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Monitoring and modeling for city shrinkage in Japan: phenomena, managing and reviving strategies

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Abstract

City shrinkage is gradually becoming a common phenomenon wide around the world. In Japan, over 90% of the municipalities are losing their population. How to deal with the shrinking issue and problems caused by its chain effects still remains a challenge for researchers from various disciplines. In the paper, the shrinking phenomena in Japan are well analysed by case study from the perspective of residential choice and land use conversion by land use data and social and cultural statistics. Aimed at maintaining life quality of residents and preserving natural environment and ecosystem, policy strategies responding to shrinking problems are proposed, and tested and compared by an innovative city model combined with a rent gap theory-based cellular automata land use change model and a multinomial logit model based residential migration model.

Keywords: City shrinkage, urban modelling, multinomial logit model, rent gap, cellular automata, residential migration

1 Background

Shrinking city means an area with a minimum population of 10,000 residents that has faced population losses in large parts for more than two years and is undergoing economic transformations with some symptoms of a structural crisis [1].

Cities in developed countries throughout the world are facing population declines at an unprecedented scale. Over the last fifty years, 370 cities throughout the world with populations over 100,000 have shrunk at least 10% [2]. Wide swaths of the U.S., Canada, Europe, and Japan are projecting double-digit decline in population in the coming decades [3].

According to the census data, from 2000 to 2005, among 2217 municipalities in Japan, about 27% municipalities lose over 10% of population in just five years, and the populations of over 93% of the municipalities are decreasing. According to the population projection of National Institute of Population and Social Security Research (NIPSSR), Japan will continue to decline in a size at a rate of approximately 800,000 of population per year between 2010 and 2050 [4].

Depopulation due to out-migration and/or lower fertility and residential preferences change leads to a shift of inhabitants from city core to the suburbs, which will give rise to city sprawling in the city fringe as well as lower density of population near city core area [5]. In the inner city, problems like large dwelling vacancy even demolition and underuse of infrastructures will occur due to low population density, at the same time, in the suburb, there is new demand for dwelling and infrastructure construction. Both population loss in the city core and sprawling peripheries will cause a dispersed city structure. In the sense of environment, large brownfields and land wastage will be left in the city core, but new expansion in the suburb will destroy natural environment and ecosystem. On the other hand, from the perspective of inhabitants, due to the over low residential density, negative influence on quality of life may be generated by difficulties to access to infrastructures, lose the sense of community and social segregation.

2 Objective and Methodology

Mechanism of phenomena highlighted in the background should be well analysed. In order to take response to current shrinking trend, the main objective is to design and examine potential urban planning policies to manage, and if possible revive shrinking cities.

Based on comparative cases studies, using land use map, census data, questionnaire survey etc. detects changes in land use, population and residential preferences. On the basis of the statistical analysis results, possible policy proposals will be considered to manage shrinking cities in Japan. A simulation model with the process of land use conversions interacting with residential migration choice will be built to project current trend of shrinking issues of case study area Japan, test the possible managing policy proposals and compare various policy scenarios.

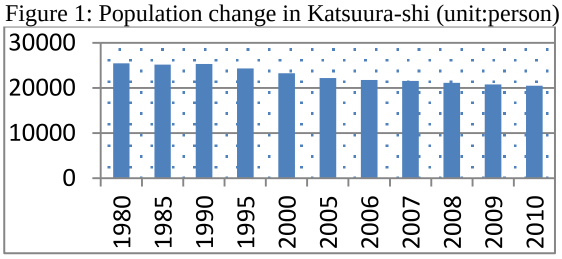
3 Case study in Japan: Katsuura-shi

Katsuura is a city located in the southern part of Chiba Prefecture, which contains 48 districts, among which relatively prosperous places are Okitsu and Katsuura. The total population is 20,518, and the area is about $94.2km^2$.

3.1 Demographic and land use change

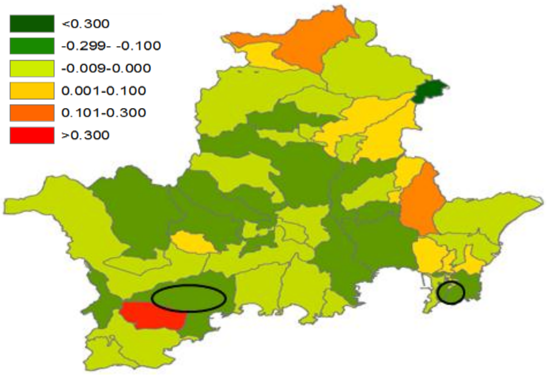
The census analysis (Figure 1) shows that the population in Katsuura-shi has been declining since 1980s, and until it has lost about 20% of population during the period from 1980 to 2010.

