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TEMPORAL STRUCTURE OF LAND USE CHANGE IN ASIA

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Abstract

To diagnose a temporal stability of land use structure assumed in many papers represented by Matsumura and Nakamura (1999), characteristics of land use change in Asian countries facing a recent drastic change since 1970s were discussed on the basis of inter annual survey on land use data. Description of statistical relationships between land use and several kinds of factor such as sociology, economy, and nature was attempted. In India, the farmland ratios increased in proportion to a growth of population density, while in Taiwan, those ratios were decreasing in regions with high population density. There seemed to be a difference of economical developing stage and structure of food supply between these two countries.

Population density as a driving force on land use change affairs both of positively and negatively depending on its range, as for the case study in Taiwan. This affection varies by stage. For the model-construction on land use change in Asian region, such temporal stability of land use structure should be carefully noticed.

KEYWORDS: *land use, population density, Asia*

1. Introduction

Presently Asia is growing rapidly, and there are marked changes in land use owing to human activities including the development of agriculture, forestry, and industry, as well as urbanization. Changes in land use directly affect the global environment in a variety of ways. It follows, therefore, that Asia is an appropriate research area for elucidating the process of land use change and predicting its future.

Matsumura and Nakamura (1999) built a system dynamics model based on the correlative relationships among economic indicators, population indicators, and the land areas of various land uses by individual countries, and predicted land use changes in various Asian countries up to a certain future time, which was of great interest. A basic assumption in that paper is the absence of temporal change in the functions that describe the relationships between socioeconomic indicators and the land areas of various land uses, i.e., the temporal stability of land use structure. Otsubo's LU/GEC model (Otsubo,

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1998) is a land use change prediction model that was built on such an approach, and it comprises two parts: a chronological model that performs long-range predictions of the socioeconomic factors that define land use, and a land use ratio function that estimates land use ratios from the predicted values. In the process of building this model, Otsubo performed a canonical correlative analysis of information including municipality-level data sets from eight prefectures in the Kanto region of Japan for the two points in time of circa 1970 and circa 1990. Despite the great changes in economic conditions between the two stages, the analysis indicated temporal stability in the land use structure. This analysis revealed the relationships between state variables at a certain point in time, which might be called a static structural analysis of land use. But to find the dynamic mechanism, i.e., the driving force, of land use change, it is necessary to analyze the factors affecting land use, with change over the analyzed term in land use being the target variable. Hoshino (1997) showed it was possible to predict land use change with greater precision by treating both initial data for the analyzed term and the change over the analyzed term as explanatory variables for land use ratios.

Meanwhile, based on the hypothesis of Kuznets (1955), Matsuoka *et al.* (1998) observed that the relationship between economic indicators (GNP) and sulfur dioxide concentration changed in conjunction with economic development and showed examples in which there was no temporal stability in the relationship between target variable and explanatory variables. The authors assumed such instability between land use and socioeconomic indicators. The authors built a chronological data base on land use ratios for individual provinces in Asian countries, and examined whether or not there was temporal stability in land use ratio functions that used socioeconomic indicators as explanatory variables. If many examples without temporal stability were found, it would signify risk in Matsumura and Nakamura's method, and necessitate caution in its application. This study aimed to diagnose a temporal stability of land use structure in Asian countries facing a recent drastic change since 1970s on the basis of inter annual survey on land use data, and to describe characteristics of the land use change.

2. Method

Although the mechanism of land use change has yet to be fully elucidated, the orthodox approach in much land use research (Matsumura and Nakamura, 1999; Otsubo, 1998; Hoshino, 1997; Chen *et al.*, 1998) involves finding the relationship between land use and the factors such as sociology, economy, and nature, and then explaining the changes using those factors as the driving forces. Accordingly this research likewise adopted a method that used land use as the target variable, and the factors such as sociology, economy, and nature as the explanatory variables, then attempted to describe the statistical relationship between the two.

This study covered 20 Asian countries (India, Indonesia, Cambodia, Lao PDR, Malaysia, Brunei, Sri Lanka, Bangladesh, Nepal, Butane, Thailand, Republic of Korea, Taiwan, China, Japan, Pakistan, Myanmar, The Philippines, Vietnam, Mongolia). For the items analyzed the authors used population density as the explanatory variable, and land use ratios (the area of a certain land use type as a proportion of the entire dry land area in the analyzed region) as the target variables for the three points in time of 1970, 1980, and 1990 (or those approximate times) in the 20 countries covered. Considering qualities and quantities of data obtained, the authors limited the discussion on the results to a part of whole 20 countries, i.e., regions with comparatively abundant data. Land use types were farmland (the

sum of rice paddies, dry fields, and orchards), rice paddies, dry fields, forest/forested land, pasture land, and residential. In consideration of diversity within each country, spatial analysis units for data were province-level administrative units. There are many conceivable social, economic, and natural factors for explanatory variables (i.e., per capita GDP, price of agricultural products, per capita energy consumption, climate), but here the authors used only population density because those data were the only kind the authors could obtain from among the many province-level administrative units in the countries covered. Table 1 shows the data sources (only those allowing us to follow chronological change in at least two points in time).

