governments and the international community to have a better understanding of paddy field changing dynamics.

Moreover, the Yangtze River and the Pearl River basins have a long history of development (Xie and Costa, 1991). The original physical and ecological environments have been totally altered and replaced with intensive human-transformed agricultural systems, along with highly concentrated population and socio-economic activities. There are many comparable instances across the world, e.g., the Nile River Basin in Egypt, and the Hindi River Basin in India. Therefore it is an imperative task to study these human-transformed environments, which are integral part of the global environmental change research.

The goal of this paper is to study the interrelations between economic growth and paddy field reduction and how the adoption of farmland protection policy affects the conversion rates of paddy field in China. The paper also develops an integrated method derived from statistics and informatics to examine the impact of policy change on paddy field conversion. An overview of environmental change research methods is presented in Section 2.1. The integrated method for policy analysis of paddy field conversion is developed in Section 2.2 with a focus on how the regression analysis is applied in policy studies. The policy analysis, case study (in Wuxian City, Jiangsu Province), and socioeconomic data preprocessing are explained in Section 2.3. The detection of paddy field conversion from remote sensed data is described in Section 2.4. Section 3 presents the findings of the case study and the analyses of the policy impact and socioeconomic influence on paddy fields conversion. Section 4 concludes the paper with discussions of the strengths, limitations and future improvements of the integrated method for studying the policy dimension of environmental changes.

2. The integrated policy analysis from statistics and informatics

2.1. Overview of environmental change research methodology

Many useful techniques have been developed and applied to quantify land use and cover changes (LUCC)

and to investigate social, political and economic forces driving the changes. Remote sensing is commonly used to obtain reliable measurements of LUCC at different spatial and temporal scales (US Climate Change Science Program, 2003). Reliable measurements of LUCC can be used to conduct a variety of biophysical and socio-demographic/economic analyses. These observations of spatial trends and rates can also be used to develop empirical diagnostic models and short-term prognostic models (Lambin, 1994). Geographic information system (GIS) is often deployed to visualize LUCC spatial patterns and to explore relationships between LUCC and other bio-physical factors in visual forms (Batty and Xie, 1994; Fischer et al., 1998; Velázquez et al., 2003).

On the other hand, census tabulation of local socio-economic data provides statistical means for looking into negative impacts of social, demographic and economic activities on land change dynamics (Uusivuori et al., 2002). Site-specific local data also provide important ancillary data to improve accuracy of LUCC measurements using remote sensing (Wagner, 1999). Another noticeable point is that policy analysis of political influences on LUCC is often implied or embedded in the selection of social-demographic-economic factors or statistical analysis interpretations (Xie and Fan, 2003).

The grand challenge to studying global and regional environmental changes is how to synthesize biophysical observations, policy factors, and socioeconomic statistics through a systematic manner to generate useful insights to guide policy making for effective management (Turner et al., 1993; NRC, 2001). Few operational models have been successfully implemented though intensified efforts were reported in conceptual discussions and system designs of synthesized models (Turner et al., 1995; Parker et al., 2002). Investigations with an exclusive focus on either biophysical or socioeconomic or political aspect are commonly seen in the literature. Any method alone, however, is not sufficient to detect complex interactions between LUCC processes and socio-economic and political transformations (Velázquez et al., 2003).

2.2. *The integrated method for socio-economic analysis of paddy field conversion*

This paper presents an integrated data-driven research method to analyze policy impacts on paddy field conversion and its interactions with demographic, economic, and social factors, and to understand how these socioeconomic factors affect paddy field change differently under varied policy regulations. This integrated approach places data and statistical analyses at its core to examine policy impacts. Regression analyses is chosen as the primary statistical technique because it is the most popular analytical method applied in policy

research and is taught in public policy curricula in North America (Mark et al., 2000; Heineman et al., 2002; Morin et al., 2002; Obach, 2002; Hess and Leal, 2003; UCLA, 2004) and is intuitive and easily explainable (Hughes, 1974; Berry and Sanders, 2000). Regression analysis derives a statistical equation for making quantitative predictions of one variable from the values of other variables. This paper, for instance, applies the regression analysis to identify and quantify the relationships between the paddy field conversion and the selected policy, demographic, and socioeconomic factors.

There are two general rules that guide how to adopt regression method in policy analysis. First, better data alone are insufficient for improved models and projections of LUCC (Lambin et al., 2001). They must be matched by enhanced understanding of causes of change (Committee on Global Change Research, 1999). Second, policy analysis often makes a presumption of continuity (Berkhout and Hertin, 2000). The trend of the future is often predicted by analyzing the present from the past. What is taking place at present is evaluated from the past current policy changes. However, this assumption does not hold in China since 1949 due to the frequent political movements and policy adjustments (Xie et al., 1997), such as, Land Reform Policy in the early 1950s, the rural householder responsibility policy in the late 1970s, and the arable land protection policy in the mid and late 1990s. These considerations determine two complementary practices of conducting regression analysis for examining policy impacts: (1) the proxy approach, and (2) the comparison approach.

