SPATIAL DIFFUSION OF ELECTRICITY SUPPLY COMPANIES THROUGH A SYSTEM OF CITIES IN JAPAN, 1887 - 1898

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Abstract An empirical adequacy of the proposition that innovations spread through a system of cities is examined, taking a case of Japanese electricity supply companies having opened during the years of 1887 to 1898. In order to define the system of cities operationally, the spatio-hierarchical position of each member city within the system was identified by measuring the spatial autocorrelation of population in the interaction space recovered by applying non-metric MDS to the data on interurban flows of bank remittance bills. The accessibility, which is based on the interurban connectivity relationship shown by weighting matrices for those distance zones where statistically significant, positive spatial autocorrelation was present, is correlated with the year of opening. As a result, a tenable proposition is conclusive.

1. Introduction

It is only recently that great importance has been attached to the relationship between innovation diffusion research and urban systems research. After Hägerstrand (1966)'s work pointing out that innovations spread through urban hierarchy, the study of interurban diffusion of innovation has made much of the hierarchical effect as a key concept. Pred (1973) demonstrated that innovations could spread not only hierarchically from larger to smaller cities, but also nonhierarchically from lower to higher order cities or between cities of identical order in the pretelegraphic U.S. As a result, this seems to imply a necessity to pay attention to the system of cities operating as a diffusion channel, in order to give a consistent interpretation of those different diffusion patterns. This assertion is applicable, particularly in the case of profit-motivated innovation: its adoptions of member cities are closely related to population agglomeration, information and capital flows, business cycles transmission, *etc*., which construct a system of cities as a whole.

However, a proposition that innovations spread through a system of cities has yet scarcely been substantiated quantitatively. One reason why this situation is taking place may be that systems of cities have not been operationally specified to be related to the innovation diffusion process. The term "operational" refers to elucidating the spatio-hierarchical arrangement of member cities within a system of cities by analyzing both their attributes and interrelation.

This paper is concerned with the examination of the proposition that innovations spread through a system of cities, taking the case of electricity supply companies having opened during the years of 1887 to 1898 in Japan. The timing of adoptions of electricity supply companies among major cities was directly related to population, compared with other entrepreneurial innovations such as daily paper publishing companies, gas supply companies, national banks, universities, higher (professional) schools, water service facilities, streetcar transportation systems and department stores, which had spread throughout Japan before World War II (Sugiura, 1978a). On a prefectural scale, electricity supply companies spread according to a market division principle specific to profit-motivated innovation (Sugiura, 1978b). Those findings give support to analyze the diffusion process of electricity supply companies with reference to system of cities.

2. Delimitation of the Study Period

The Japanese electricity supply industry originally began to provide a new kind of lighting to replace obsolete lighting such as paper covered lamp stands, candles, oil lamps and gas lamps, in order to improve safty and convenience, to inhibit increases in petroleum imports, and to promote the development of commerce and industry (Kotake, 1980). Although electricity supply companies had first adopted thermal power generation, the rising price of coal and technological development gradually led to the adoption of water power generation. And then, the improvement of power-transmission technology accelerated water power generation in far distant places from consumers, so that electricity generated by water power exceeded that made by thermal power, by the 1910s (Minami, 1965). A new market for electric motors was exploited to make efficient use of surplus electricity in the daytime as a result of increased production. Nevertheless, electricity consumed by motors did not exceed that used for lighting until the mid-1910s (Minami, 1965).

Taking note of both methods of power generation, and power-transmission technology, the early stages of development of the Japanese electricity supply industry can be divided into the three parts (Kurihara, 1964) : i) the intra-urban supply stage during the years of 1887 to 1898 ; ii) the short-distance transmission stage during the years of 1899 to 1906 ; iii) the long-distance transmission stage during the years of 1907 to 1913.

Only the intra-urban stage is examined here because in this period electricity supply companies provided electricity for light exclusively, and their service areas were limited to the cities concerned and their surroundings. Whereas this paper discusses the pre-industrial period when the electricity supply industry was not instrumentally involved in industrialization, each city can be defined as an innovation adopting unit.

3. Diffusion Process of Japanese Electricity Supply Companies

The first electricity supply company in Japan, the Tokyo Electric Power Company, started business in 1887. Thereafter, electricity supply companies spread among a total of 48 cities, towns and villages during the study period. Figure 1 shows the year of the opening of electricity supply companies by methods of generation. Electricity supply companies in Kobe, Osaka, Kyoto, Nagoya, Yokohama, Kumamoto and Sapporo were operating by 1891. These subsequent openings owed much to the propagating activities of the Tokyo Electric Power Company. In 1883 the Tokyo Electric Power Company tested to light in Kyoto and Osaka in advance of the creation of electricity supply companies there (Nitta, 1936). And then, after the opening of his business the president visited Kyoto and Osaka to advise businessmen to establish electricity supply companies (Nitta, 1936). The Tokyo Electric Power Company also gave technical support to newly established electricity supply companies in Kobe, Kyoto, Nagoya, Yokohama, Sapporo and Kumamoto (Nitta, 1936). This suggests a kind of information spread from the first adopter-city, Tokyo, to lower-ranking cities throughout Japan.