Figure 1: Population change in Katsuura-shi (unit:person)



Source: Census data and local residence survey of Katsuura

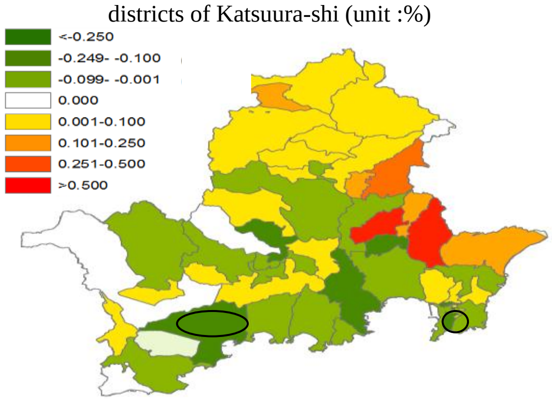
Figure 2: Population change during 2000~2005 in 48 districts of Katsuura-shi (unit:%)



Source: Census data

As Figure 2 shows although few districts are still growing, most districts of the city are losing their population, and the two places which used to be relatively prosperous in Katuura city (Okitsu and Katsuura) which are marked by black circles, are losing population at relatively higher rate than other districts. The number of households (Figure 3) has not been declining as fast as rate of population, even though Okitsu and Katsuura are still obviously losing households at higher rate than average in Katsuura city.

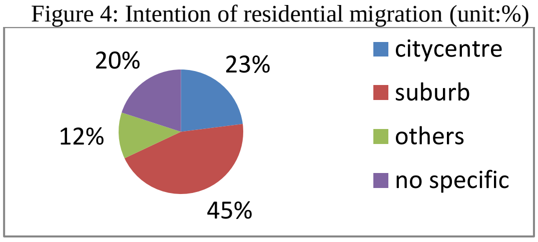
Figure 3: Households change during 2000~2005 in 48 districts of Katsuura-shi (unit :%)



Source: Census data from

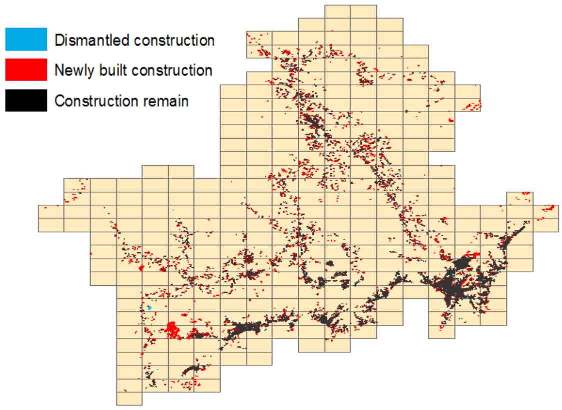
Households demand survey made the inquiry about the intention of residential choice, 114 households in Katsuura-shi have responded to the questionnaire survey. According the responses of 114 surveyed households, Figure 4 shows about 45% of surveyed residents would like to move to the suburb area in the future, but only 23% of respondents showed the intention to move to the near city core area. The preference of moving to the suburb is very obvious in the survey, which will lead to even less population at near city core area in Katsuura-shi.

Figure 4: Intention of residential migration (unit:%)



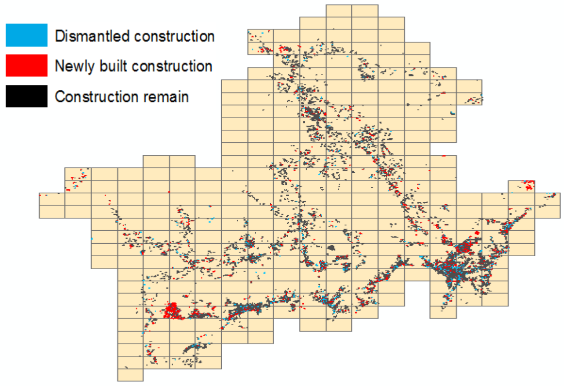
Source: Households demand survey in 2005