Table 1. Data sources.

India
Statistical Abstract by Census
Statistical Organization (1972, 1982, 1990)
The Philippines
Philippine Forestry Statistics (1981)
Philippine Statistical Yearbook (1982, 1991, 1994)
Bangladesh
Statistical Yearbook of Bangladesh (1975, 1981)
Lao PDR (Laos)
Basic Statistics 1975-1990
Basic Data 1982
Republic of Korea
Korea Statistical Yearbook (1971, 1981, 1991)
Korean Economic Indicators (1991, 1993)
Regional Statistical Yearbook of Korea (1991)
Malaysia
Paddy Statistics Malaysia
by Kementerian Pertanian Malaysia (1980, 1990)
General Report of the Population Census
by Department of Statistics (1970, 1980, 1990)

In accordance with the foregoing, the authors performed the following two tasks for the region covered.

1) For the relationship between population density and land use ratios at 10-year intervals (1970, 1980, 1990) and on an individual country basis, the authors plotted province-level administrative unit

data in scatter diagrams, and investigated how that relationship changed over the analyzed term. Scatter diagrams in this research excluded data with values that diverged widely from the values of other province-level administrative units.

2) The authors classified province-level administrative units into several groups according to population density, and investigated the diachronic change for each group at individual locations.

3. Relationship between Population Density and Land Use Ratios for Each Province-Level Administrative Unit

3.1 Changes in Forest/Forested Land

1) India

India has a low forested land ratio, with many states below about 4% (Figure 1). From 1970 to 1980 the main states had population density increases, but hardly any change in forested land ratio, making for low correlation between the two. Over India as a whole, the forested land ratio dropped from 1.2% to 1.0% during this decade.

2) Taiwan

In 1970 the forested land ratio had gradually increased along with a population density increase, and most regions had an average ratio of about 10% (Figure 2). But from 1980 there was a prominent forested land ratio's peak at a population density in the neighborhood of 300 people/km^2. Regions with low population densities in 1970 had hardly any subsequent density increase, although they did have a slight increase in forested land ratio (*see* Fig. 10). The increase in forested land ratio was large until 1980. In regions whose population densities were already high, population densities grew considerably while forested land ratios remained unchanged (i.e., province-level administrative units around Taipei). During this time period the forested land ratio for Taiwan as a whole increased from 11.4% to 16.3%.

3) The Philippines

Forest ratios in the Philippines were quite high at between 40% to 60% in almost all regions (Figure 3). Except for one or two points, from 1980 to 1990 those ratios slowly declined as population density increased, and then started climbing again after density reached about 200 people/km^2, a relationship that has not changed. And while population densities have increased in all regions, the forest ratios have, except for two regions, remained unchanged or slowly decreased. During this time period the forest ratio for the Philippines as a whole decreased from 55.6% to 52.9%.

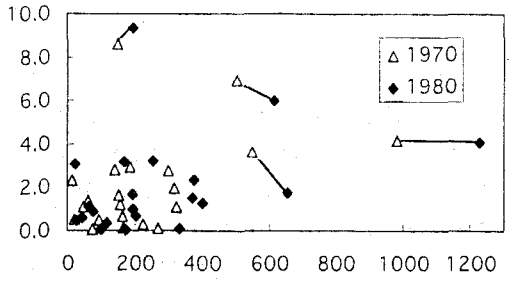

Figure 1. Relationship between population density and forested land ratio in India.
Y: Forested land ratio in India (%)
X: Population density (people/km^2)
Vectors of change over the ensuing decade for some province-level administrative units were shown.

