The Impact of Agglomeration Economies on Energy Efficiency in Japan

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Abstract
With environmental constraints being strengthened worldwide, an important question that arises for Japan's economic policy is how best to achieve regional economic growth along with energy efficiency. This study examines the impacts of agglomeration economies, which boost economic growth, on the energy efficiency of Japanese manufacturing industries. Using a prefectural-level panel dataset from the Energy Consumption Statistics by Prefecture, this study obtains new empirical results: (1) agglomeration economies improve the energy efficiency of Japanese manufacturing industries; (2) localization economies positively impact the improvement of energy efficiency in rural areas, while urbanization economies positively impact the improvement of energy efficiency in large metropolitan areas. Thus, it is determined that agglomerating similar industries is effective in improving energy efficiency in rural areas; however, in large metropolitan areas, it is more effective to agglomerate diverse industries in order to improve energy efficiency. In general, industrial agglomeration as a result of economies of agglomeration, based on localization, occurs for the most part in medium-sized cities. The finding therefore suggests that it is more appropriate to formulate strategy in terms of medium-sized cities than large metropolitan cities in improving the energy efficiency of manufacturing industries located in rural areas.

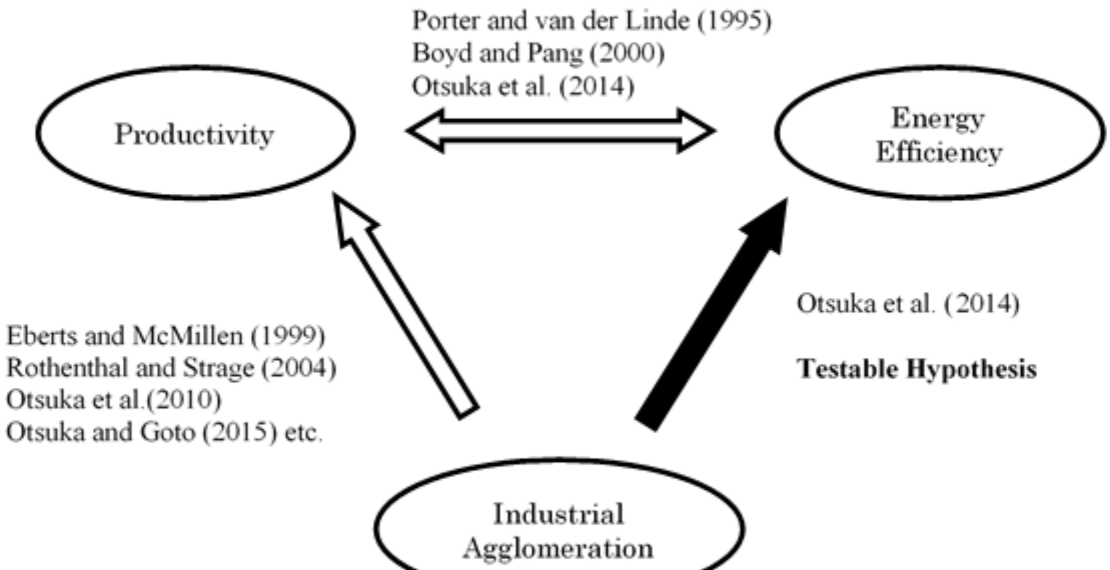
Keywords: Energy Efficiency, Agglomeration Economies, Regional Science

Introduction

One of the most important issues in Japan, as a country confronting environmental constraints, is to find a way to reduce CO2 emissions by improving energy efficiency while improving economic growth at the same time. Following the two energy crises in the 1970s, manufacturers within the industrial sector, which represents the major share of energy consumption within our country, have worked to improve energy conservation due to stringent environmental regulations. Manufacturing industry is an important sector in Japan and has the continuing ability to improve regional economies. However, in recent years, due to the globalization of the economy and the influence of policy factors such as environmental regulations, Japan's ability to compete internationally has been impaired. This has resulted in a significant reduction in the strength of Japanese manufacturing industry, with a consequent negative impact on regional economic growth. Therefore, in order to promote regional economic growth under the environmental constraints of reducing CO2 emissions, it has become necessary to improve productivity whilst still achieving energy conservation. In other words, it is important to balance the issues of improving energy efficiency and increasing productivity within the manufacturing sector. Examining these issues is crucial not only for improving the developmental policies of regional economies, but also for improving energy and environmental policies.

