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"A Reconsideration of the NAS-Rule from an Industrial Agglomeration Perspective"

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A Reconsideration of the NAS Rule from an Industrial Agglomeration Perspective

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Abstract

An empirical regularity designated as the *Number-Average Size* (NAS) *Rule* was first identified for the case of Japan by Mori, Nishikimi and Smith [71], and has since been extended to the US by Hsu [50]. This rule asserts a negative log-linear relation between the number and average population size of cities where a given industry is present, i.e., of industry-choice cities. Hence one of its key features is to focus on the presence or absence of industries in each city, rather than the percentage distribution of industries across cities. But despite the strong empirical regularity of this rule, there still remains the statistical question of whether such location patterns could simply have occurred by chance. Indeed, chance occurrences of certain industry-choice cities may be quite likely if, for example, one includes cities where only a single industrial establishment happens to appear. An alternative approach to industry-choice cities is proposed in a companion paper, Mori and Smith [73], which is based on *industrial clustering*. More specifically, this approach utilizes the statistical procedure developed in Mori and Smith [72] to identify spatially explicit patterns of agglomeration for each industry. In this context, the desired industry-choice cities are taken to be those (economic) cities that constitute at least part of a significant spatial agglomeration for the industry.

With respect to these *cluster-based industry-choice cities*, the central objective of the present paper is to reconfirm the persistence of the NAS Rule between the years 1981 and 2001, as first observed in Mori et al. [71]. Indeed the NAS Rule is in some ways stronger under this new definition of industry-choice cities in that *none* of outlier industries in the original analysis show any significant agglomeration, and hence can be excluded from the present analysis. A second objective is to show that there has been a substantial churning of the industry mix in individual cities between these two time periods, and hence that persistence of the NAS Rule is even more remarkable in this light. Finally, these persistence results are extended to both the Rank Size Rule and the Hierarchy Principle of Christaller [13], which were shown in Mori et al. [71] to be intimately connected to the NAS Rule.

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1 Introduction

Japan experienced rapid urbanization after the World War II as indicated, for example, by the fact that the population share of *densely inhabited districts* (DID),[1] nearly doubled between 1950 and 2000 from 34.9% to 65.2%, while accounting for only 3.3% of the national land.[2] Moreover, this rapid urbanization does not appear to be a simple proportional increase of economic activities in all urban areas. Rather, the spatial distributions of industries and population within the 258 metro areas (cities) of Japan are quite skewed. The population of the largest city, Tokyo, exceeded 30 million in 2000 and accounted for more than a quarter of the national population. The ten largest cities together accounted for more than a half of the national population. Moreover, if the *industrial diversity* of a given city is defined in terms of the number of industries exhibiting significant agglomeration within that city (see Section 3.2 below), then the population sizes of cities also appear to be highly correlated with their industrial diversities (see Section 4.2 below).

Against this background, our main interest is to ask whether these skewed spatial distributions of industries and population exhibit any clear relationship, or whether they might simply have happened by chance. In Mori, Nishikimi and Smith [71], a strong empirical regularity was identified between the size and industrial composition of cities in Japan. This regularity, designated as the *Number-Average Size* (NAS) *Rule*, asserts a negative log-linear relation between the number and average population size of those cities where a given industry is present, i.e., of the *choice cities* for that industry. More recently, this same regularity (with comparable definitions of industries and cities) has been reported for the US by Hsu [50].

But despite the strong empirical regularity of the NAS Rule, there still remains the statistical question of whether such location patterns could simply have occurred by chance. Of particular importance here is the focus of this rule on the presence or absence of industries in each city, rather than on the percentage distribution of industries across cities. Indeed, chance occurrences of certain choice cities may be quite likely if, for example, one includes cities where only a single industrial establishment happens to appear. Hence there is a need to clarify exactly what constitutes a *substantial industrial presence* in a given city. While it is possible to characterize "substantial" in terms of some threshold number or share of industrial establishments or employment, such conventions are necessarily ad hoc. Hence an alternative approach is proposed in a companion paper, Mori and Smith [73], which characterizes "substantial" in terms of significant industrial agglomeration. More specifically, this approach utilizes the statistical procedure developed in Mori and Smith [72] to identify spatially explicit patterns of significant clustering (agglomeration) for each industry. In this context, the desired choice cities for each industry are taken to be those (economic) cities that share at least part of a significant spatial cluster for the industry, and are hence designated as *cluster-based choice cities*.

With this new definition, it is shown in Mori and Smith [73] that the NAS Rule not only

[1] Densely Inhabited Districts are defined in the Population Census of Japan [54, 55] as a geographic areas having a residential population of at least 5,000 with a population density greater than $4{,}000/km^2$. These DIDs are also used in the World Urbanization Prospects [96] definition of "urban shares" of population.

[2] A similar drastic urbanization has been observed, for example, in South Korea where the "urban share of population" nearly quadrupled from 21.4% in 1950 to 79.6% in 2000. The corresponding percentages for the US, Western Europe and Eastern Asia are from 64.2% to 79.1%, 63.8% to 75.3%, and 16.5% to 40.4%, respectively.

continues to hold for Japan, but in some ways is even stronger. In particular, the few industrial outliers identified for the NAS Rule in the original analysis of Mori et al. [71] are here shown to be *without exception* industries for which no significant spatial agglomerations can be identified. Hence these results serve to suggest that the NAS Rule may in fact be an observable consequence of underlying coordination between spatial agglomerations of industry and population.

But unlike the original analysis in Mori et al. [71] the NAS Rule in Mori and Smith [73] is only examined for the year 2001. Hence there remains the question of whether this rule continues to exhibit the same *persistence* over time that was seen in the original analysis. The results for 1981 have now been completed,[3] and indeed confirm persistence of the NAS Rule over this twenty-year period. Hence the main objective of the present paper is to develop these new results and to compare them with the original analysis in Mori et al. [71].

This persistence is particularly remarkable given that it does not arise from simple proportional growth, such as a proportional increase in the number of cluster-based choice cities across industries, or a proportional increase in the average sizes of these cities. On the contrary, there has been a substantial *churning* of these choice cities across industries (as developed in Section 3.4 below).

It was also shown in Mori et al. [71] that there is an intimate theoretical connection between the NAS Rule and both the classical Rank Size Rule for cities and Christaller's [13] Hierarchy Principle for industrial location behavior. Hence a final objective of the present paper is to analyze the persistence of these two additional regularities with respect to cluster-based industry-choice cities over the given twenty-year period.

To develop these results, we begin in the next section with an overview of both the city and industry data employed in this analysis. Section 3 then focuses on cluster-based choice cities (and cluster-based choice industries), as constructed in Mori and Smith [73]. These cities are analyzed both with respect to their relative employment concentrations and their key churning properties with respect to industry mix. This is followed in Section 4 with a review of the NAS Rule itself, and a presentation of the new findings of persistence. In the same section, this pattern of persistence is extended to both the Hierarchy Principle and Rank Size Rule. Finally, the paper concludes in Section 5 with a brief discussion of ongoing work and directions for further research.

2 Data

The data used in the present analysis is very similar to that used in the original two-period analysis of Mori et al. [71]. Hence in the discussion below we focus on the differences between the two. We begin with city data and then consider industrial data.

[3] This involved restricting the admissible set of industries to those which are comparable between the two time periods, It should also be mentioned here that several months of computer time were required to generate sufficient "random" cluster patterns for testing the significance of agglomerations in each of these observed industrial location patterns.

2.1 Cities

The basic regional units in the present study used to identify both economic cities and industrial agglomerations are *municipalities*. The 3230 municipalities used in Mori et al. [71] were based on data in 2000. In the present paper, the municipality boundaries in 2000 are converted to the latest definition in 2001, creating certain minor differences. More importantly, the 13 "major municipalities" (such as Tokyo, Osaka, Nagoya and Kyoto) have been divided into their individual "wards", which are comparable in size to most other municipalities. This increases the total to 3363 as of October 1, 2001. Finally, since industrial agglomerations are identified in terms of road-network distances (see Section 3.1 below), we focus on the 3207 municipalities that are *geographically connected to the major islands of Japan (i.e., Honshu, Hokkaido, Kyushu and Shikoku) via a road network* (refer to Figure 1). The excluded municipalities account for only 1.6% of the total population in both 1980 and 2000, and should not have a significant effect on the analysis.

Figure 1 here

In terms of these basic regional units, an (*economic*) *city* is formally defined to be an *Urban Employment Area* (UEA), as proposed originally by Kanemoto and Tokuoka [58]. Each UEA is designed to be an urban area of Japan that is comparable to the Metropolitan Areas (MA) of a Core Based Statistical Area (CBSA) in the US (see U.S. Office of Management and Budget [79] for the definition of a CBSA). Hence each UEA consists of a core set of municipalities designated as its *business district* (BD) together with a set of *suburban municipalities* from which workers commute toward the BD. Following Kanemoto and Tokuoka [58], UEAs are constructed as aggregations of municipalities by a recursive procedure that is detailed in Mori et al. [71]. Basically this construction starts with a large "seed" municipality, designated as the *central municipality* of the UEA. This in turn is extended to a BD and an appropropriate set of suburban municipalities. However, the analysis in Mori et al. [71] used only *Metropolitan Employment Areas* (MEA), i.e., UEAs with central municpality populations of at least 50,000. In the present analysis, we include all UEAs as defined by Kanemoto and Tokuoka [58] to include those with central municipality populations of at least 10,000. Those with central munipality populations below 50,000 are designated as *Micropolitan Employment Areas*. This broader definition yields 309 cities (UEAs) in 1980 and 258 cities in 2000 (versus the respectively smaller sets of 105 and 113 MEAs used in Mori et al. [71]).