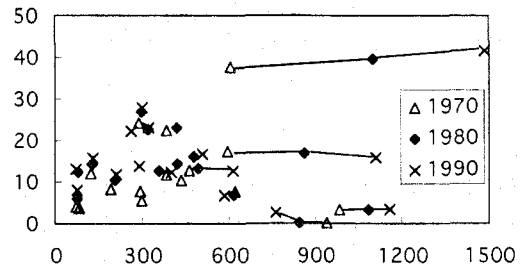

Figure 2. Relationship between population density and forested land ratio in Taiwan.
Y: Forested land ratio in Taiwan (%)
X: Population density (people/km^2)
Vectors of change over the ensuing decade for some province-level administrative units were shown.

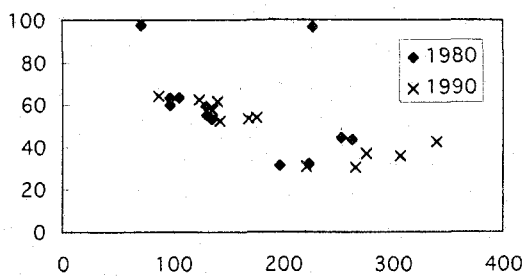

Figure 3. Relationship between population density and forest ratio in The Philippines.
Y: Forest ratio in The Philippines (%)
X: Population density (people/km^2)

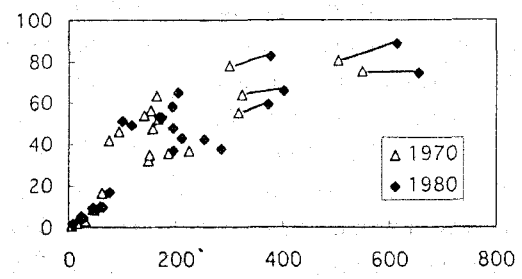

Figure 4. Relationship between population density and farmland ratio in India.
Y: Farmland ratio in India (%)
X: Population density (people/km^2)
Vectors of change over the ensuing decade for some province-level administrative units were shown.
1970: Y=0.1505X+12.9 (r: 0.840)
1980: Y=0.1295X+13.7 (r: 0.843)

3.2 Changes in Farmland

1) India

From 1970 to 1980 there was not much change in the relationship between population density and the farmland ratio in India (Figure 4). States with high population densities also had high farmland ratios, and there was no change in this relationship. During this time period the farmland ratio for India as a whole increased from 50.0% to 53.2%. If one follows the changes point by point over this decade in the main states, there is revealed a relationship in which the farmland ratios increased in concert with the increases in population densities, which shows that new farmland becomes necessary to feed the population (*see* Fig. 7, Fig. 8). A conceivable underlying reason is that there is little economic difference among regions despite their varying population densities, and basically each state is nearly self-sufficient in food. But at about 300 people/km^2 the increase in the farmland ratio in response to population density slowed, suggesting that changes happen to the aforementioned need for new farmland to supply more food.

2) Lao PDR

From 1980 to 1990 the trend in high-population-density regions of Laos was for high rice paddy ratios, but then the paddy ratios in those regions declined (Figure 5). During this decade, the rice paddy ratio for Laos as a whole declined from 3.1% to 2.8%.

3) Taiwan

From 1970 to 1980 there was a big change in the relationship between population density and the farmland ratio in Taiwan (Figure 6). Just as in India, regions with high population densities also had high farmland ratios in 1970, but in 1980 the farmland ratio began to decline at a population density of about 600 people/km^2. Even in 1990 this trend continued, but population density grew very rapidly especially in regions with high densities (i.e., province-level administrative units around Taipei). A look at farmland by dividing it into rice paddies and dry fields showed that rice paddy change accounted for most of the change in the farmland ratio, and that there was almost no change in dry fields. Examining the changes point by point over these two decades in the main regions showed that farmland ratios increased slightly in regions with low population densities and there were gradual increases in the farmland ratios in regions with stable population densities, while the farmland ratios fell in regions which in 1970 had already had population densities of over 500 people/km^2 (*see* Fig. 9). During this time period the farmland ratio for Taiwan as a whole underwent only a negligible decrease from 25.2% to 25.0%. Thus it appeared that the farmland increases in low-population-density regions cancelled out the farmland decreases in high-population-density regions. During these two decades, there was a breakdown in the agriculture-dependent social structure that the authors saw in India, i.e., new farmland becomes necessary to feed the population, and it would seem that relatively affluent regions with high population densities experienced an industrial structure's shift from being self-sufficient in food to supporting their communities with industry. The occurrence of this shift will change, through the industrial structure, the relationship between population density and the farmland ratio. Actually, results of regression analysis lost its significance stage by stage (Figure 6). The

