研　究　論　文

An Examination of the Risk of Becoming Uninhabited at the Small Area Scale: Using Data from the Web System of Small Area Population Projections for the Whole Japan

Takashi INOUE and Nozomu INOUE

The Web System of Small Area Population Projections for the Whole of Japan (SAPP for Japan) was released by the first author in 2016. The purpose of this study is to attempt an examination of the risk of becoming uninhabited at the small area scale in Japan using data from SAPP for Japan and to demonstrate its application capability through the examination. We performed the analysis by applying two logit models to the 2010 small-area census population and the projected population obtained from SAPP for Japan. We also formulated the (a) risk-of-disappearing dummy, (b) marginal-village dummy, (c) non-DID dummy, and (d) nonmetropolitan-area dummy. Variables were assigned a value of 1 if a small area satisfied one of the following four criteria, and 0 if they did not: (a)The female population aged 20-39 declines by more than or equal to 50 percent from 2010 to 2040; (b)The proportion of the population aged 65 and older in 2010 is 50 percent or more; (c)The population per square kilometer in 2010 is less than 4,000 persons; (d)The location is outside of the three major metropolitan areas including the 11 prefectures (Saitama, Chiba, Tokyo, Kanagawa, Gifu, Aichi, Mie, Osaka, Kyoto, Hyogo, or Nara). The analysis results are summarized as follows: First, the condition satisfying the marginal-village criterion is the most influential risk factor in terms of small areas' becoming uninhabited in the future. This suggests that the risk is extremely high in small areas where the population is significantly aging. Second, the condition satisfying the risk-of-disappearing criterion is also an influential risk factor for small areas. This suggests that the decline in the young female population in small areas greatly increases the risk. Third, the non-DID and nonmetropolitan-area criteria have little influence on the risk. In other words, low population density in small areas does not always increase the risk. Forth, as a result, it has been proven that SAPP for Japan has a capability for the demographic analysis.

1. Introduction

The first author released the original website of *The Web System of Small Area Population Projections for the Whole of Japan* in 2016 (Inoue 2016, 2018). "SAPP for Japan" stands for this system, which opened small-area (about 217 thousand areas), long-time (2015 - 60), and nationwide projected population of Japan for the first time on internet. This system enables us to perform various types of demographic analysis by making the most of the advantage of population forecasting on a per-small-area basis. In fact, the first author has indicated the efficacy of the system through a few demographic analyses (Inoue 2018; Inoue and Komatsu 2018; Inoue and Inoue 2018). The purpose of this study is to attempt an examination of the risk of becoming uninhabited at the small area scale in Japan using data from SAPP for Japan and to demonstrate the application capability of the system through the examination.

Regional Population Projections for Japan: 2010-2040 practiced by the National Institute of Population and Social Security (2013) assumed that population migration rates would converge to a certain extent in the future. In contrast, the Japan Policy Council (2014) assumed that migration among regions would not converge in the future and that, as a result, the young female population of 896 municipalities (49.8 percent of the total) would decrease by more than or equal to 50 percent by 2040. Of these 896 municipalities, there are 523 municipalities (29.1 percent of the total) whose population is less than 10,000. The Council designated the municipalities where the female population aged 20-39 would decrease by 50 percent or more from 2010 to 2040 as the "cities at risk of disappearing." In the meantime, Ohno (1991) advocated the new term "marginal village" for villages where more than or equal to 50 percent of the population is ages 65 and older. Marginal villages face difficulties in maintaining their functions as communities. The Rural Development Planning Commission (2006) surveyed some problems peculiar to the marginal village[1]. Several studies critically and empirically discussed the possibility that the marginal village would become uninhabited (e.g., Sakuno 2012; Yamamoto 2014).