2.2 Industries

As in Mori et al. [71], the industrial employment data used for the analyses in this paper are classified according to the three-digit Japanese Standard Industry Classification (JSIC) taken from the Establishment and Enterprise Census of Japan in 1981 and 2001 (Japan Statistics Bureau [56, 57]), and applied to the respective population data in 1980 and 2000. But unlike Mori et al. [71] the present analysis focuses on manufacturing. For while services and wholesale-retail industries tend to be found almost everywhere, i.e., are unbiquitous, manufacturing industries exhibit a much larger diversity of location patterns at the three-digit level. Hence, as observed in Mori et al. [71], the NAS Rule itself is far more interesting for manufacturing industries.[4]

There were 152 and 164 manufacturing industries at the three-digit level in 1981 and 2001, respectively. Hence, to achieve comparability between industrial location patterns in these two years, industries in each year have been aggregated in a manner that yields the largest number of common classifications with a positive number of establishments for both years. This aggregation resulted in 147 common manufacturing industrial classifications for both years.[5] This number is further reduced to 139 industries that exhibit at least some degree of significant agglomeration (as discussed in Section 3.1 below).

3 Cluster-Based Choice Cities and Industries

As stated in the Introduction, the central objective of this paper is to re-examine the NAS Rule with respect to *cluster-based* (cb) choice cities for each industry. Since the identification of cb-choice cities for industries is developed fully in Mori and Smith [72, 73], we only sketch the main ideas here in Section 3.1. Given the definition of *cities* in Section 2.1 above, the focus here will be on the identification of significant industrial clusters. These clusters are used to define *cb-choice cities* for each industry in Section 3.2. From the city perspective, there is a completely parallel concept of *cb-choice industries* for each city, also defined in Section 3.2. This is followed in Section 3.3 with a brief consideration of the relative industrial employment concentration in cb-choice cities versus all other cities. Finally, the churning of industrial locations is considered from both industry and city viewpoints in Section 3.4.

3.1 Industrial Clusters

Our approach to the identification of significant clusters of regions (municipalities) for a given industry is closely related to the statistical clustering procedures proposed by Besag and Newell [8], Kulldorff and Nagarwalla [63], and Kulldorff [62]. To test for the presence of clusters, these procedures start by postulating an appropriate null hypothesis of "no clustering". In the present case this hypothesis is characterized by a uniform distribution of industrial locations across regions.[6] Such clustering procedures then seek to determine the single "most significant" cluster of regions with respect to this hypothesis. Candidate clusters are typically defined to be approximately circular areas containing all regions having centroids within some specified distance of a given reference point (such as the centroid of a "central" region).

The approach developed in Mori and Smith [72] entends these procedures in two ways. First, the notion of a "circular" cluster of regions is extended to the more general (metric-space) concept of a *convex solid*, as defined with respect to the shortest travel-distance metric on the

[4]This can be seen quite dramatically in Figure B1 of Appendix B in Mori et al. [71], where the 125 manufacturing industries shown (see Mori et al. [71, footnote 14]) are a subset of those used here.

[5]See Appendix A for the details of this industrial aggregation.

[6]Here "uniformity" is defined with respect to an areal measure of the *economic area* of each region (municipality). Details of this measurement procedure are given in Mori and Smith [72].

given set of regions.[7] Next, individual (convex solid) *clusters*, C, are extended to the more global concept of "cluster schemes". If the set of relevant *regions* (municipalities), r, is denoted by R, then each *cluster scheme*, $\mathbf{C} = (R_0, C_1, .., C_{k_\mathbf{C}})$, is taken to be a partition of R into one or more disjoint clusters, $C_1, .., C_{k_\mathbf{C}}$ together with the residual set, R_0, of all non-cluster regions. Each cluster scheme then induces a family of possible location-probability models, called *cluster probability models*, $p_\mathbf{C} = [p_\mathbf{C}(j) : j = 1, .., k_\mathbf{C}]$, in which industrial establishments are implicitly hypothesized to locate more likely in one of the cluster regions than in a non-cluster region [and where $p_C(R_0) = 1 - \Sigma_j p_\mathbf{C}(j)$]. Each cluster probability model, $p_\mathbf{C}$, thus amount formally to multinomial sampling models on their underlying cluster schemes, $\mathbf{C}$.[8]

In this context, the local problem of finding a single "most likely" cluster is replaced by the global problem of finding a cluster probability model that "best fits" the full set of industry locations. In turn, this is seen to be an instance of the general statistical "goodness-of-fit" problem, i.e., the problem of selecting a best-fit model from among a family of candidate probability models for a given set of sample data. While many model-selection criteria have been proposed for doing so, the criterion chosen here is the *Bayesian Information Criterion* (BIC) first proposed by Schwarz [88].[9] Essentially this criterion involves a tradeoff between the "likelihood" of the given sample data under each candidate model and the number of parameters (i,e., cluster probabilities) used in the model. (Further details are given in Mori and Smith [72, 73].)

To find a best cluster model with respect to this criterion, it would of course be ideal to compare all possible cluster schemes constructible from the given system of regions. But even for modest numbers of regions this is a practical impossibility. Hence the approach taken in Mori and Smith [72] is to develop an heurisitic algorithm that searches among the set of candidate models for the best model with respect to the BIC criterion. To do so, one starts by finding the best cluster probability model with an underlying cluster scheme consisting of exactly one single-region cluster (municipality). More elaborate cluster schemes are then grown by (*i*) adding new disjoint clusters, or by (*ii*) either expanding or combining existing clusters until no further improvement in the BIC model-selection criterion is possible. The final result is thus guaranteed to yield at least a "locally best" cluster scheme with respect to this criterion. (See Mori and Smith [72] for further details.) If the set of manufacturing industries is denoted by I, then let the *best cluster scheme* found for industry, $i \in I$, be denoted by $\mathbf{C}_i = (R_{i0}, C_{i1}, .., C_{ik_i})$.

Cluster schemes for each of the 147 manufacturing industries were constructed for both 1981 and 2001. Since the construction procedure and analysis of these cluster schemes is identical for both years, we drop time distinctions and simply take $\mathbf{C}_i$ to be a generic representation of both cluster schemes for each industry i. In addition it should be noted that both cluster schemes for each of these 147 industries contain at least one cluster, and hence are nondegenerate.

But even when cluster schemes are nondegenerate, there remains the statistical question of whether such clustering could simply have occurred by chance. Indeed, even completely

[7] Here shortest travel distance is defined with respect to *road-network distance*, as detailed in Mori and Smith [72].

[8] Other models of this type include the model-based clustering approach of Dasgupta and Raferty [16], and the Bayesian approach of Gangnon and Clayton [41, 42]. See Mori and Smith [72, footnote 7] for further discussion.

[9] Among the many other model-selection criteria that are applicable here, the most prominent are *Akaike's* [1] *Information Criterion* (AIC) and the *Normalized Maximum Likelihood* (NML) *Criterion* by Kontkanen and Myllymäki [59]. A comparison of these criteria in the present context will be presented in Smith and Mori [91].

random location patterns will tend to exhibit some degree of clustering.[10] Hence for each industry i one can ask how the *optimal criterion value*, BIC_i, obtained for $\mathbf{C}_i$ compares with typical values obtained by applying the same cluster-detection procedure to randomly generated spatial data. This tesing procedure can be formalized in terms of the null hypothesis of *complete spatial randomness*, which asserts that individual establishment locations are independently and uniformly distributed over the economic areas of regions. Hence under this hypothesis, the probability, $P(r)$, that any given establishment will locate in region (municipality), $r \in R$, is taken to be proportional to the size of economic area of region r. Monte Carlo simulation can then be employed to estimate the sampling distribuiton of BIC_i under this hypothesis, and a one-sided test can be performed to determine whether the observed value of BIC_i is significantly large relative to this distribution. Those industries with clustering that is not significant at the 5% level are said to exhibit *spurious* clustering. (For futher details see Mori and Smith [72]).

Among the 147 industries for which clusters were identified, all were extremely significant (with P-values close to zero) except for 8 industries where complete spatial randomness could not be rejected at the 5% level. These include 6 arms-related industries (JSIC381,383-387), together with tobacco (JSIC194)[11] and coke manufacturing (JSIC273). Besides the small numbers of establishments in these industures,[12] they are also are rather special in other ways. Tobacco manufacturing and arms-related industries are highly regulated industries, so that their location patterns are not determined by market forces. Finally, Coke is a typical declining industry in Japan (steel industries have gradually replaced coke production by less expensive powder coal after 1970s).

Hence our present analysis is based on the remaining 139 industries that exhibit some degree of *significant clustering*. For these industries, the percentages of establishments included in clusters range from 39.1% to 100% (with an average of 94.1%) in 2001, while the corresponding percentages in 1981 range from 51.8% to 100% (with an averge of 95.7%). See Mori and Smith [73] for further discussion.

3.2 Definition of CB-Choice Cities and CB-Choice Industries

For each industry with significant clustering, we can now define its set of corresponding cluster-based choice cities as follows. First, if the set of all cities (UEAs) in a given year is indexed by U, and if the subset of cities with *positive employment* in industry i is indexed by $U_i^+ \subseteq U$ (where again we drop time distinctions), then a city, $k \in U_i^+$, is designated as a *cluster-based* (*cb*) *choice city* for industry i if and only if there is some cluster, $C_i \in \mathbf{C}_i$, such that

$$UEA_k \cap C_i \neq \varnothing \tag{1}$$

[10]In fact, the complete absence of clustering is statistically consistent with a *significantly dispersed* (*ubiquitous*) pattern of industrial locations, which is the complete opposite of clustering (agglomeration).

[11]Establishment location data are not available for “tabacco manufacturing” (JSIC194) in 1981 since it was operated by the national government.

[12]All have less than 40 establishments, with an average of 7.89 establishments (compared to the average of 6183 establishments for the other industries in 2001).

In other words, UEA_k is a *cb-choice city* for i if and only if it shares at least one positive i-employment municipality with some cluster in $\mathbf{C}_i$.[13] Let the set of cb-choice cities for i be indexed simply by U_i. To distinguish this notion from the original set of choice cities, U_i^+, proposed in [71], it is convenient to designate all cities in U_i^+ as *presence-based* (*pb*) *choice cities* for industry i.