The proxy approach of applying regression in policy studies is to use measurable variables that have direct responses to a policy change as policy proxy variables or indicators. The values of budget surplus, the level of inflation, and the measure of trade openness, for instance, are used as the proxies to the fiscal policy, monetary policy, and trade policy, respectively when studying the relationship between national economic policy, economic growth and foreign aid (Burnside and Dollar, 2000; Easterly et al., 2003). For this approach of regression-based policy analysis, it is important to identify quantitative variables that have causal relationship with the policies in study. Unfortunately, the proxy or causal relationship is often contaminated with measurement errors due to many reasons (Brumm, 2003). For example, there could be additional unmeasured effects in omitted variables that should have been included, or there might exist reverse causality or selection bias among proxy variables (Stock and Watson, 2003). For these reasons, alarming criticism has been made toward untested use of regression technique in predicting policy impacts without thorough review of the data and the pre-assumed causal relations (Goertzel, 2002). Some technical solutions have been

developed to handle the problem of regression measurement errors. The adoption of instrumental variables is a popular technique for identifying more exogenous variables to count for unmeasured errors (Angrist and Imbens, 1995; Stock and Watson, 2003). However, there still exist serious limitations with these technical methods. Cautious analyses of the causes between policy proxy variables and adequate pre-processing of policy indicators are often required for applying regression analysis successfully (Brumm, 2003).

The comparison approach used in policy analysis is to apply regression method to data sets that are longitudinal or observed during different time periods that correspond to significant policy changes (Lijphart, 1971; Diggle et al., 1994). It is a common practice to construct a categorical policy variable to record different status of a policy (Jaeger and Page, 1996). This categorical policy variable is often re-coded as several dummy variables to be included in a regression model, and each dummy variable indicates the existence or non-existence of a specific policy impact (Crown, 1998; Miles and Shevlin, 2001). For instance, several dummy variables indicating the absence, loosened presence, and strict presence of a state legislation on abortion are constructed to study the policy impacts on abortion incidences (New, 2004).

The integrated policy analysis developed in this paper to study the paddy field conversion is depicted in Fig. 1. The analysis starts with a policy review to introduce the

background information and to identify important policy changes in China concerning arable land protection. Then the analysis conducts data mining to identify causal relationship between paddy field losses and socioeconomic factors during the periods (1990–1995 and 1995–2000) with significant policy changes. Step-wise multiple regression analysis is adopted because it automatically assigns relative importance to each independent variable by applying certain statistical assumptions and criteria (Gotelli and Ellison, 2004). The findings of the multiple regression analyses mark out the socioeconomic factors that have direct correlations with paddy field losses under different policy directions. Afterwards, a dummy variable, POLICY, is constructed to represent the absence (during 1990–1995) and presence (during 1995–2000) of the farmland protection legislation and to run a regression analysis with the variables that are identified through the data mining (regression analyses) during the two periods with distinct policies. The paper further examines the output of this new regression model to extract insights on the correlation between the paddy field conversion and the POLICY change and its impacts on demographic and socioeconomic factors. A better understanding of the impacts of the farmland legislation on paddy field losses and on economic growth is thus summarized. Furthermore, it should be noted that an accurate account of paddy field conversion is obtained through the LUCC detection analysis derived from remote sensing technique. The analysis of the associations between the POLICY, paddy field conversion and socioeconomic factors is made visual and intuitive with GIS mapping techniques.

2.3. The farmland protection policy, case study, and socioeconomic data

Following the visit of Mr. Deng Xiaoping to the southern parts of China in 1992, the rapid economic upswing in China has resulted in a boom of township enterprise development, as manifested by a large decrease in cultivated land (Fischer et al., 1998; Sun et al., 1999). When entering 1996, the problem, coupled with an overheated economy, became very severe and the Chinese government started taking various measures to keep farmland losses under control (Li, 1997). The central government eventually issued an administrative decree in April 1997. The decree orders local governments to reexamine all the areas of former arable land that were occupied by non-agricultural uses during the period of 1991–1995, and also to freeze the conversion of additional arable land into non-agricultural uses for one year (CEI, 1997). Several comprehensive research projects were conducted to study the LUCC and related socioeconomic transformations between 1991 and 1995 (Li, 1997; Fischer et al., 1998). Therefore, the year of

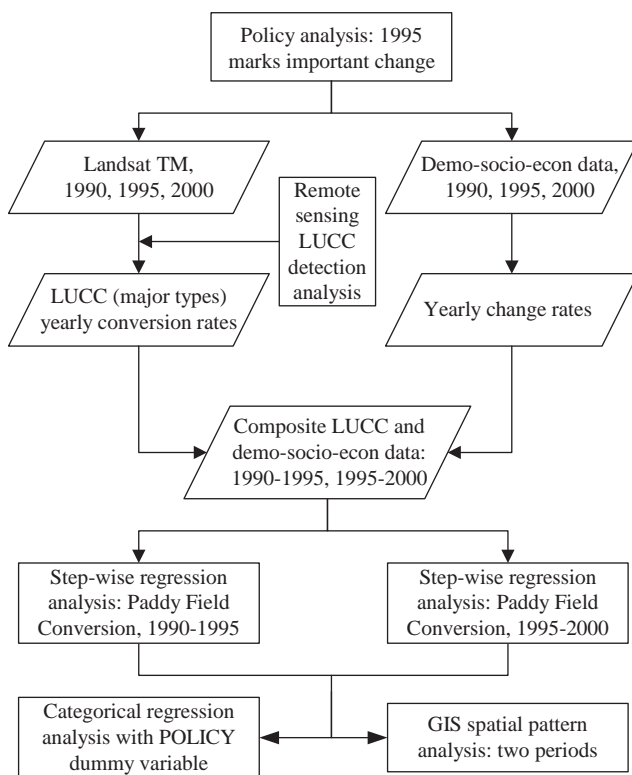


Fig. 1. Integrated method for studying interactions between environmental changes and policy-socioeconomic factors.