In 1883, a rumor spread that a fire in the Imperial Diet Building had been caused by a short circuit in the electrical wiring , and so the public began to regard electricity as dangerous (Kotake, 1980). The growth of electricity supply companies slowed down for a time following this accident (Fig.2). It was not long before this rumor was dispelled, and so electricity supply companies gradually spread to smaller cities and towns. As compared with the Tokyo Electric Power Company, which promoted the establishment of eclectricity supply companies throughout the country, the Osaka Electric Power

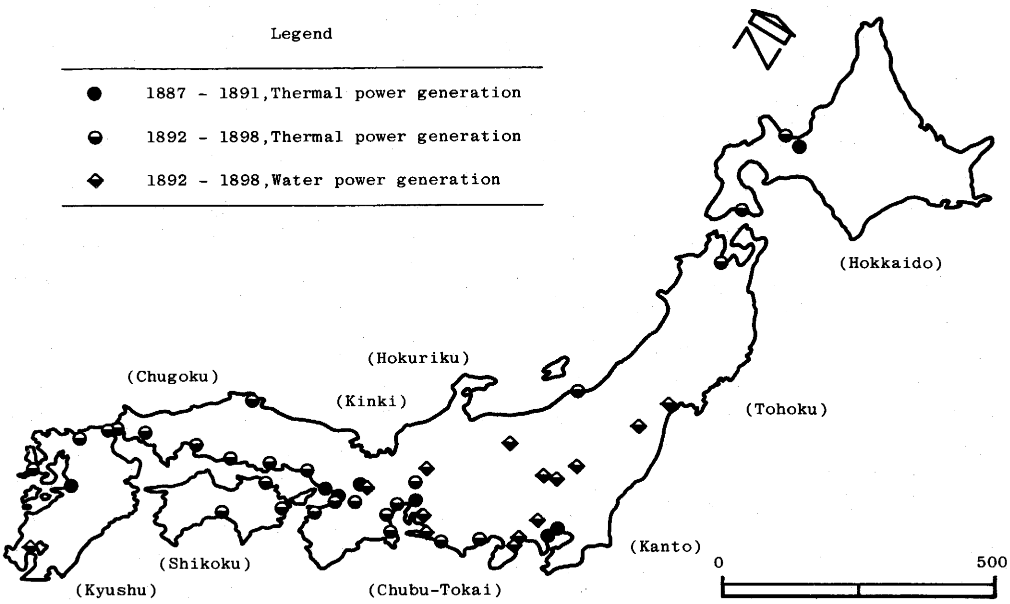

Fig. 1 The year of opening of electricity supply companies

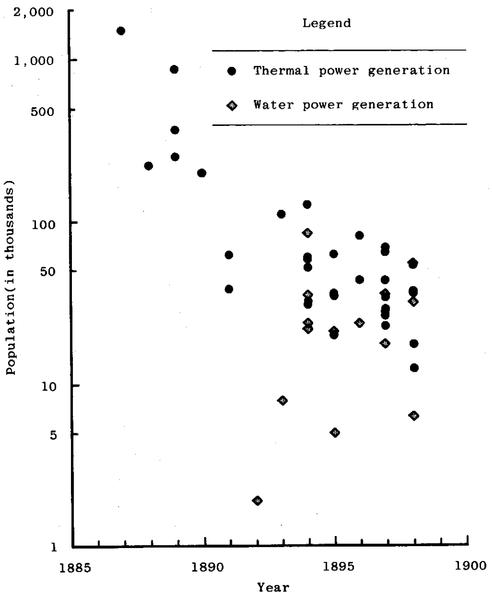

Fig. 2 Correlation between the year of opening of electricity supply companies and population of adopter-cities

Company, influenced by its Tokyo counterpart, did not receive any technical support directly, and generally sold relevant machinery and tools to electricity supply companies located in such western cities as Sakai, Nara, Wakayama, Himeji, Okayama, Hiroshima, Shimonoseki and Nagasaki (Hagiwara, 1925). This fact suggests that the Osaka Electric Power Company seems to have mainly fostered electricity supply companies in western cities.

Information spread from Tokyo and Osaka via major regional cities to lower-ranking cities and neighboring towns, for example, was demonstrated by the opening of electricity supply companies of Fukuoka and Yamaguchi, which directly received the impulse from those of Nagasaki and Shimonoseki, respectively (Toho-denryokushi-hensan'i'inkai, 1962; Chugokuchiho-denkijigyoshi-henshui'inkai, 1974). Also information searching behaviors of lower-ranking city entrepreneurs for higher-ranking cities are that of Fukushima which inspected the lighting by already-opened electricity supply company of Sendai (Fukushimashishi-hensan'i'inkai, 1974) and that of Matsue which visited to investigate already-opened electricity supply companies of such higher-order cities in western Japan as Osaka, Kobe, Okayama and Hiroshima in advance of the creation of its business management (Chugoku-chiho-denkijigyoshi-henshui'inkai, 1974).

As regards an empirical regularity, a correlation (r =-0.621**) is obtained between the year of opening in the city concerned and its population size, as of 1898, suggesting the hierarchical effect (Fig. 2). This would result from the fact that timing of adoption varies with market size in such a way that the most profitable cities are exploited first, and successively less profitable, smaller cities are developed later, in addition to the hierarchical spread of information already mentioned. And, since electricity supply companies in those days put the equipment reliance on plant imports, they could well manage, only if sufficient capital could be raised (Kurihara, 1964). Capital availability is directly related to urban size (Moseley, 1974), so that larger cities were likely to adopt electricity supply companies earlier.