Note that the intersection in (1) can be interpreted in terms of individual cities as well as industries. In particular, one may designate industry i as a *cb-choice industry* for city k iff $k \in U_i^+$ and (1) holds for some cluster, $C_i \in \mathbf{C}_i$. As a parallel to U_i, one may then index the set of cb-choice industries, $i \in I$, for city k by I_k. Hence, in the same way that the number ($\#U_i$) of cd-choice cities for a given industry reflects its *location diversity*, the number ($\#I_k$) of cb-choice industries for a given city reflects its *industrial diversity*. These diversity measures exhibit great variation across industries and cities alike. With respect to the 139 industries studied, $\#U_i$ ranges from 14 to 275 (with an average of 116.3) cities in 1981, and ranges from 12 to 227 (with an average of 101.7) cities in 2001. Similarly, for the 309 cities identified in 1980, $\#I_k$ ranges from 2 to 139 (with an average of 52.3) industries in 1981, and for the 258 cities identified in 2000, $\#I_k$ covers the full range from 1 to 139 (with an average of 54.8) industries. We shall examine some additional empirical properties of these dual relations in Section 3.4 below.

3.3 Industrial Concentration in CB-Choice Cities

Next, recall that the primary motivation for the present definition of cb-choice cities was to characterize "substantial industry presence" in terms of agglomeration behavior. Hence we next consider how this endogenous approach relates to more exogenous "threshold" approaches in terms of industrial concentration. Such concentration can be measured either in terms of employment or numbers of establishments in cities. The key finding here is that with respect to both these measures, cb-choice cities for industries do indeed exhibit larger concentrations than do other cities in which the industry is present.

To state this more precisely, let E_{ik} and N_{ik} denote respectively the *employment size* and *number of establishments* of industry i in city k. Then, the *employment-concentration ratio*, R_i^{emp}, of average i-employment in cb-choice cities, U_i, to that in all other cities with positive i-employment, $U_i^+ - U_i$, is given by:

$$R_i^{emp} \equiv \frac{\frac{1}{\#U_i} \sum_{k \in U_i} E_{ik}}{\frac{1}{\#U_i^+ - \#U_i} \sum_{k \in U_i^+ - U_i} E_{ik}} \tag{2}$$

Similarly, the *establishment-concentration ratio*, R_i^{est}, of the average number of i-establishments in cb-choice cities, U_i, to that in all other cities with positive i-employment, $U_i^+ - U_i$, is given by:

$$R_i^{est} \equiv \frac{\frac{1}{\#U_i} \sum_{k \in U_i} N_{ik}}{\frac{1}{\#U_i^+ - \#U_i} \sum_{k \in U_i^+ - U_i} N_{ik}} \tag{3}$$

[13]Here it should be noted that the "convexity" requirement on clusters in $\mathbf{C}_i$ implies that a cluster may contain some municipalities with no i employment. Hence as a minimum condition, cb-choice cities for i are required to share cluster municipalities in $\mathbf{C}_i$ with *positive* i employment.

The frequency distributions of concentration ratios, $R_i^{emp}$and R_i^{est}, over all 139 industries, i, with significant clustering in 2001 are shown in Figures 2 and 3, respectively. Here R_i^{emp}ranges from 1.17 to 121.00 (with an average value of 15.19), and R_i^{est} ranges from 1.47 to 71.74 (with an average value of 15.05). Notice in particular that *all* ratios are greater than one. Hence it is clear that cb-choice cities for each industry i do indeed host relatively large concentrations of i without imposing ad-hoc threshold sizes on such concentrations.

Figures 2 and 3 here

3.4 Churning of CB-Choice Cities and CB-Choice Industries

Recall from Section 3.2 above that for each time period there is a wide range in both the locational diversities of industries and the industrial diversities of cities. But even more important is the fact that there has been a considerable amount of churning of industries across cities and visa versa. One way to examine these effects is to consider changes in the number of cb-choice cities for each industry i between 1981 and 2001, as shown in Figure 4. Here Figure 4(a) shows these changes as calculated using the respective city boundaries identified for each year. Figure 4(b) shows these changes using the 2000 city boundaries for both years (so that only changes in industrial agglomeration patterns are reflected). In both figures, industries are ordered by their *locational diversity* (i.e., number of cb-choice cities) in 1981. The vertical bar shown for each industry is divided into two segments. The length of the upper segment corresponds to the number of new cb-choice cities for this industry in 2001 that were not cb-choice cities in 1981, and the length of the lower segment is the number of old cb-choice cities in 1981 that ceased to be cb-choice cities by 2001. These two diagrams suggest that, regardless of changes in city boundaries, there are significant numbers of both exiting and entering cb-choice cities for most industries.

Figure 4 here

An alternative way to examine these churning effects is to measure changes in the *set* of cb-choice cities for each industry between these two years. If the sets of cb-choice cities for each industry $i \in I$ in 1981 and 2001 (with respect to 2000 city boundaries) are denoted respectively by U_i^{1981} and U_i^{2001}, then the *churning of cb-choice cities* for i can be measured as follows

$$CHURN_i^{cities} = 1 - \frac{\#(U_i^{1981} \bigcap U_i^{2001})}{\#(U_i^{1981} \bigcup U_i^{2001})} \tag{4}$$

Hence *complete churning* corresponds to $CHURN_i^{cities} = 1$, where all cb-choice cities for industry i have changed from 1981 to 2001. Similarly, $CHURN_i^{cities} = 0$, implies *no churning*. The frequency distribution of these churning values across all 139 industries with significant clustering is shown in Figure 5. The values of $CHURN_i^{cities}$ range from 0.22 to 0.94 with an average of 0.59. Here more than half of the cb-choice cities for 39 (28.1%) of these industries were replaced during this twenty year period [and more than a quarter were replaced for at least 80% of the industries]. In short, these industries have exhibited dramatic churning of their locations during this period. Similar *rapid* adjustments of industrial locations have been documented for France and the US by Duranton [24].[14]

Figure 5 here

Such churning can also be measured from the *city* perspective. Here we focus on the 258 cities identified in 2000, and use their 2000 boundaries for analysis. As a parallel to industries above, we first consider changes in the number of cb-choice industries for each city, k, during this twenty-year period, as shown in Figure 6. Here cities are ordered on the horizontal axis in terms of their *industrial diversity* (i.e., number of cb-choice industries) in 1981. The length of the upper segment of the vertical bar for each city k now cooresponds to the number of new cb-choice industries for k in 2001 that were not cb-choice industries for k in 1981, and the length of the bottom segment corresponds to the number of cb-choice industries for k in 1981 that had ceased to be cb-choice industries for k by 2001.

Figure 6 here

It is clear from the figure that the change in industrial composition is smallest for the most diversified and the least diversified cities. This is partly due to the fact the industry classification is fixed, so that the number of choice industries has little room for increase in the most diversified cities. Similarly, there is little room for decrease in the least diversified cities. But, as Figure 6 shows, there is also little decrease for the most diversified cities, and little increase for the least diversified cities. So the industrial diversification of cities at both ends of the spectrum appears to be relatively stable during this twenty year period. Thus, churning of cb-choice industries occurs mostly in cities with intermediate levels of industrial diversity.

As with industries, these churning effects can also be examined by measuring changes in the sets of cb-choice industries for cities. To do so, let the sets of cb-choice industries for each city k in 1981 and 2001 (with respect to 2001 city boundaries) be denoted by I_k^{1981} and I_k^{2001}. Then the *churning of cb-choice industries* for k can be measured as follows

$$CHURN_k^{indus} = 1 - \frac{\#(I_k^{1981} \bigcap I_k^{2001})}{\#(I_k^{1981} \bigcup I_k^{2001})} \tag{5}$$

where *complete churning* of industries for k again corresponds to $CHURN_k^{indus} = 1$, and where $CHURN_k^{indus} = 0$ again implies *no churning*. The frequency distribution of $CHURN_k^{indus}$ across

[14]The employment share-based measure of churning of industrial locations adopted by Duranton [24] is somewhat problematic when relatively disaggregated industries are considered (as in the present study) since employment shares may often be zero.

all cities, k, is shown in Figure 7. Here the values of $CHURN_k^{indus}$ take on the full range from 0.0 to 1.0, with an average of .583. As with cb-choice cities above, there is substantial churning of cb-choice industries. Here more than half of the cb-choice industries for 77 (30.0%) of these 258 cities are replaced [and more than a quarter were replaced for 216 (83.7%) of these cities].

4 The NAS Rule and its Associated Empirical Regularities

Given the definitions and preliminary findings above, we turn now to the major results of this paper. Here we begin with the NAS Rule itself in Section 4.1 below, and consider its persistence properties for the case of Japan under our new definition of cluster-based choice cities. These persistence properties are then extended to the associated Hierarchy Principle and Rank Size Rule in Sections 4.2 and 4.3 respectively.

4.1 The NAS Rule

In the present setting, the *Number-Average Size* (*NAS*) *Rule* first formulated in Mori, Nisikimi and Smith [71] (in terms of pb-choice cities) now asserts that there is a log-linear relationship between the number and average size of *cb-choice cities* for industries. With respect to this new definition of choice cities, the main result of the present paper is shown in Figure 8.

Figure 8 here

Here the logs of both the number of cb-choice cities ($\#CITY$) and average size of cb-choice cities ($\overline{SIZE}$) are plotted for the relevant 147 manufacturing industries in both 1981 and 2001.[15] The specific points corresponding to the eight industries with spurious clustering are indicated on figure, and show that *all outliers* are in this group. Hence for those 139 industries with significant clustering the relations shown for each year are *almost exactly log linear*. This can be verified by a simple OLS regression, which yields the following results for each year,[16]

$$1980/1981: \quad \log(\overline{SIZE}) = \underset{(0.0309)}{16.92} - \underset{(0.00668)}{0.734} \log(\#CITY), \quad R^2 = 0.996 \tag{6}$$

$$2000/2001: \quad \log(\overline{SIZE}) = \underset{(0.0286)}{17.01} - \underset{(0.00635)}{0.716} \log(\#CITY), \quad R^2 = 0.996 \tag{7}$$

where the values in parentheses are standard errors. It should be noted that since the dependent variables are neither normally distributed nor independent by construction, the linear estimates in (6) and (7) are best regarded as "curve fitting" rather than genuine statistical models (as pointed out by Eaton and Eckstein [30, p.452, footnote 19]).[17] However, it should also be

[15] In terms of the notation in Section 3.2 above, for each industry i, $\#CITY_i = \#U_i$ and $\overline{SIZE}_i$ is the average size of all cities in U_i.