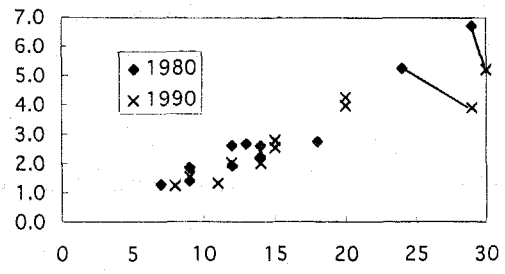

Figure 5. Relationship between population density and rice paddy ratio in Lao PDR.
Y: Rice paddy ratio in Lao PDR (%)
X: Population density (people/km^2)
Vectors of change over the ensuing decade for some province-level administrative units were shown.
1980: Y=0.241X–0.71 (r: 0.968)
1990: Y=0.170X–0.08 (r: 0.929)

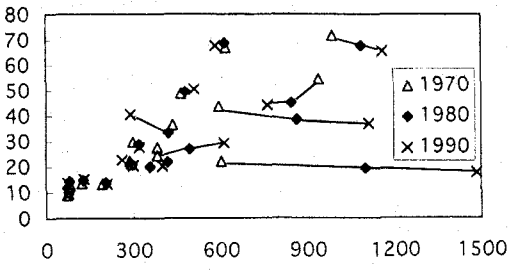

Figure 6. Relationship between population density and farmland ratio in Taiwan.
Y: Farmland ratio in Taiwan (%)
X: Population density (people/km^2)
Vectors of change over the ensuing decade for some province-level administrative units were shown.
1970: Y=0.0620X+6.0 (r: 0.870)
1980: Y=0.0348X+13.8 (r: 0.626)
1990: Y=0.0193X+20.8 (r: 0.443)

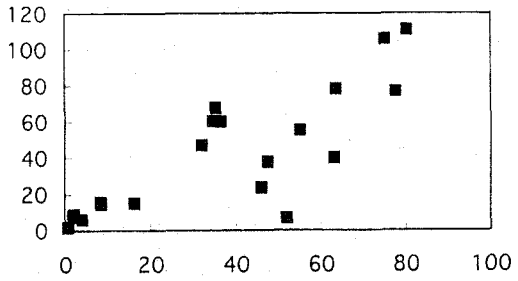

Figure 7. Relationship between initial farmland ratio and population density change over the ensuing decade in India.
Y: Population density change in India (1970-1980: people/km^2)
X: Farmland ratio in 1970 (%)

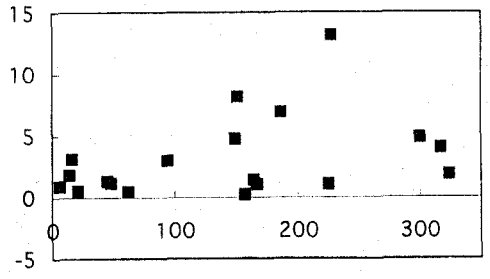

Figure 8. Relationship between initial population density and farmland ratio change over the ensuing decade in India.
Y: Farmland ratio change in India (1970-1980: %)
X: Population density in 1970 (people/km^2)

LU/GEC model assumes that the driving force behind land use change is temporally stable, but in present-day's Asia many countries are developing rapidly, and are likely approaching the same shift that Taiwan has experienced. This calls for caution when considering the driving forces behind land use change in these countries.

4. Is Population Density Sufficient as the Driving Force behind Land Use Change?

4.1 Introduction

In the LU/GEC model, socioeconomic factors, of which population density is representative, are regarded as candidates for the driving forces behind land use change, and the correlative relationship between socioeconomic factors and land use ratios are used for investigating whether they are driving forces. However, in rapidly developing Asian countries there is no assurance of temporal stability in the relationship between the two, making it hard to say that this method is always appropriate. Therefore to examine whether population density is a driving force of land use change, one must investigate the correlative relationship between the population density at a certain point in time, and the land use change over the ensuing 10 years. 10 years are relative longer to describe the land use changes but inevitable due to the data limitation. At the same time, it is possible that land use ratios themselves are driving forces that underlie changes in socioeconomic factors, in which case it should be possible to describe the relationship between the two and predict them both simultaneously in the form of a system dynamics model. If the authors set the population density in 1970 as $X(70)$ and the land use ratio as $Y(70)$, then $f[X(70)]dt$ will be described as a linear function of $X(70)$, and if the correlative coefficient is high, it is possible to predict $Y(80)$ by $X(70)$ and $Y(70)$ in the following equation.

$$Y(80)=Y(70)+f[X(70)]dt \quad (dt=10 \text{ years}) \quad (1)$$

Similarly, if it is possible to predict $X(80)$ by $X(70)$ and $Y(70)$, then it is possible to predict $Y(90)$ by $Y(80)$ and $X(80)$. Using this approach, the authors show some examples of investigating, by country and by type of land use, whether or not population density is a driving force of land use change.