Figure 5: Construction change analysis in Katsuura-shi during 1997~2003



Source: Zmap town GIS data

Figure 6: Construction change analysis in Katsuura-shi during 2003~2009



Source: Zmap town GIS data

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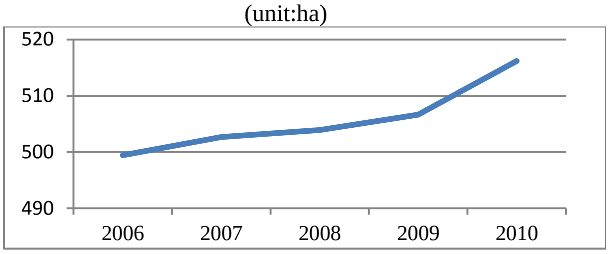
According to the land use overlay analysis during the period 1997~2003 (Figure 5), there are many new constructions built in the suburb area, and the city structure has a city sprawling pattern.

During the period 2003~2009 (Figure 6), there is still few new construction built, but many constructions have been dismantled especially the constructions near the city centre area. After city sprawling during 1997 to 2003 and construction demolition during 2003 to 2009, the structure of the city has been more dispersed than before.

Figure 7: Change in area of residential land in Katsuura-shi (unit:ha)



Source: Tax department of Katsuura local government

The population is constantly declining, but the residential area is still expanding (Figure 7), which causes even lower population density. Lots of new dwellings have been constructed, until 2003 the vacant rate of dwellings has jumped to 30.5% from 23.4% in 1993.

According to the past and current situation analysis by social and land use statistics, Katsuura-shi is a typical shrinking city. City dispersion with over low population density and large land wastage is not a sustainable way of development. As explained in the background, on one hand, new expansion in suburb occupying arable land and forest would destroy natural environment and ecosystem, at the same time leaving large brownfield, vacant houses and under-utilized infrastructure in the inner city area; on the other hand, due to over low density of population, the life quality of residents will be negatively influenced by having difficulties to get access to infrastructure and service, gradually losing the sense of community and possibly causing social segregation.

The city should be restructured. The main goals should focus on maintaining the life quality of residents as well as preserving the environment.

3.2 Policy proposal

Aiming at maintaining the life quality of residents as well as preserving the environment, the policy proposal is to concentrate population in a proper sized city area in order to achieve better residential environment with a higher density by limiting new expansion on the arable land or undeveloped land, at the same time to redevelop the existing city area by improving infrastructures and services to attract residents move back to the inner city area.

3.3 Simulation

In order to test the efficiency of policy, simulation is conducted by a land use change model based on rent-gap theory cellular automata interacting with a migration model based on multinomial logit analysis.

3.3.1 Rent-gap based cellular automata

Cellular automata is mainly based on the states of cells and the change rules.

Studied area is divided into cells (the size of the cell is 125m*125m). Land use types are defined as the states of cells including residential land, commercial land, industry land, arable land, open space, and undeveloped land.

In order to trigger development or redevelopment in the city, rent gap theory is used in the rules of cells conversion [6]. Rent gap theory utilizes essentially a measure of the difference in a site's actual value and its potential value at 'best use.' When the overall rent gap in an area is determined to be great, it is suggested that the area will undergo redevelopment as developers identify this difference as an economic opportunity on which to capitalize [7]. In the model, if the potential land value is bigger than the actual land value, then the development or redevelopment may be triggered.

$$\text{Rentgap} = \text{Potential value} - \text{Actual value} \quad (1)$$

As equation (1) shows, to calculate rent gap, actual land value and potential land value is needed. Actual land price is calculated by comparing to the published land price. The comparing conditions are divided into different levels (e.g., best, better, normal, worse, and worst) by distribution probabilities, according to the form of comparing price, the actual price of objective land can be calculated.

The potential land value is calculated by hedonic price model. Rosen (1974) defines hedonic prices as “the implicit prices of attributes and are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them” [9]. A natural logarithmic form of hedonic price model as equation (2) is used in the research.

$$\text{In}(\mathrm{p}_i) = In(x_{0i}) + \sum_{j=1}^{n} In(x_{ji}) * \beta_j + \varepsilon \quad (2)$$

where p_i is the land price of the cell i, β_j is the coefficients of the characteristic j of cell i, x_{ji} is the characteristic j of cell i , ε is the random term. Results of hedonic price model are displayed in Table 1, Table 2, and Table 3. The values of Adjusted R-squared indicate a relatively high prediction capacity in the process.

