RIETI Discussion Paper Series 17-E-013

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RIETI Discussion Paper Series 17-E-013

February 2017

Evolution of Sizes and Industrial Structure of Cities in Japan from 1980 to 2010: Constant churning and persistent regularity[1]

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Abstract

This paper investigates the evolution of the Japanese economy between 1980 and 2010 from the viewpoint of population and industrial structure of cities. With the rural-to-urban transformation settling by the 1970s, Japan experienced the second stage of urbanization through the integration of nearby cities. This led, on average, to a disproportionate 24% population growth of a set of core cities. In the meantime, cities experienced substantial churning of industrial composition: on average, 35% of the three-digit manufacturing industries present in a city in 1980 had left by 2010, while on average, 30% of industries present in a city in 2010 were absent in the same city in 1980. Remarkably, these substantial relocations of population and industries among cities took place while preserving a simple yet rigid relationship between the size and industrial composition of cities characterized by the roughly constant elasticity between the number and average size of cities in which an industry was present. This paper discusses the policy implications of this persistent regularity and the possible underlying mechanisms.

Keywords: Agglomeration, Co-agglomeration, City systems, Transport costs, Cluster analysis, Power laws, Central place theory

JEL classification: R12, C33

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[1] This research was conducted as part of the project, “An empirical framework for studying spatial patterns and causal relationships of economic agglomeration,” undertaken at the Research Institute of Economy, Trade and Industry. The road network data for Japan has been obtained from the Center for Spatial Information Science of the University of Tokyo. This research has been partially supported by the Grant in Aid for Research (Nos. 25285074, 26245037, 15H03344) of the MEXT, Japan.

1 Introduction

The thirty years between 1980 and 2010 studied in this paper coincide with the period of major economic upheaval in Japan. Recovering from the economic turmoil caused by the two oil shocks and the end of the fixed exchange-rate system in the 1970s, Japan experienced moderate growth triggered by major financial policies and public infrastructure investment during the first half of the 1980s. This was followed by the asset price bubble, its burst in 1991, and the long economic stagnation, called the "lost 20 years."

As far as the the rise and fall of individual cities are concerned, however, they do not reflect these fluctuations at the national level.[1] Rather, their relative locational advantages determined by the expanded highway and high-speed railway networks especially during the growth period in the 1970s and 1980s appeared to have a long-lasting impact on the fate of individual cities and regions. As will be shown in Section 2, more than 30% of the variations in the population growth of individual cities between 1980 and 2010 are related to transport development. While the nationwide development of the transport network enhanced the accessibility of all locations in Japan, those cities that were associated with major transport hubs, intersections, and terminals gained more, which in turn attracted industries and population to these cities, and resulted in their disproportionate growth. These "selected" cities experienced on average 24% population growth by swallowing the surrounding cities. Their growth was accompanied by the decrease in the number of cities from 309 to 221.

Cities do not result solely from population agglomerations, but are usually associated with industrial agglomerations. As will be clear in Section 4.2, it is most natural to characterize the industrial structure of a city in terms of the *absolute* rather than the relative presence of each industry, i.e., in terms of *agglomerations* rather than specialization. In this study, the *significant presence* of each of the 110 three-digit manufacturing industry of the Japanese Standard Industrial Classification (JSIC) is identified by using the agglomeration-detection approach developed by Mori and Smith (2014), so that the *industrial composition* of a city can be defined by the set of industries whose agglomerations overlap with this city.[2] In this context, a larger city naturally houses a larger number of industries. However, the list of industries present in a given city appears to change drastically over the thirty years, even if the number of industries changes little. More specifically, the cities included in our data experienced substantial *churning of industrial composition*: for the cities remained throughout the thirty years, on average, 35% of the three-digit manufacturing industries present in a city in 1980 had left by 2010, while on average, 30% of the industries present in a city in 2010 were absent in the same city in 1980.[3] That is, even for the

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[1] The definition of cities will be given in Section 2.

[2] As industrial classifications vary year by year, only the set of industries that appear throughout the study period are included to make the comparison between different time points meaningful.

[3] Our interest here is the range of industries in a given city. Thus, it is natural to look at the *presence* of industries. Alternatively, Duranton (2007) proposes a measure of industrial churning based on employment

growing cities, their industrial diversity did not simply expand, but a sizable portion of the industrial composition of each city was replaced.

Despite the substantial relocations of both populations and industries among cities, the size distribution and the relative industrial composition of cities remained remarkably similar over the period studied. As for the former, the upper tail of the city-size distribution exhibits *the persistence of the power law coefficient*. As for the latter, *the hierarchy principle* held to a large extent, i.e., the set of industries present in a smaller city is the subset of that in a larger city. More specifically, it is possible to identify, on average, roughly 70% of the industrial composition of a given city based on this principle, *despite the frequent churning of the industrial composition of cities*. When taken together, these two regularities imply the persistent log-linear relationship between the number and average size of cities in which a given industry is present, designated as *the number-average size rule* (Mori et al., 2008; Mori and Smith, 2011).

Often, the economic policies at the city and regional levels are targeted at population growth and promotion of industries. However, in the presence of these persistent regularities between size and industrial structure of cities, such policies may have little influence. This is because the relative sizes of cities are largely dictated by the persistent power law, and the relative position of a city in the city-size distribution, in turn, dictates the industrial composition of the city via the hierarchy principle.

The rest of the paper proceeds as follows. Section 2 describes the evolution of the sizes and locations of cities in Japan between 1980 and 2010. It is shown that the nationwide development of a high-speed transport network in the 1970s and 1980s had a substantial impact on the growth patterns of cities. Section 3 lays out the evidence for the churning of industrial compositions of cities that focused on manufacturing industries. Section 4 shows evidence of the persistent regularities in city-size distribution and the relationship between the size and industrial composition of cities. Section 5 discusses the implications of this study for theoretical modeling and regional economic policies, while Section 6 concludes the paper.

2 Growth and decline of cities

The spatial structure of the economy in a given country can perhaps most precisely be described in terms of the city system. "Cities" here refer to *metropolitan areas* which are combinations of working and residential places connected by commuting ties, rather than

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distribution across industries. But, then the evaluated "churning level" reflects the variation of labor intensity and production scales across industries. For instance, the disappearance of labor intensive industries will be more pronounced than that of capital intensive ones. Also, while a large employment of a given firm usually implies a larger output value of that firm *within a given industry*, it is not often true when firms in different industries are compared. So, his measure is somewhat misleading as a measure of industry churning. To gauge the range of industries in a city, thus this paper adopts the count of industries that have a statistically significant presence (i.e., agglomeration) in that city.

municipalities as delineated by jurisdictional boundaries. The metropolitan areas are usually identified as a bundle of municipalities for which population and commuting data are available. In this study, we adopt the definition of *Urban Employment Area* (UEA) as proposed by Kanemoto and Tokuoka (2001), which is the most popular definition of a metropolitan area in Japan.[4] Hereafter, we will use *cities* and metropolitan areas interchangeably. For simplicity of analyses, this study covers only the cities on islands which are connected to either Honshu (the main island) or Hokkaido island (refer to Figure 2) by road, i.e., isolated small islands are omitted.[5] Cities thus defined are endogenous and their boundaries vary over time in response to changes in commuting patterns. Hence, not only can the boundaries of existing cities expand or shrink, but new cities may also form as old cities disappear.

By 1980, the rural-to-urban transformation in Japan had almost settled, and the inhabited lands were saturated with cities that accounted for 87% of the total population. Thus, there has been not much of a change in urbanization rates thereafter. Nonetheless, the cities exhibited substantial volatilities in population sizes between 1980 and 2010 as indicated by the distribution of population growth rates for this period in Figure 1. More specifically, of the 309 cities that existed in 1980, 114 were either absorbed into other cities or simply disappeared, while 26 cities were newly formed, leaving 221 cities in 2010. The cities that were present in both 1980 and 2010 experienced, on average, 24% population growth (with a standard deviation of 47%).

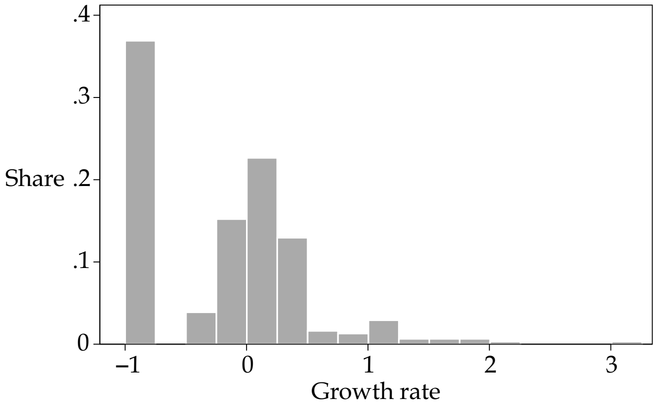

Figure 1: Population growth rates of cities

As mentioned in the Introduction, the extensive development of highways and high-speed railway networks occurred throughout Japan in the 1970s and 1980s. Figure 2 depicts the development of the high-speed railway network, where the gray cells in the background represent the cities in 2010.[6] The development began in the section linking Tokyo and Osaka (the red segment in the figure) in 1964 triggered by the Tokyo Olympics

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[4] The set of UEAs used in the present study is available online at `http://www.csis.u-tokyo.ac.jp/UEA/index_e.htm`.