1995 has been identified as an important turning point in China's policies concerning economic development and arable land management. This date is used in this paper to compile data into two periods of 1990–1995 and 1996–2000 for investigating the impacts of land management policy changes on LUCC.

The case study was conducted in Wuxian City, Jiangsu Province, the immediate suburb of Suzhou City. Southern Jiangsu (Sunan) provided one of the models for the development of rural industries (the diversified collective enterprise run by a local municipality model) in the mid-1980s and early 1990s—others being the Wenzhou model (household-level enterprise and homeworking model) and the Liaoning model (heavy-industry linked model) (Tan, 1986; Xie and Costa, 1991). Here there is a demonstrable link between agricultural specialization, agricultural surpluses, and investments in non-farm enterprises (Kirkby, 2000; Marton, 2000).

The demographic and socioeconomic data came from the published statistical yearbooks (Wuxian City Statistical Bureau, 1991, 1996, 2001). 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 and villages (29 in total). The yearly increase rates were computed

from the observed values of the selected variables between 1990–1995 and 1995–2000, based on the equation,

$$R_i = \left[\frac{V_2}{V_1} \right]^{1/n} - 1, \quad (1)$$

where R_i is the increase rate of the observed value of a demographic or socio-economic indicator; V_1 the value of an indicator i at the date t_1 ; V_2 the value of the indicator i at the date t_2 ; n the difference of years between the two dates (4 years between 1990–1995 and 1995 and 2000 in this case study).

2.4. Detecting the paddy field conversion from remote sensed images

The biophysical data of LUCC were obtained through the change detection analysis of remote sensing. Three times Landsat Thematic Mapper (TM) images in 1990, 1995 and 2000 were interpreted to obtain land-use vector datasets. Obtaining images at near anniversary dates is considered important for change detection studies (Pilon et al., 1988; Quarmby and Cushnie, 1989). The geometric registration was done using the quadratic method. The specification for image to image registration is 0.3 pixel in both directions and this

Table 1
List of the selected demographic and socioeconomic variables

Abbreviation	Description	Unit
A-POP	Agricultural population	IND ^a
NA-POP	Non-Agricultural population	IND
T-POP	Total population	IND
C-LAND	Land area in cultivation	MU ^b
TAFHF	Total output value of agriculture, forestry, animal husbandry and fishery.	MY ^c
GDPV	Gross domestic product value	MY
GPSI	Gross product value of primary and secondary industries	MY
GTI	Gross product value of tertiary industries	MY
TFAI	Total value of fixed assets investment	MY
TIRE	Total income of rural economy	MY
IAFHF	Income in agriculture, forestry, animal husbandry and fishery	MY
N-IAFHF	Income in non-agriculture, non-forestry, non-animal husbandry and non-fishery	MY
TERE	Total expense in rural economy	MY
TIF	Total income of the farmers	MY
TVIA	Total value of industrial assets	MY
NVFA	Net value of the fixed assets	MY
NF	The number of factories	CNT ^d
EMPL	The number of employed people at the year end	IND
TTAX	Total tax value	MY
SRPV	Sold ratio of the product value	%

^aIND: the individual count of all people.

^bMU: 1 mu = 1/15 h = 1/6 acre.

^cMY: Million Chinese Yuan.

^dCNT: the count of all factories.

precision requirement was met for all three years. The city land-use vector datasets were created by interpreting TM images assisted with the 1:50,000 topography maps. During the interpreting process, topography, geomorphology, vegetation, precipitation and temperature datasets were used as the ancillary data. There are many methods for detecting land cover changes available in the literature. Several well-known ones among them are the image differencing (Quarmby and Cushnie, 1989), the principal component transform (Wang, 1993), the tasseled cap transform (Fung, 1990), the Gramm-Schmidt transform (Collins and Woodcock, 1994) and the image classification (Gordon, 1980). The post-classification image comparison method was adopted in this study to extract the dynamic change vector datasets of land-use. The TM images in 1995 were used to interpret the dynamic change vector data by comparing with the vector data derived from interpreting TM images in 1990, while the same method was applied for the period 1995–2000. Before interpreting the images, field trips were conducted to train the image analysts. The quality control was executed by checking up the identities and the boundaries of the land use patches to decrease incidences of errors. According to the check-up result, the classification accuracy of the changes of land use-cover patches is 97.6% (Liu et al., 2002a, b). The wrong identities of land use patches were all corrected.

The conversion rate for each major land use-cover type was calculated according the following formula (FAO, 1996):

$$Rc = \left[1 - \frac{S_1 - S_2}{S_1} \right]^{1/n} - 1, \tag{2}$$

where Rc is the rate of conversion process, S_1 the area of land use-cover category c at the date t_1 ; S_2 the area of land use-cover category c at the date t_2 ; and n the difference of years between the two dates (4 years between 1990–1995 and 1995 and 2000 in this case study).

