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Agglomeration economies in Japanese industries: the Solow residual approach

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Abstract This paper proposes a new approach to measuring agglomeration economies in Japan. Under the proposed approach, we used the Solow residual to measure agglomeration economies and confirmed that agglomeration economies exist in both manufacturing and non-manufacturing industries. Furthermore, this paper shows that social overhead capital has a positive effect on agglomeration economies. Currently, agglomeration economies are robust only in metropolitan areas; however, they are present throughout Japan because of the disproportionate allocation of social overhead capital within the nation.

JEL Classification D24 · R11 · R12

1 Introduction

With both a declining population and a rapidly aging society, Japan must encourage economic growth by improving its total factor productivity. To realize this goal, increasing population growth and utilizing agglomeration economies are key tasks for both urban and regional policymakers. Simultaneously, the government of Japanese Prime Minister Shinzo Abe emphasizes providing cost-effective social overhead capital to achieve regional economic growth. Therefore, it is crucial to investigate the

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connection between agglomeration economies, a driving force behind improvements in total factor productivity, and social overhead capital.

The importance of agglomeration economies for regional economic growth has long been debated by regional scientists (Fujita and Thisse 2002). The term "agglomeration economies" refers to the positive externality acquired by firms through increased productivity generated from the spatial concentration of industry. Rosenthal and Strange (2004) summarized previous research on agglomeration economies by examining the relationship between industry agglomeration and city size. They concluded that labor productivity for a firm increases from 3 to 8 % when the size of a city doubles. Glaeser et al. (2001) indicated that agglomeration economies exist for consumption, although most studies focus on explaining agglomeration economies in production. In addition, many previous empirical studies demonstrated that agglomeration economies play an important role in improving the production efficiency of local firms and industry (Beeson and Husted 1989; Mitra 1999, 2000; Driffield and Munday 2001; Tveteras and Battese 2006; Otsuka et al. 2010; Otsuka and Goto 2013). Furthermore, Otsuka et al. (2014) indicated that agglomeration economies result in reduced costs and increased tax revenue for local governments, which positively influences their cost efficiency levels. This study proposes a new approach to identify agglomeration economies in production because of their demonstrated importance.

Most studies of agglomeration economies assume several hypotheses and verify them using different types of production functions, such as the Cobb–Douglas, Constant Elasticity of Substitution (CES), and translog production functions. Examples include Moomaw (1981, 1983), Nakamura (1985), Henderson (1986, 2003), Kanemoto et al. (1996), Ciccone and Hall (1996), Ciccone (2002), Graham and Kim (2008), and Graham (2009). Furthermore, many researchers assume Hicks-neutral technological progress when measuring agglomeration economies and attempt to ascertain agglomeration economies as an element of total factor productivity. However, these approaches have a disadvantage because they must assume a specific type or form of production function. When they attempt to identify agglomeration economies with a specific production function, the result may differ depending on the specific formulation of the function. In concrete terms, if one study determines the influence of agglomeration economies using a Cobb–Douglas function that influence may not be detected in another study using a CES or a translog function. The problem is that the agglomeration effect depends on the type of production function, which is arbitrarily selected by the researcher. Since previous findings are mixed, it is difficult for us to identify which type of function results in agglomeration, or which specific element increases the benefits of agglomeration.

To overcome the problems involved in selecting a specific functional form, this study attempts to measure total factor productivity as the Solow residual. This approach enables us to ascertain the robustness of agglomeration economies as an element of total factor productivity and to investigate the relationship between industry clustering and social overhead capital using a direct connection between total factor productivity and agglomeration economies.

Section 2 describes the new method used to measure total factor productivity with the Solow residual. The results of the investigation are presented in Sect. 3. Section 4 concludes the paper.

2 The Solow residual approach

Economies of agglomeration, or agglomeration economies, are often expressed as economies of scale at the city and regional levels. Kanemoto et al. (1996) describe the theoretical relationship between agglomeration economies and economies of scale. According to them, agglomeration economies are assumed to be an external effect in corporate production functions. If the agglomeration economy is internalized in the aggregation process at the regional level, then it is measured as economies of scale in regional production functions. McCann (2001) also states that the size of agglomeration economies in a region can be measured as economies of scale in production. Therefore, this study has assumed that economies of scale in production for a region are agglomeration economies.