Distribution of electricity supply companies as of 1898 characteristically shows a spatial pattern that they were densely located in western Japan, and sparsely located in eastern Japan (see Fig. 1): there were 18 adopter-cities in eastern Japan, while there were 30 adopter-cities in western Japan. Assuming 75 cities with populations exceeding 20,000 as of 1898 to be potential adopter-cities, this tendency becomes much clearer. Of them, 35 cities were non-adopters: 19 eastern cities and 16 western cities. For the former city group, except for the three prefectural seats of Toyama, Kanazawa and Fukui in the Hokuriku District, the only prefectural seats were Tottori, Matsuyama and Saga. For the latter city group, on the other hand, the seven prefectural seats of Morioka, Akita, Yamagata, Utsunomiya, Mito, Chiba and Kofu had not yet adopted electricity supply companies.

Such a spatial pattern seems to be caused by the following two factors in addition to the hierarchical effect. The first factor is whether generation was done through thermal power or water power. In the case of thermal power in which case coal is used as fuel, the ratio of the coal cost to the revenue or the expenditure by the electricity supply company was, on the average, about 30 % (Table 1) and likely to increase with the cost of coal. Availability of coal, therefore, could have had some influence upon the timing of opening.

For 18 electricity supply companies which purchased as fuel, coal mined in the Chikuho coalfield of the Northern Kyushu District in 1912, the relationship between distance from

Table 1 Ratio of coal cost to revenue or expenditure by electricity supply company

Electricity supply company	Year	Coal cost/ revenue(%)	Coal[1] price index
Kyoto	1889(L)	36.1[2]	125
Nagoya	1892(L)	14.0	115
	1893(L)	15.0	135
	1894(L)	24.0	146
	1895(L)	31.0	146
	1896(L)	35.0	155
	1897(L)	44.0	206
Yokohama	1893(L)	22.6	135
	1897(L)	49.3	206
Okayama	1899(F)	49.4[3]	173

(F) : The first half (L) : The latter half

1) National average coal price in 1887 is set to 100.

2) Coal cost/expenditure (%)

3) Coal cost/cost of sales (%)

that coalfield and coal price purchased is positively correlated ($r = 0.760^{**}$). It is obvious that coal prices directly varied with distance from the coalfield: the coal price purchased by the electricity supply company of Nagoya, far distant from the Chikuho coalfield amounted to about twice as much as that purchased by the electricity supply company of Wakamatsu near the Chikuho coalfield (Fig. 3).

In those days Japanese major coalfields were in Hokkaido, Nagasaki, Saga, Yamaguchi and Fukushima-Ibaraki Prefectures as well as the Chikuho and the Mi'ike coalfields in Fukuoka Prefecture. Those coalfields of the Northern Kyushu District yielded the most total coal output of Japan. Consequently, cities in the Kyushu to Kinki Districts facing the Inland Sea of Japan, to which coal could be cheaply shipped from the coalfields of the Northern Kyushu District, appear to have easily realized earlier openings of electricity supply companies by adopting the thermal power generation.

With respect to main railroads in those days, on the other hand, only the Tokaido Line leading from Tokyo to Kobe and the Tohoku Line leading from Tokyo to Aomori had been built for through traffic (Nishioka and Hattori, 1956). Especially railroad networks in the coastal areas facing the Sea of Japan and the inland areas of Honshu or the Main Island were not developed enough to carry coal. Thus the opening of electricity supply companies in the inland areas was not feasible until the technological development of water power generation. This conjecture is partly based on the fact that electricity supply companies adopting water power generation were almost located in the central to northern parts of Honshu in those days when thermal power generation dominanted electricity production (see Fig. 1).

All of the potential hydro-electric sites surveyed in 1921 being assumed to be good electrical generation sites, their prefectural density map reveals that high density areas consisted of the Hokuriku District and the inland prefectures of the central to northern parts of Honshu as if they were negatively correlated with the coalfield distribution (Sugiura, 1978b). The prefectural water mill distribution map (figure is omitted here) in 1892, which likewise suggests locations of water power resources, shows the same

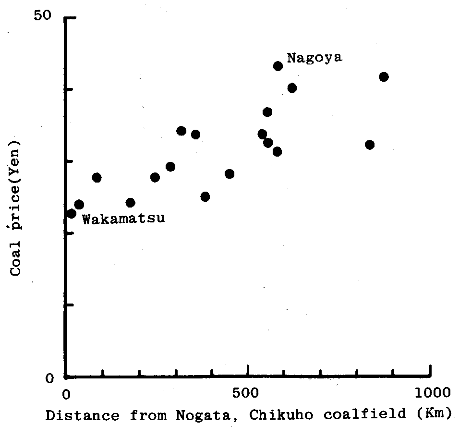

Fig. 3 Barrier effect of distance on coal price purchased

pattern: the central part of Honshu was assessed as a highly potential area for exploiting water power resources (Sueo, 1980). While water rights often intensified the water use competition between water mills and electricity generation (Sueo, 1980), locally the traditional use of water mill effectively contributed to electricity production. Hakone-yumoto is one example (Kurihara, 1964), which has deviated from the overall trend in Fig. 2 together with small towns and villages of Nikko, Atami and Gujo-hachiman. Thus, the technological development of water power generation allowed electricity supply companies to gradually trickle down to remote, smaller towns with relatively high accessibility to water power resources.