As mentioned above, the condition of becoming a city at risk of disappearing focuses only on the young female population, and by contrast, the condition of becoming a marginal village focuses only on the elderly population. A decline in the number of young women who reproduce the population leads to a reduction in the number of children, which eventually results in population decline. Furthermore, areas with a high percentage of elderly people tend to have a relatively low production-age population, which makes it difficult to maintain the community and promotes population decline in the area. Although either of the above conditions is a factor in population decline, there are few studies that compare the two conditions in terms of their influence on increasing the risk of becoming uninhabited in Japan. This study attempts an examination of the risk of becoming uninhabited at the small area scale in Japan through a demographic analysis, specifically by applying logit models to the 2010 small-area census population and the projected population obtained from SAPP for Japan. Since this analysis demonstrates the condition that provides more explanatory factors for the risk, it is also possible to identify areas where the population will excessively decline in the future. Section 2 explains the data and specific methods used in the analysis. Section 3 describes analysis results by applying logit models. The final section summarizes the analysis results and refers to future issues.

1) Many other studies discussed problems on the marginal village (e.g., Ohno 2005, 2008; Odagiri 2009).

2. Data and Methods

This section describes the data and methods used in the analysis. Two types of data were used. The first one is the census demographic data by sex and 5-year age group on a per-small-area basis in 2010. The second one is the projected population data from the official version 2.0 of SAPP for Japan. As mentioned above, this system first offered web-based access to small-area (approximately 217,000 *cho-cho*s and *aza*s), long-term (2015 - 60), and nationwide population projections for Japan by sex and 5-year age group. Before developing this system, Inoue (2014, 2017) proposed a new method to smooth the two demographic indicators (cohort change ratio and child-woman ratio) on the analogy of the population potential by Stewart (1947). The method smooths the two demographic indicators of a small area by using those of a municipality including the small area and is written in the following equation:

$$\hat{x}_i = \frac{\sqrt{p_i}}{\sqrt{p_i}+\sqrt{P}} \cdot \frac{q_i}{p_i} + \frac{\sqrt{P}}{\sqrt{p_i}+\sqrt{P}} \cdot \frac{Q}{P}, \quad (1)$$

where p_i and q_i show the population of small area i, P and Q show the population of a municipality including the small area, and $\hat{x}_i$ denotes an estimator of demographic indicator q_i / p_i of small area i. If p_i and P show the population regarding a certain cohort at one time point and if q_i and Q show the population regarding the same cohort at another time point, both q_i / p_i and Q / P indicate a cohort change ratio. If p_i and P show the female population aged 20-39 and if q_i and Q show the population aged 0-4, both q_i / p_i and Q / P indicate a child-woman ratio. The projected population of SAPP for Japan have been calculated based on the cohort change ratio method[2] using the above two demographic indicators smoothed by Equation (1). As is well known, the population projections by this method is performed under the precondition that all cohort change ratios and all child-woman ratios at the beginning of a projection period are constant during the period[3]. Because the child-woman ratio is one of indicators showing fertility or a fertility rate, we can consider the cohort change ratio method to be a demographic technique established under the precondition that the cohort change ratio and the fertility rate are constant.

To perform the above-mentioned demographic analysis by logit models, we attempted to measure the risk of becoming uninhabited in small areas by comparing the projected 2060 population data with the 2010 census data. The analysis focused on 203,373 small areas with a population greater than or equal to 10 in 2010. According to SAPP for Japan, the proportion of those small areas to the total is 93.66 percent on a number basis, 88.22 percent on an area basis, and 99.99 percent on a population basis.

Based on four criteria, we defined four dummy variables as explanatory ones of logit models:

2) This method was formulated by Hamilton and Perry (1962) and is most usually used for small area population projections at present.

3) Under this precondition, if once an area becomes uninhabited, the area never becomes inhabited.

criteria and variables regarding the "city at risk of disappearing," the "marginal village," the non-DID[4), and the nonmetropolitan area (hereinafter referred to as risk-of-disappearing, marginal-village, non-DID, and nonmetropolitan-area criteria/dummies, respectively). The chief aim of this analysis was to compare the risk-of-disappearing criterion with the marginal-village criterion. Nevertheless, the non-DID and nonmetropolitan-area criteria were also added to generate the dummy variables in this regression, because the non-DID or nonmetropolitan-area criteria indicate a small area with low population density or a certain level of rurality, and both indicate that the small area is likely to become uninhabited. Given the above, we formulated the (a) risk-of-disappearing dummy, (b) marginal-village dummy, (c) non-DID dummy, and (d) nonmetropolitan-area dummy. Variables were assigned a value of 1 if a small area satisfied one of the following four criteria, and 0 if they did not:

(a) The female population aged 20-39 declines by more than or equal to 50 percent from 2010 to 2040;

(b) The proportion of the population aged 65 and older in 2010 is 50 percent or more;

(c) The population per square kilometer in 2010 is less than 4,000 persons;

(d) The location is outside of the three major metropolitan areas including the 11 prefectures (Saitama, Chiba, Tokyo, Kanagawa, Gifu, Aichi, Mie, Osaka, Kyoto, Hyogo, or Nara).