If the threshold in the Figure 10 is set 0, using the rule in Figure 10 to trigger new development, residential development starts from the cell with highest rent gap value. Figure 8 shows the 250 cells firstly triggered. The triggered new development are on the arable land and undeveloped land, that is to say, as current trend, new residential land expasion will occupy arable land and undeveloped land in the future, which fits the former land use data survey in chapter 3.1. For a city with a shrinking population, continuing to expand the residential land is obviously unsustainable.

If higher threshold to trigger new residential development on arable land and undeveloped land in Figure 10 is set （in the experiment, the threshold is set 4）, residential redevelopment near city core can be achieved (Figure 9), which indicates that in order to achieve city core redevelopment and prevent from city sprawling, government intervention to limit the new expansion in suburb like charge for higher tax for new development, at the time to cut budget to help the redevelopment in the inner city area is necessary .

Table 1: Hedonic analysis of residential price

Variable	Coef.	Std.Err.	t	P
Hospital	-0.0475	0.1262	-3.76	0.000
Common meeting place	0.1913	0.0247	7.74	0.000
Old centre	-0.0591	0.0106	-5.56	0.000
Nursery	-0.0344	0.0118	-2.91	0.002
Primary school	-0.0222	0.0143	-1.54	0.062
Middle school	-0.0379	0.0134	-2.83	0.003
Shop	-0.0144	0.0129	-1.11	0.133
Station	-0.0931	0.0120	-7.76	0.000
Population	0.1488	0.0176	8.45	0.000
CBD	-0.2153	0.01890	-11.35	0.000
Building rate	0.1532	0.0779	1.97	0.025
Distance to commercial cell	0.0365	0.0114	3.19	0.001
Distance to industry cell	0.0172	0.0106	1.63	0.052
Distance to forest cell	0.0414	0.0085	4.87	0.000
Distance to open space	-0.0196	0.0096	-2.03	0.022
Residential aggregation	0.0101	0.0204	0.49	0.311
Constant	12.2105	0.3786	32.25	0.000

Observations=824
R-squared=0.6961
Adj R-squared=0.6901

Source: Published land price in 2005

Table 2: Hedonic analysis of commercial price

Variable	Coef.	Std.Err.	t	P
Station	-0.1473	0.0301	-4.89	0.000
Population	0.8355	0.1450	5.76	0.000
CBD	-0.0468	0.1098	-0.43	0.336
Building rate	1.2915	0.7376	1.75	0.042
Distance to residential cell	-0.0645	0.0796	-0.81	0.210
Distance to industry cell	0.0946	0.0619	1.53	0.065
Distance to forest cell	0.0266	0.0513	0.52	0.303
Distance to open space	-0.0760	0.0756	-1.01	0.159
Commercial aggregation	-0.1613	0.0919	-1.76	0.041
Constant	5.9820	1.7018	3.52	0.001

Observations=103
R-squared=0.6915
Adj R-squared=0.6617

Source: Published land price in 2005

Table 3: Hedonic analysis of industrial price

Variable	Coef.	Std.Err.	t	P
Station	-0.1495	0.0672	-2.23	0.014
Population	0.0635	0.0138	4.61	0.000
CBD	-0.4254	0.0590	-7.32	0.000
Building rate	0.7874	0.3244	2.43	0.009
Distance to residential cell	0.0196	0.0493	0.40	0.346
Distance to commercial cell	0.0060	0.0508	0.12	0.453
Distance to forest cell	-0.0246	0.0331	-0.79	0.215
Distance to open space	-0.0684	0.0449	-1.52	0.066
Industrial aggregation	-0.0290	0.0331	-0.88	0.192
Constant	13.9723	0.7432	18.80	0.000