It can be pointed out that the second factor responsible for shaping the distribution of electricity supply companies as of 1898 would be accessibility to (cotton) spinning companies that had to generate their own electricity for lighting the factories. The Tokyo Electric Power Company, having given technical support to many electricity supply companies as already mentioned, also installed (cotton) spinning companies with electric lights (Nitta, 1936). In the 1900s the Japanese spinning industry came to a transitional period from the manufacture system stage to the factory system stage. While in the former stage factors such as raw cotton and water availability forced spinning companies to locate in rural areas, in the latter stage factors such as steam power, labor force and market brought them to urban areas. Therefore, (cotton) spinning companies were largely located in the Keihanshin and Chugoku Districts (Wada, 1963). Those districts bordered on the main cotton-producing areas, where coal was also easily available from the Chikuho coalfield because of the water transport allowed by the proximity to the Inland Sea. Especially, the Osaka Spinning Company's factory located in Sangenya near Osaka City was an innovative one in that it was the first large-scale mechanized factory privately adopting electric light for night lighting (Kotake, 1980). Thereafter, electric light became a condition necessary for nighttime work, so that many (cotton) spinning companies successively started generating their own electricity for lighting their factories

The extent to which electric lighting adopted by (cotton) spinning companies positively promoted the establishment of electricity supply companies is ambiguous, but at least people were certainly interested in electric lighting. For example, many people came a long way to see the electric lighting in such spinning companies as the Osaka, the Nagasaki, the Shimada, the Kurume and the Owari (Kinukawa, 1937, 1938, 1939). Of them, the Osaka Spinning Company's adoption of electric lighting became a stimulus to establish the Osaka Electric Power Company (Kurihara, 1964); the president of the Nagasaki Spinning Company himself established the Nagasaki Electric Power Company later (Kinukawa, 1938).

Engineers of the Tokyo Electric Power Company, who had installed the Okayama Spinning Company with electric lighting in 1888, so earnestly advised local businessmen to establish an electricity supply company that interested persons demonstrated lighting by using the machine owned by the Okayama Spinning Company on the streets in Okayama City in order to prepare to establish a company (Chugokuchiho-denkijigyoshi-henshui'inkai, 1974). An electricity supply company also appeared in Sendai at that time, which purchased electricity generated by the Sendai Spinning Company for lighting the factory (Tohokudenryoku-kabushikigaisha, 1960).

In any case, (cotton) spinning companies' conversion to electric lighting would have a demonstration effect on encouraging entrepreneurs to establish electricity supply companies. Provided that such a demonstration effect was supposed to be a kind of neighborhood effect, it is likely that it had a greater influence on western Japan where a lot of (cotton) spinning companies were located.

The above consideration has suggested that electricity supply companies, which were conditioned by the factors of market size, capital availability, and information flow, spread from larger to smaller cities, step by step, and that their distribution, as a result, specifically shows a spatial pattern that they were densely located in the west, and sparsely located in the east. Taking into account all the potential adopter-cities, methods of generation and accessibility to (cotton) spinning companies might account for the resultant distribution of electricity supply companies, in addition to the hierarchical

Table 2 Means of relevant variables for adopter-cities and non-adopter-cities

Variable	Adopter-city (N=40)	Non-adopter-city (N=35)	Significant difference (t-value)
Population	120,909	30,643	Yes(2.24)*
Distance from Tokyo or Osaka	228	227	No(0.03)
Distance from the nearest larger city	103	48	Yes(2.98)**
Availability of coal[1)]	0.082	-0.093	No(0.67)
Existence of (cotton) spinning companies in the prefecture (1, otherwise 0)[2)]	0.600	0.429	No(1.48)

* Significant at the 0.05 level ** Significant at the 0.01 level

1) Availability of coal is expressed numerically by the resultant 1st component score obtained through principal component analysis of the following two variables: i) binary variable representing whether coastal city or not, that is numeral of 1 is given to cities located within 20 kilometers of the coast, otherwise 0 ; ii) availability potential of coal (P_i) is defined as:

$$P_i=\sum_{j=1}^{7}\frac{C_j}{d_{ij}}$$

, where C_j is respective coal output of the Hokkaido, Fukushima-Ibaraki, Yamaguchi, Chikuho, Mi'ike, Saga and Nagasaki coalfields in 1897 (Sumiya, 1968); $d_{ij}$is distance between the i'th city and the j'th coalfield.

2) Existence of (cotton) spinning companies in the prefecture is defined as follows: numeral of 1 is given to city in the prefecture where one (cotton) spinning company or more had once been located during the years of 1887 to 1897, otherwise 0.

effect.

In order to substantiate this conjecture, first, a test of the significance of difference between means of relevant variables was performed for adopter-cities and non-adopter-cities both with populations of more than 20,000 as of 1898. Table 2 shows that there are statistically significant differences between means, only for distance from the nearest larger city and population. The magnitude of their means suggests that the farther away from the nearest larger city and the larger in population was the potential adopter-city, the higher probability to open an electricity supply company it had.

Second, a forward stepwise regression analysis was employed with the year of opening as the dependent variable. The result shown in Table 3 reveals that about 50 % of the total variation of the year of opening is explained by population and distance from the nearest adopter-city. The directions of signs of standardized partial regression coefficients indicate that the larger in population and the farther away from the nearest adopter-city was the potential adopter-city, the earlier the adoption took place there.

Those statistical analyses have revealed that the availability of coal and existence of (cotton) spinning companies were not significantly related to the opening of electricity supply companies. If what is described in relevant literature, such as histories of companies, is taken into consideration, however, these factors would locally influence the opening. It is rather population as a surrogate for urban size and distance from the nearest adopter-city or distance from the nearest larger city as a surrogate for spatial arrangement of cities, that account for adopter-city's characteristics and the timing to open. Thus, since both urban size and spatial arrangement of cities reflect the spatio-hierarchical aspect of the system of cities, it becomes necessary to examine the diffusion process with reference to the system of cities.