Table 1 represents basic statistics by groups of small areas determined according to whether they satisfied each criterion, i.e., whether each dummy variable equals 1 or 0. Every population

Table 1 Basic Statistics by Groups of Small Areas Divided by Whether Each Dummy Variable is Equal to 1 or 0

value of each dummy variable		number of small areas	total area (square kilometers)	2010 total population (1,000 persons)	2010 average population per small area (persons)	2060 total population (1,000 persons)	2060 average population per small area (persons)	population index in 2060 (2010=100)
(a) risk-of-disappearing dummy	1	64,693	106,329	20,040	310	10,512	162	52.5
	0	138,680	222,476	108,002	779	75,976	548	70.3
(b) marginal-village dummy	1	9,231	39,486	1,111	120	261	28	23.5
	0	194,142	289,319	126,932	654	86,227	444	67.9
(c) non-DID dummy	1	124,416	320,267	52,801	424	30,797	248	58.3
	0	78,957	8,537	75,241	953	55,692	705	74.0
(d) nonmetropolitan-area dummy	1	130,643	280,177	62,586	479	36,045	276	57.6
	0	72,730	48,628	65,456	900	50,444	694	77.1

4) DID (Densely Inhabited District) is a type of statistical area in Japan. Its core criterion is that the population density is more than or equal to 4,000 persons per square kilometer. For the details, please see Statistics Bureau HP. (https://www.stat.go.jp/english/data/chiri/did/1-1.html).

index at the right end in Table 1 was calculated by dividing the total population in 2060 by that in 2010, or by dividing the average population per small area in 2060 by that in 2010. The indices showed the highest value when the nonmetropolitan-area dummy = 0, indicating that the population declines relatively slowly in the metropolitan areas. On the other hand, the indices showed by far the lowest value when the marginal-village dummy = 1, indicating that the population rapidly declines in areas with a very high aging rate. Focusing on the differences in the indices, we found that the differences between the cases where dummy =1 and dummy = 0 were 17.8, 44.4, 15.7, and 19.5 percent points for the four variables, respectively, and that the marginal-village dummy displayed the largest difference (44.4). This suggests that the marginal-village criterion can most distinctly delineate extremely depopulated areas.

The above four dummy variables correspond to the explanatory ones that were input into logit models constructed in this study. Meanwhile, the objective variables of these logit models were formulated by using the above-mentioned population indices. Based on these indices, if we judged that a small area would almost or completely become uninhabited, 1 was given to the objected variables, and otherwise, zero was given to them. To decide the judgement criteria, we defined the following six stages according to the population index:

1) Stage I: index > 100;
2) Stage II: 100 index > 50;
3) Stage III: 50 index > 25;
4) Stage IV: 25 index > 10;
5) Stage V: 10 index > 0;
6) Stage VI: index = 0.

Of these six stages, only Stage I indicates that the population of small areas increase from 2010 to 2040, and only Stage VI indicates that small areas become completely uninhabited by 2040. Table 2 represents the number of small areas by value of each dummy variable and by stage. By comparing the two modes in the cases of dummy = 1 and dummy = 0 for each dummy variable, we can realize which variable is more efficient for detecting small areas with the risk of becoming uninhabited. As regards the risk-of-disappearing dummy, Stage Ⅲ and Stage Ⅱ are equivalent to the mode when dummy = 1 and dummy = 0, respectively. As regards the marginal-village dummy, Stage Ⅳ and Stage Ⅱ are equivalent to the mode when dummy = 1 and dummy = 0, respectively. By contrast, as regards the non-DID and nonmetropolitan-area dummies, Stage Ⅱ is equivalent to the mode when both dummy = 1 and dummy = 0. These facts suggest that the risk-of-disappearing and marginal-village dummies are more efficient for detecting small areas that might become uninhabited than the non-DID and nonmetropolitan-area dummies.