4.2 India

The authors investigated whether the relationship between population density and farmland ratio could be described with Equation (1). The authors found a positive correlation between the farmland ratio in 1970 and the population density change over the ensuing decade (Figure 7). Specifically, a high farmland ratio leaded to population increase. On the other hand, while the relationship between 1970's population density and the farmland ratio change over the ensuing 10 years was not distinct, there was a slight positive correlation, and nationally the farmland ratio increased (Figure 8). The foregoing

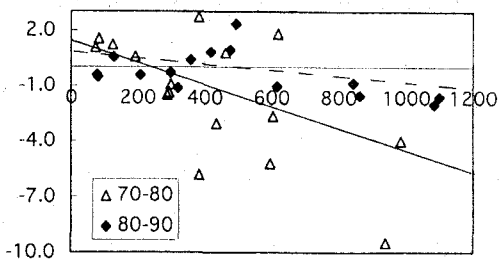

Figure 9. Relationship between initial population density and farmland ratio change over the ensuing decade in Taiwan.
Y: Farmland ratio change in Taiwan (%)
X: Initial population density (people/km^2)
1970-1980: Y=–0.00580X+1.30 (r: –0.576) : solid line
1980-1990: Y=–0.00167X+0.49 (r: –0.492) : dashed line

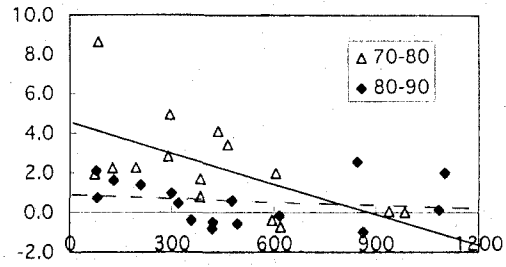

Figure 10. Relationship between initial population density and forested land ratio change over the ensuing decade in Taiwan.
Y: Forested land ratio change in Taiwan (%)
X: Initial population density (people/km^2)
1970-1980: Y=–0.00530X+4.51 (r: –0.615) : solid line
1980-1990: Y=–0.00028X+0.69 (r: –0.083) : dashed line

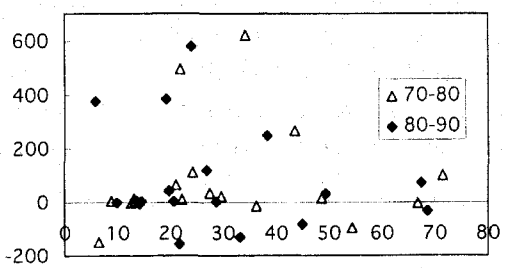

Figure 11. Relationship between initial farmland ratio and population density change over the ensuing decade in Taiwan.
Y: Population density change in Taiwan (people/km^2)
X: Initial farmland ratio (%)

suggested that population density and farmland ratio, through food supply and demand, acted as driving forces on each other.

4.3 Taiwan

The authors found a negative correlation between 1970's population density and the farmland ratio change over the ensuing 10 years (Figure 9). Specifically, low population density acted as a positive driving force on the farmland ratio change, while high population density acted as a negative driving force. It appeared that a 1970's population density of under 200 people/km^2 was a driving force that increased the farmland ratio, while a density of 300 people/km^2 or greater acted to decrease the ratio. After 1980 this trend was no longer distinct, showing that driving forces also changed with the times. Such trends could also be discerned in examples of forested land ratios (Figure 10). Further, population density increased only in regions with low farmland ratios, showing that, unlike India, population increase depended on the agricultural production of other regions (Figure 11).

5. Conclusions

To diagnose a temporal stability of land use structure assumed in many papers represented by Matsumura and Nakamura (1999), characteristics of land use change in Asian countries facing a recent drastic change since 1970s were discussed on the basis of inter annual survey on land use data. Description of statistical relationships between land use and population density were attempted. In India, the farmland ratios increased in proportion to a growth of population density, while in Taiwan, those ratios were decreasing in regions with high population density. There seemed to be a difference of economical developing stage and structure of food supply between these two countries.

Population density as a driving force on land use change affairs both of positively and negatively depending on its range, as for the case study in Taiwan. This affection varies by stage. For the model-construction on land use change in Asian region, such temporal stability of land use structure should be carefully noticed.

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