[5] The omitted population is less than 1% of the total population.

[6] The municipality boundaries have been generated by Municipality Map Maker by Takashi Kirimura at `http://www.tkirimura.com/mmm/`.

the same year. The network first expanded westward to Fukuoka by 1975, then eastward to Morioka and northward to Niigata by 1982. The rest of the extensions came mostly after 2000; thus, the network structure in the 1980s seemed to have the strongest influence on the growth of cities in the 1990s and 2000s.[7]

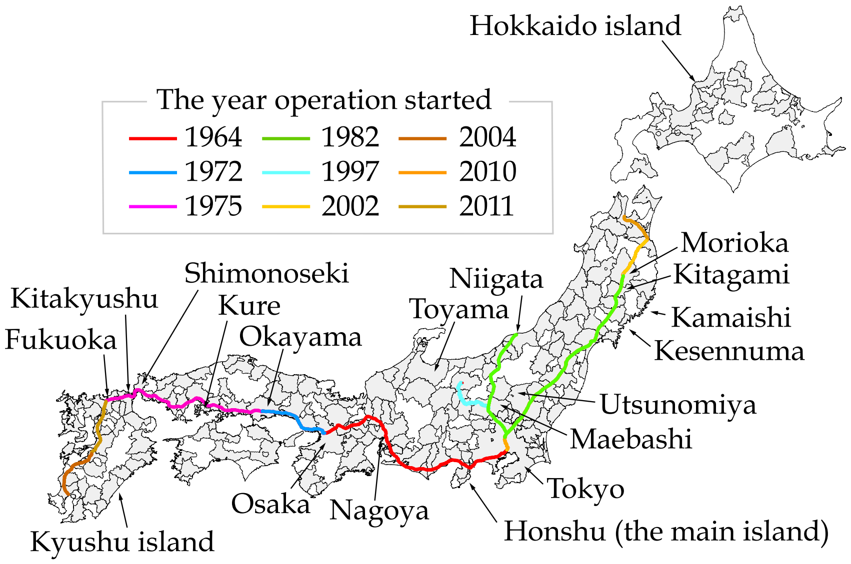

Figure 2: Development of high-speed railway networks

The development of highway networks followed that of high-speed railways in the 1970s and 1980s as shown in Figure 3. From the 1990s, the network expanded to cover the more rural parts of the country.

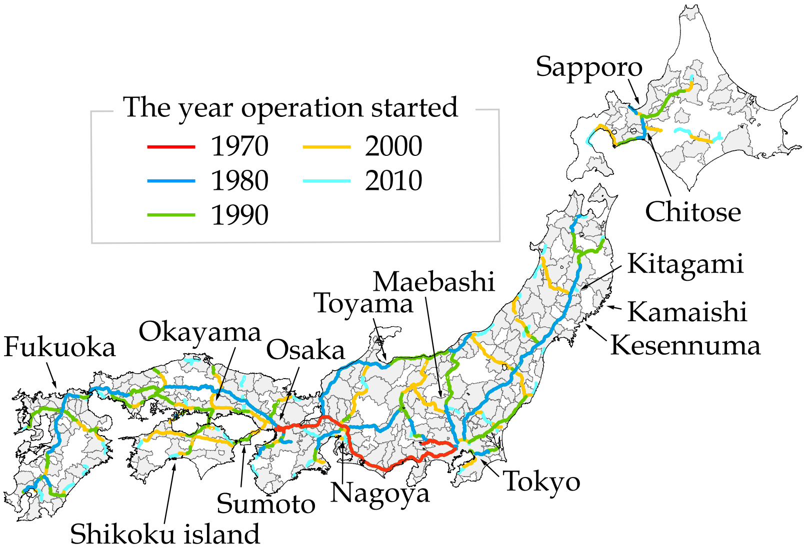

Figure 3: Development of highway network

These transport network developments up to the 1980s seemed to play the key role in the drastic rise and fall of cities. To show this, Figure 4 plots the growth rates of individual

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[7] The data for high-speed railways and highway networks are available from the National Land Numerical Information download service of Japan at `http://nlftp.mlit.go.jp/ksj-e/index.html`.

cities which existed in both 1980 and 2010. The red horizontal line indicates the 9% growth rate of the national population. The cities labeled in red, blue and green are located at the major high-speed rail stations, highways, and 24-hour airports, respectively.

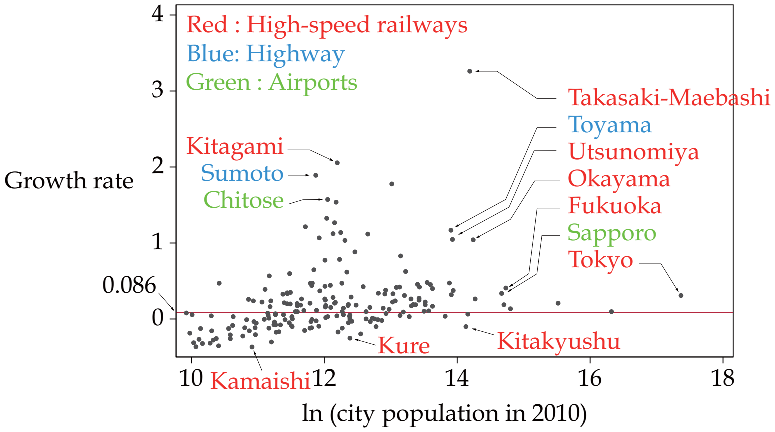

Figure 4: Population growth rates of individual cities

In all types of transport networks, Tokyo emerges as a particularly major terminal. To reach from the west of Tokyo to either the east or north of Tokyo by high-speed railway, passengers must change trains at Tokyo, which contributes to the locational advantage of Tokyo. Moreover, as shown in Figure 3, highways expand radially from Tokyo, indicating that the transport network developments in Japan are highly biased to improve accessibility to and from Tokyo.

There are other obvious examples of high growth rates at major terminals and intersections of the networks. Shikoku island, one of Japan's four major islands (refer to Figure 3), was connected to the main island for the first time in 1988 via Okayama. Thus, Okayama became a gateway for the Shikoku region, which doubled the population of the Okayama metropolitan area from 750,188 to 1,532,146.[8] A similar advantage boosted the population size of Sumoto (indicated in Figure 3). Kitagami has grown as a key intersection of the highway and high-speed railway. Fukuoka has been a terminal of the high-speed railway since 1975,[9] and together with its 24-hour international airport, has emerged as a gateway to Kyushu island (indicated in Figure 2). Utsunomiya and Takasaki-Maebashi are located at the origin of the eastward and northward high-speed railway lines from Tokyo, respectively.[10] Locations of major airports will also boost the city population there. The airport at Chitose boosted not only the population of that city, but also that of Sapporo.

While the expansion of transport networks improves the accessibility at all cities along

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[8] It should be noted that the city definition by Kanemoto and Tokuoka (2001) is sensitive to the redefinition of municipality boundaries. The disproportionate growth of Takasaki-Maebashi and Okayama in Figure 4 may be partly overstated due to this redefinition.

[9] In 2004, the high-speed railway was extended beyond Fukuoka. However, passengers must still change trains at Fukuoka. Thus, the terminal advantage of Fukuoka continued after 2004.

[10] Toyama on the northern coast experienced substantial growth of population from 504,353 to 1,093,247 as indicated in Figure 4, without any significant improvement in transport access relative to other cities. This may have been a reflection of the expectation of a high-speed railway network planned there in 2015.

the network, the effects are not uniform. Typically, the locations near the major hubs tend to lose relative locational advantage to the hubs, and hence lose population and industries. This phenomenon is often called *the straw effect* (e.g., Behrens et al., 2009) meaning that the growth potential of a location is swallowed by the nearby location with a better advantage.[11] Typical examples of declining cities owing to straw effects are Kure and Kitakyushu along the high-speed railway line leading to Fukuoka (see Figure 2). Both were major industrial cities, with the latter in particular being the eighth largest city in 1980. However, their transport accessibility correspondingly declined substantially compared to Fukuoka at the west end of the network. The port city of Kamaishi lost its advantage, as it deviated either from both the highway and the high-speed railway network.

