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A Time-Dependent Statistical Analysis of the Large-Scale Municipal Consolidation

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Effects of the large-scale municipal consolidation on a statistical property of urban areas in a geographical domain (a prefecture) are analyzed through rank-ordering statistics of the area data of cities. The validity of a regression model is confirmed with a residual analysis followed by Durbin-Watson testing. As specific domains, Japanese prefectures containing many cities ($n \geq 15$, where n stands for the number of cities) are considered. The results show that the rapid consolidation, which is far from being spontaneous, has indeed dealt a fatal blow to an organized whole emerging via a long-term competitive coexistence among cities in a limited domain.
Key words: Municipalization, Urban Dynamics, Self-Organized Cities, Rank-Size Rule

1. Introduction

In the natural world there exist a diversity of cellular patterns. In addition to the cosmic structure, one can find their examples in the grain system of a polycrystal, the domain structure of a ferromagnet, the aggregation of various froths, the pillared crevice of a basalt, and the cellular tissue of a plant skin (Yonezawa and Ninomiya, 1983). In ecology the pattern of space division by territories was shown to obey Voronoi statistics (Hasegawa and Tanemura, 1976). In recent years, dynamical phenomena due to urbanism have been considered to be an interesting research topic in statistical sciences, where the underlying kinematics of urban systems was studied in the context of Zipf's law (Gunther *et al.*, 1996; Zanette and Manrubia, 1997; Manrubia and Zanette, 1998; Gabaix, 1999) and of percolation theory (Makse *et al.*, 1998). Here we note that all the land regions in the world are cellularized into administrative elements. For instance, continents are composed of nations; in some nations a number of states are united; besides, modern nations such as France and Japan are divided into administrative units termed prefectures, the system of which seems to originate from Roman Empire. Of these, Japan is partitioned into 47 prefectures, each of which is composed of subunits such as cities, towns, and villages. One of the requirements for transition from a town to a city is that its population attains a prescribed level; once municipalism is realized, the inverse transition never occurs even if later the population falls below the level. For this reason, urban areas in Japan can be modeled by growing systems. Usually, the growth can be regarded as being spontaneous as well as sporadic. However, an external force due for instance to a special law concerning local municipalities could significantly promote the growth process. One may find good examples in a series of active variations due to the large-scale municipal consolidation (LSMC) that has been executing since the beginning of the present century. Actually the LSMC has yielded a large number of new cities at the sacrifice of several historied cities. At present, we should lose no opportunity of investigating effects of the LSMC on the statistical property of city aggregations in the prefectures. In this paper time-dependent properties of urban areas in Japanese prefectures are analyzed through rank-ordering statistics of the area data of cities. With this method one can identify how strongly these are organized through competitive coexistence within a two-dimensional closely packed domain (Hayata, 2003). The validity of a regression calculus is checked with a residual analysis followed by Durbin-Watson testing, which is useful for discriminating the genuine solution from the spurious solution. Typical results are shown for Japanese prefectures containing many cities.

2. Analytical Method

First, to obtain rank-ordered statistics the area data S_i ($i = 1, 2, \ldots, n$) of cities in a prefecture should be sorted with the descending order. For instance, for the system of Stage I in Table 1 they are given as

$$(X, S) = (1, 1121.12), (2, 865.02), (3, 830.36), \ldots, (34, 55.99) \quad (1)$$

where X and S (km^2), respectively, represent the rank and the area of each city. These rank-ordered data are used in the subsequent regression analysis. In this paper we concentrate on the regression of S^q versus $\log X$ (Hayata, 1997, 2003; Laherrere and Sornette, 1998),

$$S^q = a - b \log X, \quad (2)$$

where q, a, and b stand for positive parameters, and the use of the common logarithm is implied. With this relation the present regression analysis can deal with the logarithmic decay along the X axis. The rank-size rule expressible by Eq. (2) has been found for several two-dimensional nontrivial systems, the elements of which are packed in

Table 1. Sequence of analytical results for Hokkaido.

Stage	Period	n	Area (km^2)	q	$\|r\|$	d	d_L	d_U
I	1/12/'04–31/8/'05	34	14097.72	1.99	0.9852	1.303	1.18	1.30
II	1/9/'05–30/9/'05	34	14619.71	1.66	0.9886	1.984	1.18	1.30
III	1/10/'05–10/10/'05	34	15223.73	1.81	0.9870	1.932	1.18	1.30
IV	11/10/'05–31/1/'06	34	16364.38	1.53	0.9921	1.668	1.18	1.30
V	1/2/'06–28/2/'06	35	16761.67	1.49	0.9931	1.791	1.19	1.31
VI	1/3/'06–4/3/'06	35	17035.70	1.49	0.9934	1.917	1.19	1.31
VII	5/3/'06–26/3/'06	35	18042.18	1.39	0.9924	1.953	1.19	1.31
VIII	27/3/'06–	35	18539.15	1.44	0.9909	1.737	1.19	1.31

Table 2. Sequence of analytical results for Ibaraki Prefecture.