Table 3 Forward stepwise regression analysis of the year of opening of electricity supply companies

Variable	Correlation coefficient	Standardized partial regression coefficient
Population	-0.621**	-0.648**
Distance from Tokyo or Osaka (log)	0.481**	—
Distance from the nearest adopter-city	-0.325*	-0.371**
Availability of coal[1)]	0.137	—
Existence of (cotton) spinning companies in the prefecture (1, otherwise 0)	-0.164	—

$R^2=0.523^{**}$

* Significant at the 0.05 level ** Significant at the 0.01 level

1) Availability of coal is recalculated for all the adopter-cities. Method is the same as note 1) in Table 2.

4. Spatial Diffusion of Electricity Supply Companies with Reference to the System of Cities

Analytical framework

Population is the most universal variable directly and indirectly representing urban size or urban hierarchy, and so attribute analysis of population should be basic to urban systems research. Although studies of city-size distributions have actually paid attention to this aspect, they fail to take into account the interdependence of cities. If each city constitutes a system as a whole, member city populations can be expected to be distributed interdependently; that is spatially autocorrelated. And these interdependent relationships would result from various kinds of spatial interaction. An interurban functional relationship should be represented in a space specific to a certain spatial interaction being termed the interaction space. Therefore, when attribute analysis of population is performed on this space, it would be realized that both attribute and interrelation analyses are conducted together, as mentioned in the introduction.

In this context, the procedure in order to identify the spatio-hierarchical position of each member city within the system of cities is as follows: the interaction space is recovered by applying non-metric Multi-Dimensional Scaling (MDS) to a given interaction matrix; spatial autocorrelation of population measured on the interaction space, then, indexes the extent to which system of cities is integrated in terms of demographic attribute (Gatrell, 1979). But, so far, the spatio-hierarchical position of each member city has not yet been identified. Information contained in the coefficient matrix of spatial autocorrelation statistic could be used to attain this purpose. A connective relationship observed in the matrix is represented in the form of binary connection matrix or valued connection matrix. A kind of nodal accessibility is derived from the application of network analysis to these matrices.

Nodal accessibility derived on the basis of the spatial autocorrelation of population in the interaction space is, by convention, assumed to index the spatio-hierarchical position of each member city within the system of cities. Because nodal accessibility is measured taking into account population and spatial interaction, it follows that the higher a city's rank is within the system of cities, the greater this city's accessibility is. Because of limited data on spatial interaction, unfortunately, this paper will consider only 36 adopter-cities with 20,000 plus populations, out of 48 adopter-cities.

Recovery of interaction space

The two-dimensional interaction space defined by Euclidean geometry was recovered by applying KYST-2A to the data on interurban flows of bank remittance bills among 57 major cities as of 1899. Figure 4 shows that cities as a whole are arranged in such a way that the six largest cities lie at the center of the configuration while the remaining regional groups of cities occupy the periphery. The fact that log-transformed distance from the origin to each city's coordinates is highly negatively correlated with its log-transformed population (r =−0.880**), suggests that cities are found to be concentrically distributed according to population size.

Specifically an interpretation of two dimensions will offer detail on the nature of the interaction space. With regard to Dimension I, eastern cities of the Kanto, Tohoku, Chubu-Tokai, Hokuriku and Hokkaido Districts occupy the positive part, while western cities of the Shikoku, Kyushu, Kinki and Chugoku Districts occupy the negative part. And cities of eastern and western Japan are linked via the six largest cities near the origin of coordinates. Accordingly Dimension I distinguishes eastern Japan from western Japan.

With regard to Dimension II, cities of the Chubu-Tokai, Kinki and Kanto Districts occupy the positive part, while most of cities of the Hokkaido, Tohoku, Chugoku, Shikoku and Kyushu Districts occupy the negative part. And the six largest cities and cities of the Hokuriku District form a transitional zone from the positive to negative part. Since cities with the positive coordinate values consist of those of the Kanto to Kinki Districts in Central Japan and cities with the negative coordinate values make up the remaining ones, Dimension II may distinguish Central Japan from Peripheral Japan.