Finally, the discussion above on the impact of transport development on city sizes can be confirmed by regressing the (log of) population growth rate of a city between 1980 and 2010 on a range of dummy variables, each of which represents the presence of nodes of transport networks and the growth rate of the number of local railway lines connected to the city.

$$\begin{aligned}\Delta \ln \mathrm{POP}_c = \alpha + \sum_{m\in M}\sum_{t\in Y}\beta_t^m \delta_{c,t}^m + \gamma \Delta \mathrm{AIR}_c + \eta \Delta \mathrm{AIR}(24\text{ hrs})_c \\ + \xi \Delta \ln \mathrm{RAIL}_c + \zeta \ln \mathrm{POP}_{c,1980} + \varepsilon_c . \qquad (2.1)\end{aligned}$$

Here, $M \equiv$ {a high-speed railway station, a high-speed railway terminal, along the highway, a node of Shikoku link} represents the set of transport advantages, and $Y \equiv \{1970, 1980, 1990, 2000\}$ represents the set of time points, so that $\delta_{c,t}^m = 1$ if city c is at the node of type m active in year t, and zero otherwise. $\Delta\mathrm{AIR}(24\mathrm{hrs})_c$ [respectively, $\Delta\mathrm{AIR}_c$] equals one if there is an airport that is [respectively, is not] in 24-hour operation within 50km from city c in 2010 but not in 1980, and zero otherwise.[12] $\Delta \ln \mathrm{POP}_c$ on the left-hand side represents the log of population growth rate of city c (between 1980 and 2010); $\Delta \ln \mathrm{RAIL}_c$ is the log of growth rate of the number of local railway lines that have stations in the city; $\ln \mathrm{POP}_{c,1980}$ is the log of population size of city c in 1980; Finally, ε_c is an error term.

Table 1 summarizes the result of the regression under ordinary least squares (OLS) estimation. Cities at terminal locations of the high-speed railway in 2000 (e.g., Fukuoka and Tokyo) and at the gateway to Shikoku island as of 1990 (Okayama) experienced particularly high growth. Although less spectacular, expansion of the high-speed railway network toward the eastern and northern regions of Honshu in the 1980s contributed to the growth of cities in these area, reflected in the significant coefficient of the 1990-dummy for high-speed railway. The effects of new transport development need not show up immediately after the development. The significant terminal effect in 2000 at Fukuoka

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[11] See Faber (2014) for a systematic evidence of the straw effects for the highway development in China.

[12] Since most cities have only one nearby airport, and most airports had already been constructed by 1980, this variable captures whether there is a newly built airport near city c between 1980 and 2010.

and Tokyo may reflect the fact that the network was so extensive in 2000 by the nation-wide expansion of high-speed network completed in 1980s and 1990s.

An interesting contrast between the impact of the high-speed railway network and that of the highway network is that while the highway connection to a given city leads to significant population growth of the city at every point in time, this is not the case for high-speed railways. Unlike highways which are less tightly associated with mass-transportations, in the case of a high-speed railway network, the frequencies and connectivities of transport services can differ greatly between major intersections/terminals and local stations, and hence the realized transport accessibilities can differ accordingly. The differential improvement in accessibility along the high-speed railway network resulted in the non-uniform population growth of cities. An example is the comparison between closely located Fukuoka and Kitakyushu (refer to Figure 2). Kitakyushu is an older industrial city that flourished during the high-growth period of the 1960s. However, when the high-speed railway line terminated at Fukuoka rather than at Kitakyushu, it appeared to have a permanent impact on the growth paths of these two cities whose population sizes were comparable in 1980. Fukuoka was already the sixth largest city with a population of 1,773,129 in 1980, and had grown by 41% to the fifth largest city with a population 2,495,552 by 2010; meanwhile, Kitakyushu's population fell from 1,524,747 to 1,370,169 in the same period. These non-uniform impacts are partly responsible for the insignificant coefficients of high-speed railway dummies. One must also note that Tokyo is a unique terminal connecting high-speed railway lines in virtually all directions, which should partly explain the disproportionate population size of Tokyo today.

The estimated coefficient of the lagged population size in (2.1) is negative significant (-0.078), meaning that it is more difficult to attain the same growth rate for a larger city under a given transport development. In fact, the transport developments account for more than 30% with the variation in the growth rate of cities after removing the effect of initial population. Namely, regressing $\Delta \ln \mathrm{POP}_c + 0.078 \ln \mathrm{POP}_{c,1980}$ on the rest of the variables yields $R^2 = 0.40$ (adj. $R^2 = 0.34$). Of course, the quantification of the underlying causal effects should involve appropriate instruments for the transport developments as in Faber (2014), which is beyond the scope of the present paper.[13]

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[13] While there are several recent attempts of measuring the impacts of transport development on regional growth (e.g. Duranton and Turner, 2012; Baum-Snow et al., 2017, 2016), few of them are successful in incorporating the non-uniform effects of transport development such as straw effects. Faber (2014) is a remarkable exception. Thus, there are more issues than endogeneity, and this literature is still subject to further refinements.

Table 1: Population growth of cities and changes in transport network structure

Dependent variable : Population growth rate between 1980 and 2010

Exp. variables	**Year**	**Coeff.**	**S.E.**	**Exp. variables**	**Year**	**Coeff.**	**S.E.**
High-speed railway	1970	−0.145	0.213	Shikoku link	1980	0.032	0.401
	1980	0.007	0.151		1990	1.681***	0.406
	1990	0.339***	0.128		2000	−0.012	0.429
	2000	0.249	0.249	ΔAIR		0.047	0.094
High-speed railway terminal	1970	−0.371	0.438	ΔAIR (24hrs)		0.131	0.080
	1980	−0.590	0.399	Δ ln #(local rail links)		−0.182	0.128
	1990	−0.292	0.416	ln Pop. size in 1980		−0.078**	0.038
	2000	1.265***	0.436				
Highway	1970	0.350**	0.136				
	1980	0.272***	0.088				
	1990	0.155*	0.090				
	2000	0.235**	0.114				
Number of obs.	195						
adj. R^2	0.290						

*, **, *** : Significant at 10%, 5% and 1% levels.

3 Churning of industrial composition of cities

It was not only population but also industries that were shuffled substantially among cities in the period studied. To show this, we adopt the cluster-detection method developed by Mori and Smith (2014) in order to identify the set of industries that have agglomerations in each city. This method, based on a simple probabilistic model of establishment location behavior, identifies the set of *agglomerations*, i.e., significant spatial clusters of establishments, for each given industry in terms of the partition of the set of *basic regions*. Each basic region is a 10km-by-10km cell, and the entire set of the basic regions consists of 3,735 cells that cover the studied location space of Japan.[14,15] The key features of this approach are as follows: (*i*) it filters out insignificant clusterings of establishments, (*ii*) determines the spatial extent of each individual agglomeration, and (*iii*) jointly identifies the set of all agglomerations of a given industry, in a certain statistically consistent manner.[16]

To highlight the churning phenomenon, we restrict the set of industries to those that appear throughout the period studied. That is, those industrial categories that do not appear in all years are excluded from this analysis. For instance, the two-digit category, "electronic parts, devices, and electronic circuits," was introduced in 2006. Thus, the industries in this category, by definition, did not exist in earlier years. However, as we

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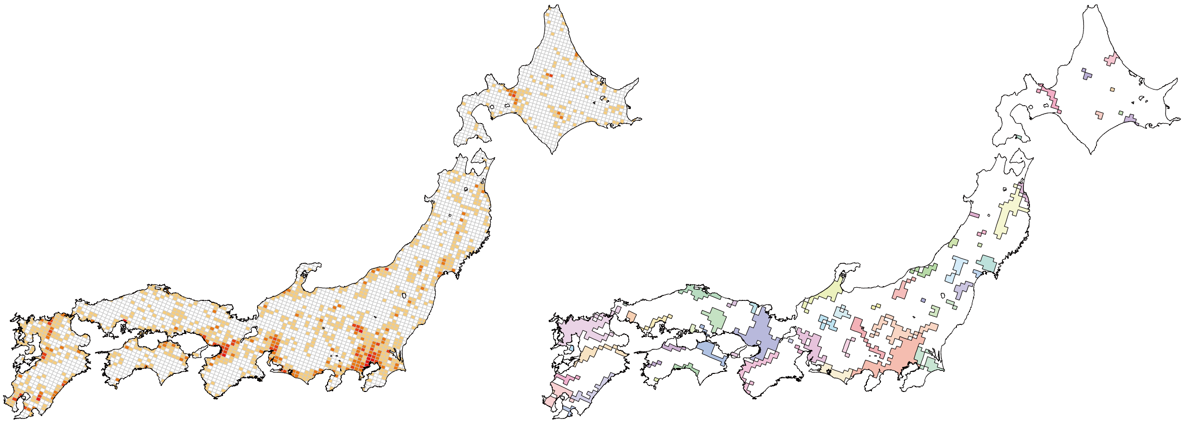
[14] Establishment locations are obtained from the micro-data of Establishment Census in 1981 and 1991, Establishment and Enterprise Census in 2001, and Economic Census for Business Frame in 2009 by the Statistics Bureau, Ministry of Internal Affairs and Communications (MIC) of Japan.