This study considered the following criteria to be reasonable for defining the objective variables: the first one is whether or not index = 0 (Stage Ⅵ); the second one is whether or not index 10 (Stages Ⅴ and Ⅵ) ; and the third one is whether or not index ≤ 25 (Stages Ⅳ, Ⅴ, and

Ⅵ). However, the first one was not adopted as criterion, because, as shown in Table 2, there were no areas belonging to Stage Ⅵ in the case of the risk-of-disappearing dummy = 0, and because the logit model in this case was not established. As a result, two binary variables were defined as objective one as follows: one variable shows 1 (if index ≤ 10) or zero (otherwise); and the other variable shows 1 (if index ≤ 25) or zero (otherwise). Two logit models formulated using the former and the latter variables were referred to as Model 1 and Model 2, respectively. Both of the two models include four explanatory dummy variables (the risk-of-disappearing, marginal-village, non-DID, and nonmetropolitan-area dummies).

The next section considers analysis results of Models 1 and 2 formulated in this section. Before beginning the consideration, let us have a brief discussion on relative risks through a contingency table, which we created by rearranging Table 2 based on the forms of those two logit

Table 2 The Number of Small Areas by Value of Each Dummy Variable and by Stage

value of each dummy variable		number of small areas						
		total	Stage Ⅰ	Stage Ⅱ	Stage Ⅲ	Stage Ⅳ	Stage Ⅴ	Stage Ⅵ
(a) risk-of-disappearing dummy	1	64,693	505	20,361	31,389	9,442	2,285	711
	0	138,680	5,975	90,760	39,408	2,455	82	0
(b) marginal-village dummy	1	9,231	0	59	2,076	4,387	2,037	672
	0	194,142	6,480	111,062	68,721	7,510	330	39
(c) non-DID dummy	1	124,416	2,068	54,792	53,893	10,865	2,110	688
	0	78,957	4,412	56,329	16,904	1,032	257	23
(d) nonmetropolitan-area dummy	1	130,643	1,726	58,672	57,734	9,951	1,968	592
	0	72,730	4,754	52,449	13,063	1,946	399	119

Table 3 Contingency Table with Relative Risks Regarding Categorizations 1 and 2

value of each dummy variable		total	Categorization 1			Categorization 2		
			Stages Ⅰ-Ⅳ index > 10	Stages Ⅴ-Ⅵ index ≤ 10	relative risk	Stages Ⅰ-Ⅲ index > 25	Stages Ⅳ-Ⅵ Index ≤ 25	relative risk
(a) risk-of-disappearing dummy	1	64,693	61,697	2,996	78.32	52,255	12,438	10.51
	0	138,680	138,598	82		136,143	2,537	
(b) marginal-village dummy	1	9,231	6,522	2,709	154.40	2,135	7,096	18.94
	0	194,142	193,773	369		186,263	7,879	
(c) non-DID dummy	1	124,416	121,618	2,798	6.34	110,753	13,663	6.61
	0	78,957	78,677	280		77,645	1,312	
(d) nonmetropolitan-area dummy	1	130,643	128,083	2,560	2.75	118,132	12,511	2.83
	0	72,730	72,212	518		70,266	2,464	

note: Models 1 and 2 in the next section are formulated on the basis of Categorizations 1 and 2, respectively.

models (Table 3). Every relative risk in Table 3 was calculated as a ratio of the risk in the case of dummy = 0 to that in the case of dummy = 1. For example, the relative risk (78.32) of the risk-of-disappearing dummy in Categorization 1 was given by (2,996 / 64,693) / (82 / 138,680). According to Table 3, the relative risk of the marginal-village dummy showed the highest value both in Categorizations 1 and 2. These facts strongly suggest that the marginal-village criterion (above-mentioned criterion (b)) would most distinctly delineate areas that are likely to become uninhabited.