Stage	Period	n	Area (km^2)	q	$\|r\|$	d	d_L	d_U
I	1/4/'01–1/2/'02	21	2185.03	1.26	0.9882	1.159	0.97	1.16
II	2/2/'02–31/10/'02	22	2220.66	1.22	0.9895	1.195	1.00	1.17
III	1/11/'02–15/10/'04	22	2245.14	1.10	0.9869	1.521	1.00	1.17
IV	16/10/'04–30/10/'04	23	2593.52	0.77	0.9900	1.332	1.02	1.19
V	1/11/'04–30/11/'04	23	2665.64	0.76	0.9907	0.960	1.02	1.19
VI	1/12/'04–20/1/'05	23	2928.15	0.77	0.9864	1.214	1.02	1.19
VII	21/1/'05–31/1/'05	24	3025.95	0.74	0.9862	1.188	1.04	1.20
VIII	1/2/'05–21/3/'05	24	3067.50	0.80	0.9846	1.155	1.04	1.20
IX	22/3/'05–27/3/'05	25	3278.08	0.95	0.9904	1.545	1.05	1.21
X	28/3/'05–31/7/'05	26	3548.82	1.07	0.9909	1.579	1.07	1.22
XI	1/8/'05–1/9/'05	27	3696.06	1.09	0.9926	1.661	1.09	1.23
XII	2/9/'05–11/9/'05	28	3862.39	1.13	0.9931	1.648	1.10	1.24
XIII	12/9/'05–30/9/'05	28	3964.97	1.05	0.9937	1.844	1.10	1.24
XIV	1/10/'05–10/10/'05	29	4298.53	1.25	0.9906	1.352	1.12	1.25
XV	11/10/'05–31/12/'05	30	4502.43	1.34	0.9880	1.100	1.13	1.26
XVI	1/1/'06–19/2/'06	30	4566.10	1.32	0.9879	1.117	1.13	1.26
XVII	20/2/'06–18/3/'06	30	4598.09	1.33	0.9876	1.093	1.13	1.26
XVIII	19/3/'06–26/3/'06	30	4706.73	1.47	0.9890	1.038	1.13	1.26
XIX	27/3/'06–31/3/'07	32	4926.08	1.41	0.9902	1.066	1.16	1.28
XX	1/4/'07–	32	5047.72	1.35	0.9908	1.203	1.16	1.28

a constrained domain; the significance as well as the origin of the rule have already been detailed in the literature (Hayata, 2003). The validity of the present regression model can be checked by using the degree of fit, $|r|$ ($0 < |r| < 1$), together with the Durbin-Watson ratio, d ($0 < d < 4$). Here the value of $|r|$ is obtainable with the formula for calculating the Pearson's correlation coefficient (Chatterjee and Price, 1977); the Durbin-Watson ratio can be written as (Chatterjee and Price, 1977)

$$d = (n-2)^{-1} \sum_{i=1}^{n-1} (\epsilon_{i+1} - \epsilon_i)^2 \tag{3}$$

with

$$\epsilon_i = e_i/s, \quad e_i = Y_i - \hat{Y}_i, \quad s^2 = (n-2)^{-1} \sum_{i=1}^{n} e_i^2, \tag{4}$$

where $Y = S^q$; the hat upon Y indicates the point on the regression line. With level alpha test being done it can be judged that if $0 < d < d_L$ (d_L being the lower critical value) there exists a positive correlation between adjacent points on the sequence of the residual data e_i ($i = 1, 2, \ldots, n$) and that if $d_U < d \leq 2$ (d_U the upper critical value) there is no correlation between them. Note that for $d_L \leq d \leq d_U$ any judgement is impossible. Therefore, a null hypothesis that there is a correlation between the neighboring residual data is rejected solely for $d_U < d \leq 2$. (For $d > 2$, d must be replaced by $4 - d$.) For typical levels the two critical values are obtainable from numerical tables available. It should be emphasized here that this test with the ratio d is necessary for discriminating the genuine solution from the spurious solution. Throughout the present paper the level 1% test, i.e., $\alpha = 0.01$, will be adopted.

3. Results

For all Japanese prefectures with $n \geq 15$ (n being the number of cities), analyses have been made for every period of the LSMC. The requirement of the number of cities, n, comes from the applicability of the Durbin-Watson testing. As a critical value of $|r|$ we shall set to be 0.99, i.e., 99% fit. Typical results are shown in Tables 1–6 and in Figs. 1–6; up-to-date data of the prefectural geography are obtained from

