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Akihiro Otsuka

Regional Energy Demand and Energy Efficiency in Japan

An Application of
Economic Analysis



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An Application of Economic Analysis

Akihiro Otsuka
Association of International Arts
and Science
Yokohama City University
Yokohama, Kanagawa
Japan

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Preface

This book explains the role of energy efficiency in economic development and analyzes trends in energy demand to explore the feasibility of regional economic growth under environmental constraints. Amidst growing environmental constraints, a comprehensive examination is needed of sustainable policies to stimulate regional economic development, while balancing energy use and addressing environmental problems. To accomplish this objective, the book closely examines energy demand trends in Japan by region and clarifies the factors behind changes in energy demand. In addition, this book focuses on the effects of energy efficiency on energy demand, demonstrates quantitatively the factors behind energy efficiency improvements, and explains the use of energy efficiency indicators. From these analyses, readers can investigate favorable regional economic and environmental policies that promote improvements in energy efficiency and contribute to the realization of a low-carbon society.

To date, while various publications have presented studies that individually evaluated energy demand levels and energy efficiencies on a country-by-country basis, I am not aware of any publications that have explained the trends and determining factors for energy demand and energy efficiency from the perspective of regional economies. In particular, hardly any investigations have been conducted on favorable energy efficiency indicators suited to the study of energy and environmental policy. To overcome this issue, I present in this book the results of an extended analysis based on an indicator that I developed to determine the factors behind improvements in energy efficiency. In addition, the book highlights various factors behind changes to energy demand within regional economies.

The purpose of this research is twofold. First, this book aims to understand the actual regional energy demand situation, in order to clarify the manner in which energy efficiency influences energy demand fluctuations. Second, this book develops an index to measure energy efficiency and analyze its determinants. Based on the above results, the present work identifies the desirable economic environments that will increase energy efficiency.

A unique feature of this book is its proposal of numerous new analytical approaches. The first approach is the use of dynamic shift-share analysis to clarify

the factors behind changes in energy demand. This new analytical method can overcome the weaknesses of traditional static shift-share analysis. I show the results of applying this method to energy demand analysis. In the second new approach, I use stochastic frontier analysis, instead of data envelopment analysis, to measure energy efficiency. I propose a new analytical approach that applies the former method.

Readers of the book will learn new methods for analyzing energy demand at the regional economic level and the factors behind improvements in energy efficiency, which are topics on which very few empirical studies have been conducted worldwide. The book will also enable readers to define precisely the role of improvements in economic efficiency in regional economic development in order to ascertain quantitatively the effects of energy efficiency improvements on regional economic growth. Such an analysis would make it possible to propose favorable regional policies toward realizing a low-carbon society.

I envisage that readers will primarily be graduate students, academic researchers, and policymakers in the fields of regional studies, energy, and environmental economics. This book introduces an analysis of regional energy demand and methods for developing energy efficiency indicators, along with case studies of their application. No other publication has addressed these areas so comprehensively, and therefore, this book can be considered to be highly original in content, with no competing texts.

This book is organized into five chapters—a new article, a translated articles, and three previously published journal articles. I have obtained permission for the reuse, for which I would like to thank Wiley-Blackwell Publishing Company and Central Research Institute of Electric Power Industry. The Japanese version of the first chapter is “Findings of Regional Energy Demand,” published in *Denryokukeizaikenkyu* (No.63, pp. 66–81). The original article of the second chapter is “Regional Energy Demand in Japan: Dynamic Shift-Share Analysis,” published in *Energy, Sustainability and Society* (Vol. 6, No. 10, pp. 1–10). The original article of the third chapter, entitled “Energy efficiency and agglomeration economies: The case of Japanese manufacturing industries,” appeared in *Regional Science Policy & Practice* (Vol. 6, No. 2, pp. 195–212). The original of the fourth, “Estimation and determinants of energy efficiency in Japanese regional economies,” was published in *Regional Science Policy & Practice* (Vol. 7, No. 2, pp. 89–101). Each chapter is a revision of the original paper.

Finally, I would like to thank my wife Harumi Otsuka for her dedication in supporting me during the book writing. In addition, I thank Prof. Mika Goto and Prof. Toshiyuki Sueyoshi as coauthors of original articles for encouraging me to proceed with the research. This work was supported by a Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research (KAKENHI) 15K17067. In addition, I have received Grant-in-Aid as Young Scientific Research by Yokohama City University.

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Chapter 1

Regional Energy Demand in Japan

Abstract In this study, the *Energy Consumption Statistics by Prefecture* were utilized and the actual conditions of energy demand in the regions of Japan were ascertained. The results revealed that Japan's national energy demand increased from the 1990s to the 2000s; and that the driving forces behind this expansion were the Residential and Commercial (ResCom) and Transportation sectors. In regional trends, the findings showed that the increase in energy demand in large metropolitan areas not only contributed greatly to the national increase, but also that energy demand in rural areas grew steadily. Upon considering the changes to regional energy demand by analyzing changes to energy demand per capita and population changes, the study found that energy demand per capita has a major impact on regional energy demand, and that in particular, the increase in energy demand in rural regions has been brought about by the increase in energy demand per capita.

Keywords Regional energy demand • Energy consumption statistics by prefecture • Region • Japan

1.1 Introduction

Following the complete liberalization of electric power in Japan, gas will be liberalized in 2017. In order to forecast demand for electric power in the future in this context, there is an urgent need to ascertain and analyze the actual conditions of total energy demand, including gas. The significance of ascertaining trends in total energy demand at the national level may diminish in future, so in addition to national surveys, empirical research on regions that is more detailed than the existing national analyses will be required. In terms of research on trends in energy demand in Japan's regions, however, the current situation is that they have not been fully investigated by the nation's major research institutions, such as national

The Japanese version of this chapter is "Findings of Regional Energy Demand," published in the Japanese magazine: Denryokukeizaikenkyu (No. 63, pp. 66–81).

agencies, universities, and other private-sector think tanks. Therefore, as an initial stage in advancing research on regional energy demand structures, data from the *Energy Consumption Statistics by Prefecture* (Agency for Natural Resources and Energy, the Ministry of Economy, Trade and Industry), which have been prepared in recent years, will be utilized in this study to ascertain the actual conditions of regional energy demand in Japan.

Below, in Sects. 1.2 and 1.3, the actual conditions of regional energy demand are ascertained for Japan nationally, by prefecture, and by sector. In Sect. 1.4, to obtain the main factors behind changes in regional energy demand, a factor analysis is carried out, focusing on energy demand per capita; the effects of energy demand per capita on regional energy demand will then be clarified. In Sect. 1.5, the method used to forecast regional demand for electric power from regional energy demand will be explained and regional trends in the electrification rate will be ascertained. Finally, conclusions and issues that should be analyzed in the future are outlined. In the appendix, an overview of the *Energy Consumption Statistics by Prefecture* is provided, and points that require attention when using these statistics are explained.

1.2 Trends in Final Energy Consumption

1.2.1 National Trends

In this section, in order to understand the actual conditions of national energy demand in Japan, the *Energy Consumption Statistics by Prefecture* are utilized and from them, the trends in final energy consumption by sector are ascertained.