Various technology assumptions can be set on production in a region. For this study, a Hicks-neutral production technology is assumed,

$$Y_t = A_t f(K_t, L_t).$$

When both sides are differentiated by time t and divided by Y, the following expression is obtained.

$$\frac{1}{Y} \cdot \frac{\mathrm{d}Y}{\mathrm{d}t} = \frac{1}{A} \cdot \frac{\mathrm{d}A}{\mathrm{d}t} + \frac{A}{Y} \cdot \frac{\partial f}{\partial K} \cdot \frac{\mathrm{d}K}{\mathrm{d}t} + \frac{A}{Y} \cdot \frac{\partial f}{\partial L} \cdot \frac{\mathrm{d}L}{\mathrm{d}t} \tag{1}$$

Let the price of a product be P, the capital-input price be P_K, and the labor-input price be P_L. The first-order condition to maximize profits then becomes

$$A \cdot \frac{\partial f}{\partial K} = \frac{P_K}{P}, \quad A \cdot \frac{\partial f}{\partial L} = \frac{P_L}{P}.$$

The following equation representing the returns to scale of production is established:

$$\frac{\partial Y}{\partial K} \cdot \frac{K}{Y} + \frac{\partial Y}{\partial L} \cdot \frac{L}{Y} = A \cdot \frac{\partial f}{\partial K} \cdot \frac{K}{Y} + A \cdot \frac{\partial f}{\partial L} \cdot \frac{L}{Y} = \gamma.$$

With this condition, Eq. (1) is rewritten as

$$\frac{\mathrm{d}\ln Y}{\mathrm{d}t} = \frac{\mathrm{d}\ln A}{\mathrm{d}t} + (1 - s_L) \cdot \frac{\partial \ln K}{\partial t} + s_L \cdot \frac{\partial \ln L}{\partial t} + (\gamma - 1) \cdot \frac{\mathrm{d}\ln K}{\mathrm{d}t},$$

where $s_L = P_L L / PY$. Here, the Solow residual SR can be defined as

$$\mathrm{SR} \equiv \frac{\mathrm{d}\ln Y}{\mathrm{d}t} - (1 - s_L) \cdot \frac{\partial \ln K}{\partial t} - s_L \cdot \frac{\partial \ln L}{\partial t},$$

and the following equation is derived:

$$\mathrm{SR} = \frac{\mathrm{d}\ln A}{\mathrm{d}t} + (\gamma - 1) \cdot \frac{\mathrm{d}\ln K}{\mathrm{d}t}. \tag{2}$$

Here, γ indicates the agglomeration effect expressing economies of scale in production.

3 Empirical analysis

3.1 Regional structure in Japan

In Japan, the geographic concentration of economic activity is remarkably large. The population of the Tokyo metropolitan area (i.e., Saitama Prefecture, Chiba Prefecture, Tokyo, and Kanagawa Prefecture) accounts for 27.24 % of the total national population, and production within this area is 32.14 % of the total national production (Table 1). However, the Tokyo metropolitan area accounts for only 7.34 % of total national livable land. In particular, the population of the Tokyo metropolitan area is significantly higher than that of the second most populous region, Kansai (16.25 %; this region includes Shiga Prefecture, Kyoto, Osaka, Hyogo Prefecture, Nara Prefecture, and Wakayama Prefecture) and of the third most populous region, Chubu (13.46 %; this region covers Gifu, Shizuoka, Aichi, and Mie Prefectures). In fact, it is roughly equivalent to the total population of the latter two regions. Similarly, production in the Tokyo metropolitan area (at 32.14 % of the national figure) is roughly equivalent

Table 1 Regional structure in Japan (2009)

Region	Inhabited area (%)	Population share (%)	Production share		
			All industries (%)	Manufacturing industries (%)	Non-manufacturing industries (%)
Hokkaido	18.04	4.36	3.45	1.61	3.99
Tohoku	20.39	9.34	7.94	7.57	8.05
Kita Kanto	8.37	6.18	5.95	8.96	5.07
Capital Area	7.34	27.24	32.14	22.70	34.91
Chubu	10.87	13.46	14.78	22.78	12.43
Hokuriku	3.54	2.42	2.35	2.55	2.29
Kansai	6.98	16.25	15.78	16.37	15.61
Chugoku	6.91	5.98	5.65	7.27	5.18
Shikoku	4.00	3.19	2.65	2.70	2.64
Kyusyu	12.61	10.46	8.60	7.32	8.97
Okinawa	0.96	1.10	0.70	0.17	0.86