3. Analysis Results

Table 4 shows the application results of Models 1 and 2. According to this table, the log likelihood is -7,017 and pseudo R^2 is 0.56 for Model 1; and log likelihood is -30,004 and pseudo R^2 is 0.44 for Model 2. These results revealed that Model 1 is more fitting than Model 2. Next, we focused on odds ratios obtained by converting the regression coefficients of each dummy variable. With regard to Model 1, the odds ratios were significant at the 1 percent level except that the ratio of the nonmetropolitan-area dummy was significant at the 5 percent level, and the marginal-village dummy had the highest ratio (100.08), followed by the risk-of-disappearing dummy (31.03). For Model 2, all odds ratios were significant at the 1 percent level, and as with Model 1, the marginal-village dummy had the highest ratio (61.89), followed by the risk-of-disappearing dummy (12.20).

Moreover, by adding interaction terms to Models 1 and 2, this study attempted to apply further two logit models, Models 1' and 2'. Although 6 interaction terms based on all combinations of 4 dummies (a) - (d) were input into the two models using the stepwise method, only 3 interaction terms (a)*(b), (b)*(c), and (c)*(d) were adopted as variable significant at the 5 percent level in Model 1' and only 3 interaction terms (a)*(d), (b)*(c), and (c)*(d) were adopted as variable significant at the 5 percent level in Model 2'. All odds ratios of newly added interaction terms were within a range of 0.2 - 1.2, and as a result, we understood that the interaction of those 4 dummies

Table 4 Application Results of Two Logit Models

		Model 1	Model 2
number of observations		203,373	203,373
log likelihood		-7,017	-30,004
pseudo R^2		0.56	0.44
odds ratio	(a) risk-of-disappearing dummy	31.03 **	12.20 **
	(b) marginal village dummy	100.08 **	61.89 **
	(c) non-DID dummy	1.73 **	5.29 **
	(d) nonmetropolitan-area dummy	1.15 *	1.57 **

note: *and** indicate statistical significance at the 5% and 1% levels, respectively.

was not strong as to greatly increase the risk of becoming uninhabited[5)].

The above results regarding Models 1 and 2 clarify the fact that the marginal-village and risk-of-disappearing criteria can more clearly delineate small areas at a risk of becoming uninhabited than the non-DID and nonmetropolitan-area, and in particular the marginal-village criterion increases the risk much higher than the risk-of-disappearing. This fact means that the demographic factors such as population aging and decline in female population increase the risk more than the geographical factors such as low population density and rurality, and that especially the population aging increases the risk more than the decline in young female population.

4. Conclusion

This study practiced an examination of the risk of becoming uninhabited at the small area scale by performing a demographic analysis by SAPP for Japan to demonstrate its application capability through the analysis. The analysis results are summarized as follows:

1) The condition satisfying the marginal-village criterion is the most influential risk factor in terms of small areas' becoming uninhabited in the future. This suggests that the risk is extremely high in small areas where the population is significantly aging.
2) The condition satisfying the risk-of-disappearing criterion is also an influential risk factor for small areas. This suggests that the decline in the young female population in small areas greatly increases the risk.
3) The non-DID and nonmetropolitan-area criteria have less influence on the risk. In other words, low population density in small areas does not always increase the risk.
4) As a result, it has been proven that SAPP for Japan has a capability for the demographic analysis.

As mentioned above, SAPP for Japan was developed based on the cohort change ratio method, and the method is considered to be a demographic technique established under the precondition that the cohort change ratio and the fertility rate are constant. This precondition is a minimum and necessary principle adopted commonly in every method of population projections, in other words, a general principle underlying in the population change, and therefore the above results have a possibility to hold in various situations of the population change. In SAPP for Japan, however, the population projections were performed using cohort change ratios and child-woman ratios of a specific time point, that is, the year of 2010, when in-migration into areas with a high aging rate was scarcely observed in Japan, and consequently the periodical effect caused by such the regional

5) The odds ratios of (a)*(b), (b)*(c), (c)*(d) in Model 1' and (a)*(d), (b)*(c), (c)*(d) in Model 2' were 0.2, 0.2, 0.7, 0.6, 0.3, 1.2, respectively. Of these ratios, only the value 1.2 means the interaction gave positive effects on the risk, and obviously the effect was not strong. On the other hand, the values 0.2, 0.2, and 0.3, each of which was a ratio regarding the marginal-village dummy, mean the interactions gave strong negative effects on the risk. We think that, because the marginal-village dummy showed an extremely high ratio by itself, an adjustment mechanism operated on those interactions to control the effect of the dummy.

demographic situation in 2010 might appear in the above result 1), which is the most important one. It is a future problem to evaluate the periodical effect accurately because it is beyond the scope of this paper.