[15] The entire set of 10km-by-10km cells can be seen in diagram (a) in each of the Figures 5 and 6. The basic regions in 1980 are 3,363 municipalities as of 2001, rather than 10km-by-10km cells, due to data availability.

[16] Except for the regional divisions adopted, the rest of the setup for agglomeration detection follows that in Mori and Smith (2014).

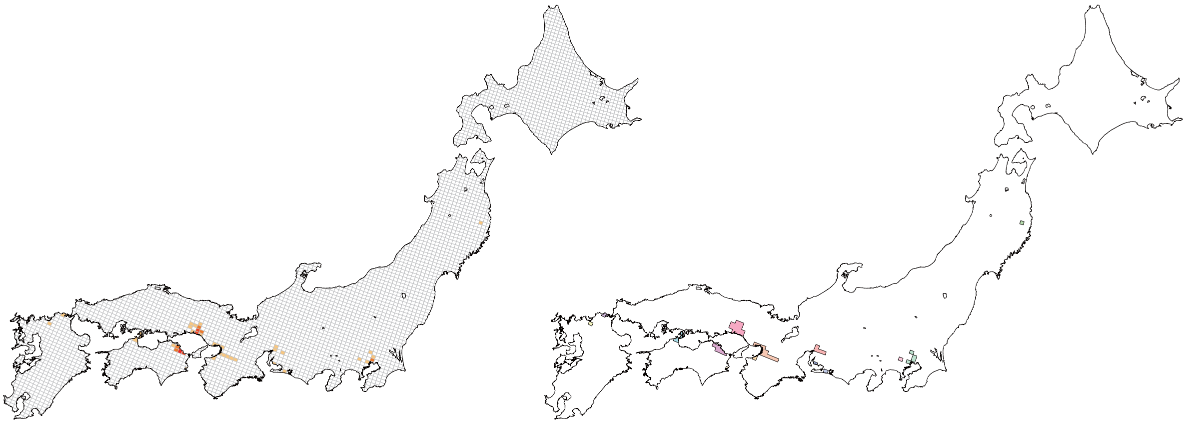
will see, even if these "new" industries are excluded, and similarly the "old" industries that are only present in earlier years are excluded, the churning of industries happening across cities is remarkable. This leaves us with the set of 110 common, three-digit manufacturing industries between 1980 and 2010.[17]

The spatial distribution of establishments and that of identified agglomerations for two example industries, "livestock products" manufacturing and "leather gloves and mittens" manufacturing, in 2010 are shown in Figures 5 and 6, respectively, where the former is a relatively more ubiquitous industry, while the latter is a relatively more concentrated one.[18] In the former (latter), 60 (14) agglomerations are identified from 3,519 (139) establishments.



(a) Distribution of establishments (b) Distribution of agglomerations

Figure 5: Spatial distributions of establishments and agglomerations of "livestock products" manufacturing in 2010



(a) Distribution of establishments (b) Distribution of agglomerations

Figure 6: Spatial distributions of establishments and agglomerations of "leather gloves and mittens" manufacturing in 2010

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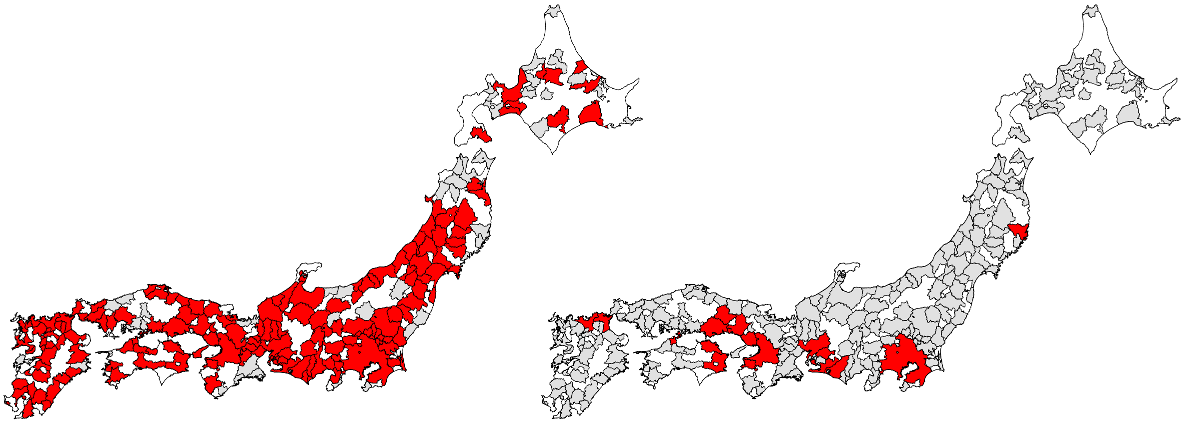
[17] Industry categories containing "miscellaneous" three-digit industries for which no specific three-digit categories could be assigned are also excluded.

[18] In diagram (a) of each figure, darker cells have higher densities of establishments of the corresponding industry. In diagram (b) of each figure, each colored patch represents a single agglomeration of the corresponding industry.

A given industry i is considered to be *present* in a given city c if an agglomeration of industry i and city c have a strictly positive area of spatial intersection. These cities are designated as the *choice cities* of industry i. The choice cities of "livestock products" ["leather gloves and mittens"] manufacturing are indicated by the 134 [15] red patches in diagram (a) [(b)] in Figure 7. To make comparisons of industrial composition of a city across different time points, we fix the city boundaries in 2010. As six cities have no agglomerations of any industry, 205 out of 221 cities are included in the analysis in this section.



(a) "Livestock products" (b) "Leather gloves and mittens"

Figure 7: Cities in which "livestock products" and "leather gloves and mittens" manufacturing industries are present in 2010

In this context, the *industrial composition* of city c can be represented by the set of industries present in the city, designated by I_c, and the *industrial diversity* of city c by the number of industries present in the city, $|I_c|$. The industrial diversity varies significantly across cities as depicted in Figure 8. While the mean diversity is 45.51 (46.68), the range is almost full, i.e., from 0 to 110 (0 to 106) with a standard deviation of 27.27 (27.10) in 2010 (1980).

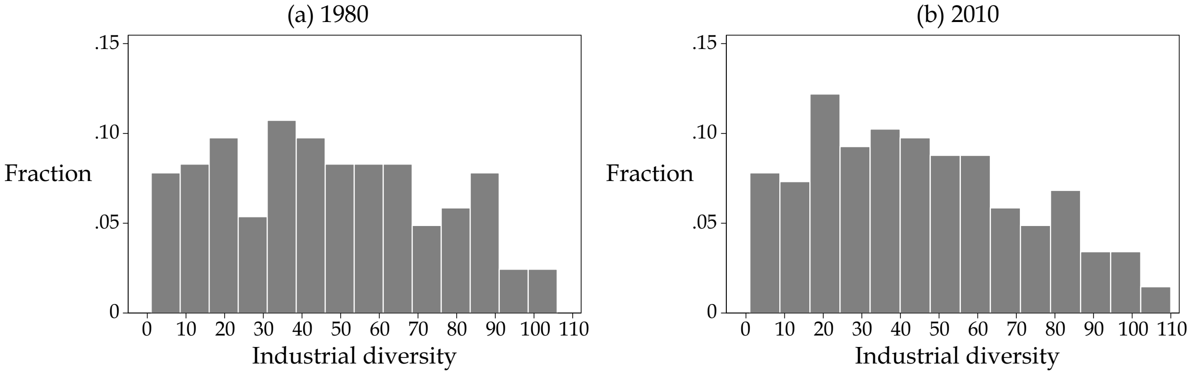


Figure 8: Industrial diversity of cities

Not surprisingly, the industrial diversity of each city is highly persistent: the correlation between industrial diversities in any two different time points is greater than 0.9, and in particular, that between 1980 and 2010 is 0.94 as indicated by Figure 9. However, this does not mean that the industrial composition of each individual city is also persistent.