[16] Because our city data is for 1980 and 2000 while our industry data is for 1981 and 2001, we shall sometines denote these two periods by 1980/1981 and 2000/2001, respectively..

[17] It should also be noted that if city sizes are distributed according to a power law (as implied by the Rank-Size Rule in Section 4.3 below), then as pointed out by Gabaix and Ioannides [40, Sec. 2.2.1], the standard errors in these regressions may be grossly under-estimated. But in the present case, with R^2 values almost one, it should be clear that such standard errors add little in the way of new information.

emphasized that these strong log-linear relations are not simply the result of some underlying tautology. In particular, the drastic outliers in Figure 8 suggest that for industries without strong agglomeration tendencies, this NAS Rule may not be relevant at all. Hence it can be conjectured that in so far as agglomeration behavior is a reflection of economic factors, the NAS Rule is most relevant for industries where location decisions are largely governed by economic considerations.

Aside from the obvious strength of this log-linear relation, it should also be emphasized that the slopes of these two regression lines are almost the *same*. This can again be tested by pooling the data for both time periods, introducing a time dummy and applying standard F-tests to evaluate coefficient shifts. While the statistical validity of such a test is again questionable in terms of normality and independence, the results clearly support invariance of the slope coefficient. However, the intercept does exhibit a significant shift, as can easily be seen from Figure 8. So while both the numbers and average sizes of cb-choice cities for individual industries have changed, they have done so in a manner that leave their "elasticity of substitution" invariant. More specifically, a 1% increase in the number of cb-choice cities for an industry between 1981 to 2001 corresponds roughly to a 0.7% decrease in the average size of these cities during the same twenty-year period.

The stability of this relation is even more remarkable in view of the dramatic churning of industries across cities during this period (as discussed in Section 3.4 above). In addition, there has also been a substantial reordering of city sizes themselves (as discussed in Section 4.3 below). Hence the invariance of the NAS Rule adds further support to the conjecture that this implicit coordination between industrial and population locations is driven by same underlying economic forces over time. While the exact nature of these forces remains an open question, the recent model proposed by Hsu [50] suggests that scale economies of production may constitute one important contributing factor.

The results in Hsu [50] together with the original analysis in Mori et al. [71] show that this NAS Rule is intimately connected with two other well-known classical regularities of city systems, namely, Christaller's [13] *Hierarchy Principle* and the *Rank-Size Rule* of city size distributions. Hence the invariance of the NAS Rule above suggests that these two regularities may also exhibit invariance properties. We now consider each of these regularities in the context of our present manufacturing data.

4.2 The Hierarchy Principle

The Hierarchy Principle originally proposed by Christaller [13] asserts that industries found in cities of a given size will also be found in all cities of larger sizes. The approach of Mori et al. [71] was to re-define this principle in terms of *industrial diversity* (i.e., the number of choice industries for a city) rather than population size. Hence our present version of the Hierarchy Principle asserts that industries in cities with a given level of industrial diversity (i.e., a given number of *cb-choice industries*) will also be found in all cities with larger industrial diversities. This version is formally somewhat weaker than the original population version of Christaller,[18] and hence

[18] See footnote 40 in Mori et al. [71]

constitutes a *necessary condition* for the classical Hierarchy Principle. The main advantage of this reformulation is that it allows the Hierarchy Principle to be tested without altering the *industrial diversity structure* of the city system. Moreover, this weaker version is in reality very closely related to the classical version. In the present case, Spearman's rank correlation between the industrial diversity levels and populations of cities is around 0.75 for both 1980/1981 and 2000/2001.

Before testing this principle in the present setting, it is useful to consider the city-industry relationships depicted graphically in Figure 9 below, using 2001 data. Here cities, k, are ordered by their industrial diversities (number of cb-choice industries) on the horizontal axis, and industries, i, are ordered by their locational diversities (number of cb-choice cities) on the vertical axis. A "plus" symbol (+) in position (k, i) indicates that k is a cb-choice city for industry i (and equivalently, that i is a cb-choice industry for city k). If we distinguish such positions as *positive*, then the Hierarchy Principle asserts that for each positive position (k, i) then there must also be a (+) in every row position $(\cdot, i)$ to the right of (k, i), indicating that all cities with industrial diversities greater than or equal to city k are also cb-choice cities for industry i. Hence it is clear from the figure that while the Hierarchy Principle does not hold perfectly, the row density of (+) values increases from left to right in virtually every row. Hence there is clearly a strong level of agreement with the Hierarchy Principle that could not have occurred by chance.[19,20]

Figure 9 here

A formal statistical test of this assertion was developed in Mori et al. [71]. To apply this test in the present context, it suffices to outline the basic elements of the test in terms of Figure 9 (see Mori et al. [71, Section 4] for a detailed development). To do so, observe first that each occurrence of a full row of (+) values to the right of a positive position (k, i) can be regarded as a "full hierarchy event" at (k, i) in the sense that it is fully consistent with the Hierarchy Principle. However, in cases where only small fraction of (+) values are missing, it is natural to regard this as being "closer" to a full hierarchy event than if all (+) values were missing. To distinguish between such cases, it is appropriate to designate the fraction of *positive* positions to the right of each positive (k, i) as the *fractional hierarchy event*, H_{ki}, at (k, i). Hence $0 \leq H_{ki} \leq 1$ with $H_{ki} = 1$ denoting a *full hierarchy event* at (k, i). Note also that since by definition each positive position (k, i) generates a unique fractional hierarchy event (of which it is the left end point), the number, h, of fractional hierarchy events is precisely the number of positive positions [(+) values] in the figure. Hence, as a measure of overall consistency with the Hierarchy Principle, we designate

[19] Note that this figure bares a strong resemblance to Figure 7 in Mori et al. [71]. The key difference for our present purposes is the new cluster-based definition of choice cites for industries. However, it should also be noted that the inclusion of Micropolitan Employment Areas in the present analysis greatly expands the range of cities with small industrial diversities (at the left end of the city scale).

[20] It should also be noted that the SIC classification system for industries is by no means exact. Hence some level of disagreement in such hierarchical relations is unavoidable.

the average of these fractional hierarchy events as the (observed) *hierarchy share*,

$$p_0 = \frac{1}{h} \sum_{ki} H_{ki} \tag{8}$$

for the given system of cities and industries. By definition, $0 \leq p_0 \leq 1$, with $p_0 = 1$ now denoting exact agreement with the Hierarchy Principle, i.e., all fractional hierarchy events are full.

In this context, one possible null hypothesis for testing the Hierarchy Principle would be that this figure is the realization of a stochastic process in which h of these (+) values are assigned randomly to (k, i) pairs (without replacement). However, it can be argued that this null hypothesis is too strong in the sense that it not only ignores industrial hierarchies, but also ignores the basic urban structure of the city system itself. For example, major cities such as Tokyo and Osaka are implicitly treated as indistinguishable from even the smallest micropolitan cities in Japan. In order to preserve actual urban structure to some degree, we thus choose to hold the *industrial diversity* of each city fixed.[21] Hence to test this Hierarchy Principle, the null hypothesis, H_0, adopted here is that the observed distribution of (+) values in Figure 9 is the realization of a stochastic process which assigns random (+) values in a manner that preserves the industrial diversity of each city, i.e., preserves the number of (+) values in each column of the figure. Since the industrial diversity of city k is given by the number of its cb-choice industries, $\#I_k$, it follows that this process is easily realized by randomly selecting $\#I_k$ cb-choice industries from I for each city k. By constructing a large number of such realizations, say 1000, and calculating the *hierarchy share*, p_m, for each realization, $m = 1, .., 1000$, one can then test the Hierarchy Principle by simply checking whether the observed hierarchy share, p_0, is "unusually large" relative to this sample of typical share values under H_0.

The results of this (one-sided) test in the present case provide a strong rejection of H_0 in favor of significantly large hierarchy shares. In particular, for the 2001 data in Figure 9, the observed hierarchy share is $p_0 = 0.775$, while the simulated hierarchy shares under H_0 ranged from 0.622 to 0.631.[22] Thus, even when the industrial-diversity structure of this city system is held fixed, the statistical evidence in favor of the Hierarchy Principle is overwhelming. A parallel application of this test to the 1981 data produced essentially the same findings, with an observed hierarchy share of $p_0 = 0.772$ and a simulated range of hierarchy shares from 0.612 to 0.618 under H_0. Hence, the similarity of these values shows that in spite of the dramatic churning of both industries and city sizes during this twenty-year period, the overall hierarchical structure of industrial locations has remained remarkably stable.

Finally, it is of interest to consider the implications of these results for the NAS Rule itself. The relation between this rule and the Hierarchy Principle is seen most easily in terms of the broader definitions of these concepts in Mori et al. [71], where the classical Hierarchy Principle (in terms of city size) was used, and where choice cities for each industry i were taken to include the larger set, U_i^+, of all cities where i is found. If this classical Hierarchy Principle were to hold

[21] Recall that since industrial diversity is highly rank-correlated with city size, this convention tends to preserve the ordering city sizes as well.

[22] The observed value of p_0 is so far above this range that larger simulation sizes would surely yield similar results.

exactly, and if we denote the *smallest choice city* for i by $\widetilde{k}_i \in U_i^+$, then U_i^+ would consist precisely of all cities with populations at least as large as $\widetilde{k}_i$. Moreover, $\#U_i^+$, would then be the number of cities at least as large as $\widetilde{k}_i$, which is by definition the (*population*) *rank* of city $\widetilde{k}_i$. Under these conditions, the NAS Rule is equivalent to a negative log-linear relation between the rank of city $\widetilde{k}_i$ and the average of all city sizes at least as large as $\widetilde{k}_i$, designated in Mori et al. [71] as the *upper-average* city size for $\widetilde{k}_i$. If the rank and upper-average city size of each city, k, are denoted respectively by $RANK_k$ and $\widehat{SIZE}_k$, then the plot of $\log(\widehat{SIZE})$ against $\log(RANK)$ for all cities in Plot (b) of Figure 10 in Mori et al. [71] showed a remarkably close relation to a plot of the actual values of $\log(\overline{SIZE})$ and $\log(\#CITY)$ in Plot (a) of Figure 10.[23]

In the present context, both the definitions of choice cities (as *cb-choice cities*) and the Hierarchy Principle (in terms of *industrial diversity*) have changed. However, as noted at the beginning of this section, there continues to be a high rank-correlation between city size and industrial diversity. This together with the test results above (as well as the direct evidence in Figure 9) suggests that the average size of *cb-choice cities* in U_i ($\subset U_i^+$), should still agree reasonably well with the upper-average city size for the *smallest cb-choice city*, $k_i \in U_i$. This relation is demonstrated in Figure 10 below, which bears a striking resemblance to Figure 10 in Mori et al. [71]. Here, using data for 2001, $\log(\widehat{SIZE})$ is again plotted against $\log(RANK)$ for all cities in Plot (b) of Figure 10. Similarly, for the present definition cb-choice cities, $\log(\overline{SIZE})$ is plotted against $\log(\#CITY)$ in Plot (a) of Figure 10.[24] Hence it is clear that the present restriction to cb-choice cities (as well as the inclusion of Micropolitan Employment Areas) has made little difference. These relations are both very close, where the slightly flatter slope of the NAS Rule again reflects imperfections in the Hierarchy Principle.