Table 1.1 shows the trends in final energy consumption by sector in Japan. In 2012 actual values, final energy consumption was 12,158 PJ. Within this, final energy consumption by the Industry sectors was 6,136 PJ, which was 50.47 % of

Table 1.1 Trends in final energy consumption by sector

	Actual values (PJ, 2012)	Growth actual values (1990 = 100)	Share (% , 2012)	Change to share (percentage point, 1990–2012)	Contribution (% , 1990–2012)
Final energy consumption	12,158	105.79	100.00	–	–
Industry	6,136	83.95	50.47	–13.13	–10.21
Non-manufacturing	497	79.64	4.09	–1.34	–1.11
Manufacturing	5,639	84.35	46.38	–11.79	–9.10
ResCom	4,956	143.19	40.76	10.65	13.01
Residential	2,016	126.00	16.58	2.66	3.62
Commercial and others	2,940	157.96	24.18	7.99	9.39
Transportation	1,067	147.59	8.77	2.48	2.99

Source *Energy Consumption Statistics by Prefecture (METI)*

Notes The 2012 values are estimates

the total. Manufacturing consumed 5,639 PJ, which was 46.38 % of the total, so more than half of Japan's energy demand is from the Industry sectors, particularly from Manufacturing. On the other hand, the ResCom sector (Residential and Commercial sectors) consumed 4,956 PJ, which was 40.76 % of the total; and within this amount, the Residential sector used 2,016 PJ and the Commercial sector 2,940 PJ, meaning that demand from the Commercial sector is slightly the larger of the two in the ResCom sector. The Transportation sector consumed 1,067 PJ, so its share of the total was small, at 8.77 %.

Looking at the growth in the actual values after standardizing them, with 1990 set as 100, we see that final national energy consumption has grown slightly, to 105.79. By sector, a feature is the contrasting movement shown by the ResCom and Transportation sectors relative to the Industry sectors. The growth in the actual values of the Industry sectors is below 100 in both the Non-manufacturing and Manufacturing sectors. In contrast, both the ResCom and Transportation sectors show significant growth greatly exceeding 100, with growth in the Commercial sector being particularly large.

In terms of changes to share, the Industry sectors' share declined by -13.13 percentage points, with the decline in the share of Manufacturing also being large, at -11.79 percentage points. In contrast, the shares of the Residential sector and the Commercial sector increased by 2.66 percentage points and 7.99 percentage points, respectively.

Therefore, on calculating the extent of the contributions to the change to national final energy consumption, we find that Manufacturing at -9.10 % contributed greatly to decreasing the national final energy consumption, but in contrast, the Residential and Commercial sectors, at 3.62 and 9.39 % respectively, contributed to a major increase in national final energy consumption.

In summary, energy demand from Industry sectors, particularly from Manufacturing, declined over the observation period, causing a major reduction in Japan's national energy demand; but in contrast, the energy demand from the ResCom sector, which is comprised of Residential and Commercial, rose over the observation period and contributed to an increase in Japan's national energy demand.

1.2.2 Regional Trends

Based on these national trends, the actual conditions of energy demand within the regions and the prefectures will be ascertained. Table 1.2 shows the 2012 levels of final energy consumption by region and their shares of national consumption, their rates of change, and the extent of their contributions to the national change. These regional divisions are defined in accordance with the electric power company jurisdiction regions.

Looking at the regions' shares of national consumption, the region with the highest share is Tokyo, at 33.15 %, followed by Kansai (13.88 %), and Chubu

Table 1.2 Trends in final energy consumption by region

	Level (PJ, 2012)	Share (%, 2012)	Rate of change (%, 1990–2012)	Contribution (%, 1990–2012)
Hokkaido	520	4.28	12.53	0.50
Tohoku	945	7.77	16.88	1.19
Tokyo	4,031	33.15	11.28	3.55
Chubu	1,553	12.78	−1.06	−0.15
Hokuriku	252	2.08	5.36	0.11
Kansai	1,688	13.88	−1.78	−0.27
Chugoku	1,438	11.83	−0.41	−0.05
Shikoku	398	3.27	7.56	0.24
Kyushu	1,268	10.43	4.98	0.52
Okinawa	66	0.54	29.49	0.13
national	12,158	100.00	5.79	—

Source *Energy Consumption Statistics by Prefecture (METI)*

Note The regional divisions are as follows. Hokkaido (Hokkaido), Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Niigata), Tokyo (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi), Chubu (Nagano, Gifu, Shizuoka, Aichi, Mie), Hokuriku (Toyama, Ishikawa, Fukui), 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), and Okinawa (Okinawa)

(12.78 %); the large metropolitan areas each have a large percentage. The rural areas with the largest shares were Chugoku and Kyushu. However, the rates of change of final energy consumption were not linked to the size of the share of national consumption. For example, while Tokyo's rate of change is positive, Kansai's and Chubu's rates of change are negative. Therefore, when looking at the contributions to the national change, Tokyo's is positive and the largest, but in contrast Kansai's and Chubu's are negative.

Figure 1.1 shows the growth in final energy consumption by region. Okinawa's growth is noticeably the highest, while the growth levels of the Hokkaido, Tohoku, and Shikoku rural areas exceed the national figure. We can also confirm that the growth levels of large metropolitan areas other than Tokyo, Kansai, and Chubu, are below the national level. We can therefore see that the regions that contributed most to the increase in national final energy consumption were Tokyo and rural areas, rather than other large metropolitan areas.

Figure 1.2 shows the prefectures' shares of national final energy consumption and their rates of change. Looking at the shares of national consumption, the region with the highest share is Chiba Prefecture at 9.23 %, followed by Kanagawa Prefecture (7.13 %), Metropolitan Tokyo (6.58 %), Aichi Prefecture (5.69 %), and Osaka Prefecture (5.39 %). All of these regions are large metropolitan areas. On the other hand, looking also at the prefectures, their rates of change of final energy consumption are not linked to the sizes of their shares of national consumption. The prefecture with the highest rate of change is Tottori Prefecture at 40.97 %, followed

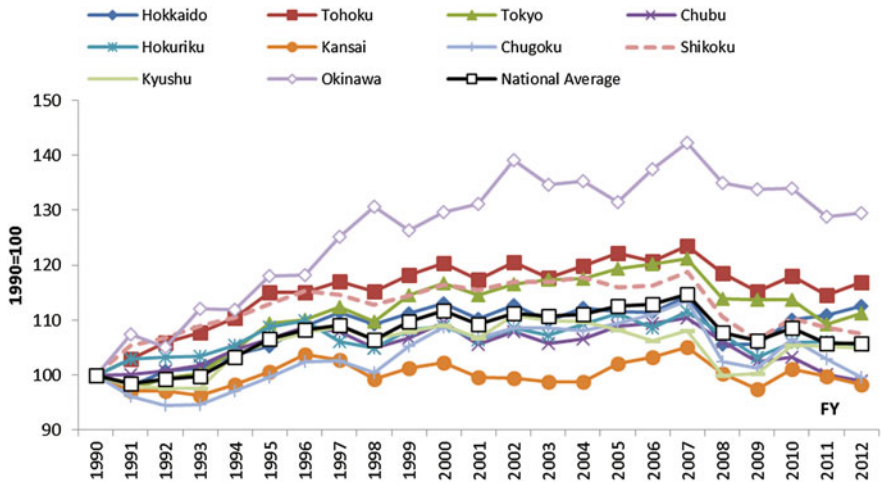


Fig. 1.1 Growth in final energy consumption by region (1990 = 100). *Source* Energy Consumption Statistics by Prefecture (METI)

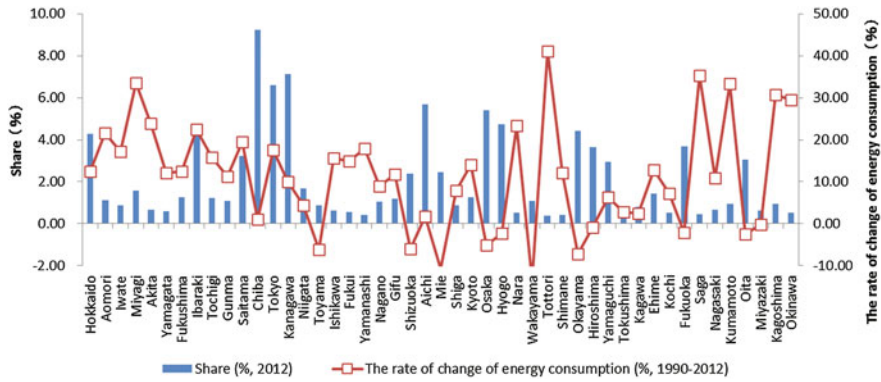


Fig. 1.2 Trends in final energy consumption by prefecture. *Source* Energy Consumption Statistics by Prefecture (METI)

by Saga Prefecture (35.26 %). The rates of changes in the prefectures that correspond to large metropolitan areas were basically positive, but compared with the sizes of their shares, these values were not that large.