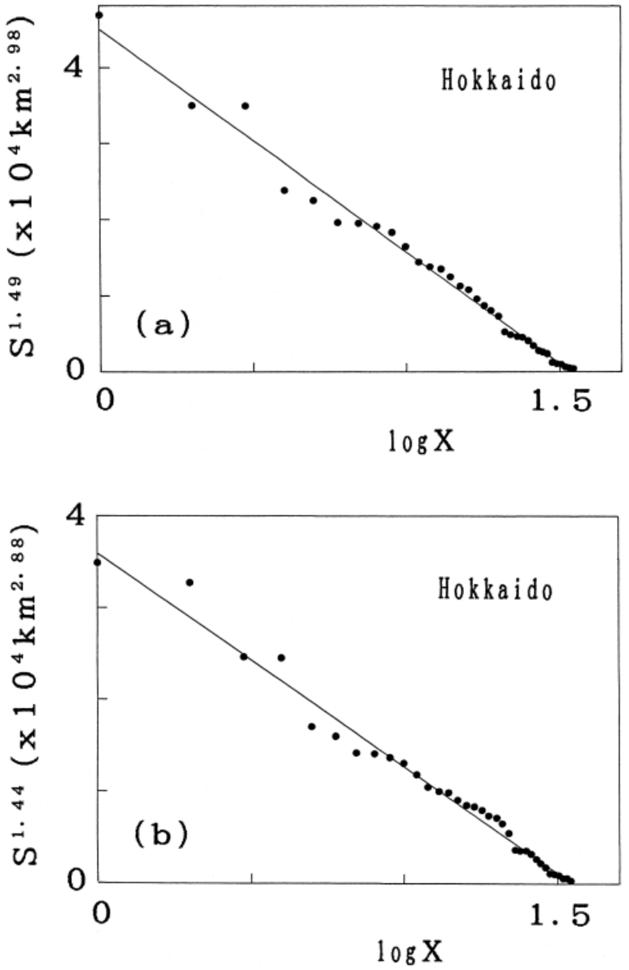

Fig. 1. Rank-ordering plot of the urban areas constituting Hokkaido. (a) Stage VI in Table 1, where $n = 35$, $(a, b) = (4.50, 2.92) \times 10^4$ km$^{2.98}$, $|r| = 0.9934$, $d = 1.917$, and $(d_L, d_U) = (1.19, 1.31)$ for level 1% Durbin-Watson test being assumed. (b) The final stage (Stage VIII) in Table 1, where $(a, b) = (3.60, 2.32) \times 10^4$ km$^{2.88}$, $|r| = 0.9909$, and $d = 1.737$; other parameters are as in (a).

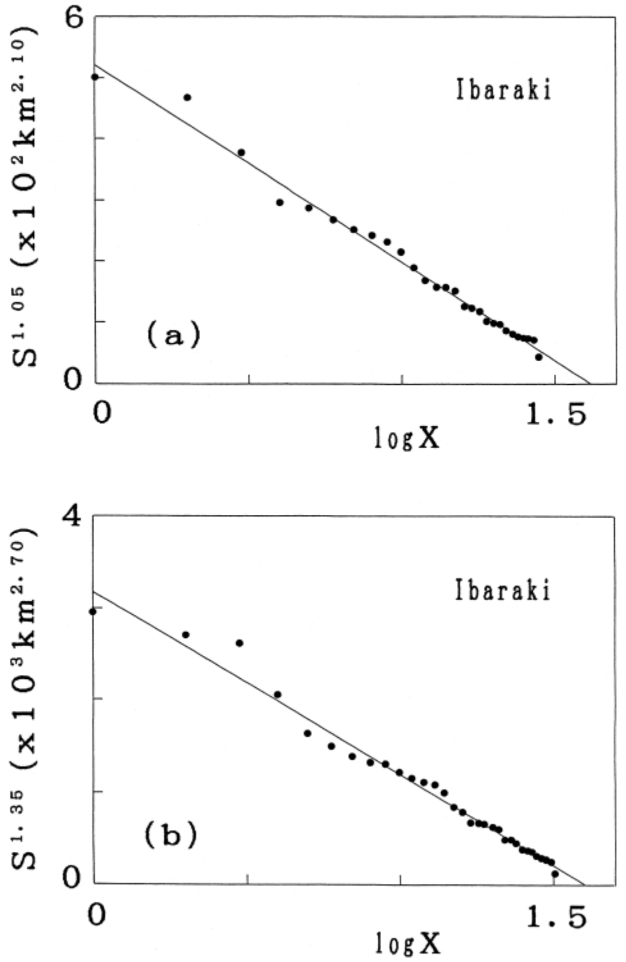

Fig. 2. Rank-ordering plot of the urban areas constituting Ibaraki Prefecture. (a) Stage XIII in Table 2, where $n = 28$, $(a, b) = (5.22, 3.22) \times 10^2$ km$^{2.10}$, $|r| = 0.9937$, $d = 1.844$, and $(d_L, d_U) = (1.10, 1.24)$ for level 1% Durbin-Watson test being assumed. (b) The final stage (Stage XX) in Table 2, where $n = 32$, $(a, b) = (3.18, 1.98) \times 10^3$ km$^{2.70}$, $|r| = 0.9908$, $d = 1.203$, and $(d_L, d_U) = (1.16, 1.28)$ for the 1% test.

source materials currently available (Yano Commemorative Association, 2005; Japan Geographic Data Center, 2006).

The results of Hokkaido, which is located at the northernmost region of Japan, are listed in Table 1. This prefecture occupies the largest area in those of Japan. Table 1 indicates that there are eight stages in the accomplishment of the entire consolidation. It can be seen from the tabularized results that throughout the entire sequence there arises no substantial variation in the numerical results, i.e., constantly $q > 1$ and $d > d_U$, which shows tolerance for perturbations due to the LSMC. As will be found in comparison between results of other prefectures, such stability could certainly be regarded as a feature unique to Hokkaido. The snapshots at Stages VI and VIII are shown in Figs. 1(a) and (b), respectively. As is seen from Table 1, Stage VI provides the best fit to Eq. (2).