Figure 10 here

Note also that if $\underline{SIZE}_k$ denotes the average of all city sizes *smaller* than city k, then in the same way that $\widehat{SIZE}_k$ represents the natural *upper bound* on $\overline{SIZE}_k$, the value $\underline{SIZE}_k$ represents a natural *lower bound*. In these terms, the plot of $\log(\underline{SIZE})$ against $\log(\#CITY)$ in Plot (c) of Figure 10 shows that within its feasible range of values, $\log(\overline{SIZE})$ is almost identical with its upper bound. As observed in Mori et al. [71], this serves to further underscore the extremely non-random nature of Plot (a).

Finally, in view of the closeness of Plot (a) to this upper bound in Plot (b), it is of interest to ask whether the stability of the NAS Rule in (6) and (7) above is also reflected in this upper-bound relation between $\log(\widehat{SIZE})$ and $\log(RANK)$. The corresponding regression results for 1980/1981 and 2000/2001 are shown below:

$$1980/1981: \quad \log(\widehat{SIZE}) = \underset{(0.00692)}{17.37} - \underset{(0.00143)}{0.806} \log(RANK), \quad R^2 = 0.999 \tag{9}$$

$$2000/2001: \quad \log(\widehat{SIZE}) = \underset{(0.00718)}{17.52} - \underset{(0.00154)}{0.805} \log(RANK), \quad R^2 = 0.999 \tag{10}$$

[23] As in footnote 15 above, for each industry i, $\#CITY_i$ here represents $\#U_i^+$, and $\overline{SIZE}_i$ is the average size of all cities in U_i^+.

[24] Plot (a) is identical with the plot of 2001 data in Figure 8 above, where all industries with spurious clustering have now been removed.

As with the NAS regressions in (6) and (7) above, an F-test using (9) and (10) confirms that only the intercept has shifted in any significant way. In fact, the slope of this Hierarchy relation appears to be even more stable than the NAS Rule over this twenty year period.

4.3 The Rank Size Rule

Finally we turn to the *Rank Size Rule* for systems of cities, which asserts that if all cities are ranked by population size, then the $RANK_k$ and $SIZE_k$ of cities, k, are (approximately) negatively log-linearly related, i.e., that for all cities,

$$\log(SIZE) \approx \sigma + \theta \log(RANK) \tag{11}$$

The classical version of this Rule also asserts that $\theta \approx -1.0$. For the present case, a plot of $\log(SIZE_k)$ versus $\log(RANK_k)$ for all cities, $k \in U$, is shown in Plot (d) of Figure 10. Here again, this plot is qualitatively similar to Plot (c) of Figure 10 in Mori et al. [71], showing that the restriction to cb-choice cities (and inclusion of Micropolitan Employment Areas) has made little difference. Log linearity is again most evident in the central range of the plot, while the relative slopes at each end are much steeper.[25] Hence, at each extreme it appears that other socio-economic mechanisms may be at work (as discussed further in Mori et al. [71]).

But our present interest focuses mainly on the relation between the Rank Size Rule in (11) and the NAS Rule. In Mori et al. [71], it was shown that in the presence of the classical Hierarchy Principle, the NAS Rule (with respect to the larger sets of choice cities U_i^+ for industries i) is asymptotically equivalent to this Rank Size Rule, i.e., they satisfy the same "asymptotic power law" (see Mori et al. [71, Corollary 1]). Hence the above stability results for the NAS Rule in (6) and (7), and for the Hierarchy Principle in (9) and (10), suggest that stability over this twenty year period may also be exhibited by the Rank Size Rule. Regressions of $\log(SIZE)$ on $\log(RANK)$ in periods 1980/1981 and 2000/2001 produced the following results:

$$1980/1981: \quad \log(SIZE) = \underset{(0.0582)}{16.85} - \underset{(0.0120)}{1.094} \log(RANK), \quad R^2 = 0.964 \tag{12}$$

$$2000/2001: \quad \log(SIZE) = \underset{(0.0786)}{17.11} - \underset{(0.0168)}{1.130} \log(RANK), \quad R^2 = 0.946 \tag{13}$$

Here again an F-test shows that only the intercept has shifted significantly, and hence that the slope of this overall relation has remained fairly stable. The regression line for 2000/2001 in (13) is shown in Plot (e) of Figure 10.[26]

As with the NAS Rule in Section 4.1 above, this stability of the Rank Size Rule is even more remarkable in view of the substantial shuffling of population ranks among cities. For the 246 cities that existed in both 1980 and 2000 (by our definition of cities), the population ranks of these cities in 2000 are plotted against their corresponding 1980 ranks in Figure 11 below. As is

[25] Here there is a slight "kink" at cities with populations of about 300,000, and a much sharper "dip" at cities below 70,000.

[26] Since the data for the Rank Size relation in 1980/1981 strongly overlap the data for 2000/2001, it is difficult to show both on the same figure. Hence we choose to display only the latter.

clear from the figure, while the largest cities remained relatively stable,[27] most cities actually moved up in the rankings, with an average jump in rank of 10.25. But there is also a great deal of variation in movement. For example, there are cities like Uozu with large upward jumps [from 245th $(49,512)$[28] in 1980 to 123th $(134,411)$ in 2000], and other cities like Okaya with large downward jumps [from 122th $(371,850)$ in 1980 to 189th $(435,367)$ in 2000].[29] In addition to this movement, there were also changes in the sets of cities themselves (again with respect to our definition of cities). Most of the reduction in cities from 309 in 1980 to 258 in 2000, was due to the absorption of one city by another. In fact, most cities that exhibited large upward jumps in the rankings grew by absorption of nearby cities.[30]

Figure 11 here

One problem with these observations is that changes in the number of cities between 1980 and 2000 makes it somewhat difficult to interpret the changes in rankings above. Hence even though these absolute rankings are the ones used in the regressions of (12) and (13), it is useful for our present purposes to consider changes in the *relative* rankings of the 246 cities existing in both years. This can be done by simply ranking these cities from 1 to 246 in 1980 and recording the changes of these ranks in 2000. But even here, it can be argued that such changes might be due largely to the changes city boundaries between 1980 and 2000 (resulting from our city definitions in Section 2.1 above). Hence it is useful to consider changes in these relative rankings using the city boundaries in 2000 for both years.[31] These changes in relative rankings are shown in Figure 12 below. By construction, the average change in rankings of cities is now zero. But the range of such changes from -32 to 42 again shows wide variation (with a standard deviation of 10.1). Hence even in terms of relative rankings with fixed boundaries, the changes in rankings over this twenty year period have been dramatic.

Figure 12 here

[27] This same phenomenon is observed in other countries as well. For the US in particular, see for example, Black and Henderson [9].

[28] The numbers in parentheses are the population levels of the city for 1980 and 2000, respectively.

[29] The most significant growths and declines of cities in the studied period seemed to be triggered by the expansion of Shinkansen (bullet train) lines. For instance, the extension of the Shinkansen line from Tokyo to Fukuoka in 1975 leads to the population growth of Fukuoka as a new center of Kyushu region from 1,762,794 to 2,323,604 (31.8%) and from 6th to 5th in the population rankings, while it also caused the population decline by 6.64% and from 8th to 11th in the population rankings of Kitakyushu, the traditional regional center of Kyushu, located 50km east of Fukuoka. Okayama experienced even more drastic population growth from 744,735 to 1,484,742 (99.4%) and moved up from 14th to 10th in the size ranking. There are two major reasons for this disproportionate growth. One is that Okayama became a transshipment point of the extended Shinkansen line between Tokyo and Fukuoka mentioned above. The other is the completion of the Seto-oh-hashi in 1988, the bridge connecting the main island to Shikoku island via Okayama.

[30] For instance, Uozu with population $49,512$ mentioned above moved up 122 ranks by absorbing Kurobe with population $72,259$. Similarly, Kitagami with population $76,633$ moveded up 100 ranks by absorbing Hanamaki with population $97,389$.

[31] See Overman and Ioannides [81] for a discussion of the choice of geographical areas for cities when making inter-temporal comparisons of city sizes.

In addition to changes in rankings, there has also been very uneven growth among cities. In Figure 13, the population growth rates of these 246 cities are plotted against their absolute rankings in 1980. The sizes of these cities increased by 17.5% on average, with a standard deviation of 32.4%. Note also from the figure that variation in growth rates appears to be higher for smaller cities.

Figure 13 here

In Figure 14 below, growth rates are plotted using fixed city boundaries from 2000. Here the average growth rate, 1.81%, is now much smaller since the (usually larger) city boundaries in 2000 are used. But even here it is remarkable that the growth rates of cities range from -36.2% to 44.3%, with a standard deviation of 13.1%.