It is well known that industrial agglomeration plays an important role in improving industrial productivity. The benefits associated with economies of agglomeration have been discussed for over a century (Marshall, 1890). In achieving agglomeration economies, specific cost savings and productivity gains can be obtained by concentrating industries spatially. These effects can be categorized as localization economies and urbanization economies (McCann, 2001). The former are the economic benefits earned from clustering similar industries and having them work together; the latter refers to the economic benefits derived from clustering and agglomerating different industries together. Agglomeration economies enhance industry productivity and serve an important role in strengthening competitive advantages worldwide, as seen in many studies (Eberts and McMillen, 1999; Rothenthal and Strange, 2004). Furthermore, it has recently been observed that an agglomerated economy displays not only significantly improved productive efficiency, but also greatly improved total factor productivity (Otsuka et al., 2010; Otsuka and Goto, 2015). However, although it has been determined that these agglomeration economies have been a factor in improving industry productivity, there has been no mention in past studies that they may also have been a significant factor in improving energy efficiency.

In order to maintain a competitive advantage worldwide, it is expected that industries that have strict environmental regulations imposed on them (such as CO2 emission reductions) will invest significantly more in research and development to increase productivity. When industries are spatially agglomerated, it makes it easier for a specific company that has developed technological knowledge to share and transfer information with other companies through face-to-face communication and the inter-organizational transfer of worker knowledge. In other words, agglomeration plays a huge role in improving the interconnectivity and synergy of an industry as a whole by creating both informal and formal mechanisms for transferring technological knowledge (Fujita and Thisse, 2002). From another perspective, innovations that arise under environmental constraints are known to be associated with the development of energy-efficient production systems. Porter and van der Linde (1995) state that efforts to improve the productivity of the entire manufacturing process to meet environmental regulations have resulted in significant reductions in energy use as well as huge improvements in productivity (the "Porter Hypothesis"). Meanwhile, Boyd and Pang (2000) and Otsuka et al. (2014) make it clear that improving productivity has a direct influence in improving energy efficiency. In other words, they claim that energy efficiency plays a role as an indicator of improved productivity. Based on these studies, it is expected that improvements in productivity achieved under environmental constraints through economies of agglomeration have a direct connection with improvements in energy efficiency (see Figure 1). In fact, it has recently been noted that urban agglomeration has had an effect on increasing energy efficiency in both the residential and the transportation sectors (Newman and Kenworthy, 1989; Bento and Cropper, 2005; Brownstine and Golob, 2009; Karathodorou et al., 2010; Su, 2011, etc.). Within the industrial sector, which accounts for a large proportion of our nation's energy consumption, there are manufacturing industries that act to pull economic growth forward at the rural level. However, few studies have looked at how these industries might influence energy efficiency were they to be clustered together. One of the exceptions in this respect is Otsuka et al. (2014), which indicated that agglomeration economies affect the energy intensity levels of the industrial sector. In order to evaluate energy efficiency properly and implement future environmental policy, it is vital to explain this effect in detail. As a continuation of Otsuka et al. (2014), this study therefore aims to clarify whether agglomeration economies in the manufacturing industry have a direct effect on energy efficiency.



Source: Otsuka et al. (2014)

Figure 1. Testable Hypothesis

Next, Section 2 discusses the determinants of energy intensity, which is treated as a proxy for energy efficiency. The data used in the analysis are explained in Section 3. Section 4 provides the results of the analysis; finally, Section 5 presents the conclusions and policy suggestions.

Determinants of Energy Intensity

Energy intensity, defined as the ratio of production output and energy consumption, is often used as a standard index to indicate energy efficiency when analyzing energy policies. This index is also used in the International Energy Association's report on the energy policies of G8 countries (IEA, 2009). This study will therefore use energy intensity as a proxy index to measure energy efficiency (*ENERGY*) as defined by the IEA.