3. Findings and analyses

3.1. Analysis of paddy field and other types of land conversion

The conversion rates of major land use-cover categories based on the Landsat image analysis are reported in Table 2. Plain dry land, plain paddy field, dense forest and dense grassland had the biggest negative conversion rates from 1990–1995. Urban construction, hilly dry land, rural construction and large factory and transportation construction had the biggest positive rates during the same period. There are noticeable variations of change among different land

Table 2
Yearly conversion rates of major land types during 1990–1995, 1995–2000

Abbreviation	Major land type	1990 (h)	1995 (h)	90–95 Change (h)	90–95 Conv. rate	2000 (h)	95–00 Change (h)	95–00 Conv. rate
P-DRY	Plain dry land	2814.0	2297.3	−516.8	−0.0398	1772.3	−525.0	−0.0506
PADDY	Plain paddy field	75335.8	71519.5	−3816.3	−0.0103	68021.0	−3498.5	−0.0100
D-FRST	Dense forest	8900.5	8745.5	−155.0	−0.0035	8568.8	−176.8	−0.0041
D-GRAS	Dense grassland	537.0	531.0	−6.0	−0.0022	485.5	−45.5	−0.0178
SHRUB	Shrub forest	417.5	414.5	−3.0	−0.0014	408.5	−6.0	−0.0029
ORC	Orchard	4360.5	4355.8	−4.8	−0.0002	4088.3	−267.5	−0.0126
LAKE	Lake	178334.0	178275.0	−59.0	−0.0001	178275.0	0.0	0.0000
H-PADDY	Hilly paddy field	56.0	56.0	0.0	0.0000	53.3	−2.8	−0.0100
RIVER	River	708.3	708.3	0.0	0.0000	708.3	0.0	0.0000
BARE	Bare land	53.5	53.5	0.0	0.0000	53.5	0.0	0.0000
SHOAL	Shoal	1598.5	1600.3	1.8	0.0002	1406.5	−193.8	−0.0255
S-FRST	Sparse forest	2178.8	2202.3	23.5	0.0021	2128.3	−74.0	−0.0068
R-POND	Reservoir and pond	10645.0	10839.0	194.0	0.0036	12128.5	1289.5	0.0227
L-F-T ^a	Large factory and transportation construction	392.0	439.3	47.3	0.0230	542.3	103.0	0.0430
R-CNST	Rural construction	8568.5	10104.5	1536.0	0.0335	12574.5	2470.0	0.0447
H-DRY	Hilly dry land	79.8	146.3	66.5	0.1289	110.8	−35.5	−0.0541
U-CNST	Urban construction	2608.8	5300.5	2691.8	0.1523	6263.3	962.8	0.0339

^aL-F-T is combined with U-CNST in the regress analyses, because L-F-T is closely related to urban development and only the towns with significant amount of L-F-T construction reported the data.

types between 1995 and 2000. Hilly dry land, plain dry land, shoal, and dense grassland witnessed the biggest losses between 1995–2000, while rural construction, large factory and transportation construction, urban construction and reservoirs and ponds saw biggest increases.

However, in terms of absolute volume of land area loss, the plain paddy field lost 3816 hectares from 1990 to 1995, or 84% of the total losses of arable and natural land covers during this period, and suffered another loss of 3499 hectares from 1995 to 2000, or 73% of the total losses of the same period. Urban construction, rural

construction, reservoir and pond, and large factory and transportation construction are the four largest beneficiaries of the paddy field conversions (Table 3).

3.2. Regression analysis of the interactions in the policy period, 1990–1995

The regression analysis revealed different influences from socioeconomic and policy factors at the two distinct periods, 1990–1995 and 1995–2000. The paddy field conversion was mainly contributed to the changes of four factors TIRE (total income of rural economy), U-CNST (urban construction), R-CNST (rural construction), and GDPV (gross domestic product value) during the period of 1990–1995 (Tables 4 and 5). Together these parameters explain 96.8% of the paddy field conversion. The regression analysis confirms that rapid economic growth in the first half of the 1990s has a direct impact on the paddy land conversion. The largest contributor is the increase of total income of rural economy (TIRE), which is much higher during 1990–1995 than its change at the period of 1995–2000 (Table 10). TIRE is the income generated from non-agricultural economic activities by collective and private enterprises registered and administrated in (Xiang and Cun) rural towns and villages (EBACE, 1993). Massive upsurge of rural industrialization is at the core of China's recent economic miracle (Sun et al., 1999). Rural nonagricultural employment constituted over one-third of the employment of rural households in the mid-1990s, and contributed above 40% of their total income. Remarkable rural industrialization demands that large amounts of farming land be converted to urban land for industrial, commercial and infrastructure construction. Steady increase of the rural economy contributes positively to reducing poverty, improving the quality of life of the rural population, and modernizing the farming sector (Oi, 1999). Rural residents who have more money in their pockets are building new, modernized and spacious houses. Therefore, TIRE, U-CNST and R-CNST strongly affect the paddy field conversion (in an opposite direction). This

Table 3
The conversion percentages of paddy field to other land types

Land use-cover type	Year 1995	Year 2000
Dense forest	0.125	0.000
Shrub forest	0.034	0.000
Sparse forest	0.187	0.000
Orchard	0.137	0.477
Dense grassland	0.054	0.821
River	0.125	0.000
Lake	2.660	0.000
Reservoir and pond	14.018	17.530
Shoal	0.007	0.000
Urban construction	39.328	32.578
Rural construction	38.099	40.443
Large factory and transportation	3.508	6.848
Plain dry land	1.719	0.157

Table 4
Summary for regression models during 1990–1995

Model	R	R ²	Adjusted R ²	Std. error of the estimate
1	0.734 ^a	0.539	0.506	4.16110
2	0.883 ^b	0.780	0.747	2.97884
3	0.980 ^c	0.960	0.950	1.32329
4	0.988 ^d	0.977	0.968	1.05117

^aPredictors: (Constant), R-CNST.

^bPredictors: (Constant), R-CNST, TIRE.

^cPredictors: (Constant), R-CNST, TIRE, U-CNST.

^dPredictors: (Constant), R-CNST, TIRE, U-CNST, GDPV.