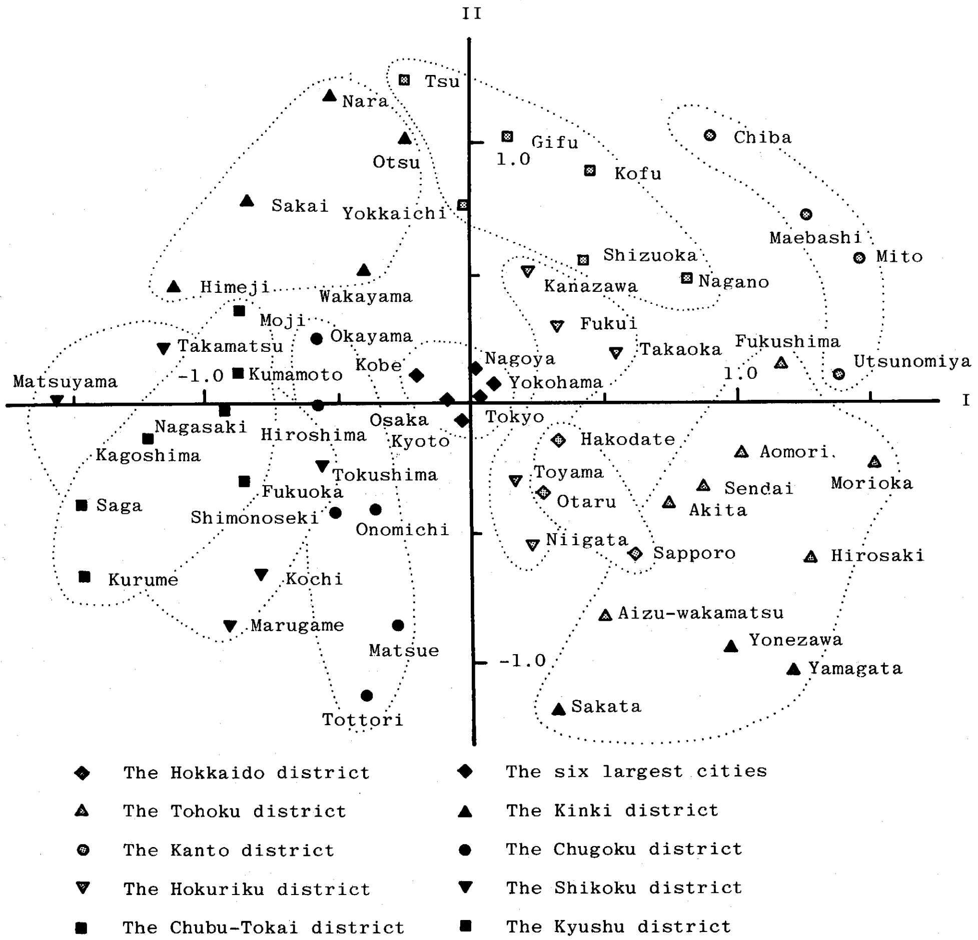

Fig. 4 Two-dimensional interaction space recovered by KYST-2A(Stress=0.219)

The interaction space where cities are arranged along two dimensions of "Eastern Japan vs. Western Japan" and "Central Japan vs. Peripheral Japan" shows, as a whole, a concentric pattern that smaller cities surround the six largest cities according to urban size.

Spatial autocorrelation of population in the interaction space

The recovered interaction space has mapped the functional relationships among cities in terms of flows of bank remittance bills. Consequently, measuring spatial autocorrelation of population on the basis of distances between cities in the interaction space shows the extent to which a set of cities as a system are interdependent. The appropriate measures of spatial autocorrelation for interval scaled data are Moran's statistic and generalized Moran's statistic (Cliff and Ord, 1973). Moran's statistic is defined as:

$$I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\delta_{ij}z_i z_j}{2A\sum_{i=1}^{n}z_i^2} \qquad (i\neq j)$$

, where n is the total number of cities; δ_{ij} is binary coefficient in which $\delta_{ij}=1$ if the i'th and the j'th cities are joined, and $\delta_{ij}=0$ otherwise; A is the total number of joints; $z_i=x_i-\bar{x}$ in which x_i is the value of the i'th city. Generalized Moran's statistic is defined as:

$$I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}z_i z_j}{W\sum_{i=1}^{n}z_i^2} \qquad (i\neq j)$$

, where w_{ij} is the weighting coefficient denoting the effect of the i'th city on the j'th city; $W=\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}$ $(i\neq j)$ in addition to previously used notation. These two statistics are applied to identify an interdependent system of cities with the aid of spatial autocorrelation values obtained.

Spatial autocorrelation of population is calculated in the following way. Provided that 57 cities constitute a system as a whole, each city should not be in an isolated state. The situation that all the cities have at least one link with others in the interaction space takes place when Chiba is connected with Kofu (see Fig. 4). The distance between these two cities is the maximum of the nearest distances between cities. This distance corresponds to 0.4642. Then, by using Moran's statistic and generalized Moran's statistic, spatial autocorrelation is measured consecutively by changing the width of distance zone by 0.01, whose initial value is set at 0.4642, until all pairs of cities are interconnected.

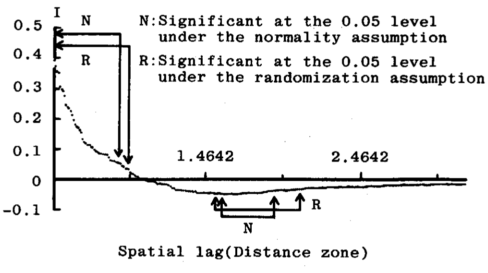

Fig. 5 Spatial correlogram for Moran's statistic

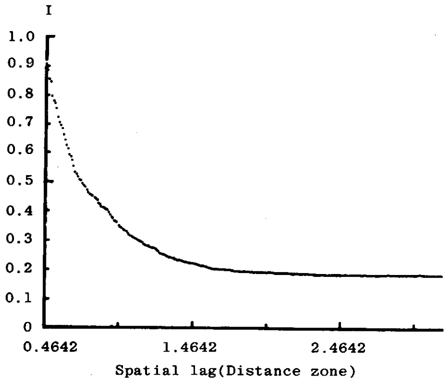

Fig. 6 Spatial correlogram for generalized Moran's statistic
(All the generalized Moran's statistics are statistically signicant at the 0.01 or 0.05 level under both the normality and randomization assumptions.)