Upon calculating the extent of the contribution to the change in the national final energy consumption by prefecture, we can confirm that the contributions are positive in the majority of the prefectures (Fig. 1.3). The greatest contribution was from Metropolitan Tokyo at 1.04 %, while Ibaraki Prefecture’s contribution was 0.82 % and Kanagawa Prefecture’s was 0.68 %, so the contributions from the prefectures in the Tokyo region were large. In contrast, the contributions from the

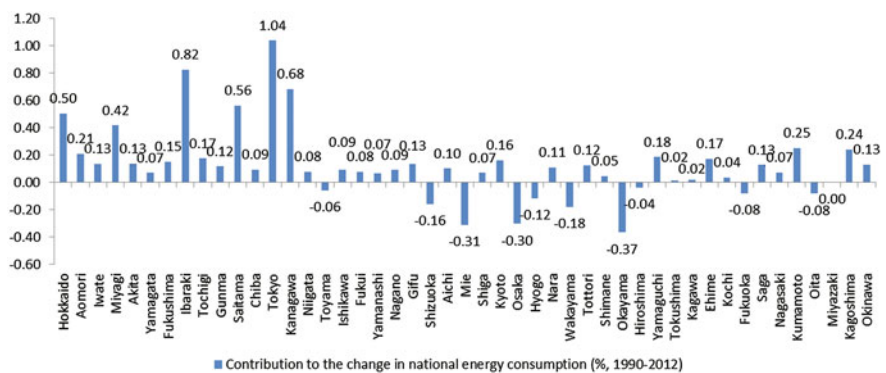


Fig. 1.3 Contributions to the change in national final energy consumption by prefecture. *Source* *Energy Consumption Statistics by Prefecture (METI)*

prefectures comprising the Kansai and Chubu regions were small. In the rural areas, the contributions were positive from all of the prefectures in the Hokkaido and Tohoku regions. Within the Shikoku and Kyushu regions, there were also many prefectures showing a positive contribution.

As described above, when looking at Japan’s energy demand by region and by prefecture, we understand that the regions within the jurisdiction of the Tokyo Electric Power Company (TEPCO) contributed greatly to the increase in Japan’s national energy demand. At the same time, we find that the growth in energy demand in the other large metropolitan areas of the Kansai and Chubu regions is below the national average and that they have practically no effect on the increase in national energy demand. Instead, we can confirm that the increase in Japan’s energy demand is from the prefectures under TEPCO’s jurisdiction, as well as from prefectures in rural areas.

1.3 Regional Trends in Energy Consumption by Sector

We will now look at regional trends in energy consumption by sector. Table 1.3 shows as a time series the regional trends in final energy consumption by sector. The Industry sectors’ final energy consumption decreased in all regions in both the Non-manufacturing and Manufacturing sectors. In Non-manufacturing, the rates of decrease exceeded the national rate in Hokkaido, Chugoku, Shikoku, and Okinawa, in addition to the large metropolitan areas of Kansai and Chubu. On comparing the rates of change in the 1990s and 2000s, we find that this figure was higher in the 1990s.

The decrease in Manufacturing’s final energy consumption was significant. In particular, the decrease in the large metropolitan areas such as Kansai and Chubu was great and above the national trend. Comparing the rates of change by decade, it

Table 1.3 Regional trends in energy demand by sector (year, TJ)

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa	National
Industry non-manufacturing	1990	60,233	80,407	139,383	77,792	16,527	36,917	47,478	100,809	4,570	623,691
	2000	48,073	74,998	113,871	69,738	16,125	32,242	35,646	87,048	4,215	537,968
	2012	47,080	65,996	116,461	61,207	13,167	26,797	34,505	86,413	3,308	496,680
	2000/1990 %	-2.23 %	-0.69 %	-2.00 %	-1.09 %	-0.25 %	-1.34 %	-2.83 %	-1.46 %	-0.80 %	-1.47 %
	2012/2000 %	-0.17 %	-1.06 %	0.19 %	-1.08 %	-1.67 %	-1.53 %	-0.27 %	-0.06 %	-2.00 %	-0.66 %
	2012/1990 %	-1.11 %	-0.89 %	-0.81 %	-1.08 %	-1.03 %	-1.45 %	-1.44 %	-0.70 %	-1.46 %	-1.03 %
Industry manufacturing	1990	161,631	307,569	2,097,745	955,741	107,427	1,156,569	199,414	708,129	12,606	6,685,331
	2000	148,917	324,157	2,265,815	939,475	97,795	1,202,244	215,590	686,636	13,714	6,746,932
	2012	154,326	273,029	1,876,446	697,117	77,336	1,051,532	186,189	588,425	12,117	5,639,155
	2000/1990 %	-0.82 %	0.53 %	0.77 %	-0.17 %	-0.93 %	0.39 %	0.78 %	-0.31 %	0.85 %	0.09 %
	2012/2000 %	0.30 %	-1.42 %	-1.56 %	-2.46 %	-1.94 %	-1.11 %	-1.21 %	-1.28 %	-1.03 %	-1.48 %
	2012/1990 %	-0.21 %	-0.54 %	-0.51 %	-1.42 %	-1.48 %	-0.43 %	-0.31 %	-0.84 %	-0.18 %	-0.77 %
ResCom residential	1990	118,202	179,681	519,184	196,107	43,884	88,473	43,356	139,031	11,916	1,599,936
	2000	153,205	241,309	679,329	248,423	52,525	114,554	62,164	180,498	15,227	2,080,619
	2012	134,659	222,090	664,888	265,685	52,356	110,423	54,445	174,385	15,169	2,015,871
	2000/1990 %	2.63 %	2.99 %	2.72 %	2.39 %	1.81 %	2.62 %	3.67 %	2.64 %	2.48 %	2.66 %
	2012/2000 %	-1.07 %	-0.69 %	-0.18 %	0.56 %	-0.03 %	-0.31 %	-1.10 %	-0.29 %	-0.03 %	-0.26 %
	2012/1990 %	0.59 %	0.97 %	1.13 %	1.39 %	0.81 %	1.01 %	1.04 %	1.04 %	1.10 %	1.06 %
ResCom commercial and others	1990	88,245	161,827	662,571	224,661	46,526	174,301	52,882	173,134	13,666	1,861,160
	2000	115,472	221,938	900,467	307,289	64,041	150,297	74,828	239,585	21,045	2,496,082
	2012	129,373	252,973	1,085,899	364,891	76,098	168,847	84,264	284,775	21,455	2,939,977
	2000/1990 %	2.73 %	3.21 %	3.12 %	3.18 %	3.25 %	2.78 %	3.53 %	3.30 %	4.41 %	2.98 %
	2012/2000 %	0.95 %	1.10 %	1.57 %	1.44 %	1.45 %	0.97 %	0.99 %	1.45 %	0.16 %	1.37 %
	2012/1990 %	1.75 %	2.05 %	2.27 %	2.23 %	2.26 %	1.79 %	2.14 %	2.29 %	2.07 %	2.10 %

(continued)

Table 1.3 (continued)

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa	National
Transportation											
1990	33,852	78,818	203,255	115,624	25,270	96,982	47,429	26,653	86,907	7,868	722,658
2000	56,919	110,841	269,263	155,943	30,567	115,141	71,696	42,146	122,860	11,426	986,801
2012	54,618	130,695	286,878	164,357	33,526	130,385	80,132	38,323	134,187	13,506	1,066,605
2000/1990 %	5.33 %	3.47 %	2.85 %	3.04 %	1.92 %	1.73 %	4.22 %	4.69 %	3.52 %	3.80 %	3.16 %
2012/2000 %	-0.34 %	1.38 %	0.53 %	0.44 %	0.77 %	1.04 %	0.93 %	-0.79 %	0.74 %	1.40 %	0.65 %
2012/1990 %	2.20 %	2.33 %	1.58 %	1.61 %	1.29 %	1.35 %	2.41 %	1.66 %	1.99 %	2.49 %	1.79 %