Table 5
Coefficients for the final regression model during 1990–1995^a

	Unstandardized coefficients		Standardized coefficients Beta	t	Sig.
	B	Std. error			
(Constant)	−0.230	1.382		−0.167	0.871
R-CNST	−0.153	0.039	−0.270	−3.935	0.002
TIRE	−0.002	0.000	−0.694	−12.864	0.000
U-CNST	−0.029	0.004	−0.558	−7.617	0.000
GDPV	0.011	0.004	0.164	2.831	0.016

^aDependent Variable: PADDY.

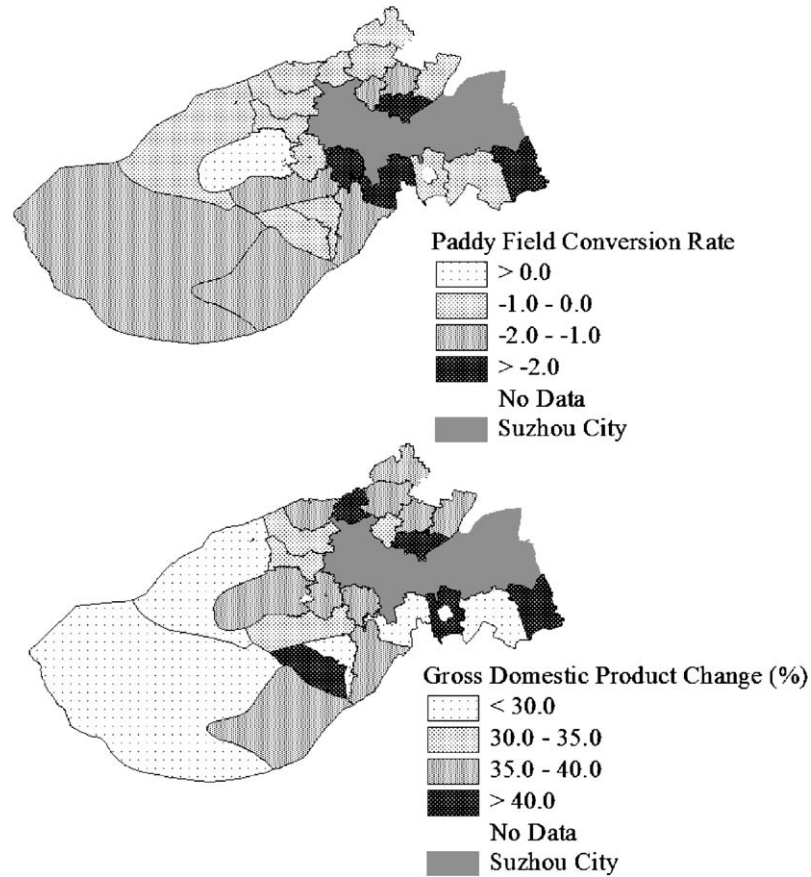


Fig. 2. Spatial patterns of paddy field conversion and socioeconomic factors in 1990–1995. (The upper is the thematic map of paddy field conversion rate (PADDY) in 1990–1995 and the bottom is the thematic map of gross domestic product value (GDPV). The values of these parameters display reversed patterns. Higher values of PADDY usually coincide with lower values of GDPV.)

explanation is easily comprehensible and consistent with China's policy intentions of that period.

The yearly increase of gross domestic product value (GDPV—a measure of the size of the economy) is at a record high of 0.37 during 1990–1995 (Table 10). However, its relationship with the paddy field conversion is reversed (Table 4), which conflicts with the common understanding that the rapid increase of GDPV should accompany with rapid loss of arable land. The GIS thematic maps reveal unmatched spatial patterns between the paddy field conversion and GDPV increase (Fig. 2). The interpretation is that GDPV contains a large portion of agriculturally related output value, though its share is diminishing (Wuxian City Statistical Bureau, 1991, 1996). Moreover, an increasing portion of rural town and village industries is for export, but this activity was not included in GDPV and the data were not collected until the late 1990s (Wei, 2002). Therefore, the GDPV indicator shows different spatial variations comparing with other economic indicators during this period.

3.3. Regression analysis of the interactions in the policy period, 1995–2000

The relationships between the paddy field conversion and the demographic and socioeconomic statistics during the period of 1995–2000 have shown a complex picture. Concerns about an overheated economy obviously caught public and governmental attention in China since 1994 (Baker, 2003). The total fixed asset investment (TFAI) decreased from the dramatic increase during 1990–1995 (0.53) to a negative increase in 1995–2000 (−0.13). The economic wheel was spinning much slower. As Table 10 discloses, almost all major economic indicators show much smaller increase rates. The increase rate of the gross product value of primary and secondary industries (GPSI) decreased from 0.7714 to 0.0181; total income of rural economy (TIRE) from 0.80 to 0.06; and non-agriculture product value (N-IAFHF) from 1.31 to 0.06.

Corresponding to the socioeconomic changes, land use-cover conversions illustrated dissimilar trends from the previous period. The paddy field conversion was

decelerated from 0.0103 to 0.01 (Table 2). Urban construction conversion was much reduced from 0.1523 to 0.0339. However, the conversion rates of other land categories increased. For instance, the rural construction (R-CNST) increased from 0.0335 to 0.0447 and plain dry land (P-DRY) from 0.0398 to 0.0506. The conversion rates of the dense forest, dense grassland, shrub forest, and orchards are all higher than those during 1990–1995. The negative environmental impacts, as the outcomes of rapid economic growth, were visible at this period (Wong and Zhao, 2000).