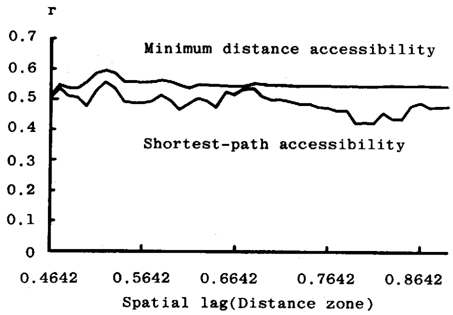

Fig. 7 Correlation coefficients between the year of opening of electricity supply companies and accessibility by distance zone
(All the correlation coefficients are statistically significant at the 0.01 or 0.05 level.)

Coefficient matrices of both the statistics are defined as follows: 1) in the case of Moran's statistic, δ_{ij} is set at 1 if any pair of two cities is located apart within a given distance zone, and $\delta_{ij}=0$ otherwise; 2) in the case of generalized Moran's statistic, w_{ij} is set at $1/d_{ij}$, where d_{ij} denotes the distance between the i'th and the j'th cities if any pair of two cities is located apart within a given distance zone, and $w_{ij}=0$ otherwise.

In this way, the spatial correlogram for Moran's statistic is constructed as shown in Fig. 5. The values of I gradually decrease as spatial lag increases. Under the normality assumption the minimum positive value of I, 0.056, statistically significant at the 0.05 level for a two-tailed test is detected in the distance zone of 0.8942, while under the randomization assumption the minimum positive value of I, 0.035, statistically significant at the 0.05 level for a two-tailed test in the distance zone of 0.9542. Negative spatial autocorrelation statistically significant under both assumptions is detected in some distance zones, but it would be appropriate to assume that there are meaningful interdependent relationships among cities only in the distance zones where population exhibits positive spatial autocorrelation statistically significant.

Figure 6 shows the spatial correlogram for generalized Moran's statistic. The values of I gradually decrease and converge as spatial lag increases. Positive spatial autocorrelation statistically significant at the 0.05 level for a two-tailed test is detected in all the distance zones under both assumptions.

Empirical test of diffusion through system of cities

Provided that the interurban connectivity relationships shown by δ_{ij}- and w_{ij}- matrices for those distance zones where there exists statistically significant, positive spatial autocorrelation could be represented in the form of a connectivity matrix or a valued connectivity matrix, member city's accessibility within the system of cities is derived from the graph-theoretic matrix multiplication. Accessibility is measured for those distance zones of 0.4642 to 0.8942 where statistically significant, positive spatial autocorrelation is present commonly under both the randomization and normality assumptions for both Moran's statistic and generalized Moran's statistic. And it is assumed that the accessibility most highly correlated with the year of opening is the index expressing the spatio-hierarchical position of each member city within the system of cities. Two types of accessibilities are calculated: the shortest-path accessibility and the minimum distance accessibility.

After computing two kinds of accessibilities for 57 major cities, correlations were obtained between the year of opening and these accessibilities for 36 adopter-cities. The results are shown in Fig. 7: there exist statistically significant correlations for each accessibility through the distance zones. The minimum distance accessibility in the distance zone of 0.5242 shows the highest correlation ($r = 0.596$**) with the year of opening. It is assumed that this accessibility best represents member city accessibility within the system of cities. The correlation coefficient of 0.596 suggests that diffusion of electricity supply companies is, to some extent, structurally related with the system of cities as a diffusion channel. Thus it is evident that a proposition that electricity supply companies spread through the system of cities appears to be plausible. However, the correlation is not so high. Rather, the year of opening is more highly correlated with log-transformed population ($r = -0.787$**). How shall we interpret this result?

Apart from a technical problem to define connection or weighting matrices of spatial autocorrelation statistic, one explanation may be attributed to the fact that the system of cities in those days was not integrated enough to allow innovation to spread smoothly (Narita, 1971). Comparing rankings of cities according to population and the minimum distance accessibility, on the other hand, another explanation can be provided. As shown in Table 4, population ranking is congruent with accessibility ranking in that the six largest cities occupy the higher-ranking, but except for those cities, the former ranking has varied from the latter too considerably to detect a certain tendency. Classifying 57 cities into adopter-cities and non-adopter-cities, however, reveals a distinctive fact: non-adopter-cities tend to be more concentrated in the lower ranks of accessibility than are observed for population; the 46th and lower-ranking cities entirely consist of non-adopter-cities in the case of accessibility ranking.

Consequently, the following inference derives itself from this finding: although electricity supply companies spread through the system of cities, adopter-cities were limited to a certain ranking of cities, and over, in terms of accessibility; and their actual opening timing mainly depended on population size. This inference would suggest that market size is the critical factor for the opening of electricity supply companies. The role which the system of cities played in the diffusion process of electricity supply companies is to distinguish between adopter-cities and non-adopter-cities.

In accepting the above interpretation, it would be very peculiar that electricity supply companies did not open in cities of the Hokuriku District at all. While according to population ranking, Kanazawa, Toyama and Fukui have occupied the 1st to 3rd ranks among non-adopter-cities, according to accessibility ranking they have constituted the higher-ranking within the system of cities together with Takaoka. Provided that the preceding inference is correct, electricity supply companies should have opened in those

Table 4 Comparative ranking of cities according to population and the minimum distance accessibility in the distance zone of 0.5242