Figure 14 here

Finally, returning to the Rank Size Rule itself, it is of interest to compare the regression results in (12) and (13) with both the classical Rank Size Rule and the NAS Rule. Notice first that the overall slope of each regression is close to -1.0, and hence appears to be in rough agreement with the classical Rank Size Rule. But it is clear for the regression line shown in Plot (e) of Figure 10 for 2000/2001 data that this slope is in fact a "compromise" between the slopes for each of the three data segments in Plot (d) decribed above.[32] In particular, the slope of the middle range in Plot (d), for which log linearity is most evident, is seen to be much flatter, and is indeed much closer to that of the NAS regression in (7) above than it is to -1.0.[33] Moreover, it can be argued this central range is "dominant" in the sense that the slope of the upper average relation in Plot (b) essentially mirrors that of this range. So, while no definitive conclusions can be drawn from such limited observations, they do suggest that the theoretical relations between the NAS Rule and both the Rank Size Rule and Hierarchy Principle developed in Mori et al. [71] are empirically most evident for cities in this dominant central range.

5 Concluding Remarks

The main purpose of this paper has been to examine the temporal stability properties of the NAS Rule under the sharper definition of *cluster-based* choice cities for industries proposed by Mori and Smith [73]. In particular, it was shown in Section 4.1 that for Japanese manufacturing industries between 1981 and 2001, the stability of this rule under pb-choice cities continues to hold for cb-choice cities as well. In addition, it was shown that, as in Mori and Smith [73], similar stability properties are exhibited by the two other regularities closely related to the NAS Rule, namely the Hierarchy Principle for industries and the Rank Size Rule for cities.

[32] This same type of compromise is also exhibited by the regression line for 1980/1981 (not shown).

[33] A regression using only this middle segment yields a slope of -0.767.

These stability results are even more remarkable given the substantial shuffling of both industries and city sizes between these two years. For the NAS Rule in particular, the results in (6) and (7) show that in spite of dramatic changes in both the cb-choice cities for specific industries and even the sizes of these cities themselves, the "elasticity of substitution" between the number and average size of these cb-choice cities across industries has remained essentially *constant*. While the corresponding log-linear relationship for the Rank Size Rule in (11) is not as sharp, the overall "elasticity of substitution" between city sizes and ranks in (12) and (13) has also remained essentially constant (and slightly larger in magnitude than for the classical model). Thus, while the underlying adjustment processes that preserve these relations remain to be established, it would appear that such processes must be relatively "fast" in comparison to this twenty-year span.

In addition, the joint stability of these three relations serves to reinforce the close relationships between them. With respect to the Rank Size Rule in particular, these relations suggest that rather than considering simple independent growth models of cities, such as Gibrat's Law and its extensions (see Gabaix and Ioannides [40]), better explanations of the skewed distribution of city sizes might be given in terms of the *co-location* behavior of populations and industries over time.

It should also be noted that while the present results for the NAS Rule involve only two points in time for a single country (Japan), this regularity appears to be far more robust. As mentioned in the Introduction, the results of Hsu [50] suggest that this same regularity can be seen in the US as well. More generally it appears that the NAS Rule is also evident in relatively self-contained subregions of nations. In particular, if one takes patterns of interregional travel behavior to define relatively self-sustained subsystems within nations (in the same way that commuting patterns have been used to define cities), then for Japan[34] there is a natural nesting of four monopolar regional systems identified by their central cities as: "Tokyo" $\supset$ "Osaka" $\supset$ "Nagoya," and "Tokyo" $\supset$ "Sapporo". Our preliminary investigations show that the NAS Rule holds with roughly the same slope coefficient for the "Tokyo", "Osaka","Nagoya" and "Sapporo" regions. These initial findings suggest that international comparisons of such regularities would perhaps be most meaningful by identifying self-contained economically comparable subregions for testing purposes. Such questions will be pursued further in subsequent research.

Finally, it should be emphasized that while the NAS Rule implies a regularity between the number and average size of cb-choice cities for each industry, it says little about the actual distribution of industries across cities. Hence from a regional policy perspective, neither the existence or stability of NAS by itself allows specific conclusions to be drawn about this distribution. However, when taken together with the closely related Hierarchy Principle, there are some policy implications that can be drawn. Indeed, if the Hierarchy Principle were to hold exactly, then the set of cb-choice cities for each industry i would be competely determined by the number of such cities, i.e., would consist of the $\#U_i$ cities with largest industrial diversities. In such a case, cities k could only hope to attract new industries i for which (i) k would then qualify

[34] Data on inter-prefectural passenger trips using mass transport modes was obtained from the Ministry of Land, Infrastructure, Transport and Tourism of Japan [69].

as a cb-choice city for i, and (ii) all cities with larger industrial diversity were already cb-choice cities. While such rigid rules are of course unrealistic, they nonetheless suggest that in regional systems where these regularities are sufficiently strong, cities are more likely to attract industries for which this addition (i) would either create or enhance a meaningful local clustering of that industry, and (ii) would be consistent with the current locational hierarchy for that industry. In particular, this suggests that smaller cities may be more likely to grow by attracting "lower order" industries that would not be "too isolated" in that city. Such policy implications will be considered more fully in subsequent work.

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Appendix

A Industry Aggregation

There are 152 and 164 classifications in the three-digit manufacturing industries in 1981 and 2001 defined in Establishments and Enterprise Census of Japan [56, 57]. Industrial classifications have been basically disaggregated over the twenty year period. Thus, in the present paper, the the classifications in 2001 have been basically aggregated to those in 1981. Besides the conversions of the classifications between the two periods specified in the census, however, the following conventions have been adopted in order to make classifications at these two time points comparable.

1. Since "forged and cast steel manufacturing" (JSIC316) and "cast iron product manufacturing" (JSIC317) in 1981 have been aggregated to "ferrous metal machine parts and tooling products" (JSIC266) in 2001, we redefined JSIC316 to represents a union of JSIC316 and JSIC317 in 1981 and JSIC266 in 2001.

2. Since the union of "headgear manufacturing" (JSIC213) and "other apparel and textile accessory manufacturing" (JSIC215) in 1981 is equivalent to the union of "Japanese style apparel and socks('tabi')" (JSIC155) and "other textile apparel and accessories" (JSIC156) in 2001, these are labeled by JSIC215.

3. Since "wooden footear manufacturing" (JSIC224) and "other wooden product manufacturing" (JSIC229) in 1981 have been aggregated to "miscellaneous manufacture of wood products, including bamboo and rattan" (JSIC169) in 2001, we let JSIC229 to represent this aggregated classification.

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Figure 1: Municipality boundaries in 2001

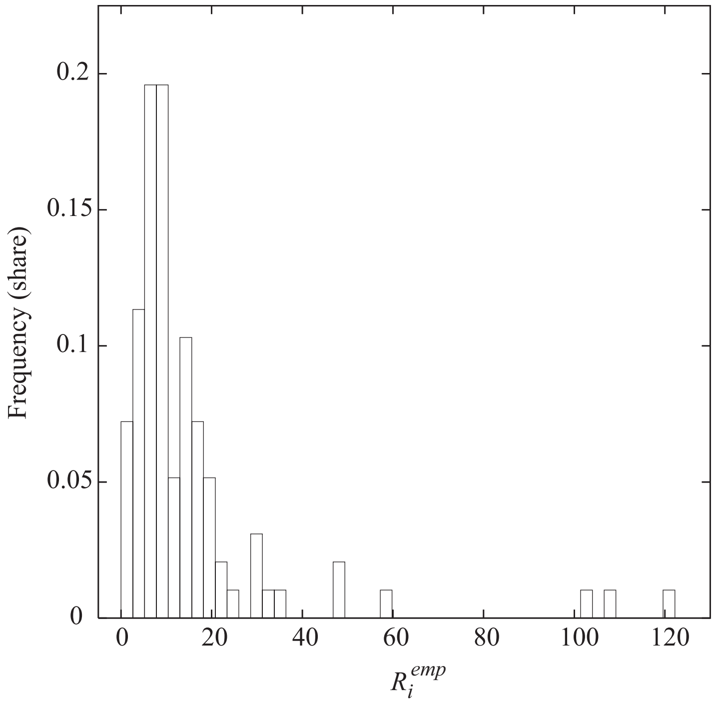

Figure 2: Average employment size of cluster-based choice cities relative to that of presence-based ones

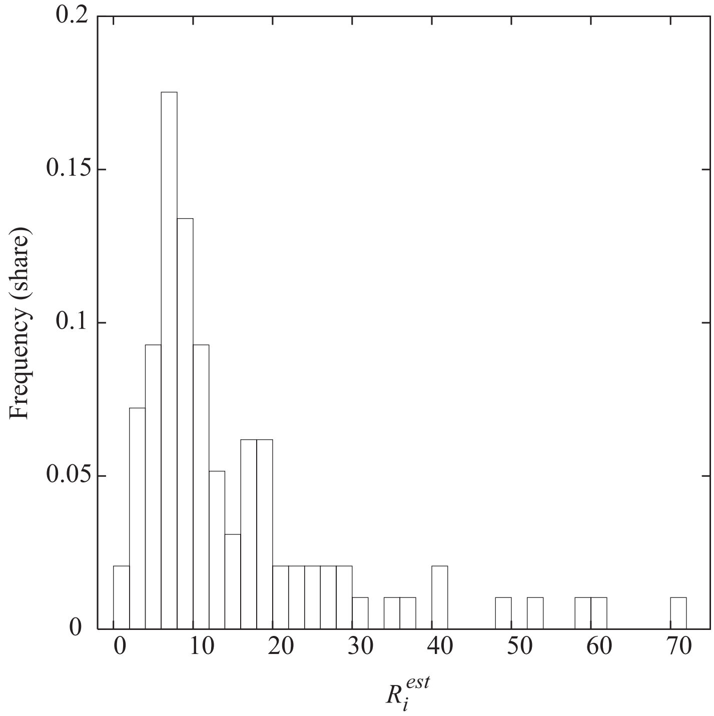

Figure 3: Average establishment count of cluster-based choice cities relative to that of presence-based ones