Furthermore, the paddy field conversion during 1995–2000 was primarily credited to the changes of five demographic and socioeconomic parameters, including agricultural population (A-POP), total output value of agriculture, forestry, animal husbandry and fishery (TAFHF), non-agricultural population (NA-POP), total tax value (TTV), and total value of industrial asset (TVIA) (Tables 6 and 7). Together the changes of these parameters can explain 94.9% of the paddy field conversion variation. A-POP is the largest contributor. Agricultural population decreased significantly from 83.0% to 74.7% of the total population, at 2.31% a year, and, as a result, non-agricultural population increased by 7.98% per year (Table 10). TAFHF kept increasing at a slightly slower pace (compared with the period of 1990–1995) though the agriculture population was decreasing. TVIA illustrated a similar impact.

Table 6
Summary for regression models during 1995–2000

Model	R	R ²	Adjusted R ²	Std. error of the estimate
1	0.818 ^a	0.670	0.646	2.61335
2	0.914 ^b	0.836	0.810	1.91243
3	0.957 ^c	0.916	0.895	1.42036
4	0.972 ^d	0.945	0.926	1.19746
5	0.983 ^e	0.966	0.949	0.99630

^aPredictors: (Constant), A-POP.

^bPredictors: (Constant), A-POP, TAFHF.

^cPredictors: (Constant), A-POP, TAFHF, NA-POP.

^dPredictors: (Constant), A-POP, TAFHF, NA-POP, TTV.

^ePredictors: (Constant), A-POP, TAFHF, NA-POP, TTV, TVIA.

Table 7
Coefficients for the final regression model during 1995–2000^a

	Unstandardized coefficients		Standardized coefficients Beta	t	Sig.
	B	Std. error			
(Constant)	1.917	1.082		1.772	0.107
A-POP	0.490	0.030	1.045	16.132	0.000
TAFHF	-0.029	0.006	-0.339	-4.967	0.001
NA-POP	0.012	0.003	0.298	4.649	0.001
TTV	0.013	0.004	0.267	3.679	0.004
TVIA	-0.005	0.002	-0.175	-2.427	0.036

^aDependent Variable: PADDY.

However, the spatial patterns of the changes for NA-POP and TTV are found to be different from the paddy field conversion (Fig. 3). The variations in the spatial

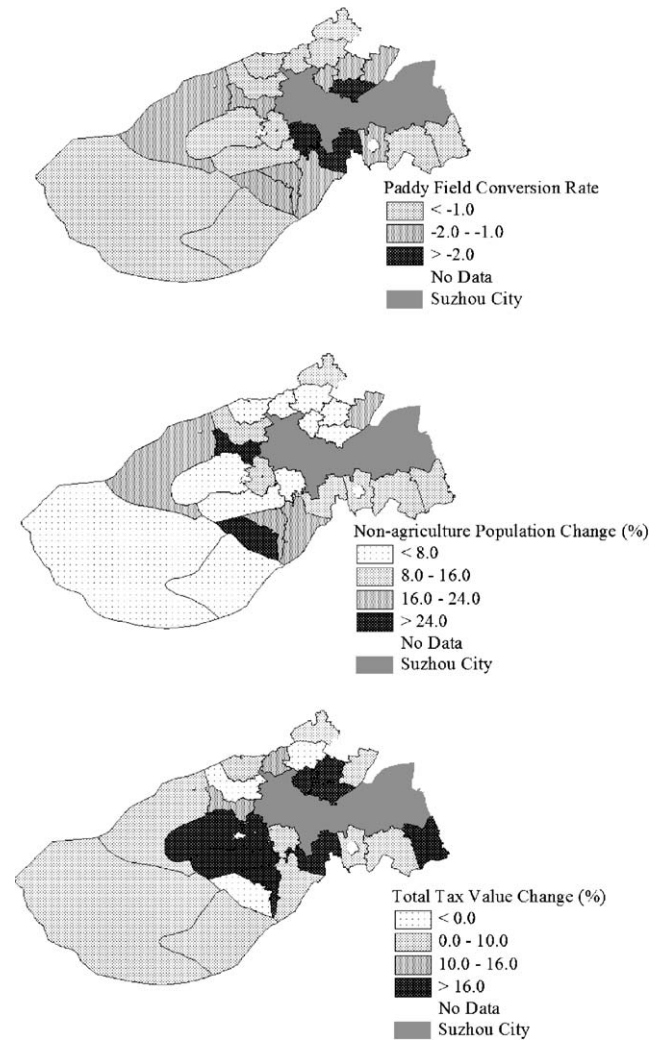


Fig. 3. Spatial patterns of paddy field conversion and socioeconomic factors in 1995–2000. (The upper is the thematic map of paddy field conversion rate (PADDY) in 1995–2000; the middle is the thematic map of non-agricultural population change (NA-POP); and the bottom is the thematic map of total tax value change (TTV)). The values of PADDY parameters display reversed patterns. The value distributions of these parameters display obvious spatial variations.)

patterns explain why the Beta values of these factors are showing reversed directions from the paddy field conversion (Table 7).

It becomes obvious that the policy changes institutionalized in the second half of the 1990s to control arable land loss and to curb overheated economy show varied successes. The Chinese government was able to control the investment (supporting by the fact that TFAI displayed a negative increase) and consequently reduce the conversion rates of the paddy field and urban construction (Sun, 2002). However, the demands of more lands for rural construction were not diminishing. Due to the strict regulations of protecting farming land, developers were forced to turn their attention to lands that are less regulated in the new policy (Wong and Zhao, 2000). Therefore the conversion rates of plain dry land, grassland, shrub forest, and orchards were increasing. If rapid economic growth is the main driving force for the land conversion in 1990–1995, the population shifting, the demand for better living standards, and the negligible attention to environmental quality are the primary causes affecting land change dynamics during 1995–2000.