Source Energy Consumption Statistics by Prefecture (METI)

Table 1.4 Rate of changes of manufactured goods shipments and energy demand (annual rate average, %)

	Manufactured goods shipments (%)		Energy demand (%)	
	1990s	2000s	1990s	2000s
Hokkaido	-0.03	0.31	-0.82	0.30
Tohoku	0.97	-1.24	0.53	-1.42
Tokyo	-1.44	-1.58	0.77	-1.56
Chubu	-0.20	0.55	-0.17	-2.46
Hokuriku	-0.32	-0.27	-0.93	-1.94
Kansai	-1.53	-0.55	-1.37	-1.37
Chugoku	-0.86	1.08	0.39	-1.11
Shikoku	-0.01	1.42	0.78	-1.21
Kyushu	0.80	0.79	-0.31	-1.28
Okinawa	1.83	-0.36	0.85	-1.03
National	-0.73	-0.33	0.09	-1.48

Source Industry Statistics (METI), Energy Consumption Statistics by Prefecture (METI)

was greater in the 2000s than in the 1990s, while Manufacturing's final energy consumption decreased greatly in each region in the 2000s.

Table 1.4 shows the comparison of the regions' rates of change for manufactured goods shipments and energy demand, according to decade. Particularly in the regions in East Japan, manufactured goods shipments decreased greatly in the 2000s. In the majority of the regions, the rates of change of shipments and energy demand are linked. However, in Chubu, Chugoku, Shikoku, and Kyushu, energy demand declined in the 2000s, despite increases in manufactured goods shipments. This signifies a decline in energy demand per shipment in these regions. A factor behind this is considered to be the progress made in energy saving, but exploring this issue is a topic for analysis in the following chapters.

Figure 1.4a, b shows the growth in final energy consumption in the Industry sectors. Non-manufacturing trended downward in the time series and there were no significant differences between regions. Conversely, Manufacturing trended basically unchanged during the 1990s, but then fell significantly in the 2000s. A feature of the two regions of Kansai and Hokuriku was that they were greatly below the national average and trended downward over the observation period.

The final energy consumption of the ResCom and Transportation sectors trended upward in each of the regions (Table 1.3). Within the ResCom sector, the increasing trend in the Residential sector in the 1990s was significant, but then in 2000s, consumption was seen to fall everywhere except Chubu. Across the observation period, the rates of increase of Tokyo, Chubu, and Okinawa exceeded the national rate, but in contrast growth was weak in Kansai. Similarly, in the Commercial sector, the increasing trend was greater in the 1990s than in the 2000s; in terms of regional trends, features were that while growth in Tokyo, Chubu,

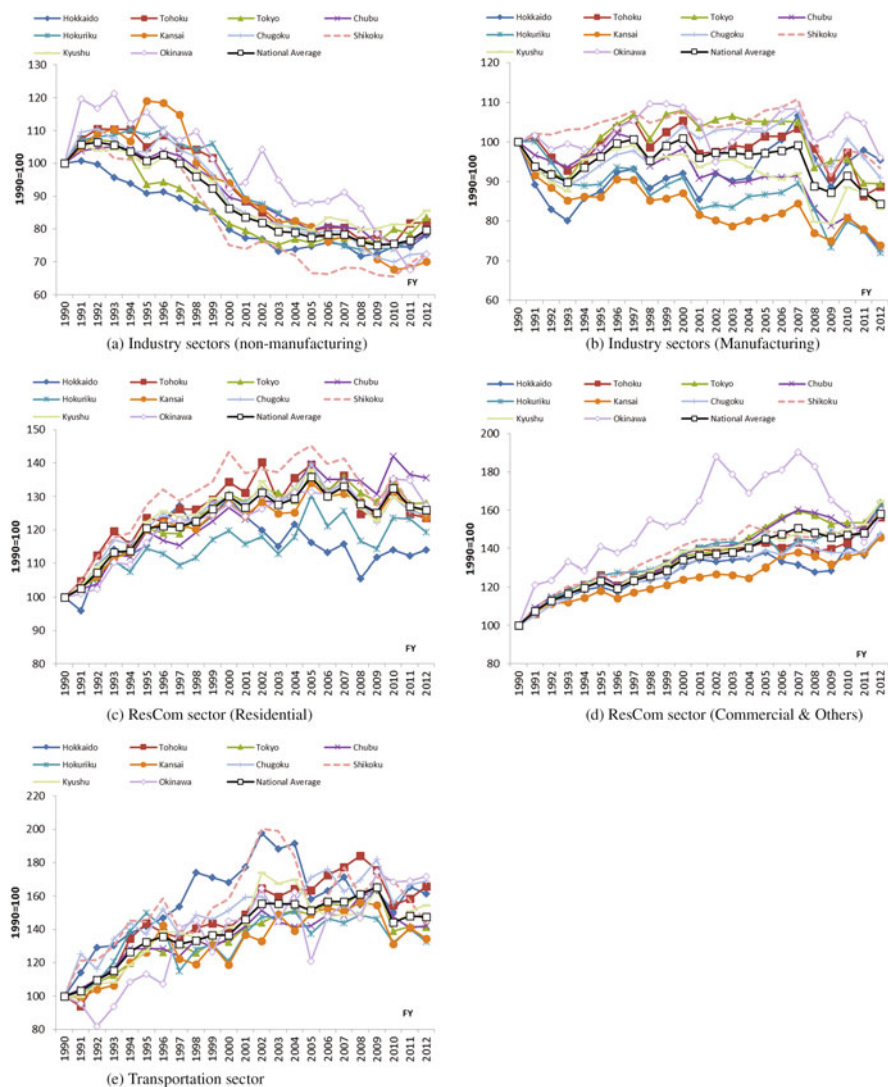


Fig. 1.4 Regional growth in energy demand by sector (1990 = 100). *Source* Energy Consumption Statistics by Prefecture (METI)

Hokuriku, Shikoku, and Kyushu exceeded that of the nation as a whole, growth was weak in Kansai.

Figure 1.4c, d shows the growth in final energy consumption in the Residential and Commercial sectors. In the Residential sector in each of the regions, there was significant growth in the 1990s, but consumption then slumped in the 2000s. The growth rate slowed from 2011 onwards, which was probably from the effects of the

Great East Japan Earthquake. In the Commercial sector, consumption increased steadily in each region, with no clear differences between the regions being observed. Unlike the Residential sector, however, looking at the trend from 2011 onwards, it is not possible to discern a trend that would seem to be from the effects of the earthquake.

Finally, the Transportation sector's final energy consumption grew significantly in each region, but not by as much as the Commercial sector (Table 1.3). As with the ResCom sector, the Transportation sector's growth rate was higher in the 1990s than in the 2000s. In particular, the growth rates exceeded 2 % in Hokkaido, Tohoku, Chugoku, and Okinawa throughout the observation period, and growth was significant in regions other than the large metropolitan areas.

Figure 1.4e shows the growth in final energy consumption in the Transportation sector. As with the Residential sector, the growth was significant in the 1990s, but in contrast consumption slumped in the 2000s. As was observed in the ResCom sector, no clear differences between regions could be seen.

1.4 Factors Behind the Changes in Final Energy Consumption

Having ascertained the trends in Japan's regional energy demand, we will now look at the factors determining the changes in regional energy demand.

Final energy consumption can be formulated as follows:

$$\text{Final energy consumption} = \text{energy demand per capita} \times \text{population}.$$

From this, the change to final energy consumption can be resolved into the change in energy demand per capita and population growth. This is expressed as follows:

$$\Delta \text{ final energy consumption} = \Delta \text{ energy demand per capita} + \Delta \text{ population},$$

where Δ is the rate of change and expresses the logarithm of the finite difference approximation.