Observations=102
R-squared=0.6383
Adj R-squared=0.6029

Source: Published land price in 2005

Figure 8: Projected land use development

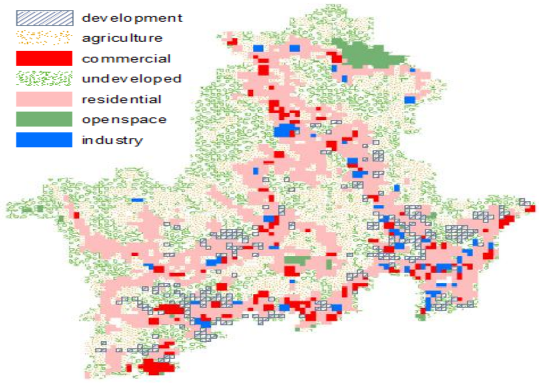


Figure 9: Land use redevelopment

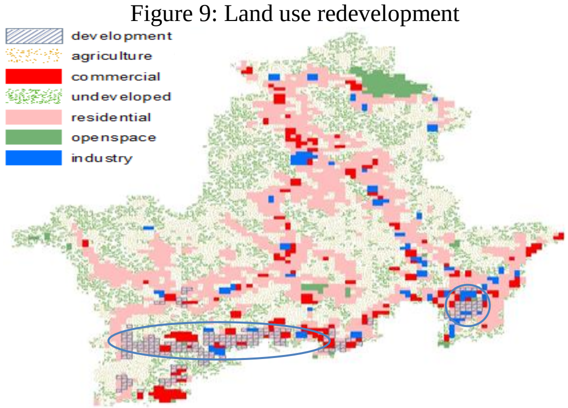


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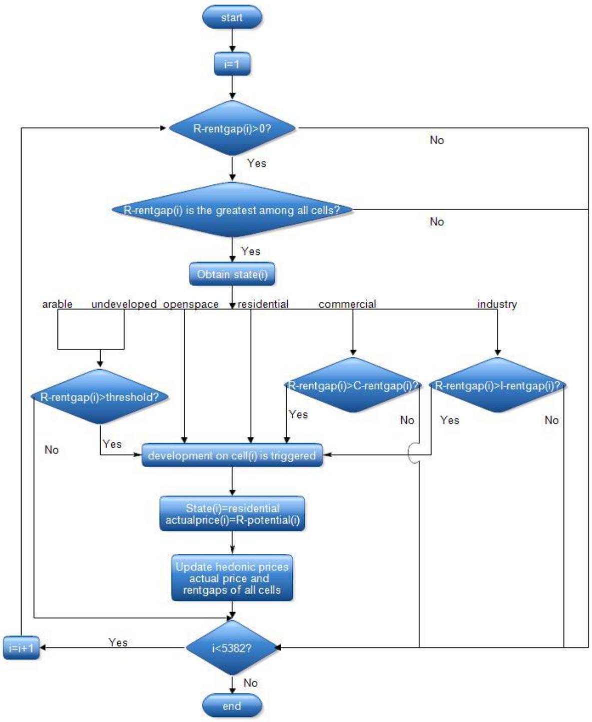
Figure 10: Flowchart of CA rule



Note: Katsuura-shi is divided into 5382 cells
R-rentgap=residential hedonic price - actualprice
C-rentgap=commercial hedonic price - actualprice
I-rentgap=industrial hedonic price - actualprice

3.3.2 Multinomial logit migration model

A migration model based on the multinomial logit model is built to predict the migration choice of residents. Let there be dependent variable categories 1, ..., J with 1 being the reference category. For k = 1, 2, ..., J, the probability is:

$$\Pr(y_i = k) = \begin{cases} \dfrac{1}{1+\sum_{j=2}^{J}\exp(x_i\beta_j)}, if\ k=1 \\ \dfrac{\exp(x_i\beta_k)}{1+\sum_{j=2}^{J}\exp(x_i\beta_j)}, if\ k>1 \end{cases} \qquad (3)$$

where y_i is the observed outcome for the ith observation on the dependent variable, x_i is a vector of the ith observations of all the independent variables, and β_j is a vector of all the regression coefficients in the jth regression.

Maximum likelihood is used for the estimation of coefficients β based on a utility function.

$$U = V + \varepsilon = X\beta + \varepsilon \qquad (4)$$

where V is the observed utility which can be described as the combination of an array of independent variables and their coefficients β, ε is the random term [8].

There are two choices in the migration model. One is to move to city core, another is to move to suburb. The samples used in the regression are 3102 households who recently relocated among 11483 surveyed households (about 27%) in the households demanding survey. Table 4 shows the result of the multinomial logit analysis. The value of Pseudo R-squared and the value of log likelihood indicate a relatively high prediction capacity in the process.