This study analyzed the data only at two time points, the years 2010 and 2060; however, SAPP for Japan provides 5-year demographic data up to 2060[6)]. Therefore, in future studies, we will identify how changes occur in the analysis results by segmenting the analysis period. Moreover, the dummy variables used as explanatory variables were based only on one population structure, such as the aging rate (i.e., the proportion of the population aged 65 and over) or the decline in the female population aged 20-39. A more explanatory model would incorporate variables based on multiple demographic structures.

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6 The new version, 3.0 of SAPP for Japan was released on Jun 1, 2019, in which the forecasting period was extended up to 2065. This study used version 2.0.

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小地域スケールにおける無居住化リスクの検証
―消滅可能性都市と限界集落の基準に着目して―

井上　孝・井上　希

SAPP for Japan は，筆頭著者が2016年に公表した「全国小地域別将来人口推計システム」の略称である．本研究の目的は，SAPP for Japan のデータを用いて日本の小地域スケールにおける無居住化リスクの検証を試み，ひいてはその検証を通じて同システムの適用性を示すことである．本研究は，２つのロジットモデルを2010年国勢調査小地域人口と同システムから得られた推計人口に適用して分析を行った．その際，日本創成会議（2014）が提示した消滅可能性都市の基準，および，限界集落の基準に着目した．

２つのロジットモデルの説明変数は共通しており，４つのダミー変数「消滅可能性ダミー」「限界集落ダミー」「非 DID ダミー」「非大都市圏ダミー」からなる．これらの変数は，当該小地域が以下に述べる各基準に該当した場合に１，非該当の場合に０となる．消滅可能性ダミーの基準は消滅可能性都市の基準に相当し，2010～40年における20-39歳女子人口の減少率が50%以上となる場合である．限界集落ダミーの基準は限界集落の人口面の基準に相当し，2010年の65歳以上人口割合が50%以上の場合である．非 DID ダミーの基準は，2010年の人口密度が DID 基準未満である場合をいう．非大都市圏ダミーの基準は，三大都市圏以外に位置する場合をいう．一方，目的変数は，当該小地域の2010年人口を100とした場合の2060年人口を指数化した値に基づいて定義され，モデル１の目的変数は「指数≦10」のとき１，そうでないとき０，モデル２の目的変数は「指数≦25」のとき１，そうでないとき０がそれぞれ与えられる．いずれの場合も，目的変数が１のとき完全もしくはほぼ無居住化が達成されたとみなす．

分析の結果，モデル１では，対数尤度が-7,017，疑似決定係数が0.56，モデル２では，対数尤度が-30,004，疑似決定係数が0.44となり，モデル１の方が適合度の良いことが明らかとなった．オッズ比については，モデル１では消滅可能性ダミーが31.03，限界集落ダミーは100.08，非 DID ダミーは1.73，非大都市圏ダミーは1.15であった．モデル２では消滅可能性ダミーが12.20，限界集落ダミーは100.08，非 DID ダミーは1.73，非大都市圏ダミーは1.15であった．モデル１では非大都市圏ダミーが５％水準，それ以外のダミーが１％水準で有意であり，モデル２では全てのダミーが１％水準で有意であった．以上の結果から，無居住化リスクは，消滅可能性都市の基準よりも限界集落の基準の方が顕著に高いことが確認できた．すなわち，人口の高齢化は無居住化リスクを高める影響力が最も高いことを表している．また，若い女性の減少も無居住化リスクに影響力があることが確認できた．これに対して，非 DID 基準や非大都市圏基準は無居住化リスクに対して影響力が低かった．さらに，以上の分析を通じて，SAPP for Japan が一定の適用性を有していることが示された．