Figure 1.5 shows the results of the factor analysis in accordance with this resolving formula for the rates of change to the prefectures' final energy consumption. We find that the change in energy demand per capita in practically all of the prefectures exceeds the population change.

The increase in energy demand per capita was largest in Tottori Prefecture, and was small in the large metropolitan areas such as Metropolitan Tokyo, Osaka Prefecture, and Aichi Prefecture. In particular, the values were negative in Osaka Prefecture and Aichi Prefecture. In each of the prefectures in the Tokyo, Kansai, and Chubu regions, total energy consumption increased from population growth, rather than from a rise in energy demand per capita. In the rural areas, however, in

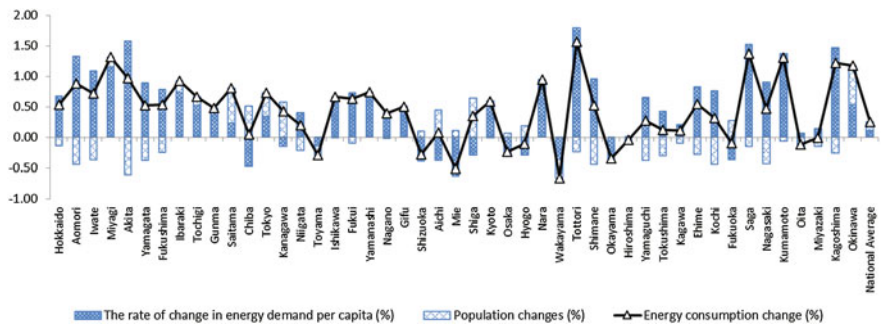


Fig. 1.5 Factor analysis of the prefectures' final energy consumption (1990–2012). *Source* *Energy Consumption Statistics by Prefecture (METI)*, *Basic Resident Register Population* (Statistics Bureau, Ministry of Internal Affairs and Communications)

the context of their declining populations, it seems likely that total energy consumption increased from the rise in energy demand per capita.

Next, we will confirm the current conditions for energy demand per capita in each of the prefectures. Figure 1.6 shows the levels of energy demand per capita in each of the prefectures (the 2012 values) and their rates of change.

Oita Prefecture had the highest level of energy demand per capita, at 310.4 GJ/person, followed by Okayama Prefecture (279.2), Yamaguchi Prefecture (247.7), Chiba Prefecture (182.6), and Mie Prefecture (162.8). Manufacturing is concentrated in all of these prefectures; in particular, they each have a petroleum-chemical industrial complex with a concentration of energy-intensive manufacturing industries. In contrast, starting with Metropolitan Tokyo (63.0), the tendency was for large metropolitan areas, including Osaka Prefecture (75.5) and Aichi Prefecture (95.3), to be below the national average (96.0). Compared with the Industry sectors, the ResCom sector's energy demand per capita is small; the assumption can be made that energy demand per capita tends to be small in regions

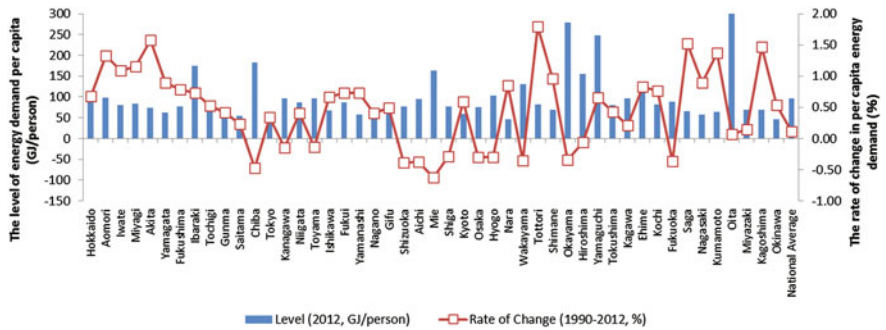


Fig. 1.6 Current conditions of the energy consumption per capita by prefecture. *Source* *Energy Consumption Statistics by Prefecture (METI)*, *Basic Resident Register Population* (Statistics Bureau, Ministry of Internal Affairs and Communications)

with concentrations of population and a major Commercial sector. The growth in energy demand per capita was higher in the rural areas than in the large metropolitan areas. A feature of each of the prefectures in the Hokkaido, Tohoku, Hokuriku, Chugoku, Shikoku, and Kyushu regions was their significant growth in energy demand per capita.

Figure 1.7 plots the relationship between the changes to energy demand per capita and population change during the observation period. As a whole, the patterns of change can be divided into the following four quadrants for consideration.

- (i) Population growth rate >0 , rate of change in energy demand per capita >0 .
- (ii) Population growth rate <0 , rate of change in energy demand per capita >0 .
- (iii) Population growth rate <0 , rate of change in energy demand per capita <0 .
- (iv) Population growth rate >0 , rate of change in energy demand per capita <0 .

On looking at the first quadrant (i), we see that it includes the Greater Tokyo Area, such as Metropolitan Tokyo and Saitama Prefecture; their surrounding areas of Ibaraki Prefecture, Tochigi Prefecture, and Gunma Prefecture; and Okinawa

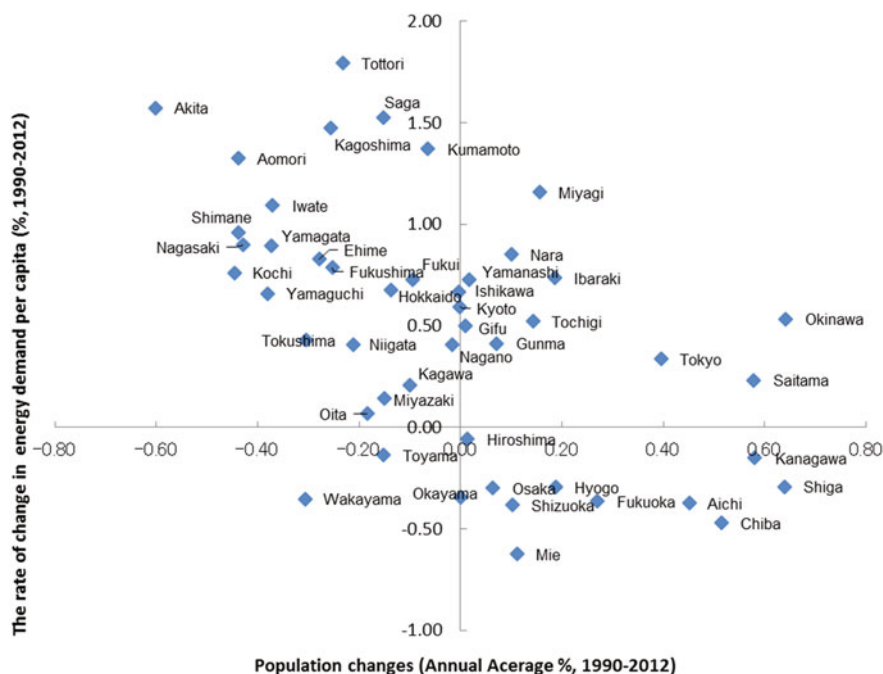


Fig. 1.7 Relationship between changes to per capita energy demand and population changes.
Source Energy Consumption Statistics by Prefecture (METI), Basic Resident Register Population (Statistics Bureau, Ministry of Internal Affairs and Communications)

Prefecture. The Commercial sector is thought to be comparatively densely concentrated in these regions. The Commercial sector is particularly concentrated in Metropolitan Tokyo, Saitama Prefecture, and Okinawa Prefecture.

Looking at the second quadrant (ii), we see it includes the Tohoku region of Aomori Prefecture, Iwate Prefecture, and Akita Prefecture; Chugoku regions such as Tottori Prefecture and Shimane Prefecture; and the Shikoku region of Ehime Prefecture, Tokushima Prefecture, and Kochi Prefecture. The population is decreasing in these regions and they are considered to be locations that do not host the major core industries of the manufacturing and service sectors. This quadrant includes many regions outside of the large metropolitan areas.