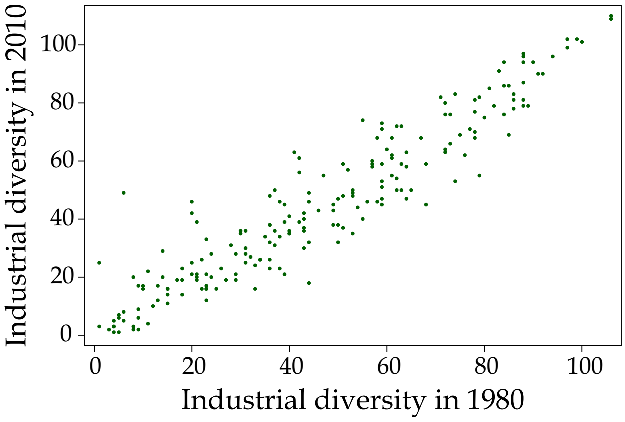


Figure 9: Comparison of industrial diversities between 1980 and 2010

Diagram (a) [(b)] in Figure 10 shows the distributions of the *entry share* [*exit share*], i.e., the share of industries in a given city which are present in 2010 [1980] but not in 1980 [2010] in the industrial composition of this city in 2010 [1980]. The average entry [exit] share is 0.33 [0.36] with a standard deviation of 0.19 [0.19]. Thus, behind the persistent industrial diversity of individual cities, there is substantial churning of the industrial composition of these cities.

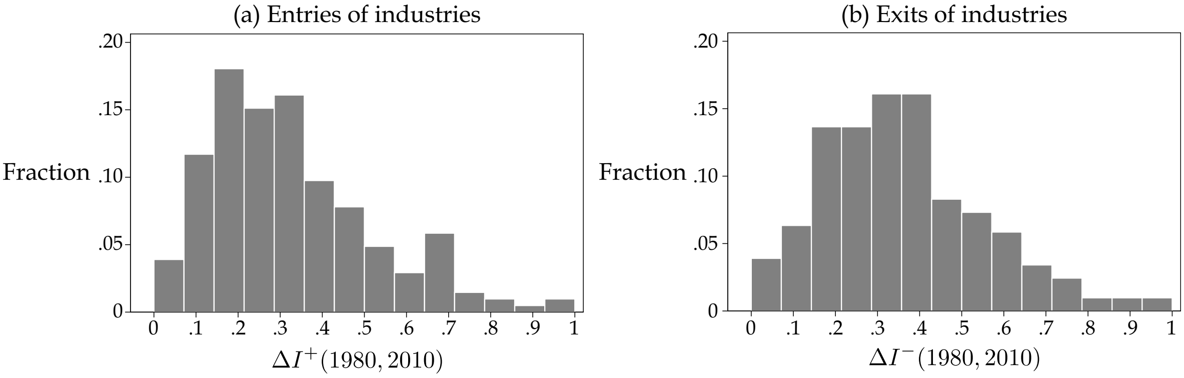


Figure 10: Entries and exits of industries for individual cities

Alternatively, the churning of industries across cities can be quantified in terms of the Jaccar index, $J_c(s,t)$, for a given city c between years s and t, computed as the ratio of the size of intersection to the size of union of the sets of industries for this city in years s and t. Figure 11 shows the distribution of $J_c(1980,2010)$, where the average of the index value is 0.50 with a standard deviation of 0.19. As is consistent with the entry and exit shares above, if a city has the same industrial diversity in 1980 and in 2010, then on average one-third of the industrial composition has been replaced. It is worth noting that the churning is substantial even for smaller time periods. That is, average values of $J_c(1980,2000)$ and $J_c(2000,2010)$ are 0.53 and 0.60, respectively.[19]

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[19] Since the largest cities such as Tokyo have almost the entire set of industries, their industrial composi-

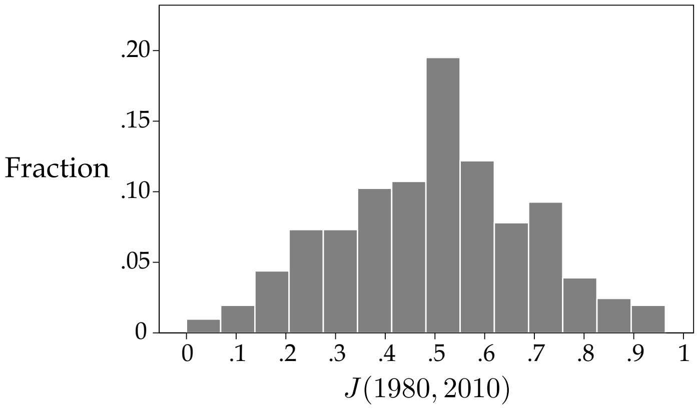

Figure 11: Jaccar index values for industrial compositions of cities between 1980 and 2010

4 Persistent regularity in size and relative industrial composition of cities

Despite the substantial churning of populations and industries across cities for the period studied, there are persistent structural regularities in the system of cities related to the population distribution and relative industrial composition of cities. Below, each of these regularities is discussed in detail.

4.1 Power law for the city-size distribution

City-size distributions are known to be well approximated by power laws across a wide range of countries (see, for e.g., Gabaix and Ioannides, 2004). Namely, if each city size, s, is treated as a realization of a random variable S with distribution P, then S is said to satisfy an (asymptotic) power law with exponent κ, if and only if for some positive constant a,

$$\lim_{s\to\infty} s^{\kappa} P(S > s) = a\,, \tag{4.1}$$

which can alternatively be expressed as

$$P(S > s) \approx as^{-\kappa}, \quad s \to \infty\,. \tag{4.2}$$

In this study, this relationship is referred to as a *power law*. If a given set of n cities is postulated to satisfy such a power law, i.e., their sizes are distributed as in (4.2), and if these city sizes are ranked as $s_1 \geq s_2 \geq \cdots \geq s_n$, such that the *rank* r_c of city c is given by $r_c = c$, then it follows that a natural estimate of $P(S > s_c)$ is given by the ratio, $c/n \equiv r_c/n$.

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tions do not change much, and hence, their Jaccar indices are close to one. On the other hand, the smallest cities typically have only ubiquitous industries, and since ubiquitous industries are similar over time, their Jaccar indices are also close to one. Consequently, the most of the industry churning quantified reflect that for the intermediate sized cities.

Thus, by (4.2), we obtain the following approximation:

$$r_c/n \approx P(S > s_i) \approx as^{-\kappa} \Rightarrow \ln(r_c) \approx \ln(an) - \kappa \ln(s_c) \tag{4.3}$$

$$\Rightarrow \ln(s_c) \approx b - (1/\kappa)\ln(r_c)\,, \tag{4.4}$$

where $b \equiv \ln(an)/\kappa$. This explains the standard log regression method for estimating κ in terms of the "rank-size" data, $[\ln(r_c), \ln(s_c)]$ for $c = 1, \ldots, n$.

Figure 12 plots $\ln s_c$ versus $\ln r_c$ for all cities, c, in each of years 1980, 1990, 2000 and 2010. As discussed in Section 2, cities with relative locational advantage have grown by absorbing surrounding cities. The number of cities fell from 309 to 283, 261, and to 221, while the average population size of cities increased from 330,075 to 391,038, 443,237, and to 545,745 in 1980, 1990, 2000 and 2010, respectively. However, the approximate log-linearity of this rank-size data in each given year shows that Japanese cities do indeed appear to exhibit a power law with exponent κ, given roughly the reciprocal of the slope of each curve.

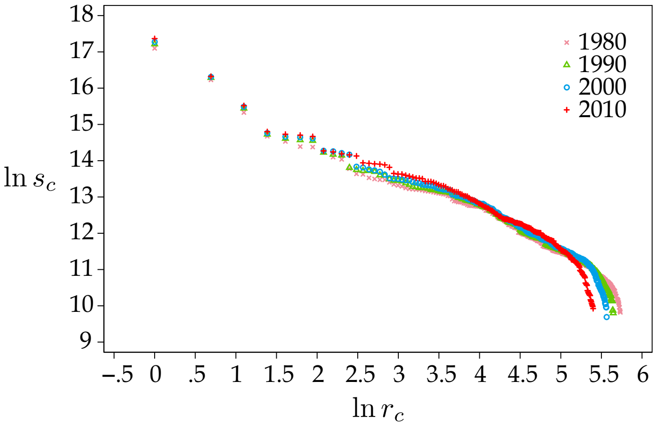


Figure 12: City size distributions

However, it is equally clear that if one estimates this slope with ordinary least squares, the downward bend in this curve for small cities will tend to produce a slope estimate which is too steep, implying that the estimate $\hat{\kappa}$ of the exponent κ will be too small. One of the simplest methods for correcting this bias, as proposed by Gabaix and Ibragimov (2011), is to reduce the rank scale by 0.5, which yields the modified regression,

$$\ln s_c = \alpha - \theta \ln(r_c - 0.5) + \varepsilon_c\,, \tag{4.5}$$

with $\theta = 1/\kappa$.