Table 4: result for multinomial logit analysis of migration choice

	Coef.	Std.Err.	Z	P
Move to city core				
Kids	-0.0122	0.2047	-0.06	0.476
Old	-0.5400	0.2927	-1.84	0.033
Oldonly	0.1414	0.5078	0.28	0.391
Persons	-0.1309	0.0617	-2.12	0.017
Safety	-0.1984	0.0836	-2.37	0.009
Sewage	2.6147	0.1469	17.8	0.000
Building rate	-0.2800	0.0875	-3.2	0.001
Hospital	-0.1593	0.0759	-2.1	0.018
Park	-0.4970	0.0662	-7.51	0.000
Union	-0.0677	0.0660	-1.03	0.153
Old center	-0.6748	0.0657	-10.27	0.000
Road	0.1260	0.0575	2.19	0.014
Bank	-0.0976	0.0697	-1.4	0.081
Railway	-0.7506	0.0718	-10.45	0.000
Nursery	-0.4403	0.1116	-3.94	0.000
Primary school	-0.7436	0.1115	-6.67	0.000
Middle school	0.2328	0.1398	1.67	0.048
Constant	12.6006	0.8754	14.39	0.000
Move to suburb				
		(base outcome)		

The reference category is move to suburb
Observations=3102
Log likelihood = -781.7175
Pseudo R2 = 0.6190

Source: households demanding survey

If randomly select 27% households to move, about 62% households will choose to move to suburb, and about 38% of households will choose to move to the near city core, which fits the phenomena that was observed in the chapter 3.1 that residents prefer to move to the suburbs.

3.3.3 Effeciencies of infrastructures improvement

In the migration model, if the accessibility to infrastructures and service has improved in near city core area, the utility to choose near city core can be higher.

In the experiment, threshold is set 4 in Figure 10 to trigger development and if development is triggered, specific infrastructure will be built within the cell, and then influence of infrastructure improvement on decision of migration will be calculated. When one cell is triggered, the decision of migration will be recalculated until all the cells have been examined.

Table 5 shows the results of change of the migration choice with residential redevelopment. In the experiment, with the residential redevelopment, the cell gets a chance to improve one specific infrastructure. According to the simulation results, investment on developing the old center will be best most effective way to change the migration pattern and revitalize

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the inner city area. The second effective way is to improve the primary school. Sewerage development which local government has the plan to develop in Okitsu and Katsuura districts is also effective. Developing park is effective within 100 redeveloped cells. Developing hospital and disaster prevention infrastructure has a little improvement for the attractiveness of inner city, while developing services like bank, post or common meeting place has no substantial effect

Table 5: Change of percentage choosing to move to city core with of residential redevelopment

	0	10	50	100	200
Sewage	38%	39.9%	43.1%	45.2%	51.3%
Nursery	38%	40.9%	45.5%	47.8%	48.8%
Old center	38%	46.2%	50.6%	54.4%	56.1%
Park	38%	39.8%	41.3%	45.1%	45.2%
Primary school	38%	41.1%	46.3%	51.6%	54.7%
Hospital	38%	40.3%	41.0%	42.1%	42.5%
Disaster prevention	38%	38.3%	38.7%	40.1%	41.2%
Bank or Post	38%	38%	38%	38%	38%
Common meeting place	38%	38%	38%	38%	38%

Note: the first line in the table shows the number of redeveloped cells; the first row shows the various infrastructures; the numbers are the percentages of households choosing moving to city core. .

4 Conclusion

According to statistical analysis, Katsuura-shi is typical shrinking city with constantly declining population but the residential area is still expanding. According to trend projection of simulation, the residents are still more willing to move to suburb and the residential land is still expanding to occupy arable land and forest in suburb, which will result in a more dispersed structure of the city.

In the simulation, residents show more interest moving to inner city. Hence, limiting new expansion on arable land or undeveloped land and improving infrastructures inner city area will be an effective way to re-concentrate the population in a right-sized city area and achieve a higher residential density.

With the comparison of the effectiveness of various infrastructures during residential redevelopment in the inner city, a possible policy strategy to manage the shrinking issue in Katsuuura-shi is that on the basis of the Katsuura local government's original plan to develop the public sewage system, developing old center for aged residents and improving nursery and primary school for young children in the inner city, at the same time preserving space for park and green land in the city core area, which will be effective ways to increase the attractiveness of inner city as well as improve the life quality of residents.

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