Regional economic database at the Central Research Institute of Electric Power Industry
Hokkaido: Hokkaido
Tohoku: Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata
Kita Kanto: Ibaraki, Tochigi, Gunma, and Yamanashi
Capital Area: Saitama, Chiba, Tokyo, and Kanagawa
Chubu: Nagano, Gifu, Shizuoka, Aichi, and Mie
Hokuriku: Toyama, Ishikawa, and Fukui
Kansai: Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama
Chugoku: Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi
Shikoku: Tokushima, Kagawa, Ehime, and Koch
Kyushu: Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima
Okinawa: Okinawa

to total production in both Kansai (15.78 %) and Chubu (14.78 %). Both population and overall economic production show similar distributions, since both are highly concentrated in metropolitan areas.

Regional distributions of manufacturing and non-manufacturing production differ slightly. Production in manufacturing industries is mainly concentrated in provincial areas, while production in non-manufacturing industries is concentrated in metropolitan areas. For example, 22.70 % of total manufacturing production activity occurs in the Tokyo metropolitan area, while the figure for Chubu is as high as 22.78 %. For other areas, production activity also accounts for a higher proportion than population does: Production in Kansai accounts for 16.37 % of the total, Kita Kanto 8.96 %, Hokuriku 2.55 %, and Chugoku 7.27 %. This may have resulted from past production policies that promoted decentralization of manufacturing industries. On the other hand, production activity in non-manufacturing industries is concentrated in metropolitan areas and accounts for 34.91 % of the total, which is a higher proportion than that of the population. That is, the distribution of manufacturing industries diverges significantly from the population distribution, while the distribution of non-manufacturing industries strongly resembles that the population distribution. This suggests that the economic activity of non-manufacturing industries may rely significantly on agglomeration economies based on the population concentration in each region.

3.2 Data

Empirical analysis was conducted using annual data for 47 Japanese administrative divisions, or prefectures, from 1980 to 2009. All industry groups, consisting of both manufacturing and non-manufacturing industries, were analyzed in this study. Although various geographic levels including the city, region, administrative division, and regional block were available for the analysis, the 47 administrative divisions were selected to facilitate appropriately targeted and aligned regional industrial policy in Japan. We expect that agglomerations are evident in large-scale industrial areas, company towns, industrial areas with large numbers of small-sized companies, and regions where universities and industry cooperate. All types of agglomerations are included in the administrative division level for this study.

Output in production is defined as value-added, while labor and capital are defined as inputs. Each prefectural industry value-added (Y) output is the real value-added in the *Japanese Annual Report on Prefectural Accounts*. Labor input (L) is measured by estimating worker-hours. Data sources are the *Japanese Annual Report on Prefectural Accounts*, the *Labour Force Survey*, and the *Monthly Labour Survey*. Capital input (K) is the real fixed capital stock adjusted by its utilization rate. Fixed capital stock is calculated from gross investment, applying the benchmark year method. The utilization rate for manufacturing industries is derived from a set of indexes describing the operating ratio published by the Ministry of Economy, Trade and Industry. Because there are no publicly available data on the utilization rate for non-manufacturing industries, a deviation calculated from the inverse of the capital coefficient[1] is used as a

[1] It is expected that variations in the logarithm of the inverse of the capital coefficient, $\ln\left(\frac{Y}{K}\right)$, have a constant slope over time under a production system employing capital-using technology over the

proxy variable. Total prefectural production and employer remuneration were used to calculate the relative labor share (S_L).

The advantage of using an approach based on the Solow residual is that it is possible for us to specify the agglomeration economy with economies of scale in production. In addition, under this setting, various elements explain agglomeration economies, including the scale and concentration of population, as well as the concentration of businesses. Here, we investigate whether developments in social overhead capital raise the effect of agglomeration to provide policy suggestions regarding social infrastructure development. This is because the development of social infrastructure is expected to improve the accessibility of a region, which means that regions with improved accessibility can easily procure intermediate goods and are thus able to produce goods at a lower cost. The enhancement effect of agglomeration economies resulting from a region's market access has been identified by Otsuka et al. (2010) and Otsuka and Goto (2013) for Japanese industries. These studies demonstrated that a region endowed with good market access attracts businesses and boosts the effect of agglomeration economies. Based on that research, we consider that social overhead capital enhances market access and strengthens economies of agglomeration.