The estimated power law coefficients $\hat{\theta}$ are 1.07, 1.08, 1.09, and 1.13, in the years 1980, 1990, 2000, and 2010, respectively. Compared with the sizes of individual cities, these values are far less volatile. The modest increase in the power coefficient is consistent with the growth of large cities (by swallowing small ones).

4.2 Hierarchy principle and the number-average size rule

There is a strong relationship between the size and industrial compositions of cities. Following Mori et al. (2008) and Mori and Smith (2011), if the cities in which industry i is present are designated as *choice cities* of industry i, then the number of choice cities of industry i, n_i, and the average population size, $\bar{s}_i$ of these cities have a log-linear relationship, called *number-average size* (*NAS*) *rule*, as indicated by the red plots in Figure 13 for the 110 three-digit manufacturing industries in 2010.

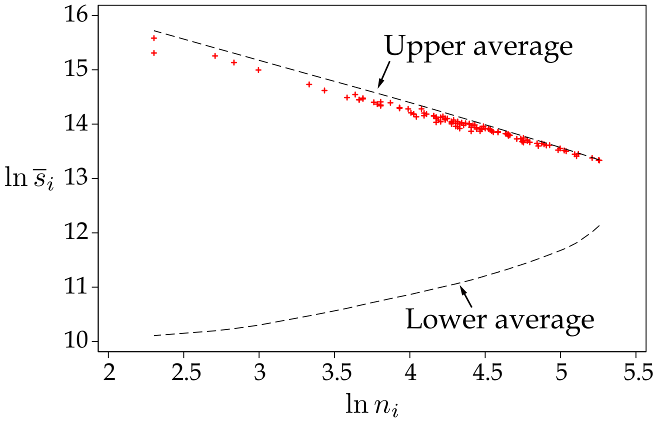


Figure 13: Number-average size rule, hierarchy principle, and the power law for a city-size distribution

The figure shows the NAS plot as well as two curves, *upper-average* and *lower-average curves*. The former is the average population size of the largest cities, while the latter is that of the smallest cities for the number of cities given by each point on the horizontal axis. Thus, these curves define the upper and lower bounds for the NAS plots. One can clearly see in the figure that the NAS plots almost hit their upper bound, meaning that the choice cities for each industry roughly consist of the largest cities. This in turn implies that the industrial composition of cities exhibits a strong hierarchical relationship. Namely, the set of industries present in a smaller city is roughly the subset of that in a larger city. When this hierarchical relationship holds, the industrial compositions of cities are said to satisfy the *hierarchy principle*, *à la* Christaller (1933).

It is also to be noted that the approximate log-linearity of the upper average curve reflects the asymptotic power law for city-size distribution (see Mori et al., 2008, Theorem 2).

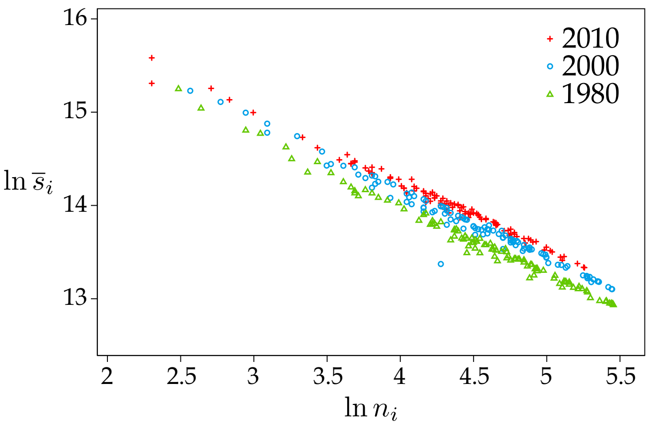


Figure 14: Number-average size rule

If the log-linear slope is fitted to the NAS plots in each year by the OLS:

$$1980: \ \ln \bar{s}_i = \underset{(0.033)}{16.93} - \underset{(0.007)}{0.74} \ln n_i, \quad R^2 = 0.99 \tag{4.6}$$

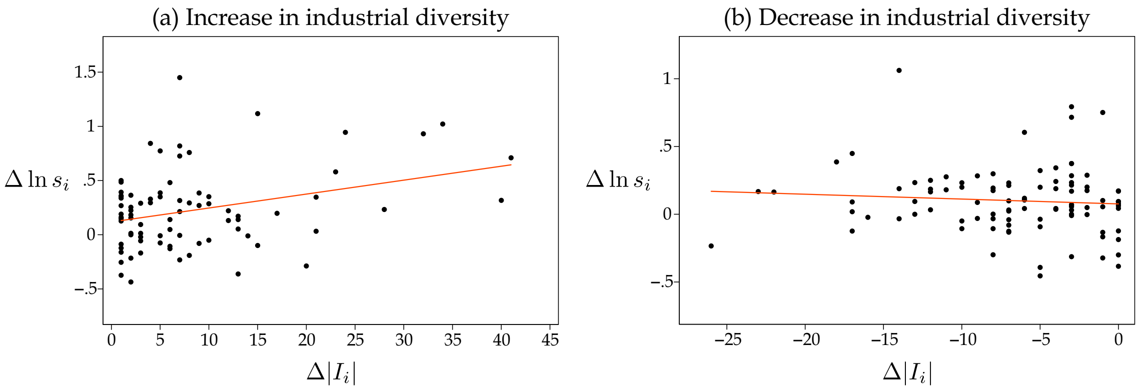
$$2000: \ \ln \bar{s}_i = \underset{(0.051)}{17.02} - \underset{(0.011)}{0.72} \ln n_i, \quad R^2 = 0.97 \tag{4.7}$$

$$2010: \ \ln \bar{s}_i = \underset{(0.030)}{17.11} - \underset{(0.007)}{0.72} \ln n_i, \quad R^2 = 0.99\,, \tag{4.8}$$

they exhibit approximate common power law reflecting the persistent power-law coefficients for city-size distribution, where the numbers in the parentheses are the standard errors. More specifically, the elasticity of the average size of choice cities with respect to the number of choice cities is around 0.72-0.74. Recall that on average, one-third of the industrial composition had been replaced in a city between 1980 and 2010. It is remarkable that this churning of industries took place while maintaining this common power law.

In the context of central place theory, the agglomeration of population and that of industries reinforce each other. Figure 15(a) shows evidence supporting this implication by plotting the population growth rate in log versus the increase in the industrial diversity of each city i, $\Delta|I_i|$, for cities which experienced increases in industrial diversity. The correlation is 0.32 and significant. Thus, an increase in the number of industries co-agglomerating goes along with the increase in population size in a city.

Figure 15(b), on the other hand, shows the similar plots for cities that experienced decreases in industrial diversity. The correlation between the change in population size and that in industrial diversity for these cities is insignificant. This may be owing to the inertia of population agglomeration, so that shrinking industrial diversity does not immediately translate into the decrease in the size of population agglomeration. The extra workers are likely to be absorbed in the non-manufacturing sectors. The period studied coincides with the period of *de-industrialization*. The share of manufacturing in the total establishment counts decreased by 33% from 13.5%, while wholesale, retail, and service increased by 22% from 49.4%; financial services by 20% from 1.3%; and transport and information by 55% from 2.5%. A similar trend can be observed in employment.


(a) Increase in industrial diversity

(b) Decrease in industrial diversity

Figure 15: Spatial coordination between industries and population

Finally, we look at quantifying the hold of the hierarchy principle. The more complete the hierarchy principle is, the fewer are the degrees of freedom for influencing the industrial composition of a given city by independent place-based policies, since the industrial composition of this city is more closely linked to the rest of the cities.

Let I_c be the set of industries present in city c, and the *hierarchy share* between cities c and d be defined by

$$H_{(c,d)} = \frac{|I_c \cap I_d|}{|I_c|}. \tag{4.9}$$

Then, the hierarchy principle implies that $H_{c,d} = 1$ for cities c and d such that $s_c \leq s_d$. If the set of *hierarchy pairs* of cities in the set C of all cities is defined as $\mathcal{H} \equiv \{(c,d) \in C : s_c \leq s_d\}$, then the degree to which the hierarchy principle holds can be quantified by

$$H = \frac{1}{|\mathcal{H}|} \sum_{(c,d)\in\mathcal{H}} H_{(c,d)}. \tag{4.10}$$

The value of H is, on average, 0.70 (0.24), 0.73 (0.20), and 0.67 (0.24) in 1980, 2000 and 2010, respectively, where the numbers in the parentheses are standard deviations. Thus, it can be said that roughly 70% of the realized industrial location patterns are consistent with the hierarchy principle.