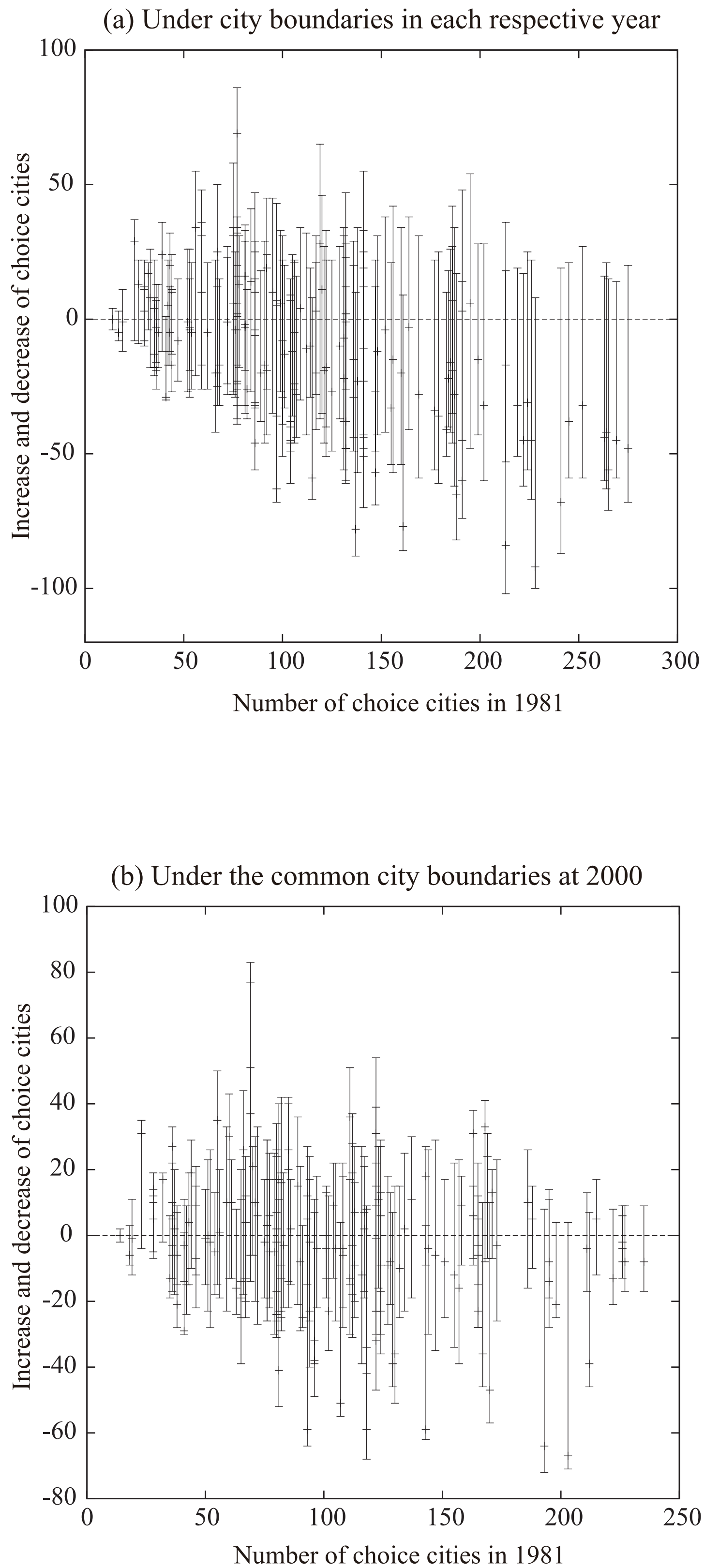

Figure 4: Change in the number of choice cities

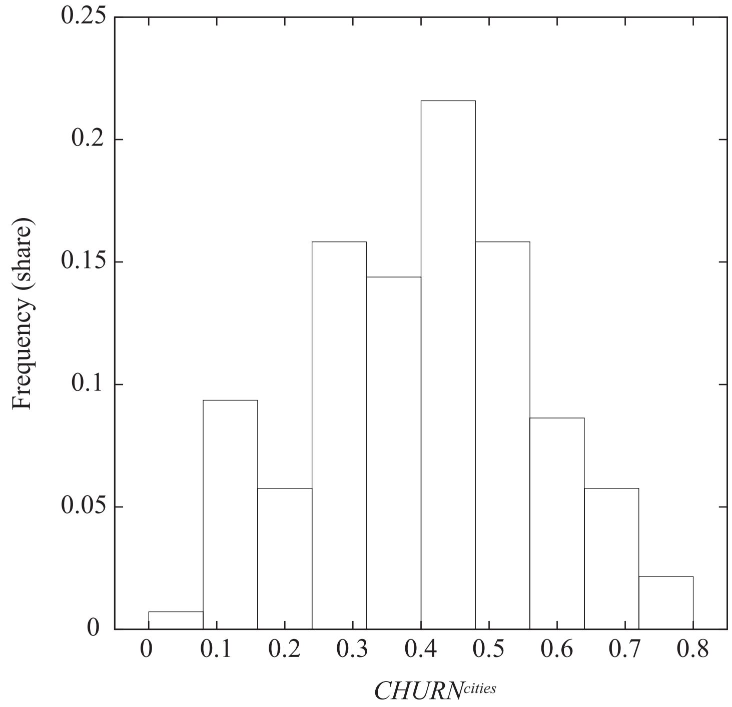

Figure 5: Churning of choice cities

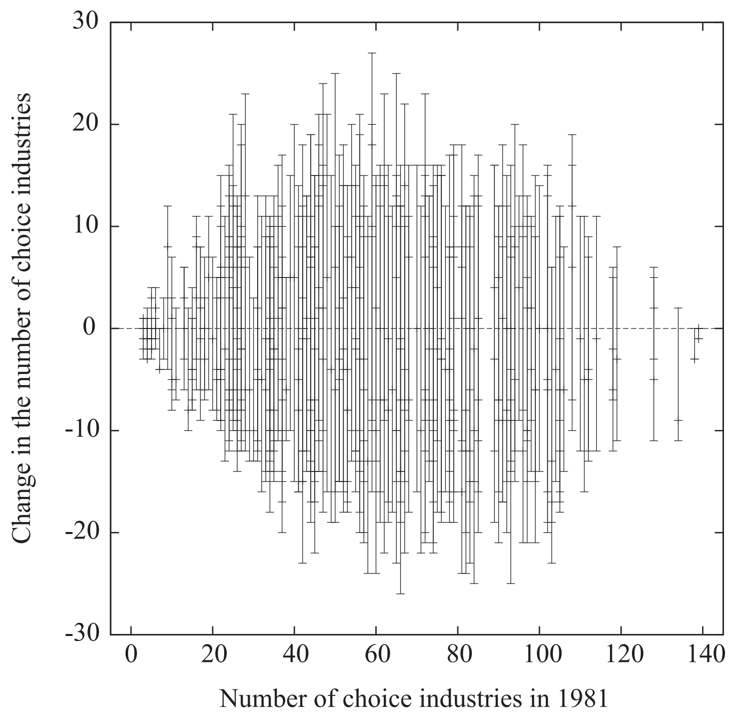

Figure 6: Change in the number of choice industries of cities

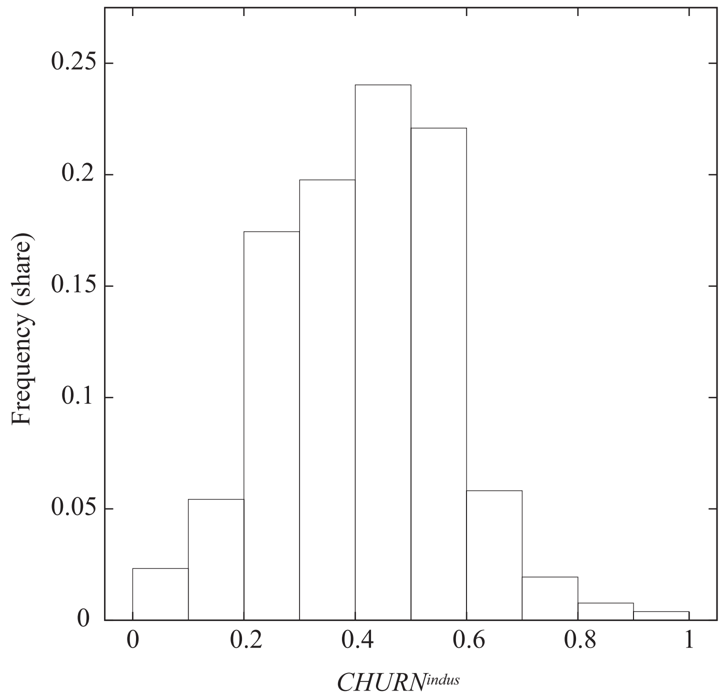

Figure 7: Churning of choice industries between 1981 and 2001

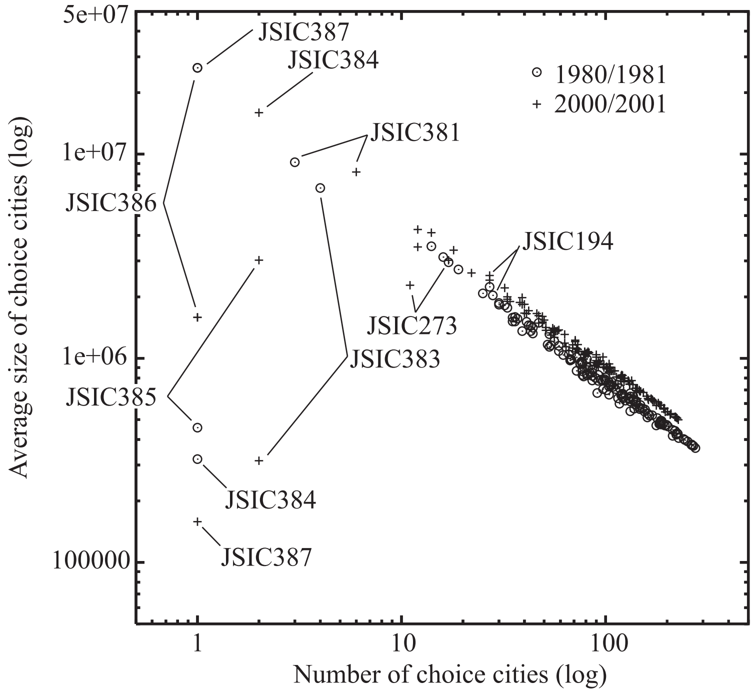

Figure 8: The Average size versus the number of choice cities of industries

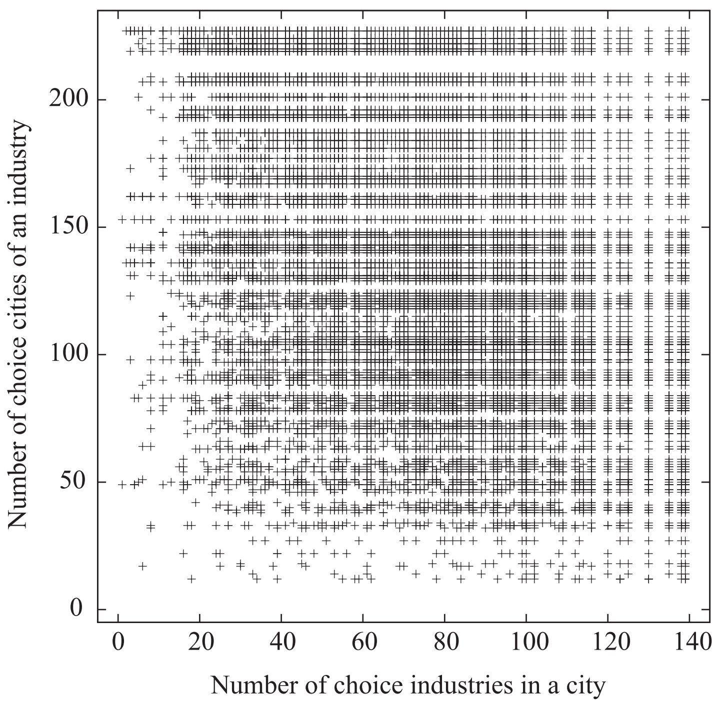