Population Rank	City	Minimum distance accessibility Rank	City	Population Rank	City	Minimum distance accessibility Rank	City
1	Tokyo	1	Tokyo	30	Himeji	30	Sendai
2	Osaka	2	Osaka	31	(Hirosaki)	31	Gifu
3	Kyoto	3	Yokohama	32	Matsue	32	Takamatsu
4	Nagoya	4	Nagoya	33	Maebashi	33	Himeji
5	Kobe	5	Kyoto	34	Takamatsu	34	Kochi
6	Yokohama	6	Kobe	35	Otsu	35	(Aizu-wakamatsu)
7	Hiroshima	7	Hakodate	36	(Mito)	36	Sakai
8	Nagasaki	8	(Fukui)	37	Tsu	37	Aomori
9	(Kanazawa)	9	(Toyama)	38	(Morioka)	38	Kagoshima
10	Sendai	10	Otaru	39	(Saga)	39	Otsu
11	Hakodate	11	Hiroshima	40	(Utsunomiya)	40	Matsue
12	Fukuoka	12	Okayama	41	Gifu	41	Fukushima
13	Wakayama	13	(Kanazawa)	42	(Takaoka)	42	Nara
14	Tokushima	14	(Takaoka)	43	Nagano	43	Tsu
15	Kumamoto	15	Wakayama	44	(Yonezawa)	44	(Marugame)
16	(Toyama)	16	Onomichi	45	Nara	45	Maebashi
17	Okayama	17	Tokushima	46	(Akita)	46	(Yonezawa)
18	Otaru	18	Shizuoka	47	(Aizu-wakamatsu)	47	(Chiba)
19	Kagoshima	19	Shimonoseki	48	(Kurume)	48	(Utsunomiya)
20	Niigata	20	Niigata	49	(Tottori)	49	(Hirosaki)
21	Sakai	21	Yokkaichi	50	Aomori	50	(Matsuyama)
22	(Fukui)	22	Kumamoto	51	(Chiba)	51	(Saga)
23	Shimonoseki	23	Nagasaki	52	(Moji)	52	(Morioka)
24	Shizuoka	24	(Moji)	53	Yokkaichi	53	(Tottori)
25	(Kofu)	25	(Akita)	54	(Marugame)	54	(Mito)
26	Sapporo	26	Sapporo	55	Onomichi	55	(Sakata)
27	(Matsuyama)	27	Fukuoka	56	(Sakata)	56	(Yamagata)
28	Kochi	28	Nagano	57	Fukushima	57	(Kurume)
29	(Yamagata)	29	(Kofu)				

Cities in parentheses are non-adopter-cities.

cities. After the study period, electricity supply companies or their branches opened there with water power generation except in the case of Takaoka which relied on thermal power generation (Shoji, 1958). Since the Hokuriku District is situated nearly between the coalfields of the Northern Kyushu and Hokkaido Districts, distance as barrier would partly impede coal transportation, and retard the opening of electricity supply companies.

Furthermore, concerning (cotton) spinning company locations, there were no companies in the Hokuriku District except for the Takaoka Spinning Company, and therefore people seem to have had few chances to be exposed to factories with electric lighting. Although statistical analyses in Chapter 3 have revealed that methods of generation or accessibility to (cotton) spinning companies did not systematically condition the opening of electricity supply companies, it may well be that these factors had influenced the smooth diffusion of electricity supply companies through the system of cities. In addition, the fact that electricity supply companies had not yet opened in the Hokuriku District during the study period, appears to be attributed to its relatively scarce entrepreneurship (Chiba, 1964).

5. Concluding Remarks

Innovation diffusion research has a proposition that innovations spread through a system of cities. A recent expansion of this proposition has led to a view that innovation diffusion research is a sub-field of urban systems research analyzing the relationship between elements constituting the system of cities. This proposition is, however, not sufficiently confirmed to support such a view. This paper has examined an empirical adequacy of the above proposition, taking the case of electricity supply companies having opened during the years of 1887 to 1898 in Japan.

As regards 48 cities where electricity supply companies opened during the study period, a certain correlation was obtained between the year of opening in the city concerned and its population : it is likely that the hierarchical diffusion resulted from such factors as market potential and capital availability as well as information flow. On the other hand, taking into account as potential adopter-cities non-adopter-cities with populations greater than 20,000, the resultant distribution of electricity supply companies as of 1898 suggests that there are two factors in addition to the hierarchical effect, which may account for the pattern: methods of generation and accessibility to (cotton) spinning companies which had to generate their own electricity for lighting factories. Statistical analyses using relevant variables have, however, revealed that the adopter-city's characteristics and the timing of its adoption are explained mainly by urban size and spatial arrangement of cities.

Given these results, 36 adopter-cities with 20,000 plus populations out of 48 adopter-cities were chosen to examine the diffusion process with reference to the system of cities. In order to define the system of cities operationally, the spatio-hierarchical position of each member city within the system was identified by measuring the spatial autocorrelation of population in the interaction space. The two-dimensional interaction space was recovered by applying non-metric MDS to the data on interurban flows of bank remittance bills among 57 major cities. Both Moran's statistic and generalized Moran's statistic were applied to measure the spatial autocorrelation of population by distance zone or spatial lag in the interaction space. Two kinds of accessibilities were calculated from the interurban connectivity relationships shown by δ_{ij}-and w_{ij}-matrices for those distance zones where statistically significant, positive spatial autocorrelation was present.

As a result, the minimum distance accessibility in the distance zone of 0.5242 has shown the highest correlation with the year of opening, thus best representing member city accessibility within the system of cities. Judging from the results that this accessibility is correlated with the year of opening and that most non-adopter-cities occupy lower-ranking of accessibility, it can be concluded that a proposition that innovations spread through a system of cities is tenable to a great extent.

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(* in Japanese, ** in Japanese with English abstract)