To test the significance of these values of H, we construct the counterfactual industrial composition of each city as follows: First, the industrial diversity of each city c is fixed at the actual value $|I_c|$. Then, for each city c, the counterfactual industrial composition is chosen by selecting $|I_c|$ industries without replacement from the set of all industries, I, with the choice probability of each industry $i \in I$ being $n_i / \sum_{j\in I} n_j$. By controlling for both the industrial diversity of cities as well as the locational diversity of industries, we generate 1,000 random counterfactual location patterns of industries. Figure 16 depicts the distribution of average hierarchy shares under random counterfactual location patterns of industries (by the gray histogram) together with the average hierarchy share under the actual location pattern of industries in 2010. The p-value for the one-sided test under the null hypothesis that the actual location pattern of industries is an instance of the random counterfactual location patterns, is virtually zero. Thus, the actual location patterns exhibit strong consistency with the hierarchy principle. The same is true for all the other years.

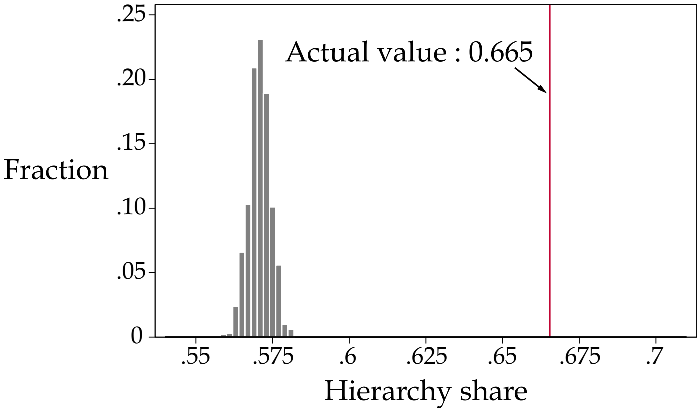


Figure 16: Distribution of average hierarchy shares under counterfactual agglomeration patterns in 2010

5 Implications for regional economic policies and theoretical modeling

The stringent spatial coordination of industries and population has been observed to take place at each point in time, despite the substantial spatial churning of population and industries at the same time. The presence of these regularities have strong policy implications, in the sense that they act as a de facto constraint for policies aimed at giving an economic boost to an individual city or industry. While there are no compelling theories to account for the observed regularity formation at this point, it is necessary to discuss potential mechanisms underlying these regularities to derive any policy relevance. The next section reviews some relevant theoretical developments, before discussing their policy implications.

5.1 Theoretical foundation of the persistent regularities

There are two key regularities that are related: the power law for city-size distribution and the hierarchy principle for the industrial composition of cities. Under the perfect hierarchy principle, it is not simply that a larger city has a larger industrial diversity, but also that this city has the entire range of industries that are present in any smaller city. Since the smaller cities are more ubiquitous (under the power law), any industry found in a larger city but not in a smaller city tends to be more localized (i.e., it has a smaller number of choice cities) than any industry which is found only in the smaller city.

Among the current theories, one approach to account for the hierarchy principle is in terms of central place theory (Christaller, 1933; Fujita et al., 1999; Tabuchi and Thisse, 2011; Hsu, 2012; Akamatsu et al., 2016a). The central tenets of this theory assert that the heterogeneity of industries, and positive (demand) externalities across industries together with the spatial extent of markets, give rise to the hierarchies of cities in terms of their industrial composition, and thus to a diversity of city sizes. In the spatial competition model by Hsu (2012), the difference among industries is only the scale economies in terms of the size of fixed costs. He shows that if the distribution of the size of fixed costs can be represented by a regularly varying function, then there is a locally stable equilibrium in which the hierarchy principle holds, city-size distribution exhibits a power law, the NAS rule also holds. Akamatsu et al. (2016a) instead adopt a many-industry, many-location extension of the new economic geography model of Fujita et al. (1999) and Pflüger (2004). In this model, each industry produces a continuum of differentiated consumption goods *à la* Dixit and Stiglitz (1977), subject to a given substitution elasticity of goods, while there are a large number of such industries which differ in the elasticity of substitution. To determine the distribution of the substitution elasticities across industries, they took a sample from the estimated substitution elasticities of more than 13000 imported products in the US by Broda and Weinstein (2006). They generated a large number of bootstrapped samples of stable equilibria of the model economy, and showed that the hierarchy principle, the power law for city size distribution, and the NAS rule are *generic properties* of stable equilibria.

As for the power laws for city-size distribution, the most popular theoretical derivation postulates that growth rates of individual cities are independently and identically distributed (*iid*) random variables (e.g., Gabaix, 1999, 2009; Duranton, 2006; Rossi-Hansberg and Wright, 2007), i.e., Gibrat (1931)'s law. However, these models do not simultaneously account for the hierarchy principle, or at least it is not explicitly obtained. In particular, the key difference between these random growth models and the central place models above is the absence and presence of space. The heterogeneity of industries and the demand externalities across industries do not automatically result in the hierarchy principle.[20]

The power law for city-size distribution depends critically on the shape of the distribution of substitution elasticities as suggested by Hsu (2012). Although it so happened that the observed distribution of substitution elasticities (or more generally that of scale economies) based on the Broda and Weinstein (2006) data is consistent with the power law, the underlying mechanism is still an open question.

5.2 Policy implications

It has been shown that the size and industrial structure of cities in Japan maintain tight regularities despite the substantial churning of population and industries across cities over time.[21]

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[20] Another very different approach to replicate the spatial distribution of economic activities resorts to variations in the first nature advantage of locations. See, for e.g., Desmet et al. (2016).

[21] The implications discussed here may be less relevant for developing countries in which urban agglomerations are not the representative form of economic locations.

Persistent power law for city-size distributions

It has been shown that the size distribution of cities exhibits a persistent power law over the 30-year period (Section 4.1) despite substantial reorganizations of the city structure through the integration of nearby cities as well as the redistribution of populations among cities (Section 2).

Evidence presented in Section 2 suggests that the latter redistribution of population is partly accounted for by the uneven improvement of transport accessibility brought about by the nationwide expansion of high-speed railway and highway networks. The objective of this public infrastructure investment was to correct regional disparities and carry out the balanced development of national land based on the Comprehensive National Development Plan of the Japanese government. Although larger population sizes do not necessarily imply higher welfare, it is indeed often the case (see, e.g., Bettencourt and West, 2010; Bettencourt, 2013).

However, the persistency of the power law exhibited by the city size distribution implies that the regional disparity is unlikely to disappear in the wake of such policies, since cities can grow only at the cost of other cities so that the distribution of the relative sizes of cities are preserved, although individual cities may experience ups and downs in their size rankings. In particular, better accessibility between the core and peripheral regions does not necessarily result in higher growth of peripheral regions, although it was the original intention of this policy. In fact, the post-war transport network development in Japan has always been in favor of Tokyo, as the network is essentially designed to improve accessibility to Tokyo, which in turn has made Tokyo even more disproportionately larger, rather than helping rural cities to catch up. In practice, the feasible way to achieve equality among regions may only be through interregional transfers.

Hierarchy principle

When industrial location is considered within the city system, the computation of hierarchy shares in Section 4.2 indicates that roughly 70% of the location patterns of individual industries are consistent with the hierarchy principle at each point in time. In particular, given the substantial (on average 30%) churning of industries among cities, this percentage is quite high, which in turn suggests that these coordination take place relatively instantaneously. From the observed NAS rule and the theoretical models discussed in Section 5.1, the spatial coordination of industries and the prevailing heterogeneity of scale economies among industries may be responsible for the realized persistency of the power law for city size distribution. If the hierarchy principle is an outcome of the spatial coordination among many industries via cross-industry positive externalities as in the central place models, then there seems to be little room for any policy by an individual city or region to have a large influence on the location behavior of a specific industry.

At the same time, however, it is also true that as many as 30% of the realized industrial locations deviate from the principle. Since the location patterns of these industries are relatively independent, other things being equal the place-based policies targeting these industries should be more effective. Figure 17 shows the distribution of the counts of industries which are present in a given city but not present in more than 70% of cities bigger than this city. The figure shows only the cities which have at least one such industry deviating from the hierarchy principle, where the darker colors represent the presence of a larger number of such industries, and the names of cities together with the names of deviating industries in parentheses are indicated for selected cities. The place-based policies targeting these industries in a given city may be less constrained by the spatial coordination with other industries, and they may contribute to improve the relative advantage of this city.