Figure 9: Industry-location events

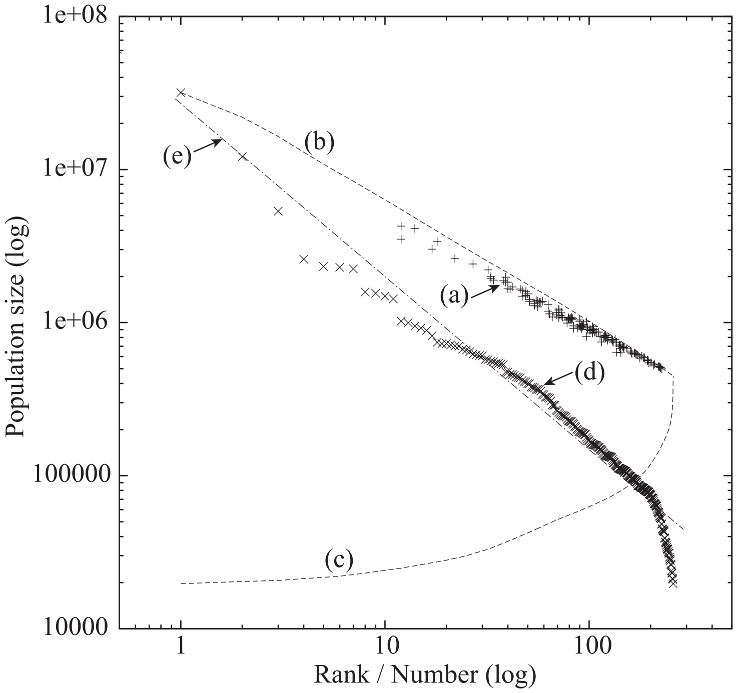

Figure 10: City size distribution and the NAS Rule

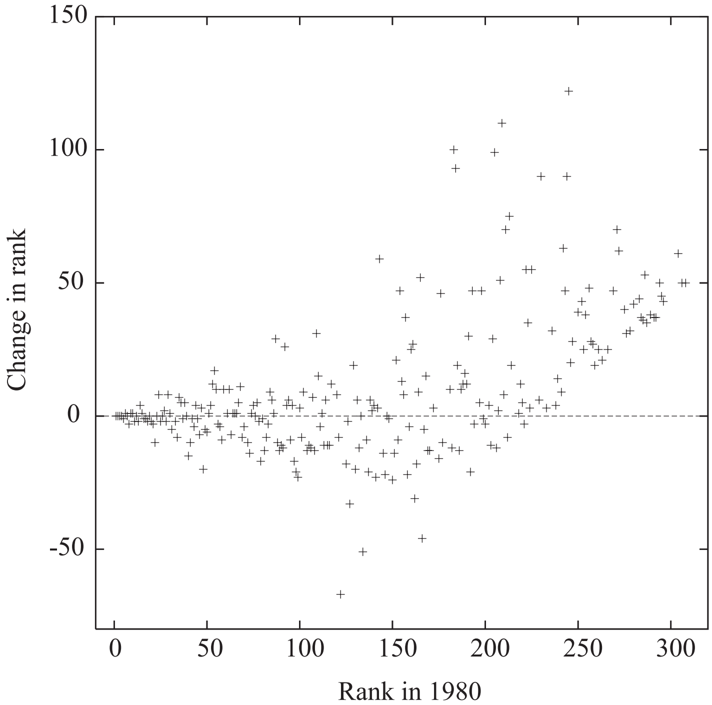

Figure 11: Change in the ranking of cities existing in both years

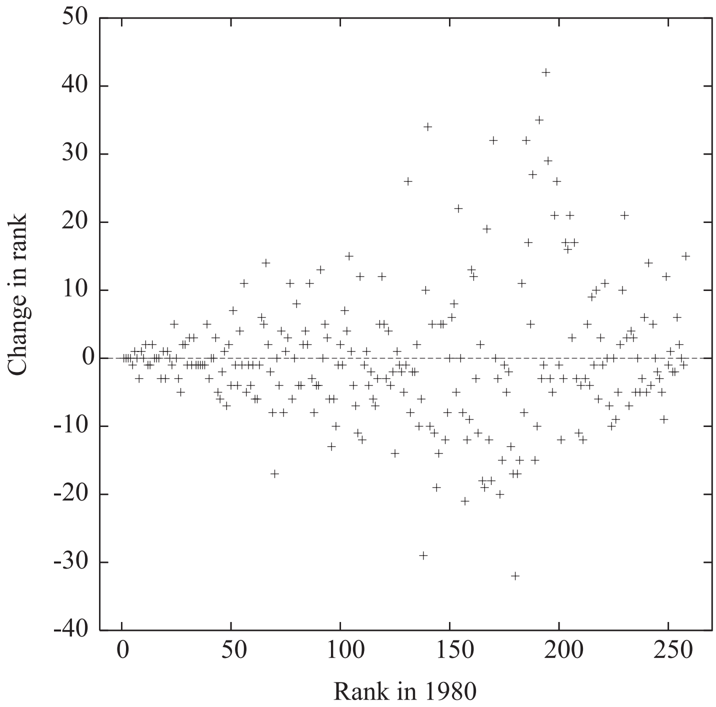

Figure 12: Change in the ranking of cities with boundaries fixed at 2000

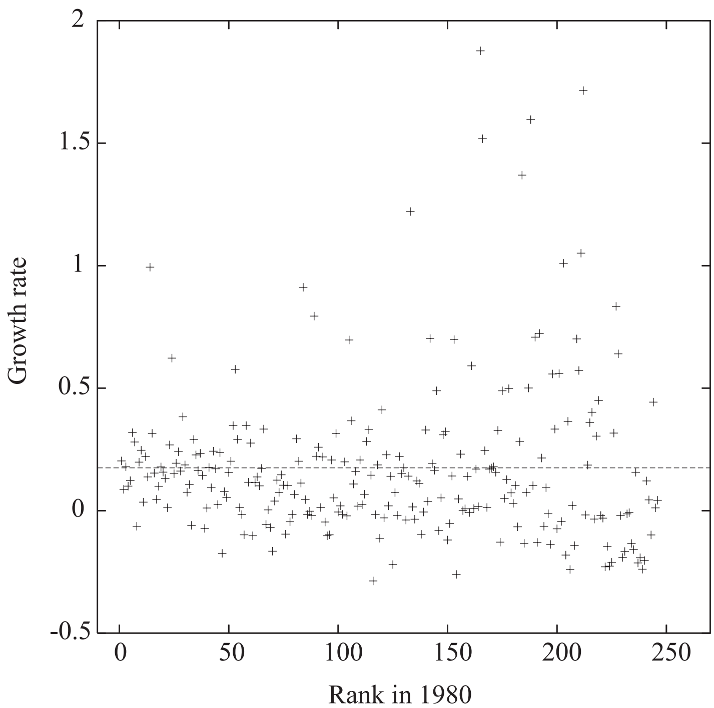

Figure 13: Change in the sizes of cities existing in both years

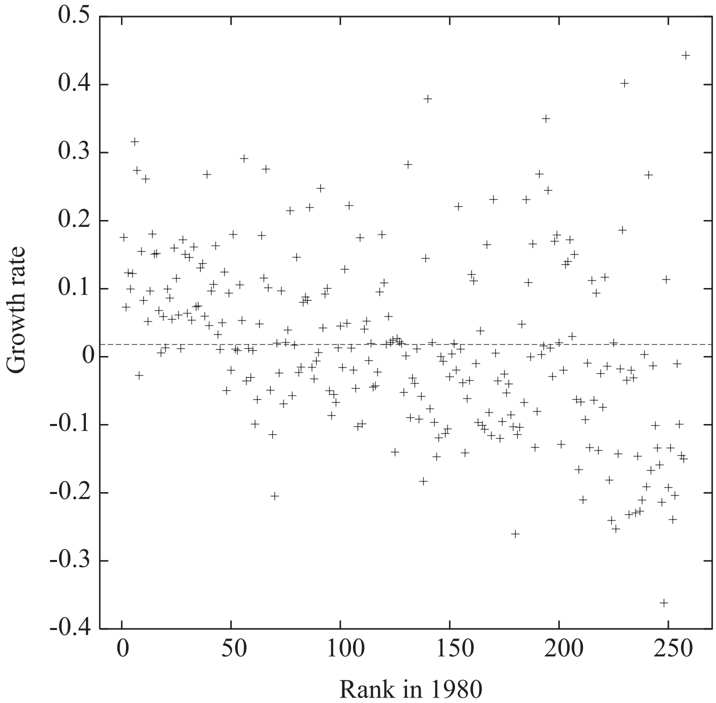

Figure 14: Change in the sizes of cities with boundaries fixed at 2000