Social overhead capital stock (G) data were taken from the regional economic database at the Central Research Institute of Electric Power Industry. Social overhead capital stock comprises agriculture, forestry and fisheries facilities, roads, harbors, airports, communications, parks, water supply and sewer systems, social insurance and welfare facilities, schools, hospitals, and soil, water control and conservation facilities. We used their combined value in our study.

Table 2 shows summary statistics and the average annual growth rate for various measurement periods. The average annual growth rate of value-added in each industry increased in the 1980s, with the growth rate of overall industry at 4.24 %, manufacturing industries at 4.44 %, and non-manufacturing industries at 4.18 %. However, the average growth rate fell to 1.02 % for all industries in the 1990s, with both manufacturing and non-manufacturing industry growth rates falling to 0.36 and 1.21 %, respectively. In the 2000s, manufacturing growth increased slightly to 0.75 %, but non-manufacturing growth fell further, to 0.19 %. The average annual growth rate for all industries across all measurement periods was 1.42 %, with the growth rate for manufacturing industries at 1.36 % and the growth rate for non-manufacturing industries at 1.43 %. The trend in the growth rate represented by these value-added figures reflects the overall growth of the Japanese economy, namely a move from higher growth in the 1980s to a prolonged slowdown throughout the 1990s and the 2000s.

Meanwhile, the employment growth rate was negative from 2000 to 2009 in all industries (manufacturing and non-manufacturing). Furthermore, the average annual employment growth rate was depressed across all periods: The employment growth rate for all industries was 0.28 %, with the growth rates for manufacturing indus-

Footnote 1 Continued
long term. However, the value fluctuates every year in an observed data set. Hence, we assume the fluctuations in $\ln\left(\frac{Y}{K}\right)$ can be attributed to a change in capital utilization, as well as a time trend. Based on that assumption, a proxy of the capital utilization rate can be measured with a residual error term (ε) in the regression $\ln(Y/K) = \alpha + \beta T + \varepsilon$, where T is a time trend and β is a time-invariant slope of $\ln\left(\frac{Y}{K}\right)$.

Table 2 Descriptive statistics

	Value-added (million yen)			Labor (people)			Capital stock (million yen)			Social overhead capital (million yen)
	All industries	Manufacturing	Non-manufacturing	All industries	Manufacturing	Non-manufacturing	All industries	Manufacturing	Non-manufacturing	
1980										
Average	6,506,742	1,484,249	5,022,494	1,143,063	281,833	861,230	7,770,225	3,097,096	4,673,129	7,012,692
Max	50,819,621	9,804,571	41,015,050	7,040,813	1,711,959	5,328,854	41,007,593	13,227,422	32,297,752	38,549,405
Min	1,325,040	101,876	1,124,369	311,395	31,293	251,677	1,058,307	232,709	689,821	2,237,826
1990										
Average	9,857,259	2,291,870	7,565,389	1,261,658	311,546	950,111	14,838,714	5,209,024	9,629,690	11,506,329
Max	83,413,308	11,539,058	71,874,250	8,274,800	1,718,244	6,556,556	97,284,770	24,487,829	84,458,419	54,177,887
Min	1,839,861	162,983	1,469,345	309,843	31,964	240,828	2,566,210	450,013	1,907,170	3,714,267
Annual growth rate (%, 1980–1990)	4.24	4.44	4.18	0.99	1.01	0.99	6.68	5.34	7.50	5.08
2000										
Average	10,910,478	2,376,725	8,533,753	1,278,406	260,164	1,018,242	21,904,323	7,172,980	14,731,343	16,687,046
Max	92,738,081	10,633,550	82,104,531	8,055,188	1,267,828	6,787,360	152,732,726	34,897,185	137,093,393	69,668,958
Min	2,034,119	207,609	1,612,244	305,096	29,268	247,471	3,933,096	685,060	2,941,218	5,606,332
Annual growth rate (%, 1990–2000)	1.02	0.36	1.21	0.13	−1.79	0.69	3.97	3.25	4.34	3.79