3.4. Regression analysis with POLICY explanatory variable, 1990–2000

POLICY is a dummy variable that has a value 0 for the period of 1990–1995 (indicating the absence of the arable land protection legislation) and a value 1

for 1995–2000 (signifying the presence of the arable land protection legislation). The regression analysis, with the explanatory variable POLICY, reveals how the policy change correlates with the paddy field loss and how other socioeconomic factors impact paddy field conversion when experiencing policy change. The regression analysis indicates several findings (Tables 8 and 9): (1) the policy change (the explanatory variable, POLICY) itself is statistically significantly correlated with the paddy field conversion, though the influence level is moderate compared with other contributors; (2) U-CNST (urban construction) and TIRE (total income of rural economy) are the two strongest factors affecting rapid paddy field conversion; and (3) the agricultural population shift is another contributor to paddy field conversion. These statistical findings lead to some interesting and important arguments on the causes of the paddy field losses in Southern Jiangsu of China. First, as China is in the take-off stage of economic growth, it is inevitable to experience arable land losses to non-agricultural uses and, in particular, rapid urban expansion. Second, in developed regions such as Sunan, the income from rural non-agricultural enterprises (household-based small-scale township- and village-run) is the primary driving force converting arable land to other uses in rural areas. Third, the decrease of agricultural population (either leaving agriculture to be engaged in non-agricultural activities or migrating to cities) accelerates farmland losses. Finally, the conversion of farmland (paddy fields in this study) is slowed

Table 8
Summary for regression models with the explanatory variable, POLICY

Model	R	R ²	Adjusted R ²	Std. error of the estimate
1	0.551 ^a	0.303	0.288	3.97360
2	0.678 ^b	0.460	0.436	3.53642
3	0.714 ^c	0.510	0.477	3.40605
4	0.784 ^d	0.615	0.579	3.05441

^aPredictors: (Constant), A-POP.

^bPredictors: (Constant), A-POP, U-CNST.

^cPredictors: (Constant), A-POP, U-CNST, TIRE.

^dPredictors: (Constant), A-POP, U-CNST, TIRE, POLICY.

Table 9
Coefficients for the final regression model with POLICY^a

	Unstandardized coefficients		Standardized coefficients Beta	t	Sig.
	B	Std. error			
(Constant)	1.409	1.451		0.971	0.337
A-POP	0.118	0.039	0.340	3.070	0.004
U-CNST	-0.030	0.006	-0.547	-4.661	0.000
TIRE	-0.002	0.000	-0.622	-4.137	0.000
POLICY	-5.799	1.694	-0.622	-3.423	0.001

^aDependent Variable: PADDY.

Table 10
Annual change rates of the socioeconomic factors used in analysis

Factors	1990–1995	1995–2000	Factors	1990–1995	1995–2000
A-POP	−0.0093	−0.0231	IAFHF	0.1499	0.0308
NA-POP	0.0474	0.0798	N-IAFHF	1.3107	0.0631
T-POP	−0.0009	−0.0024	TERE	0.9596	0.0700
C-LAND	−0.0135	−0.0319	TIF	0.3759	0.0508
TAFHF	0.1171	0.0879	TVIA	0.3791	0.2761
GDPV	0.3700	0.1097	NV-FA	0.4189	0.0331
GPSI	0.7714	0.0181	NF	0.0022	0.0442
GTI	0.5826	0.1430	EMPL	−0.0199	−0.0159
TFAI	0.5318	−0.1319	TTAX	0.8000	0.1026
TIRE	0.8035	0.0607	SRPV90	1.1609	−0.0004

and curtailed with the decree of arable land protection legislations (see Table 10).

4. Discussion

4.1. Reflections on the integrated LUCC research method

This paper presents a case study of policy changes and related environmental responses through investigating the paddy field conversion and its causal relations with the demographic and socioeconomic factors. First, this study illustrates an integrated research method to explore how policy and socioeconomic factors interact with each other to drive land use-cover changes. The study suggests conducting a policy review to determine important historical events of policy change and to use these episodes to guide policy research design. This human and policy dimension drives data compilation and analysis. Second, the paper acquires accurate biophysical data (i.e., land use-cover change vectors) from the Landsat images at different time scenes through remote sensing analysis. Though the detection methods and the quality of remote sensed data may affect the accuracy level, this method definitely fills a gap in studying land use changes in China because the Chinese statistical data on land use changes is very questionable (Lohmar, 2001; Ma, 2002). Third, the paper merges the LUCC data with the demographic and socioeconomic data at fine-scale (rural towns and villages) and conducts statistical analyses (including the multiple and categorical regression analyses) to discern how the policy change correlates with the paddy field conversion and how socioeconomic factors interact with each other to drive land use-cover changes under two periods (1990–1995, and 1995–2000) with distinct policy variations. Fourth, the paper adopts GIS scientific visualization to interpret abnormal associations between paddy field conversion and socioeconomic factors from the perspective of spatial pattern analysis.