The results for Ibaraki Prefecture are shown in Table 2. As is found in the table, the twenty stages are needed to finish the whole process of the LSMC. Comparison between the first (I) and the final (XX) stages indicates that the growth rate of the urban area is significant. In a series of the stages it is observable that over Stages IX–XIV the results meet the present criteria, $|r| > 0.99$ with $d > d_U$. As illustrative examples the regression results at the intermediate and the final stages, respectively, are depicted in Figs. 2(a) and (b). It should be noticed here that in the latter, $d_L < d < d_U$, signifying that for the final stage the validity of the present rank-size model is not judgeable.

In Table 2 one finds transients from the first (I) to the final (XX) stage, where nine stages contain a period within a month; in particular, Stage IX contains only six days! Indeed, in contrast to the constant growth in the number of cities (n) and in their area, throughout the transients the magnitudes of q, $|r|$, and d exhibit fluctuations. Because the municipal consolidation, in general, results from the highly political tactics among neighboring municipalities, the behavior could be regarded as being stochastic rather than being deterministic. To analyze the tactics a game theory might be useful.

The results for Saitama Prefecture are listed in Table 3. Evidently, one finds a pronounced feature of this prefecture in a number of cities coexisting in a small area. Analysis

Table 3. Sequence of analytical results for Saitama Prefecture.

Stage	Period	n	Area (km^2)	q	$\lvert r\rvert$	d	d_L	d_U
I	1/5/’01–31/12/’04	41	1894.48	0.92	0.9898	0.691	1.26	1.35
II	1/1/’05–31/3/’05	41	1953.04	0.74	0.9873	0.394	1.26	1.35
III	1/4/’05–30/9/’05	40	2397.09	0.26	0.9650	0.515	1.25	1.34
IV	1/10/’05–31/12/’05	40	2516.57	0.28	0.9703	0.579	1.25	1.34
V	1/1/’06–9/1/’06	40	2590.57	0.49	0.9654	1.042	1.25	1.34
VI	10/1/’06–	40	2643.56	0.51	0.9663	1.092	1.25	1.34

Table 4. Sequence of analytical results for Nagano Prefecture.

Stage	Period	n	Area (km^2)	q	$\lvert r\rvert$	d	d_L	d_U
I	1/9/’03–31/3/’04	17	3484.22	1.06	0.9932	1.867	0.87	1.10
II	1/4/’04–31/12/’04	18	3596.52	1.05	0.9939	2.008	0.90	1.12
				0.90	0.9936	1.993	0.90	1.12
III	1/1/’05–31/3/’05	18	3930.03	0.45	0.9881	0.903	0.90	1.12
IV	1/4/’05–30/9/’05	18	4965.76	0.62	0.9934	1.989	0.90	1.12
				0.20	0.9931	1.984	0.90	1.12
V	1/10/’05–31/12/’05	19	5630.99	0.60	0.9936	1.582	0.93	1.13
VI	1/1/’06–5/3/’06	19	5731.14	0.55	0.9902	0.909	0.93	1.13
VII	6/3/’06–30/3/’06	19	6106.41	0.93	0.9903	0.772	0.93	1.13
VIII	31/3/’06–	19	6566.58	1.91	0.9817	0.728	0.93	1.13

Table 5. Sequence of analytical results for Fukuoka Prefecture.

Stage	Period	n	Area (km^2)	q	$\lvert r\rvert$	d	d_L	d_U
I	1/4/’03–23/1/’05	24	2221.97	0.37	0.9847	0.880	1.04	1.20
II	24/1/’05–4/2/’05	25	2274.68	0.36	0.9839	0.834	1.05	1.21
III	5/2/’05–19/3/’05	25	2379.84	0.32	0.9923	0.698	1.05	1.21
IV	20/3/’05	26	2497.39	0.37	0.9919	0.579	1.07	1.22
V	21/3/’05–27/3/’05	26	2537.06	0.41	0.9895	0.473	1.07	1.22
VI	28/3/’05–10/2/’06	26	2545.20	0.42	0.9904	0.488	1.07	1.22
VII	1/2/’06–19/3/’06	27	2685.19	0.50	0.9908	0.429	1.09	1.23
VIII	20/3/’06–25/3/’06	27	2764.73	0.48	0.9926	1.009	1.09	1.23
IX	26/3/’06	27	2907.06	0.57	0.9957	1.465	1.09	1.23
X	27/3/’06–30/9/’06	27	3020.19	0.62	0.9950	1.494	1.09	1.23
XI	1/10/’06–28/1/’07	27	3079.51	0.66	0.9931	1.174	1.09	1.23
XII	29/1/’07–	28	3184.63	0.68	0.9908	0.949	1.10	1.24

of the present prefecture before the LSMC has yielded a well organized structure as shown in Fig. 3(a), i.e., $|r| = 0.9916$, $d = 1.465$, and $(d_L, d_U) = (1.27, 1.36)$ for $n = 43$. However, as soon as the consolidation occurs (see Stage I in Table 3), this structure begins to collapse. Note that the collapse continues up to the final stage (see Stage VI in Table 3). For comparison with Fig. 3(a) the cross section of Stage VI is juxtaposed in Fig. 3(b). The results of the present prefecture will be discussed in the subsequent section.