Table 1. Energy intensity in manufacturing, GJ/million yen

	Y 2008	Change from 1990 (%)		Y 2008	Change from 1990 (%)
1 Hokkaido	77.84	-18.00	25 Shiga	19.17	-32.06
2 Aomori	57.37	-54.26	26 Kyoto	9.86	-48.58
3 Iwate	30.70	-40.07	27 Osaka	27.25	-32.50
4 Miyagi	40.04	10.51	28 Hyogo	57.01	-25.94
5 Akita	27.03	-23.91	29 Nara	17.47	15.39
6 Yamagata	12.56	-38.27	30 Wakayama	70.14	-57.62
7 Fukushima	18.71	-46.30	31 Tottori	35.84	9.55
8 Ibaraki	68.32	-28.72	32 Shimane	28.27	-34.35
9 Tochigi	17.15	-28.63	33 Okayama	177.06	-34.69
10 Gunma	17.86	-21.82	34 Hiroshima	73.83	-36.29
11 Saitama	16.49	-31.82	35 Yamaguchi	138.66	-26.10
12 Chiba	169.34	-31.52	36 Tokushima	31.90	-47.22
13 Tokyo	3.92	-60.54	37 Kagawa	51.81	-32.57
14 Kanagawa	63.25	15.42	38 Ehime	86.73	-2.32
15 Niigata	36.42	-32.38	39 Kochi	86.16	-5.54
16 Toyama	31.68	-35.91	40 Fukuoka	58.23	-41.66
17 Ishikawa	12.61	-31.11	41 Saga	17.05	-30.38
18 Fukui	26.19	-31.12	42 Nagasaki	14.03	-26.25
19 Yamanashi	12.00	-18.81	43 Kumamoto	23.21	-30.06
20 Nagano	12.54	-35.81	44 Oita	187.69	-49.73
21 Gifu	22.33	-28.44	45 Miyazaki	35.46	-61.00
22 Shizuoka	17.88	-46.62	46 Kagoshima	22.11	-39.50
23 Aichi	27.10	-29.39	47 Okinawa	61.19	-20.87
24 Mie	68.20	-51.91	Mean	47.18	-34.47

Table 1 shows the energy intensity statistics of the manufacturing sector in 47 prefectures in Japan. Tokyo, with the highest population concentration, shows the lowest value of 3.92 GJ/million yen. Energy intensity is also low in other prefectures with relatively high population densities, such as Kyoto. On the other hand, energy intensity is high in regions like Chiba, Oita, Okayama, and Yamaguchi prefectures, where petrochemical complexes are found. This may be because energy-intensive industries are located in these areas. When comparing energy intensity figures for 1990 and 2008, it is clear that energy intensity statistics are improving nationwide. It is assumed that this is a result of an increase in manufacturers' capital investments to improve energy efficiency amidst the heightened need for environmental control and management.

The focus of this research is to reexamine the relationship between energy intensity and agglomeration economies. This study will use location quotient (*LQ*) as an index to demonstrate localization economies. The location quotient for industry *i* in location *j* will be defined as follows, with *Y* as the amount of production:

$$LQ_{ij} = \frac{Y_{ij} / \sum_{i} Y_{ij}}{\sum_{j} Y_{ij} / \sum_{i} \sum_{j} Y_{ij}}$$

The numerator is the production share of industry *i* in region *j*. The denominator shows the production share of industry *i* nationwide. Therefore, if the measurement exceeds 1, then that region has a high production share of industry *i* when compared with other regions in the nation. When the number surpasses 1, that particular industry is characterized as a core industry, indicating that it is concentrated in a specific area.

This study will use population density (*DENS*) as a proxy index to demonstrate urbanization economies. The driving force behind urbanization economies is the diversity of industrial structures (Fujita and Thisse, 2002). "Density" is used as an index based on the assumption that diverse industries will be agglomerated in high-density areas (Ciccone and Hall, 1996). In measuring population density, the denominator is calculated as the residential area with lakes, forests, and fields deducted from the total area. Population density is known to increase energy consumption efficiency in the residential and transportation sectors. However, the type of impact that population density has on energy efficiency in the industrial sector has not yet been revealed.

This study will add several socioeconomic variables to explain differences in energy intensity in agglomeration economies. The selection of socioeconomic variables (with the exception of agglomeration economies) is based on the variables used in studies by Otsuka et al. (2014). First, the capital-labor ratio (*KL*) is incorporated. This will help in considering how much capital concentration or density affects differences in energy intensity. Second, this study will consider the implicit impact of the vintage of capital stock. Low replacement investments in capital stock may lead to the possibility of low energy efficiency in that local industry. On the other hand, a local industry with high replacement investment in capital stock has an increased probability of its being replaced with more energy-efficient capital stock, resulting in higher energy efficiencies. In order to measure this vintage effect, this paper will consider the investment rate of capital stock per year (*IK*).

The study will also incorporate climate data, in order to consider the influence of climatic changes on production activities. Heating degree days (*HEAT* and cooling degree days (*COOL*) will be specifically considered. Since the population tends to concentrate in areas where the climatic conditions are pleasant, the above indices will be considered to control for and measure the impact of climate. Previous studies have indicated that these indices influence energy consumption. Finally, the time trend (*TREND*) variable will also be considered to explain annual changes in energy efficiency over time.