Table 2 continued

	Value-added (million yen)			Labor (people)			Capital stock (million yen)			Social overhead capital (million yen)
	All industries	Manufacturing	Non-manufacturing	All industries	Manufacturing	Non-manufacturing	All industries	Manufacturing	Non-manufacturing	
2009										
Average	11,219,023	2,541,274	8,677,749	1,167,389	210,988	956,401	25,251,063	8,469,297	16,781,766	18,070,794
Max	93,598,435	12,480,468	83,411,942	7,206,859	938,693	6,287,304	187,711,453	43,976,067	172,161,493	70,721,332
Min	1,912,928	204,858	1,522,368	262,418	29,095	221,992	4,406,332	828,810	3,268,722	6,316,431
Annual growth rate (%, 2000–2009)	0.31	0.75	0.19	−1.00	−2.30	−0.69	1.59	1.86	1.46	0.89
1980–2009										
Average	9,782,316	2,193,289	7,589,026	1,239,886	273,510	966,377	17,536,021	5,935,442	11,600,579	13,559,909
Max	103,252,534	16,637,807	91,557,541	8,410,857	1,741,519	6,930,154	187,819,901	43,976,067	172,357,066	71,183,506
Min	1,325,040	101,876	1,124,369	262,418	28,496	221,992	1,058,307	232,709	689,821	2,237,826
Annual growth rate (%, 1980–2009)	1.42	1.36	1.43	0.28	−0.10	0.40	2.85	2.27	3.18	2.30

tries at −0.1 % and non-manufacturing industries at 0.4 %. In contrast, capital stock maintained a relatively high growth rate in both manufacturing and non-manufacturing industries from the 1980s through the 2000s. Across all measurement periods, the average annual growth rate in capital stock was 2.85 % for all industries, 2.27 % for manufacturing industries, and 3.18 % for non-manufacturing industries. These observed trends in employment and capital stock indicate a change in the industrial structure over the measurement periods, from a labor-intensive structure toward a capital-intensive structure. The average annual growth rate for social overhead capital was high in the 1980s (5.08 %) and in the 1990s (3.79 %). However, owing to a reduction in public spending that is partly attributed to government efforts to increase its fiscal health, the average annual growth rate of social overhead capital fell sharply in the 2000s to 0.89 %.

3.3 Concerns about estimating agglomeration economies

In traditional analysis of agglomeration economies, it is necessary to use a production function with a specific functional form. Two potential concerns are raised when a production function is estimated (Graham 2009). However, we can avoid these concerns when we measure the Solow residual.

3.3.1 Endogeneity

The first potential problem raised by estimating a specific production function is the endogeneity of the agglomeration effect. When estimating the agglomeration effect from a production function, the general assumption is applied to the error term, where it is distributed independently from the regression variables. The presence of endogeneity could violate this assumption because it implies that the element increasing the agglomeration effect is associated with productivity and may thus be an endogenous variable. For example, corporate management, hoping to succeed in business, seeks the region that will increase productivity the most. As a result, places that increase productivity are expected to become agglomeration areas with a high concentration of employment (population) and businesses, because businesses move to such areas. If this process holds true, high productivity could breed high agglomeration as those elements move into productive areas. What stipulates the directionality of this causal connection is not well developed in agglomeration theory. However, agglomeration may be determined from productivity.

The endogeneity problem of agglomeration has been studied recently by Ciccone and Hall (1996), Ciccone (2002), Henderson (2003), and Rosenthal and Strange (2005). Henderson (2003) estimates agglomeration economies using panel data at a corporate level where generalized method of moments (GMM) estimates are usable. Meanwhile, other studies have responded to the endogeneity problem by adopting the two-stage least-squares regression method and employing instrumental variables. Ciccone and Hall (1996) used the long-term lag of population density as an instrumental variable. Their argument is that the density we observe today is determined by the influence of past population density patterns that do not correlate with the productivity level occurring at the present time. The difficulty with this approach is that it requires detailed spatial information relating to density spanning past decades, and these data are especially hard to come by for small spatial areas. Ciccone (2002) used the total land area of the EU as an instrumental variable, while Rosenthal and Strange (2005) used data relating to types of geographic features that do not correlate with productivity.