The results of Nagano Prefecture are given in Table 4, where there emerge twin solutions for Stages II and IV. It is evident from the tabular results that for Stages I to V the aggregation of cities is well organized. However, after Stage V the structure experiences an abrupt collapse. In order to provide illustrative examples, in Figs. 4(a), (b), and (c) the snapshots at Stages II, V, and VIII, respectively, are juxtaposed. Note that a transition of phase occurs at Stage III, where the magnitude of q in Eq. (2) significantly decreases.

Table 5 traces the sequence of the results for Fukuoka Prefecture. Here we find that after a long-term transient the system appears to be organized; at Stages IX and X both the values of $|r|$ and d peak. However, it can be seen that after Stage X the fit to Eq. (2) deteriorates. At the final period (Stage XII) one finds that $d < d_L$, from which we should judge that at this period the regression model of Eq. (2) is not appropriate. In illustration of the collapsing process the

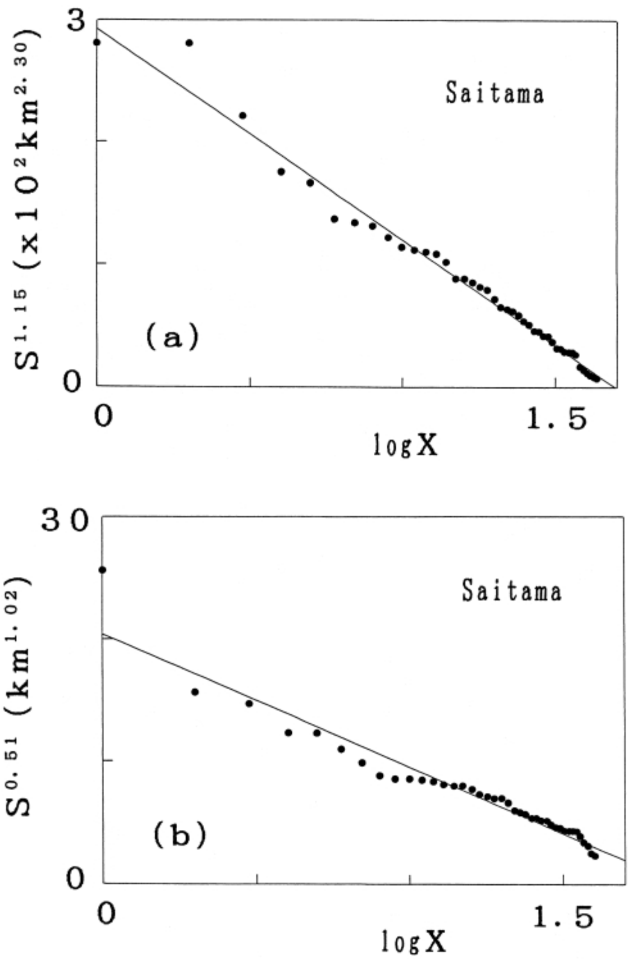

Fig. 3. Rank-ordering plot of the urban areas constituting Saitama Prefecture. (a) Distribution prior to the first stage in Table 3, i.e., the cross section at the last period (1996–2001) in Table 7, where $n = 43$, $(a, b) = (2.93, 1.73) \times 10^2$ km$^{2.30}$, $|r| = 0.9916$, $d = 1.465$, and $(d_L, d_U) = (1.27, 1.36)$ for level 1% Durbin-Watson test being assumed. (b) The final stage (Stage VI) in Table 3, where $n = 40$, $(a, b) = (20.41, 10.85)$ km$^{1.02}$, $|r| = 0.9663$, $d = 1.092$, and $(d_L, d_U) = (1.25, 1.34)$ for the 1% test.