Data

This study analyzes manufacturers in the following industry sectors across 47 prefectures in Japan; 1) Chemical, Chemical Textile, Pulp, and Paper; 2) Iron and Steel, Non-ferrous metal, Cement, and Ceramics; and 3) Machinery. The final energy consumption share for the Chemical, Chemical Textile, Pulp, and Paper industries in the manufacturing sector is 42%, followed by 34% for the Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries. Both of these industrial sectors are extremely energy intensive. On the other hand, the final energy consumption share of the Machinery sector is as low as 3%. Due to availability of data, the period for analysis is from 1990 to 2008. The data analyzed are from the annual panel data of each prefecture.

The final energy consumption data for the industry sectors used in this paper are from the “Energy consumption statistics by prefecture” produced by the Ministry of Economy, Trade, and Industry (METI). Data regarding the amount of production, the denominator used to calculate energy intensity, are based on actual production values according to economic activity as indicated in the “Annual Report on Prefectural Accounts” issued by the Japanese Cabinet Office. The rest of the socioeconomic data are mainly derived from the Central Research Institute of the Electric Power Industry (CRIEPI) regional database. Data on heating degree days and cooling degree days are calculated from national meteorological agency data[1]. Since climate data are obtained from meteorological centers located in each city, prefectural climate data is the mean of city data.

Tables 2 demonstrate the descriptive statistics of the variables. When observing energy intensity, manufacturers in total averaged 62.082 GJ/million yen based on all samples; 247.146 GJ/million yen for Chemical, Chemical Textile, Pulp, and Paper; and 166.037 GJ/million yen for Iron and Steel, Non-ferrous Metal, Cements, and Ceramics. Both figures far exceed that of the entire manufacturing sector and are low in terms of energy efficiency. On the other hand, Machinery shows a low figure of 5.320 GJ/million yen, proving to be high in energy efficiency. When examining the changes over time, it is clear that the manufacturing sector has seen significant improvements in energy efficiency between 1990 and 2008, with a reduction of –34% over this period. During the observation period, Iron and Steel, Non-ferrous Metal, Cements, and Ceramics also showed an improvement in energy efficiency. In contrast, the energy efficiency level of the Chemical, Chemical Textile, Pulp, and Paper sector is clearly getting worse, with the energy efficiency figure increasing by 25% when comparing the statistical data of 1990 and 2008.

Looking at the variables that represent agglomerated economies, the location quotient is on average 1.029 in the manufacturing sector; this is greater than 1, which indicates that many regions in Japan specialize in manufacturing. Furthermore, from 1990 to 2008 the location quotient has increased, implying an increase in agglomeration among similar trades and industries. In all three industrial sectors considered, the mean of the location quotient of all samples exceeds 1. This figure has increased each

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[1] The number of heating degree days in one year is the cumulative difference between 14°C and the average temperature on each of the days in one year in which the average temperature drops below 14°C. The number of cooling degree days in one year is the cumulative difference between 22°C and the average temperature on each of the days in one year in which the average temperature goes above 24°C.

year. Population density, like the location quotient, seems to have increased slightly as well. In 1990, population density was 1336 persons/km^2 and in 2008, it increased to 1363 persons/km^2. At the same time, the agglomeration of diverse industries seems to have strengthened. Based on the above points, it is assumed that industrial agglomeration increased during the observation period.

Table 2. Descriptive statistics

		ENERGY (GJ per million yen)				LQ				DENS (people per area)
		Manufacturing	Chemical, Chemial textile, Pulp & Paper	Iron & Steel, Non-ferrous metal, Cement & Ceramics	Machinery	Manufacturing	Chemical, Chemial textile, Pulp & Paper	Iron & Steel, Non-ferrous metal, Cement & Ceramics	Machinery	
1990	Average	72.001	225.484	188.766	8.557	0.984	0.986	1.044	0.900	1335.625
	Standard deviation	73.514	297.848	196.368	9.275	0.360	0.797	0.677	0.568	1573.908
	Max	373.346	1326.228	781.784	59.741	1.915	4.047	2.677	2.460	8455.839
	Min	9.939	2.610	5.197	0.000	0.233	0.055	0.292	0.007	259.334
2000	Average	64.267	242.659	155.548	3.895	1.042	1.047	1.093	1.027	1350.236
	Standard deviation	63.249	382.494	173.255	2.760	0.369	0.906	0.676	0.579	1585.034
	Max	272.602	2089.242	729.857	16.411	1.954	4.895	2.706	2.391	8412.870
	Min	10.532	0.000	0.499	0.000	0.271	0.053	0.283	0.018	259.501
2008	Average	47.184	279.244	167.137	2.483	1.059	1.088	1.124	1.136	1363.230
	Standard deviation	43.737	685.758	200.413	1.881	0.364	1.065	0.788	0.579	1660.391
	Max	187.686	4032.789	811.404	7.978	1.802	5.195	3.201	2.467	8924.134
	Min	3.922	0.000	0.000	0.000	0.220	0.045	0.239	0.012	254.400
full-sample	Average	62.082	247.146	166.037	5.320	1.029	1.033	1.091	1.014	1353.887
	Standard deviation	61.752	525.749	178.118	5.435	0.367	0.894	0.705	0.565	1584.638
	Max	373.346	11059.129	910.027	59.741	1.982	5.327	4.053	2.881	8924.134
	Min	3.922	0.000	0.000	0.000	0.219	0.021	0.239	0.005	254.400