Only two regions, Toyama Prefecture and Wakayama Prefecture, were classified into the third quadrant (iii), and they do not have any noteworthy characteristics. The fourth quadrant (iv) includes large metropolitan areas such as Kanagawa Prefecture, Chiba Prefecture, and Aichi Prefecture, and in addition prefectures such as Shiga Prefecture, Mie Prefecture, Okayama Prefecture, and Shizuoka Prefecture. All of them are locations where manufacturing is concentrated. Prefectures such as Chiba Prefecture, Mie Prefecture, and Okayama Prefecture have a petroleum-chemical industrial complex and many materials-type industries. In contrast, a characteristic of prefectures such as Aichi Prefecture and Shiga Prefecture is that they have many processing and assembly industries, like transportation machinery and precision machinery.

1.5 Regional Trends in the Electrification Rate

If we can calculate energy demand per capita and at the same time obtain the electrification rates, the electric power demand per capita may be ascertained. The electric power demand per capita can be calculated as follows:

$$\text{Electric power demand per capita} = \text{energy demand per capita} \\ \times \text{electrification rate.}$$

The electrification rate is calculated as shown below:

$$\text{Electrification rate} = \text{electric power consumption/final energy consumption.}$$

The relationship between them is shown by the fact that electric power demand per capita is determined by both the energy demand per capita and the electrification rate. In other words, if the energy demand per capita and the electrification rate can be accurately calculated, the electric power demand per capita can be determined.

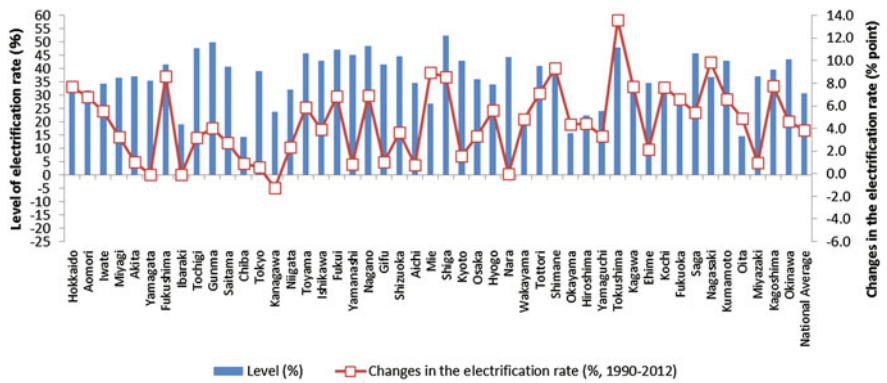


Fig. 1.8 Trends in the electrification rates by prefecture. *Source* Energy Consumption Statistics by Prefecture (METI)

Next and finally, in order to see the regional electric power demand by region, we will ascertain the trends in the regional electrification rates, which form an important element of this analysis.

Figure 1.8 shows the current conditions for the electrification rates and the rates of change by prefecture. The electrification rate levels in 2012, which is the latest year in which the statistics could be collected, show that Shiga Prefecture was the highest at 52.5 %, followed by Gunma Prefecture (49.8 %), Nagano Prefecture (48.6 %), Tokushima Prefecture (48.0 %), Tochigi Prefecture (47.6 %), and Fukui Prefecture (47.2 %). Conversely, the prefectures with the lowest electrification rates were Chiba Prefecture (14.3 %), Oita Prefecture (14.5 %), and Okayama Prefecture (15.7 %), with the levels becoming lower in regions with a petroleum-chemical industrial complex in which materials-type industries are concentrated.

Looking at the changes to the electrification rates over the observation period, we see that the speed of electrification was fastest in Tokushima Prefecture at 13.55 %, while it was also fast in Hokkaido, the prefectures in Hokuriku, and the prefectures in Shikoku and Kyushu. Conversely, the pace of electrification was moderate in the large metropolitan areas. For example, this corresponds to areas within the TEPCO jurisdiction of Saitama Prefecture, Chiba Prefecture, Metropolitan Tokyo, and Kanagawa Prefecture; within the Chubu Electric Power Company jurisdiction of Gifu Prefecture, Shizuoka Prefecture, and Aichi Prefecture; and within the Kansai Electric Power Company jurisdiction of Osaka Prefecture.

Looking at the growth in the electrification rates over the observation period, we find that the Hokkaido, Kyushu, Chugoku, and Shikoku rural areas exceeded the national level (Fig. 1.9). In contrast, within TEPCO’s jurisdiction, the tendency was

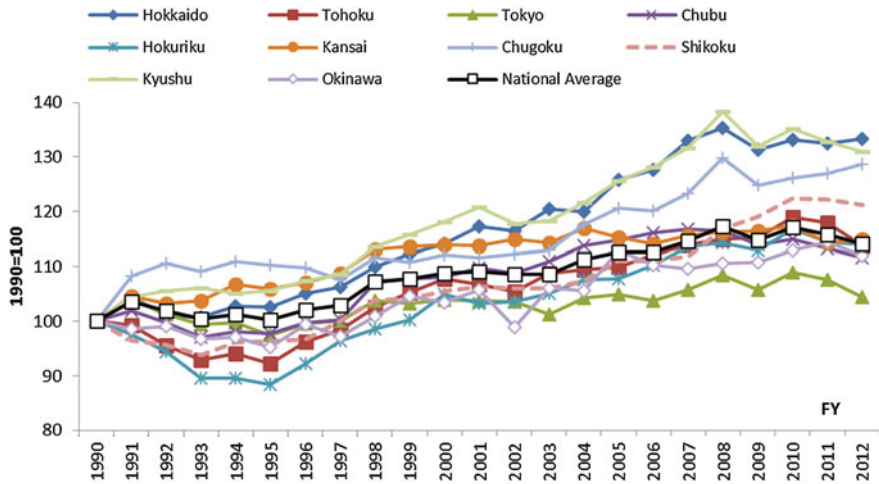


Fig. 1.9 Growth in the electrification rate by region (1990 = 100). *Source* Energy Consumption Statistics by Prefecture (METI)

for weak growth in the electrification rate. If this electrification trend continues into the future, it is estimated that even if the populations of Hokkaido and Kyushu decrease, electric power demand per capita could increase due to the rises in the energy demand per capita and the electrification rates.

Looking at the regional electrification rate by demand sector, we can understand which demand sectors influence the growth in the national electrification rate. Table 1.5 shows the trends in the regional electrification rates by demand sector. We can confirm that Hokkaido and Kyushu have significant increasing trends in the electrification rates for the Industry sectors (Manufacturing) and the Residential sector. In particular, the growth in the electrification rate in the Residential sector probably expresses the effects of the business model of the electric power companies, of an all-electric home sales strategy. Further, a characteristic of the Residential sector is the significant rate of growth in the electrification rate in the Hokuriku region, where optional supply provisions have been increasing remarkably (Fig. 1.10).

Looking by sector, we see that the growth of the electrification rate is large in the Residential sector, but small in the Industry sectors and the Commercial sector. Going forward, it would seem necessary to focus on the trend in the Residential sector in order to consider the growth in electric power demand.