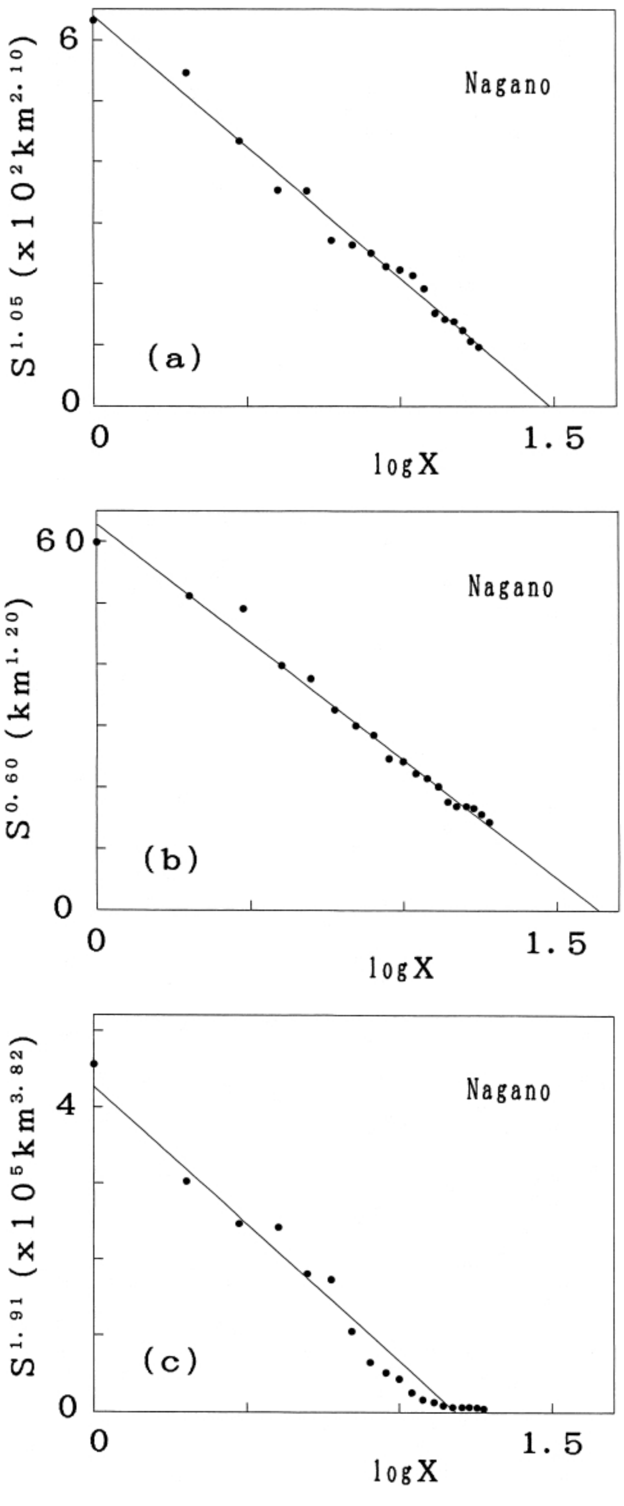

Fig. 4. Rank-ordering plot of the urban areas constituting Nagano Prefecture. (a) Stage II in Table 4, where $n = 18$, $(a, b) = (6.40, 4.30) \times 10^2$ km$^{2.10}$, $|r| = 0.9939$, $d = 2.008$, and $(d_L, d_U) = (0.90, 1.12)$ for level 1% Durbin-Watson test being assumed. (b) Stage V in Table 4, where $n = 19$, $(a, b) = (62.99, 38.36)$ km$^{1.20}$, $|r| = 0.9936$, $d = 1.582$, and $(d_L, d_U) = (0.93, 1.13)$ for the 1% test. (c) The final stage (Stage VIII) in Table 4, where $(a, b) = (4.28, 3.61) \times 10^5$ km$^{3.82}$, $|r| = 0.9817$, and $d = 0.728$; other parameters are as in (b).

cross sections in the latter three periods (Stages X–XII) are juxtaposed in Figs. 5(a), (b), and (c), respectively.

In Table 6 the results for Kagoshima Prefecture are listed, where there are two solutions for Stage I. First, one can see from the tabular results that evidently the sequence is separable into the two terms, i.e., the first (Stages I to IV, where $q < 1$) and the second group (Stages V to VIII, where $q > 1$). It thus appears that a phase transition occurs at Stage V. It is interesting to note that the behavior in the vicinity of the final stage is akin to the one in Table 5. Again, after the peak being seen at Stage III the rank-size structure is gradually destroyed. The snapshot at the final period (Stage VIII) is shown in Fig. 6(a), together for comparison with its counterpart (Fig. 6(b)), where cities on detached islands are excluded ($n = 16$). In comparison between Figs. 6(a) and (b) it could be concluded that in contrast to the former the latter result is organized. This could be explained by the smaller total urban area, which seems to be responsible for enhancing interactions between cities.

4. Discussion

From the numerical results tabulated in the preceding section, we conclude that for the greater part of Japanese prefectures the LSMC leads indeed to the collapse of ex-

Table 6. Sequence of analytical results for Kagoshima Prefecture.

Stage	Period	n	Area (km^2)	q	$\|r\|$	d	d_L	d_U
I	1/5/'05–30/6/'05	15	3318.29	0.37	0.9868	2.004	0.81	1.07
				0.53	0.9859	1.998	0.81	1.07
II	1/7/'05–10/10/'05	16	3708.68	0.60	0.9942	1.568	0.84	1.09
III	11/10/'05–6/11/'05	16	3740.24	0.56	0.9943	1.568	0.84	1.09
IV	7/11/'05–31/12/'05	16	4410.33	0.92	0.9861	1.476	0.84	1.09
V	1/1/'06–12/3/'06	17	4984.39	1.12	0.9910	1.406	0.87	1.10
VI	13/3/'06–19/3/'06	17	5086.14	1.27	0.9930	1.263	0.87	1.10
VII	20/3/'06–30/11/'07	17	5264.53	1.34	0.9934	1.048	0.87	1.10
VIII	1/12/'07–	18	5622.38	1.42	0.9927	0.975	0.90	1.12

Table 7. History of Saitama Prefecture.

Period	n	Area (km^2)	q	$\|r\|$	d	d_L	d_U
1972–1976	38	1723.75	1.22	0.9906	1.648	1.23	1.33
1976–1986	39	1763.68	1.20	0.9912	1.539	1.24	1.34
1986–1991	40	1797.63	1.18	0.9915	1.541	1.25	1.34
1991–1996	42	1862.86	1.17	0.9914	1.463	1.26	1.36
1996–2001	43	1894.48	1.15	0.9916	1.465	1.27	1.36

Table 8. History of Osaka Prefecture.