		KL (million per capita)				IK				WARM (degree day)	COOL (degree day)
		Manufacturing	Chemical, Chemial textile, Pulp & Paper	Iron & Steel, Non-ferrous metal, Cement & Ceramics	Machinery	Manufacturing	Chemical, Chemial textile, Pulp & Paper	Iron & Steel, Non-ferrous metal, Cement & Ceramics	Machinery		
1990	Average	16.690	43.249	38.448	12.733	0.112	0.099	0.090	0.159	1033.401	408.033
	Standard deviation	7.119	22.912	25.070	4.471	0.021	0.030	0.026	0.042	435.361	167.911
	Max	39.039	97.822	122.349	23.883	0.154	0.214	0.154	0.254	2479.345	921.711
	Min	7.465	8.024	11.369	2.011	0.066	0.044	0.033	0.042	1.572	17.853
2000	Average	27.734	65.136	62.818	21.246	0.069	0.064	0.058	0.100	1120.986	404.752
	Standard deviation	10.106	33.081	38.052	6.068	0.017	0.021	0.040	0.035	563.481	152.062
	Max	60.954	148.268	191.233	33.957	0.115	0.134	0.289	0.205	3053.700	917.641
	Min	12.336	12.494	18.620	5.519	0.045	0.027	0.023	0.049	0.752	27.917
2008	Average	36.647	87.617	84.332	26.340	0.089	0.081	0.070	0.131	1024.501	365.452
	Standard deviation	11.573	79.240	42.588	7.790	0.021	0.039	0.027	0.048	502.026	185.886
	Max	66.178	540.293	200.295	43.869	0.145	0.204	0.148	0.270	2582.736	1047.309
	Min	15.124	14.750	18.393	5.668	0.058	0.030	0.024	0.018	30.469	4.049
full-sample	Average	26.629	63.560	59.914	20.251	0.076	0.073	0.061	0.108	1081.547	357.312
	Standard deviation	11.444	41.137	37.691	7.172	0.024	0.036	0.030	0.047	500.517	181.444
	Max	70.340	540.293	218.555	43.869	0.241	0.370	0.296	0.489	3053.700	1251.458
	Min	7.465	8.024	11.369	1.907	0.030	0.016	0.014	0.011	0.207	0.000

Source: Otsuka et al. (2014)

If the capital-labor ratio is regarded as a characteristic socioeconomic variable acting outside of agglomeration economies, the average capital-labor ratio of the entire manufacturing industry is 26.629 million yen per capita. In contrast, compared with the entire manufacturing industry, the average sample of the capital-labor ratio of the Chemical, Chemical Textile, Pulp, and Paper; and Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries are higher at 63.560 and 59.914 million yen per capita, respectively, which is considered capital intensive. Yet another contrast is with the Machinery sector, where the capital-labor ratio is registered at a low value of 20.251 million yen per capita. When observing the sequential change in all industries from 1990 through 2008, it is understood that there will be increases in capital intensity. This is because of advances in mechanization related to production processes. Finally, the investment capital ratio of the entire manufacturing sector is 0.076. There could be a small variation within each industry. The average value for the Machinery sector is 0.108. There is also the possibility of upgrading production facilities.

Empirical Results

Based on Otsuka et al. (2014), an analysis of agglomeration economies and energy efficiency is performed. The model used in this analysis is:

$$\begin{aligned}\ln\left(ENERGY_{jt}\right) = \beta_1 \ln\left(LQ_{jt}\right) + \beta_2 \ln\left(DENS_{jt}\right) + \beta_3 \ln\left(KL_{jt}\right) + \beta_4 \ln\left(IK_{jt}\right) \\ + \beta_5 HEAT_{jt} + \beta_6 COOL_{jt} + \beta_7 TREND + \alpha_j + u_{jt}\end{aligned}$$

The main variables used are logarithmic values; j = region ($j = 1,\ldots, J$) and t = time ($t = 1,\ldots,T$). Energy is energy intensity, or in other words, the amount of final energy consumption per unit of production. *LQ* is the location quotient and *DENS* is the population density. Both *LQ* and *DENS* are variables that represent agglomeration economies. *KL* represents the capital-labor ratio obtained by dividing capital stock by the number of employees. *IK* is the investment capital ratio obtained by dividing capital expenditures by private sector capital stock. *HEAT* are the heating degree days and *COOL* are the cooling degree days. *TREND* is the time trend, while ε is the item error.