Physical, social, and political systems are interacting in complex ways to drive LUCC dynamics. It is difficult to understand the temporal trajectory and spatial imprint of LUCC simply from quantitative (statistical) analysis and qualitative (policy) assessment. Interactive and synthetic data exploratory analyses supported by GIS scientific visualization help discern spatial interactions between LUCC and its driving forces. The thematic maps of spatial relationships of the paddy field conversion with the gross domestic product in 1990–1995 (Fig. 2) and with the changes of non-agriculture population and total tax value during 1995–2000 (Fig. 3) help to understand and clarify the extent and direction of their interactions. In this integrated manner, several important findings are extracted to advance our understanding of the issues of environmental changes and the associated driving forces.

Caution must be exercised when adopting informatics and statistical methods to study policies. Society is a complex system in which science and technology are integral elements and play increasingly active roles. However, the roles of science and technology in shaping policies are hardly studied. In other word, policies are seldom explained plainly with science and modeling (Odum, 1997). Science and modeling are often developed as crude tools to obtain a preliminary examination of complicated social issues or policy impacts (Batty, 1997). A fuller appreciation of what is going on must be matched by enhanced understanding of political and anthropologic causes (Committee on Global Change Research, 1999). Moreover, there are several serious statistical limitations when applying regression methods in studying policies. Specification error directly relates to choosing appropriate explanatory variables. Availability and selection of the right indicators for policy studies have been a great challenge for convincing the applicability of regression method in policy studies (Hammond et al., 1995; World Bank, 1997; Goertzel, 2002; Brumm, 2003). Statistical considerations of

multicollinearity and heteroskedasticity which exist among explanatory variables make it more rigid to apply the regression method (Crown, 1998; Miles and Shevlin, 2001). It is critical to conduct thorough examination and experimentation between large number of explanatory variables for determining the best suitable regression models and to have good knowledge of policy issues to construct a valid statistics-based policy analysis (Burnside and Dollar, 2000; Brumm, 2003; Easterly et al., 2003).

4.2. *Comments on China's land control policy and its impacts on LUCC*

China's policies during the period of 1990–1995 were prioritized to promote socioeconomic development and to improve people's living standards. As a result, fast economic growth brought about rapid urban expansion and an increasing proportion of affluent rural residents who were consuming much arable land for residences and services. Dramatic demands for construction have largely resulted in land degradation, deforestation, habitat fragmentation, biodiversity loss and reduction of environmental services (Table 2). The overheated economy and negative LUCC dynamics forced the Chinese government to issue the new policy directives in the mid-1990s. However, there remains a political and practical vacuum because diverse forces are operating in a negotiated or reconciled manner to provide only a few feasible paths for action (Blaikie, 1996; Jones, 2002). The new farmland protection law stipulates tough rules on fixed asset investment, urban construction, and farmland (paddy field) loss, but less strict regulations on marginal lands (dry plain and shrub lands, in particular) that are less productive but are environmentally sensitive. Moreover, the protection law does not provide measures to curb the increasing demands for more constructions inspired by growing economy and aspirations for better living standards. Therefore, more marginal lands were consumed and the new policy showed varied levels of success in controlling arable land losses. This clearly demonstrates that the new policy with a narrow focus hardly achieves its original goals.

Under different policy dimensions, socioeconomic factors interact in different ways to drive land use-cover changes. During 1990–1995, total income in the rural economy (TIRE) and gross domestic product value (GDPV) are two critical economic indicators driving the paddy land conversion. The large magnitude of urban construction, large factory and transportation construction and rural construction also accelerated the consumption of paddy field. This finding is consistent with the common notion of environmental change studies and regional development theories. However, the period of 1995–2000 illustrated a different socioeconomic

permutation. The strict measures of controlling investment and urban expansion are noticeable. However, it is very hard for the Chinese governments to discourage rural residents to build more comfortable or spacious houses if they become affluent. It is very challenging to prevent farmers from selling their paddy field to developers if they are living in relatively backward areas and want to find quick ways of getting rich.

More profoundly, the opportunities for better jobs, future improvements and better qualities of life in cities attract more rural people leaving agriculture and joining urban living. Furthermore, the improvement of productivity and machinery use in agriculture released more surplus agricultural labors. As a result, the Chinese population is pouring from farms into cities in tidal waves (Yardley, 2004), which is a primary force driving urban expansion and farm land loss in recent years. These demographic dynamics and associated social demands challenge the government policy of protecting farmland. Though the Chinese government wants to regulate farmland resource loss, it cannot be done with a narrowed focus on farmland itself. Any new policies that would expect to have positive impacts must include comprehensive measures to act on the driving forces for land use change, to provide economic options and policy incentives for obtaining equality between farms and cities, and to point out alternatives for achieving sustainable societal development.

Another point worth mentioning is that the state control and centralized decision making in land resource management is rapidly relaxing after the economic reforms in China since 1978. Accordingly, the central government has adopted more indirect than direct techniques to control the society. Under this rationality, cities and towns and even enterprises have gained more power in determining measures and making decisions in land development and planning (Tang, 2000). Locality must be given more attention in policy analysis during this episode of loosened state control.

This paper concentrates on a case study of a critical global environmental issue for long developed human ecological systems. Though the data used in this paper cover a relatively small region and a limited longitudinal dimension, the knowledge gained through the case study is crucial for developing regional and global models of land-use/land-cover change under human and policy influences. Though the analytical methods deployed in this paper only count a small subset of the available research techniques (US Climate Change Science Program, 2003), the approach illustrated in this paper serves as a demonstration of the integrated research methodology, combining the scientific methods and technologies in a coherent manner that is interactive and comprehensive in general and adjustable and focused in specific for seeking better understanding of a unique environmental concern.

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