Not surprisingly, the industries which deviate from the hierarchy principle tend to reflect strong natural advantage of location. Concentrations of "musical instruments" manufacturing, for instance, are often tied to the availability of wood resource and dry weather. Similarly, "cray refractories" manufacturing is tied to the ceramics-pottery producing districts. Some industries such as "aircraft", "watches and clocks" as well as leather/fur related manufacturing may have a historical background.

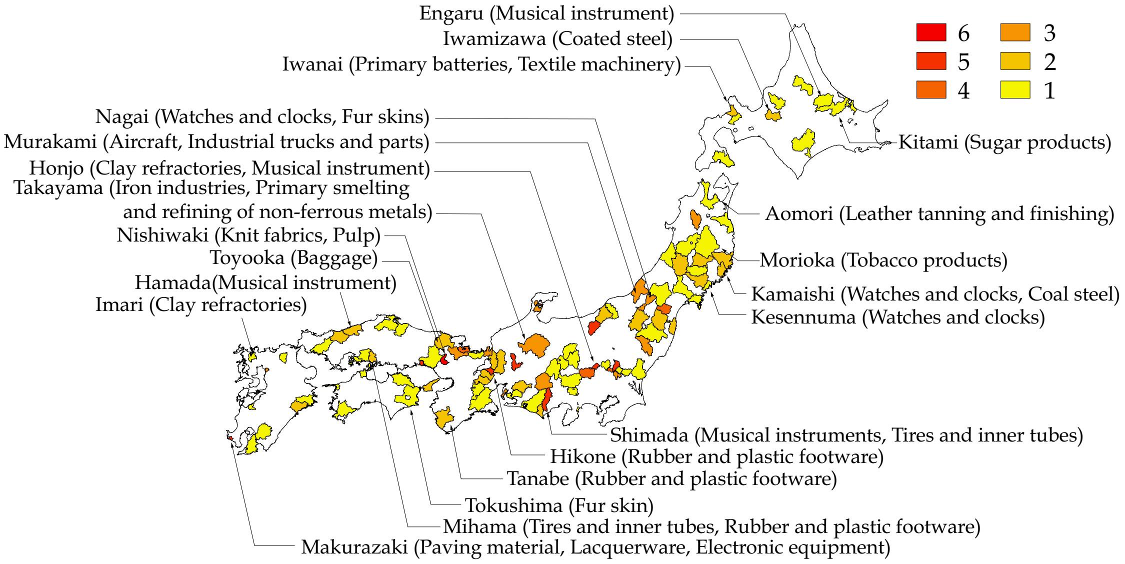

Figure 17: Industries deviating from the coordination in 2010

It is also worth investigating the set of industries that exhibit high consistency with the hierarchy principle. Namely, under the hierarchy principle, each city has the entire set of industries which are present in any smaller city. Thus, if the industrial location patterns are highly consistent with the hierarchy principle, for a given city, the industries that are present in the majority of smaller cities would also likely be found in this city, and hence, other things being equal, such industries may be attracted with less effort. This is rather intuitive, since the industries that are present in smaller cities are the more ubiquitous ones that seek for the proximity to consumers, they are also likely to be present in larger cities associated with a larger consumer population.

Figure 18 shows the distribution of the counts of industries which are absent in a given city but are present in more than 70% of cities smaller than this city, where the darker colors represent the presence of a larger number of such industries, and the names of cities together with the names of absent industries in parentheses are indicated for selected cities.

Although it is beyond the scope of this paper, it should be noted that to identify the set of potential industries to be attracted in a given city in practice, it is important to control for the location determinants of the potential industries. For instance, while there are a large number of cities that are specialized in "seafood products" manufacturing, these cities are typically located along the coast. Although "seafood products" manufacturing is one of the most ubiquitous industries so that it is likely to be found in many sufficiently large cities with larger markets, it is unlikely for an inland city to attract this industry.

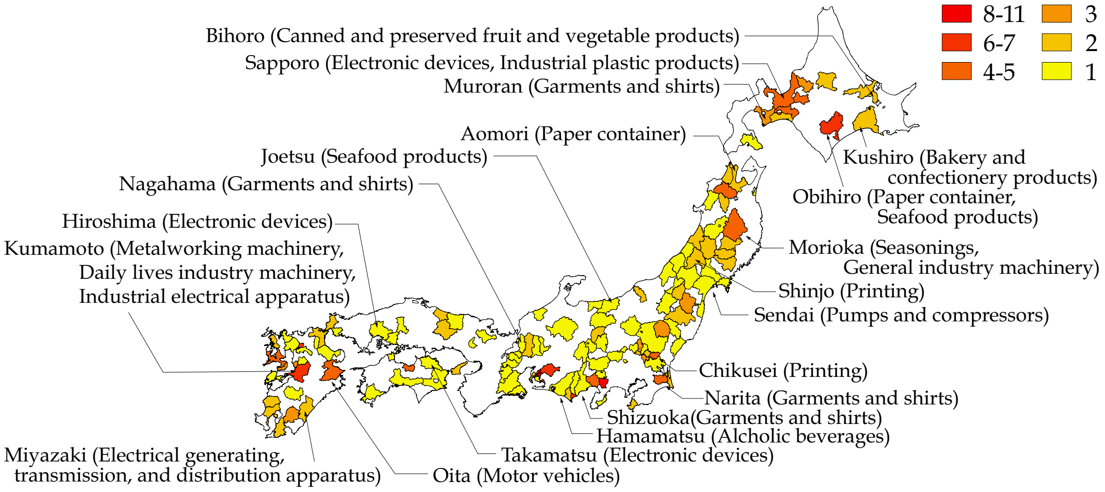

Figure 18: Potential industries to be attracted to each city in 2010

6 Concluding remarks

This paper investigated the evolution of the city system in Japan for the period 1980 to 2010 from the viewpoint of population sizes and industrial structure of cities, and offers evidence for the key stylized facts about the presence of constant churning and persistent regularities in the population and industrial distribution among cities.

With regard to the city-size distributions, findings of this study are not particularly new, as their power law properties at the country level are widely recognized together with substantial volatilities of individual city sizes (e.g., Batty, 2006). In the case of Japan, the development of the nation-wide transport infrastructure appeared to have a certain influence, where the growth and decline of cities reflected differences in the relative advantage in transport access among cities.

A novelty of this study is that it shows the persistent correspondence between the population size and industrial structure of each individual city in the form of the hierarchy principle under the constant churning of industries across cities. This, in turn, implies that the spatial coordination of agglomerations among industries may be playing a key role in the prevailing diversity in city sizes and their power law properties. While the frequent churning of industries among cities and that of establishments have been reported in different contexts (e.g., Dumais et al., 2002; Duranton, 2007), this study is unique in that both the churning and coordination of industries are expressed in terms of the presence of agglomerations of individual industries in each city, and hence, both these phenomena can be considered as the properties of industrial agglomerations.[22] While the fact that the majority of industries follow the hierarchy principle is important constraint in designing place-based industrial policies, it can also help identify the most effective industries to promote in each city.

As for the power laws for city-size distributions which hold together with the hierarchy principle, the central place models (Hsu, 2012; Akamatsu et al., 2016a) place the responsibility on the underlying distribution of scale economies across industries. In fact, the distribution of substitution elasticities of US imports by Broda and Weinstein (2006) are consistent with the power law for city-size distributions, although the underlying mechanism which results in the observed distribution of substitution elasticities is an open question.[23]

The mechanism behind the churning of industries across cities is another open question. The change in the number of agglomerations is significantly influenced by the sensitivity to transport costs, in keeping with the existing theories of agglomeration (Akamatsu et al., 2016b). Consistent with these theories, Mori et al. (2016) have shown that industries disperse more, i.e., the number of agglomerations increases, if they became more sensitive to transport costs, where the sensitivity to transport costs for each industry is measured by the shipment cost for a unit distance for a unit product value of this industry. They show that between 1995 and 2010, the log of sensitivity to transport costs ranges from -2 to 3 with an average 0.01 and a standard deviation of 0.79. Thus, while no simple tendency is observed for the importance of transport costs for industries, their finding is consistent with the churning of industries across cities observed in this study. However, the sources of the variation in the sensitivity to transport costs are diverse: from changes in shipment technologies, the increasing dominance of internet communication, changes in production technologies, and exchange rates, to product cycles. The investigation of the causes of industry churning and the distribution of the prevailing scale economies are left for future research.

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[22] See, e.g., Schiff (2015) and Davis and Dingel (2014) for related researches focusing on the presence of industries (rather than specialization) in each city.

[23] Random growth models (e.g., Gabaix, 1999; Duranton, 2006; Rossi-Hansberg and Wright, 2007) are consistent with the power law for city size distributions. However, so far no mechanism has been proposed in this context to generate the hierarchy principle in combination with the power law.

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