The estimated parameters are α and β. In order to use panel data, α expresses the individual effect. It is predicted that $\beta 1$ and $\beta 2$ will be negative when agglomeration economy improves energy efficiency. The coefficient $\beta 3$ is negative when capital and energy consumption are negatively correlated; it is positive when capital and energy consumption are positively correlated. It is predicted that the coefficient $\beta 4$ will be negative, since new capital investment is expected to improve energy efficiency. In addition, if energy efficiency is growing with time, $\beta 7$, which is the coefficient of the time trend variable, has a positive sign; if the opposite is true, it has a negative sign. In addition, it can be inferred that in order to compare the regression coefficients, a standardized variable may be used.

Table 3 shows the estimation results. The *F*-test, which was performed to confirm whether the individual effect actually exists, finds the null hypothesis—that no individual effect exists—rejected in all industries at the 1% significance level. The Hausman test, which assumes that the observed individual effect is a result of the random influence, rejects the null hypothesis at the 1% significance level. Therefore, the estimated results shown in Table 3 are the results of the fixed-effect model. Furthermore, in addition to the test conducted for individual effects, a test that uses model accounting for annual effects is also conducted. However, since it is confirmed that the variable that accounts for the annual effects appears as a trend, it is decided that the annual effect is available as a time-trend variable.

First, the entire manufacturing sector is examined. The result shows that agglomeration economies lead to higher energy efficiency. Because both the explanatory value and the dependent variable are logarithmic values, $\beta 1$ through $\beta 4$ correspond to the elasticities. For that reason, the bigger the value of the estimated parameter (i.e., the greater the elasticity of the associated variable), the bigger is the influence of the explanatory variable on the dependent variable. Thus, the influence of population density is far greater than the influence of the location quotient. More specifically, the result of the variable of local quotient is –0.5122, whereas the result of the variable of population density is –0.6403, showing that the effect of the latter is far greater. In other words, looking at the entire manufacturing sector, there is greater energy efficiency when there is an agglomeration of diverse industries rather than an agglomeration of similar industries. This result is contrary to Otsuka et al. (2014). The "plus" sign in the capital-labor ratio shows that capital and energy efficiency have a complementary relationship. The investment capital ratio shows a "minus" sign, which is the expected result. The time trend ratio also shows a "minus" sign, but these estimated parameters are not large and their impact is not as important.

Table 3. Estimation results

	Manufacturing	Chemical, Chemical textile, Pulp & Paper	Iron & Steel, Non-ferrous metal, Cement & Ceramics	Machinery
ln(*LQ*)	–0.5122 ***	–0.4238 ***	–0.5423 ***	–0.1352 ***
	-0.0285	-0.0668	-0.0639	-0.0522
ln(*DENS*)	–0.6403 ***	–0.0060	–2.5626 ***	–0.3200
	-0.2036	-0.7061	-0.7376	-0.5061
ln(*KL*)	0.3485 ***	0.2318 ***	–0.9814 ***	–0.0098
	-0.0318	-0.0774	-0.0811	-0.0436
ln(*IK*)	–0.0410 ***	–0.0113	0.0189	–0.0206
	-0.0055	-0.0176	-0.0196	-0.0133
HEAT	–0.0292	–0.0095	0.1409	0.1062 *
	-0.0227	-0.0846	-0.0875	-0.0584
COOL	0.0331 ***	–0.0092	–0.0464	–0.0311
	-0.0106	-0.0405	-0.0418	-0.0276
TREND	–0.0573 ***	–0.0384 ***	0.0555 ***	–0.0372 ***
	-0.0034	-0.005	-0.0071	-0.0043
F test	289.39 ***	34.544 ***	42.321 ***	62.631 ***
Hausman test	88.376 ***	30.699 ***	173.55 ***	83.458 ***
Adjusted R^2	0.9846	0.7741	0.7607	0.8956