Period	n	Area (km^2)	q	$\|r\|$	d	d_L	d_U
1967–1970	28	1406.00	0.77	0.9953	1.785	1.10	1.24
1970–1971	30	1469.39	0.75	0.9951	1.624	1.13	1.26
1971–1987	31	1494.68	0.72	0.9955	1.684	1.15	1.27
1987–1991	32	1541.52	0.67	0.9948	1.551	1.16	1.28
1991–2005	33	1577.63	0.67	0.9943	1.481	1.17	1.29
1/2/'05–	33	1593.01	0.63	0.9957	1.227	1.17	1.29

isting organized structures, which would be formed spontaneously through a long-term competitive coexistence among neighboring cities. In order to discuss the collapse process we shall review the analytical results for Saitama Prefecture (Table 3 along with Figs. 3(a) and (b)). In Table 7 the results prior to the LSMC are given; the plot already shown in Fig. 3(a) corresponds to the last period (1996–2001) in the present table. It is much interesting to note that over approximately thirty years the city aggregation exhibits a well organized feature. Throughout the whole period there was no artificial disturbance such as, e.g., the annexation of a certain city to another one. The increase in the number of cities, n, arises from the sporadic generation of a new city, i.e., due to the transition from a town which had met several administrative requirements. We thus find that before the present LSMC the urban area of Saitama Prefecture had grown spontaneously, in sharp contrast to the recent growth due to the consolidation, in which highly political as well as financial motivations are dominant. Only recently have circumstances in the course of the LSMC been discussed through a voting game analysis (Suzuki, 2005). In order to reinforce the present argument, similar calculation has been performed for Osaka Prefecture, most of which is occupied by many satellite cities adjacent to a single megacity, and one may find geographic features common to Saitama Prefecture. The analytical results are listed in Table 8, where only the last peiod corresponds to the urban area after consolidation. Although the influence of the consolidation is not so drastic as that being observed in Table 3, the indication of collapse can slightly be seen. Note that at the final stage of Table 8, $d_L < d < d_U$, signifying that the appropriateness of the present rank-size model cannot be judged.

In comparison between the results in Table 7 and those in Table 8, one finds that the latter is better organized in the sense that, independent of the period, the magnitude of $|r|$ is larger than that of the former. This could be explained by noticing the fact that the ratio of the city area to the total area of Osaka Prefecture shows a value much higher than that of Saitama Prefecture. For instance, in 1999, the former attains 83% in contrast to 50% in the latter. The difference of q between Table 7 and Table 8 may be attributed to the same reason.

Besides the urban systems, similar analyses have been made for other geographic systems in the world, such as states in the United States of America ($n = 50$), nations on the Continent of Africa ($n = 53$), and those belonging to the European Union ($n = 15$), in addition to the prefectures