However, we anticipate that the potential endogeneity bias in the agglomeration estimate is small from the results of previous studies. Ciccone and Hall (1996) and Ciccone (2002) noted that the estimated value of agglomeration economies using instrumental variables only differed slightly when compared to the least-squares estimate. In the same way, Rosenthal and Strange (2005) concluded that the influence of the endogenous regression coefficient was limited. Henderson (2003) also reported that the correlation between the endogenous regression coefficient and the error terms was not important. Thus, it can be concluded that recent studies have not found strong evidence of an endogeneity bias. Meanwhile, this study can avoid the endogeneity problem because we do not estimate a production function with specific factors representing externalities, but we use the Solow residual measurements to determine the degree of agglomeration instead.

3.3.2 Input/output element measuring errors

The second potential problem when estimating agglomeration economies relates to measurement errors in the input and output variables. Production is often used as a proxy variable for output that includes output price and volume. Input variables often use only two elements, namely labor and capital, and there is no precise information about the range of the "quality" or "frequency of use" of these elements. Ideally, one should break down inputs into land, raw materials, and energy, but it is usually not easy to access those data. In addition, capital is measured in monetary values, expressed in Japanese yen, not in physical values like labor input. This could cause another measurement problem. In practice, it is possible that the price of capital input, especially the price of land and buildings, has a positive correlation with city or regional scale.

Since the ideal proxy variables for input are difficult to obtain empirically, this study considers utilization rates of labor and capital to alleviate these potential problems. In concrete terms, we use working hours for labor and capital utilization for capital. Because of data constraints, we do not consider any variables relating to input quality, which are hard to express concisely.

3.4 Results

Table 3 shows the fundamental statistics for the Solow residual measurements. The table indicates that the mean value for all industries in 1980 was 0.4499, with the maximum value at 0.9877, for Tokyo, and the minimum value at 0.1758, for Fukui. The mean values remained stable during the 1980s and 1990s, but increased after 2000 and fell significantly in 2009. Tokyo consistently had the maximum value throughout

Table 3 Fundamental statistics for the Solow residual

	All industries				Manufacturing industries				Non-manufacturing industries			
	1980	1990	2000	2009	1980	1990	2000	2009	1980	1990	2000	2009
Mean value	0.4499	0.4364	0.4776	0.4044	0.2605	0.3333	0.4946	0.7285	0.5436	0.5094	0.5158	0.4013
Standard deviation	0.1512	0.1515	0.1453	0.1659	0.2120	0.2330	0.2984	0.3763	0.1517	0.1600	0.1401	0.1685
Maximum value	0.9877	1.0530	0.9566	0.9925	1.0150	1.3627	1.6796	2.1562	0.9569	0.9835	0.8453	0.8405
Minimum value	0.1758	0.1970	0.2287	0.0679	−0.2510	−0.1562	−0.1347	0.1143	0.2027	0.1844	0.2258	0.0085

the observation period. Moreover, this value gradually increased over time, expanding the regional disparities of the Solow residual. Table 3 also shows a different trend for manufacturing industries when compared with all industries. That is, the Solow residual increased throughout the observation period for manufacturing industries. In 1980, the mean value was 0.2605, but by 2009, it had increased significantly, to 0.7285. The Solow residual for Tokyo (namely the maximum value) also increased substantially. The minimum value also increased, but the maximum value grew by a greater extent, indicating an increasing difference between the minimum and maximum values.

It should be noted that trends observed in non-manufacturing and manufacturing industries differ over the period. The mean value of the Solow residual for non-manufacturing industries remained practically unchanged during the 1980s and 1990s and then fell substantially in 2000 because of a decline in technological progress within those industries. Even the maximum value, for Tokyo, declined from 0.9569 to 0.8405. Non-manufacturing industries experienced declining production efficiency over the same period because of the slow pace of changes in those industrial structures. On the other hand, manufacturing industries strengthened their international competitiveness through an aggressive R&D investment in tandem with globalization. Therefore, gains from productivity decreased in non-manufacturing industries.