Notes. Standard deviation is listed within parentheses. The symbols ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Next, the estimation results of the Chemical, Chemical Textile, Pulp, and Paper industries are reviewed. In these industries, few variables are statistically significant, including the location quotient variable and capital labor ratio variable; however, the time trend variable is more significant. As expected, the elasticity of the location quotient is a "minus." However, compared with the entire manufacturing sector, the parameters are smaller and the impact that agglomeration economies have on energy efficiency is also relatively small for this industry. As for the Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries, both the location quotient variable and the population density variable show a statistically significant "minus." In particular, the elasticity of population density is substantial and demonstrates that the agglomeration of diverse industries has a strong effect on energy efficiency. In addition, the capital-labor ratio coefficient also shows a "minus." In contrast to the result from the entire manufacturing sector, capital and energy consumption are inversely related. The elasticity of time trend is a "plus," and this result also differs from that of the overall manufacturing sector. Although the impact is not large, it is significant. Finally, the results for the Machinery sector show a "minus" in the location quotient coefficient that is statistically significant. This demonstrates that the localization economy has a significant effect on energy efficiency. However, the size of the parameter for the Machinery industry is small compared with those for the other industries. The result for the time trend variable in the Machinery industry shows a "minus" sign, but this is also not large, although it is significant.

The impact of localization economies is observed in all manufacturing sectors. On the other hand, the impact of urbanization economies is only observed in the Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries. This impact is relatively significant. Therefore, there is a strong possibility that the results of these particular industries reflect the impact of urbanization economies on the entire manufacturing sector. With these results as a background, it can be seen that there is a difference in business dynamics between different industries (Otsuka et al., 2014)

The key focus of this analysis is to demonstrate how much agglomeration economies can contribute to improvements in energy efficiency. Table 4 shows the annual percentage rates of change that agglomeration economies have made on energy efficiency, based on an estimation equation. Regarding the mean changes in energy efficiency of manufacturers nationwide, localization economies show an annual rate of –0.384%, whereas urbanization economies show an annual rate of –0.013%. This implies that the influence of location quotient far exceeds that of population density. Despite the fact that population density does not change during the observation period, the change of location quotient is relatively significant.

The rate of change in localization economies is the highest in Kyushu at –1.724%; that of Tohoku is also high. On the contrary, in the greater Tokyo areas and in Kansai, where large cities are located, the annual rate of localization economy shows a "plus" rate, and therefore demonstrates that it has a negative effect on energy efficiency. A decrease in the economic activity of manufacturing industries has influenced these regions. On the other hand, urbanization economy greatly improved energy efficiency in the greater Tokyo areas where population density increased, such as Saitama, Chiba, Tokyo, and Kanagawa Prefecture. As the manufacturing industries grew in rural areas, localization economy played a big role in improving energy efficiency. In large metropolitan areas, it is speculated that urbanization economy played a role in improving energy efficiency as a result of the increase in population density. These results are in line with Otsuka et al. (2014); thus, we can confirm that these results are robust.

Examining specific sectors, the Chemical, Chemical Textile, Pulp, and Paper industries experienced only a limited influence from localization economies and much less than the manufacturing industry as a whole. In other words, energy efficiency would be improved by these industries agglomerating, yet the degree of improvement would be fairly insignificant. The degree of contribution of localization economies to the Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries far exceeds the national average compared with that of the urbanization economies. In comparing regions, it is clear that localization economies as well as the entire manufacturing sector have strengthened in rural areas, especially in Tohoku. On the other hand, urbanization economies have had a huge impact in the greater Tokyo areas. Finally, the results show that the Machinery sector has contributed far more to localization economies than any other industries. This is observed mainly in the Kyushu area during the observation period, where it is assumed that this is due to the growth of the auto industry. Other regions where contributions have been high are Hokkaido, Tohoku, Chubu, Hokuriku, and Chugoku. Improvements in energy efficiency in these areas are considered to be due to increased production in the Machinery sector.

Table 4 Contribution of industrial agglomeration effects to energy efficiency in 1990-2008 (annual % rate)