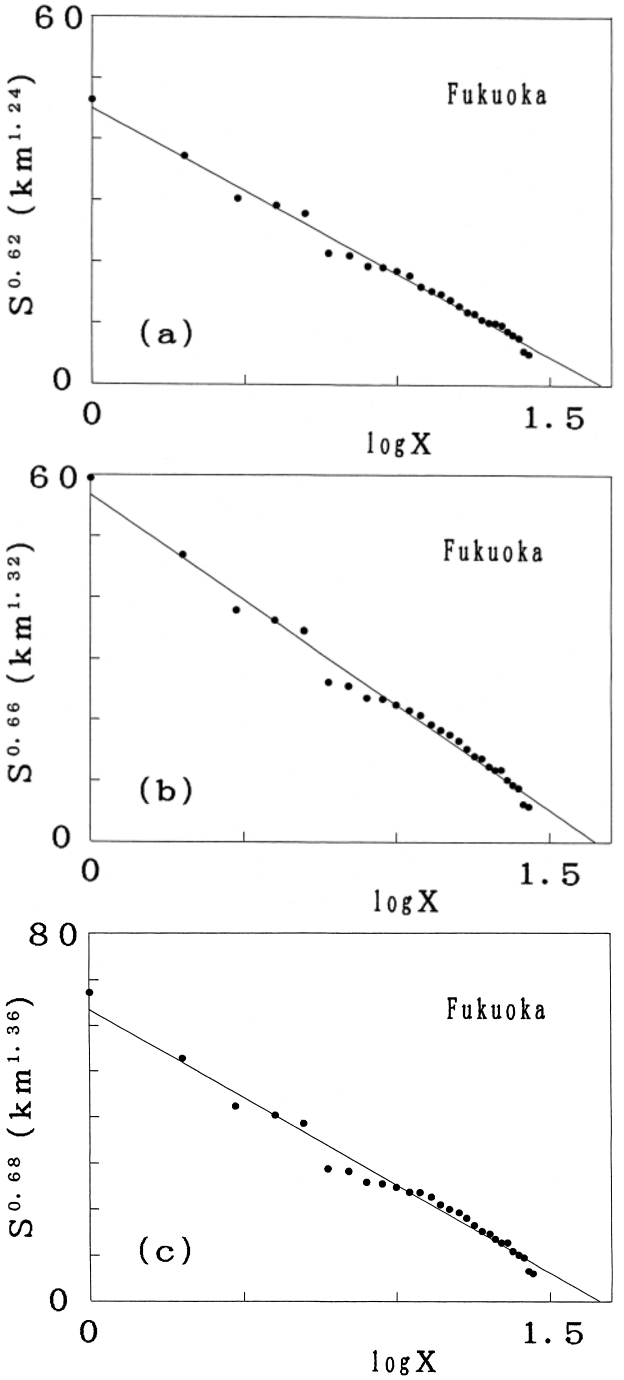

Fig. 5. Rank-ordering plot of the urban areas constituting Fukuoka Prefecture. (a) Stage X in Table 5, where $n = 27$, $(a, b) = (45.02, 26.91)$ $\mathrm{km}^{1.24}$, $|r| = 0.9950$, $d = 1.494$, and $(d_L, d_U) = (1.09, 1.23)$ for level 1% Durbin-Watson test being assumed. (b) Stage XI in Table 5, where $(a, b) = (56.85, 34.46)$ $\mathrm{km}^{1.32}$, $|r| = 0.9931$, and $d = 1.174$; other parameters are as in (a). (c) The final stage (Stage XII) in Table 5, where $n = 28$, $(a, b) = (63.50, 38.25)$ $\mathrm{km}^{1.36}$, $|r| = 0.9908$, $d = 0.949$, and $(d_L, d_U) = (1.10, 1.24)$ for the 1% test.

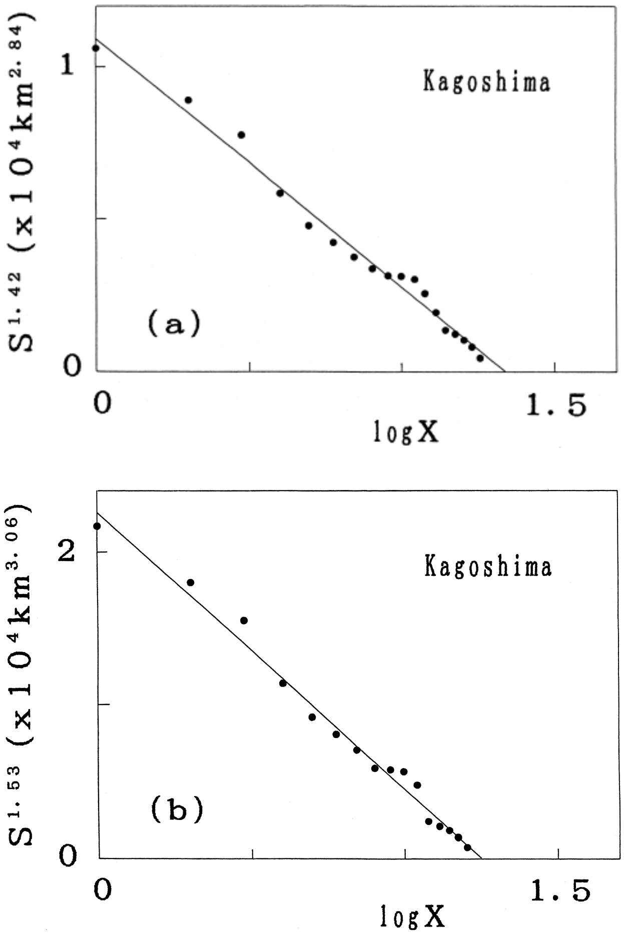

Fig. 6. Rank-ordering plot of the urban areas constituting Kagoshima Prefecture. (a) The final stage (Stage VIII) in Table 6, where $n = 18$, $(a, b) = (1.09, 0.82) \times 10^4$ $\mathrm{km}^{2.84}$, $|r| = 0.9927$, $d = 0.975$, and $(d_L, d_U) = (0.90, 1.12)$ for level 1% Durbin-Watson test being assumed. (b) The final stage but cities on detached islands are excluded, where $n = 16$, $(a, b) = (2.26, 1.80) \times 10^4$ $\mathrm{km}^{3.06}$, $|r| = 0.9934$, $d = 1.432$, and $(d_L, d_U) = (0.84, 1.09)$ for the 1% test.

themselves (not cities) in the whole of Japan ($n = 47$). The conclusion is that none of them exhibits the rank-size rule as is expressible by Eq. (2), indicating that for forming the organized whole the aggregation of elements in a limited domain is necessary. This property being confirmed for the urban system might bear some analogy, for instance, to the molecular systems, where curious physical properties could be observed through aggregation above a certain critical density.

5. Conclusion

Effects of the large-scale municipal consolidation (LSMC) on a statistical property of urban areas in Japanese prefectures have been analyzed through rank-ordering statistics of the area data of cities coexisting in the areas. The validity of a rank-size regression model has been tested by means of a correlation analysis with the Durbin-Watson ratio. The analytical results have shown quantitatively that a series of the exceedingly rapid consolidations, most of which appear far from spontaneous, have dealt a deathblow to an organized structure that would emerge through a long-term competitive coexistence among neighboring cities.

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