The sizes of agglomeration economies, measured as economies of scale in this study, were estimated using Solow residual measurements. Specifically, assuming a constant rate of regional technical progress, Eq. (2) is reformulated as the following equation:

$$\mathrm{SR}_{jt} = \alpha_0 + (\gamma - 1)\,\Delta K_{jt} + \varepsilon_{jt}. \tag{3}$$

Table 4 shows the estimation results of Eq. (3) obtained by the pooling least-squares method (Plain OLS).

All regression coefficients were statistically significant at the 1 % level. The strength of agglomeration economies γ, as a measure of economies of scale, was 1.1135 for all industries. Because γ was greater than one, economies of scale can be said to exist. A comparison between manufacturing and non-manufacturing industries shows that agglomeration economies are marginally higher for manufacturing industries. That is, the regression coefficients were 1.0601 for manufacturing industries and 1.0313 for non-manufacturing industries, respectively.

Next, we examine the impact of social overhead capital as an element that strengthens economies of agglomeration. Kanemoto et al. (1996), using an estimation of a

Table 4 Estimation results in Eq. (3)

	All industries	Manufacturing industries	Non-manufacturing industries
α_0	−0.0061 (0.0014)**	0.0138 (0.0031)**	−0.0062 (0.0013)**
γ	1.1135 (0.0301)**	1.0601 (0.0638)**	1.0313 (0.0264)**
$\overline{R}^2$	0.0104	0.0007	0.0010

Values within parentheses show the standard error
** Significance at the 1 % level
* Significance at the 5 % level

Table 5 Estimation results in Eq. (4)

	All industries	Manufacturing industries	Non-manufacturing industries
α_0	−0.0069 (0.0014)**	0.0127 (0.0031)**	−0.0065 (0.0014)**
δ	0.0708 (0.0019)**	0.0681 (0.0040)**	0.0649 (0.0017)**
$\overline{R}^2$	0.0172	0.0077	0.0018

Values within parentheses show the standard error
** Significance at the 1 % level
* Significance at the 5 % level

specific production function, examined the effect of social overhead capital, which they considered as an element to enhance economies of agglomeration. Therefore, we compare our results with the previous research.

When we assume $\gamma = g(G)$, the productivity effect of social overhead capital can be measured by the following equation:

$$\mathrm{SR}_{jt} = \alpha_0 + \left(\delta G_{jt} - 1\right) \Delta K_{jt} + \varepsilon_{jt}. \tag{4}$$

Table 5 shows the estimation results from the pooling least-squares method (Plain OLS) for Eq. (4).

For all industries, the coefficient of the social overhead capital, δ, was 0.0708, with statistical significance at the 1 % level. Kanemoto et al. (1996) indicated a smaller coefficient at 0.026, thus smaller economies of scale, for metropolitan areas. The results of this study exhibit a relatively large influence of social overhead capital on productivity when compared with Kanemoto et al. (1996), because we adopted the Solow residual approach and used administrative division data in our study. Such differences suggest that social overhead capital provision has a major influence on production activity at the administrative division level but not at the metropolitan level. Manufacturing industries had a slightly higher impact for social overhead capital (0.0681) than the impact for non-manufacturing industries (0.0649). This suggests that the marginal impact of an increase in total factor productivity from providing social overhead capital was larger for manufacturing industries. The difference between manufacturing and non-manufacturing industries can be attributed to the unique characteristics of manufacturing industries. That is, manufacturing industries exchange more intermediate goods with other regions during the production process than non-manufacturing industries do. Thus, it is expected that the level of social infrastructure development in a region (e.g., roads) is positively correlated with the impact of social overhead capital on productivity. For example, industrial manufacturing areas are often located near highway interchanges because these industries depend on highway infrastructure for their businesses. In contrast, the production of goods for non-manufacturing industries, particularly service industries, is usually completed within the region. The exchange of intermediate goods with other regions is extremely low when compared with manufacturing industries, which suggests that social overhead capital is unlikely