Table 1.5 Regional trends in the electrification rates by sector (year)

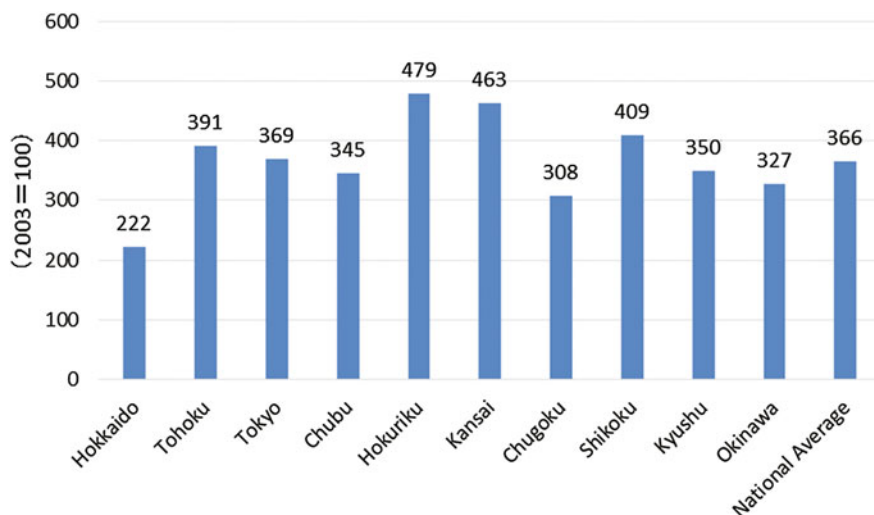


Fig. 1.10 Changes to the optional supply provision electric power totals by region (2013: 2003 = 100). *Source* Electricity business handbook

1.6 Conclusion

In this study, the *Energy Consumption Statistics by Prefecture* were utilized and the actual conditions of energy demand in the regions of Japan were ascertained. The results showed that Japan's national energy demand increased from the 1990s to the 2000s; and that the driving forces behind this increase were the ResCom sector, comprising Residential and Commercial, and the Transportation sector. Looking at regional trends, the analysis showed not only that the increase in energy demand in prefectures under TEPCO's jurisdiction contributed greatly, but also that energy demand grew steadily within prefectures outside of the large metropolitan areas. Upon considering changes to regional energy demand by analyzing changes to energy demand per capita and population changes, the results showed that energy demand per capita has a major impact on regional energy demand, and that in particular, the increase in energy demand in rural regions has been brought about by the increase in energy demand per capita.

The findings of this study suggest that in order to understand the trends in regional energy demand in the future, a major key will be ascertaining the trends in energy demand per capita. In particular, there is a need to resolve the factors behind the significant growth in energy demand per capita and to clarify if they arise from structural factors in the demand sector, or from factors specific to that particular region. Following the Great East Japan Earthquake, the demand structures in each of the sectors may also have been changing. With regard to this point, while considering the availability of data, an absolutely essential step will be to analyze and verify regional differences in the energy intensity by sector in order to ascertain

the demand for energy in the regions. In addition, accurately understanding the trends in the electrification rates would seem to be important in order to forecast trends in electric power demand in the future.

Appendix: Explanation of the Energy Consumption Statistics by Prefecture

In this appendix, the feature of the *Energy Consumption Statistics by Prefecture* are explained (Kaino 2012a, b). The *Energy Consumption Statistics by Prefecture* are based upon the *General Energy Statistics*.

The Thinking behind the Energy Consumption Statistics by Prefecture

The *Energy Consumption Statistics by Prefecture* are the recounted totals of the divided estimates by prefecture only for those sectors that can be regionally divided within the *General Energy Statistics* (Table 1.6). The current situation with regard to the sectors for which regional divisions are difficult in the *General Energy Statistics* is that the regionally divided estimates are not carried out within the *Energy Consumption Statistics by Prefecture* and they are excluded from the calculations. Therefore, as is described below, the national total value in the *Energy Consumption Statistics by Prefecture* is not consistent with the same value in the *General Energy Statistics*.

The method of dividing the regions in the *Energy Consumption Statistics by Prefecture* is as described below.

Manufacturing Sectors: The data from the individual surveys in the *Current Survey of Energy Consumption Statistics* are re-totaled by prefecture and the same calculation method as in the *General Energy Statistics* is applied.

Agriculture and Forestry, Mining, Construction, Small- and Medium-Sized Manufacturing Sectors, Commercial and Others (Tertiary Industry) Sectors: The consumption amounts by industry and by energy estimated from the industry input-output table, and from the *General Energy Statistics*, are estimated from the composition ratios of the national amounts of intermediate inputs for the relevant industries from the *Annual Report on Prefectural Accounts*.

Residential Sector, Family Income/Car (Transportation) Sector: The prefectural capital aggregated values in the *Family Income and Expenditure Survey* are used and the same calculation method as in the *General Energy Statistics* is applied.

The structure of the Energy Consumption Statistics by Prefecture

The sectors targeted for the estimates in the *Energy Consumption Statistics by Prefecture* are as follows (please refer to Table 1.6 for more details).

Table 1.6 Sectors included in the estimates of the Energy Consumption Statistics by Prefecture

Statistical sector classification	Corresponding sector classification in the General Energy Statistics
#5000 Final energy consumption (#6000–#8000 total)	#5000 Final energy consumption (#6000–#8000 total)
#6000 Industry (#6100, #6500 total)	#6000 Industry (#6100, #6500 total)
#6100 Non-manufacturing (#6100A–#6100B total)	#6100 Non-manufacturing
#6100A Agriculture, forestry, and fisheries	#6100 Agriculture, forestry, and fisheries
#6100b Construction and mining	#6120 Mining, #6150 Construction
#6500 Manufacturing (#6500A–#6500E total)	#6500 Manufacturing
#6500a Chemical, chemical textile, pulp and paper	#6520 Pulp and paper products, #6550 Chemical, #6530 Chemical fibers
#6500B Iron and steel, non-ferrous metal, cement and ceramics	#6580 Iron and steel, #6570 Ceramics, stone, and clay, #6590 Non-ferrous metals, #6560 Glass products
#6500c Machinery	#6600 Machinery
#6500d Duplication adjustment	#6700 Duplication adjustment
#6500E Other industries and SMEs	#6800 Other industries and SMEs, #6510 Food produce, #6540 Petroleum products (other products)
#7000 ResCom (#7100, #7500 total)	#7000 ResCom (#7100, #7500 total)
#7100 Residential	#7100 Residential
#7500 Commercial and others (#7500A–#7900 total)	#7500 Commercial and others
#7500A Water supply, sewage and waste disposal	#7510 Water supply, sewage and waste disposal
#7500B Trade and finance services	#7600 Commercial and finance
#7500C Public services	#7700 Public services
#7500D Commercial services	#7810 Commercial services
#7500E Retail services	#7850 Retail services
#7900 Others and miscellaneous	#7520 Electricity and gas businesses, #7530 Transportation ancillary services, #7540 Communication broadcasting, #7900 Other, Classification unknown, error
#8000 Transportation (= #8110)	#8000 Transportation
#8110 Passenger car	#8110 Passenger car

Source Prepared based on Kaino (2012a, b)

Notes 1. The sectors not included in the *Energy Consumption Statistics by Prefecture* are as follows. (Transportation sector: vehicles other than passenger) #8115 bus, #8120 railway, #8130 ships, #8140 aviation (transportation sector: cargo) #8500 cargo

2. The above correspondence table is based on the *General Energy Statistics* (2010 edition). As the document explaining the statistics in the 2015 revised edition of the *General Energy Statistics* had not been published at the time this paper was written, it was not possible to confirm the correspondence relations for the estimated sectors

Non-manufacturing Sector—Agriculture, Forestry, and Fisheries Industry; Mining Industry; Construction Industry: Within the *Energy Consumption Statistics by Prefecture*, the agriculture, forestry, and fisheries industry, and the mining and construction industries have been aggregated into two sectors: Agriculture, Forestry and Fisheries; and Construction and Mining. The regional division estimates for the agriculture and forestry, and fisheries industry and the mining and construction industry are made using “the industry association estimates method.”

Manufacturing Sector: Within the *Energy Consumption Statistics by Prefecture*, Manufacturing is aggregated into five sectors: Chemical, Chemical Textile, Pulp and Paper; Iron and Steel, Non-ferrous Metals, Cement and Ceramics; Machinery; Duplication Adjustment; and Other Industries and SMEs. With regards to the four sectors other than the Other Industries and SMEs sector within Manufacturing, the values are estimated by retotaling and processing the individual surveys in the *Current Survey of Energy Consumption Statistics*. Conversely, the Other Industries and SMEs sector is generally estimated using “the industry association estimated method.” The reason for aggregating the sectors compared with those in the *General Energy Statistics* is because in the majority of cases there is only one factory or business establishment per prefecture, such as for iron and steel or chemical, so if the data are disclosed without aggregating them, this will come into conflict with the provisions of the Statistics Act in terms of protecting the privacy of individual companies, so it would not be possible to disclose the statistical values.