	Manufacturing		Chemical, Chemical textile, Pulp & Paper		Iron & Steel, Non-ferrous metal, Cement & Ceramics		Machinery	
	Localization Economies	Urbanization Economies	Localization Economies	Urbanization Economies	Localization Economies	Urbanization Economies	Localization Economies	Urbanization Economies
Hokkaido	–0.372	0.097	1.273	0.000	–0.277	0.388	–0.636	0.000
Tohoku	–1.371	0.211	–0.771	0.000	–1.614	0.846	–0.353	0.000
Kita-Kanto	–0.530	–0.096	–0.986	0.000	–1.090	–0.382	–0.061	0.000
Greater Tokyo Area	1.091	–0.439	–0.001	0.000	0.265	–1.759	0.329	0.000
Chubu	–0.442	–0.083	0.041	0.000	0.128	–0.333	–0.152	0.000
Hokuriku	–0.216	0.042	–1.290	0.000	–0.837	0.168	–0.346	0.000
Kansai	0.049	–0.063	0.007	0.000	–0.500	–0.251	0.031	0.000
Chugoku	–0.558	0.202	1.924	0.000	1.188	0.81	–0.438	0.000
Shikoku	–0.554	0.257	–0.699	0.000	1.178	1.029	–0.391	0.000
Kyushu	–1.724	0.091	0.409	0.000	–0.008	0.363	–0.688	0.000
Okinawa	0.403	–0.361	–0.975	0.000	0.626	–1.446	–0.540	0.000
Mean	–0.384	–0.013	–0.097	0.000	–0.086	–0.052	–0.295	0.000

Notes: Zero values are due to the regression coefficient not being significant.
The relationships between the prefectures and regions are as follows:
Hokkaido (Hokkaido)
Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Niigata)
Kita-Kanto (Ibaraki, Tochigi, Gunma, Yamanashi)
Greater Tokyo Area (Saitama, Chiba, Tokyo, Kanagawa)
Hokuriku (Toyama, Ishikawa, Fukui)
Chubu (Nagano, Gifu, Shizuoka, Aichi, Mie)
Kansai (Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama)
Chugoku (Tottori, Shimane, Okayama, Hiroshima, Yamaguchi)
Shikoku (Tokushima, Kagawa, Ehime, Kochi)
Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima)
Okinawa (Okinawa)

Conclusion and Policy Implications

With environmental constraints continually being strengthened, an important question that arises for Japan's economic policy is how best to achieve regional economic growth and energy efficiency. The purpose of this paper is to demonstrate and reanalyze how industrial agglomeration affects energy efficiency in the manufacturing sector, based on Otsuka et al. (2014).

In order to strengthen competitive advantages worldwide, manufacturing industry is pushing forward to improve energy efficiencies by developing and improving energy-saving technology. As a result, looking at energy consumption as a whole, the share used by manufacturing industry continues to decline. However, the proportion still exceeds 50%, and this is still high compared with other industries. It becomes particularly clear that energy efficiency has not improved in industries that use a great deal of energy, particularly in the Chemical, Chemical textile, Pulp, and Paper sector. Many studies performed in the United States show that the more highly populated a region is, the more efficiently energy is used by its residential and transportation sectors. However, previous studies that target the industrial sector (manufacturing industry) could not be found. Reexamining Japan's energy policy reveals that short-term as well as mid- and long-term energy conservation, to be achieved through improvements in production processes, will be required.

The results of this study make it clear that agglomeration economies may lead to improved energy efficiency. From the values of the elasticities, it has been found that there is greater energy efficiency when there are more diverse industrial structures represented in high population density areas. While this trend is observed in the Iron and Steel, Non-ferrous metal, Cement, and Ceramics industries, the impact of population density is not statistically significant in the Chemical, Chemical Textile, Pulp, and Paper industries, or in the Machinery industries. This finding shows a discrepancy in the linkages between different industries, as mentioned by Otsuka et al. (2014).

In order to measure the degree of impact of agglomeration economies on energy efficiency, the changes in energy efficiency with different types of agglomeration during the observation period are calculated, and it becomes clear that the impact of localization economies is greater than the impact of urbanization economies. However, the trend also varies between regions. Specifically, the contribution to energy conservation due to localization economies where there are similar industries is much larger in rural areas than in large metropolitan areas. Conversely, the contribution to energy conservation due to urbanization economies where there are diverse industries is much greater in large metropolitan areas than it is in rural areas. It has therefore been determined that while agglomerating similar industries is effective in improving energy efficiency in rural areas, it is more effective in large metropolitan areas to agglomerate diverse industries to improve energy efficiency.

In general, industrial agglomeration undertaken as a result of economies of agglomeration, based on localization, occurs for the most part in medium-sized cities. In order to avoid congestion and soaring land prices, it is more desirable to agglomerate similar industries in medium-sized cities in order to enjoy the benefits of localization economies alone. In contrast, it is more advantageous to be in a large metropolitan area to profit from urbanization economies. The results of this analysis show that it is more effective to formulate strategy in terms of medium-sized cities than large metropolitan cities in order to improve the energy efficiency of manufacturing industries located in local areas. This suggests that an effective policy for improving energy efficiency of local manufacturing industries would promote the establishment of "compact cities" and the spreading of "smart communities."

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