Table 6 Economies of scale considering social overhead capital effects

	All industries		Manufacturing industries		Non-manufacturing industries	
	2009	$\Delta\delta G$	2009	$\Delta\delta G$	2009	$\Delta\delta G$
Hokkaido	1.2763	0.0708	1.2273	0.0681	1.1685	0.0648
Tohoku	1.3092	0.0714	1.2589	0.0687	1.1987	0.0654
Kita Kanto	1.2564	0.0732	1.2081	0.0704	1.1503	0.0670
Capital Area	1.3393	0.0552	1.2878	0.0531	1.2262	0.0505
Chubu	1.3097	0.0677	1.2594	0.0651	1.1991	0.0620
Hokuriku	1.2202	0.0749	1.1733	0.0720	1.1172	0.0686
Kansai	1.3171	0.0639	1.2665	0.0614	1.2059	0.0585
Chugoku	1.2717	0.0696	1.2228	0.0670	1.1643	0.0637
Shikoku	1.2289	0.0742	1.1817	0.0713	1.1251	0.0679
Kyushu	1.3047	0.0719	1.2546	0.0691	1.1946	0.0658
Okinawa	1.1499	0.1085	1.1058	0.1043	1.0528	0.0993

to have the same level of impact on production activity for non-manufacturing industries as it does for manufacturing industries.

Table 6 evaluates the degree of agglomeration across 11 regions. The evaluation is based on social overhead capital data at the administrative division level. The results of agglomeration were greater than unity for all industries in all regions; therefore, we conclude that economies of scale exist. In 2009, the highest value appeared in the Capital Area, at 1.3393; Kansai had the second highest value of 1.3171; and Chubu was third highest, with a value of 1.3097. The results indicate that metropolitan areas have higher values. In other regions, values were comparatively low, particularly in Okinawa, which had the lowest value of 1.1499. However, agglomeration economies increased in those regions between 1980 and 2009. This trend was strongest in Okinawa, followed by Hokuriku and Shikoku, indicating that agglomeration economies strengthened in rural regions more than in metropolitan areas. The result shows that investment in social overhead capital was distributed favorably toward rural regions rather than metropolitan areas during the observation period. Indeed, regional areas had excessive investment in social overhead capital under the government's regional policy. This investment, which aimed to strengthen regional economic activity, resulted in stronger economies of agglomeration. Agglomeration economies were greater for manufacturing industries than for non-manufacturing industries in all regions. Thus, it is evident that social overhead capital investment played an important role in improving the productivity of manufacturing industries and enhanced economic growth in metropolitan areas.

4 Conclusion

This study examined the influence of agglomeration economies on regional economic growth. We proposed a new approach using the Solow residual and measured the economies of agglomeration in Japanese administrative divisions. Specifically, this study attempted to determine the degree of agglomeration economies using Solow residual measurements, from which economies of scale are constructed, rather than using a production function that can be accompanied by specification error bias. The findings indicate that economies of scale exist in the 47 Japanese administrative divisions for industry as a whole, and in both manufacturing and non-manufacturing industries.

Furthermore, we investigated the effects of social overhead capital as a factor accelerating agglomeration economies. The results showed that social overhead capital had a significant positive effect on productivity growth, which was greater for manufacturing industries than non-manufacturing industries. Moreover, using social overhead capital data, this study investigated the varying degree of agglomeration in 11 Japanese regions. The results indicated that agglomeration economies were strongest in metropolitan areas in Japan; specifically the Capital Area, followed by Kansai, and Chubu. However, a review of the annual changes in the robustness of agglomeration economies found that the other regions had stronger growth in agglomeration over time, specifically Okinawa, Hokuriku, and Shikoku, compared with metropolitan areas. Such larger changes were attributed to the disproportionate investment in social overhead capital in regional areas.

In conclusion, economies of agglomeration play a significant role in regional growth and development. In particular, investment in social overhead capital is critical to increase the degree of agglomeration. However, disparities exhibited in the level of economic activity between regions are not corrected by social overhead capital investment under Japan's current regional policy. That is, social overhead capital has not been invested in regions with high agglomeration, but is instead focused on regions with low agglomeration. Past Japanese national plans have diverted a great deal of public spending to provincial areas, and as a result, many superfluous roads, harbors, and airports have been built in those regions. The problem is that they are not utilized effectively. To increase economic efficiency with limited resources, focused investments are increasingly important for the Japanese national plan, which implies that Japan should increase its allocation of social overhead capital investment to large cities with robust agglomeration economies.

In the future, further investigation into how agglomeration economies affect inter-regional trade will be necessary because both inter-regional collaboration and more open regional economies are inevitable for increased regional development. Specifically, a method for quantitatively examining the extent to which agglomerations in metropolitan areas affect local regions and other regions (i.e., inter-regional trade) will be required.

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