Commercial and Others Sector: Within the *Energy Consumption Statistics by Prefecture*, the Commercial and Others sector (tertiary industry) is the aggregation of six sectors: Water supply, Sewage and Waste Disposal; Trade and Finance Services; Commercial Services; Retail Services; Public Services; and Others and Miscellaneous. The regionally divided estimates for these sectors are carried out using “the industry association estimation method.” When estimating regional divisions using this method, there exist relatively large estimation errors for the Commercial and Public Service industries compared with industries such as Manufacturing, and caution is required when the error reaches the range of 10–20 % (Kaino 2012a, b).

Residential Sector and Family Income/Car Sector: Within the *Energy Consumption Statistics by Prefecture*, with regard to the Residential sector and Family Income/Car sector, the energy consumption by general households in each prefecture is estimated using the trends in the household average spending per prefectural capital location, and per item in the *Family Income and Expenditure Survey*. However, as there is bias in the choice of households that are surveyed in the *Family Income and Expenditure Survey*, rather than using the numerical values corresponding to the direct calculations, the energy consumption amounts are calculated after carrying out various types of correction processing in order as to have the surveyed households match as far as possible the image of the average household in each of the prefectures.

Points to be aware of when using the energy statistics

Basically, the *Energy Consumption Statistics by Prefecture* use unchanged the calculation method used in the *General Energy Statistics*. Due to the presence of errors in the regional division estimates, however, specific calculation methods are also used as exceptions. Therefore, as described above, it is necessary to be aware that the totals in the *Energy Consumption Statistics by Prefecture* will not necessarily be consistent with those in the *General Energy Statistics*.

In particular, when using the *Energy Consumption Statistics by Prefecture*, researchers need to be aware of the following three points (Kaino 2012a, b):

1. The existence of errors from the *General Energy Statistics* and of errors from the regional division estimates.
2. The transportation cargo sector and the energy conversion sector are excluded from the calculations.
3. Renewable energy, such as geothermal and biomass, is excluded from the calculations.

Further, it is necessary to be aware of the point that the latest year for the statistics is fiscal 2012. Since the final confirmed values in the *Annual Report on Prefectural Accounts*—which is one of the published sets of statistics used to compile the *Energy Consumption Statistics by Prefecture*—are published after a delay of two years, in order to wait for their publication, a delay of one year occurs compared with the publication of the *General Energy Statistics*. Therefore, the estimates are from a regression analysis using the trends in a time series in the intermediate input amounts in the *Annual Report on Prefectural Accounts*, with the estimated values from the most recent fiscal years being used to supplement the delay period in question. This point should be kept in mind when using these statistics.

References

- Kaino, K. 2012a. *Explanation of the energy statistics by prefecture/fiscal 2010 edition*, The Research Institute of Economy, Trade and Industry (in Japanese).
- Kaino, K. 2012b. *Explanation of the general energy statistics/fiscal 2010 revised edition*, The Research Institute of Economy, Trade and Industry (in Japanese).
- Otsuka, A. 2016. *Findings of Regional Energy Demand*, Denryokukeizaikenkyu, 63, 66-81 (in Japanese).

Chapter 2

Determinants of Regional Energy Demand: Dynamic Shift-Share Analysis

Abstract In order to investigate the future trends of energy demand in Japan accurately, there is a need to clarify the factors that cause fluctuations in energy demand across regions; more specifically, to determine whether the energy demand fluctuations across regions arise from compositional factors, that is, differences in energy users, or from regionally unique factors. This study analyzes the determinants of energy demand change to clarify the factors that have affected the fluctuations in regional energy demands in Japan, using dynamic shift-share analysis. The results show that the energy demand fluctuations can be explained by both compositional effects and regional effects. With regard to the compositional effects, the energy demand growth increased most remarkably in the regions that specialize in residential and commercial sectors. However, energy demand did not increase in the regions that specialize in manufacturing sectors. With respect to the regional effects, there were constraints on energy demand in large metropolitan areas due to the improved energy intensity achieved through energy conservation. The results imply that having a mixture of industry and ResCom (Residential and Commercial) sectors in a region potentially flattens out fluctuations in energy demand changes. This finding suggests that when moderating changes in regional energy demand, an important step is to diversify the industrial structure in each region.

Keywords Regional energy demand • Regional energy consumption • Dynamic shift-share analysis • Region • Japan

2.1 Introduction

The recent ambitions of the Japanese government to improve consumption and conservation include the development of an energy master plan (METI 2015). To create such an aspirational political instrument, it is essential to analyze thoroughly

The original article of this chapter is “Regional Energy Demand in Japan: Dynamic Shift-Share Analysis,” published in *Energy, Sustainability and Society* (Vol. 6, No. 10, pp. 1–10, 2016).

the present structure of energy demands in Japan. The present study provides this analysis, in terms of the regional and the sectoral aspects relevant to the energy demand in Japan during 1990–2011. Japan's energy demands grew throughout the 1990s and 2000s. Energy demand in Japan increased at an annual average rate of 0.33 % from 1990 to 2011, which was in line with economic growth (0.32 %). However, regional differences in the energy demand increases are apparent in that period; e.g., Japan's rural energy demand increases differed from those in its large metropolitan area, such as the Greater Tokyo Area, Kansai, and Chubu.

To investigate the future energy demand trends in Japan accurately, it is important to clarify the factors that determine the energy demand fluctuations across Japan's regions; specifically, whether the energy demand fluctuations across regions are due to compositional factors, that is, differences in energy users, or are due to regionally unique factors. Globally, there is very little previous research on regional energy demand, because of a lack of relevant data. Bernstein et al. (2003) and Metcalf (2008) targeted individual states in the United States, while Raupach-Sumiya et al. (2015), Otsuka et al. (2014), and Otsuka and Goto (2015) investigated regions in Germany and Japan. However, each of these studies analyzed the factors determining the energy efficiency, rather than the dynamic changes in the regional energy demand. This study clarifies the factors that bring about energy demand changes in Japan's regions, by applying a shift-share analysis to newly released regional energy demand data. To the best of the author's knowledge, there are no previous cases of applying shift-share analysis to regional energy demand analysis.

Shift-share analysis, first introduced by Dunn (1960) in 1960, is an analytical method often used in the field of regional science. This method decomposes the relevant factors affecting an economic system; these factors relate mainly to production and employment changes. Shift-share analysis uses identical equations to analyze the growth rates by industry for each region. The method uses three factors: the national effect (factors common among all industries nationally), the compositional effect (industry-specific factors at a national level), and the regional effect (factors unique to each industry at a regional level). The method then evaluates the contributions of each effect to the overall regional growth rate (e.g., Dinc and Haynes 1999; Haynes and Dinc 1997). Shift-share analysis has many proponents; however, it is also criticized for numerous different reasons (Dawson 1982; Knudsen and Barff 1991). There are many extensions and revisions of Dunn's (1960) traditional method (Artige and Neuss 2014; Barff and Knight 1988; Esteban-Marquillas 1972; Haynes and Dinc 1997; Haynes and Machunda 1987; Markusen et al. 1991; Marquez et al. 2009). Notably, Barff and Knight (1988) propose a dynamic shift-share analysis that applies the traditional analysis to cross-year data, a method that is adopted in many subsequent studies (e.g., Hirobe 2015; Kobayashi 2004; Mitchell and Carlson 2005; Nissan and Carter 1994; Shi et al. 2007). Barff and Knight's (1988) dynamic shift-share analysis solves some of the well-known problems with Dunn's (1960) static shift-share analysis.

This study uses the dynamic shift-share analysis method, which is constantly being refined, to analyze Japan's regional energy demands. Dynamic shift-share

analysis analyzes the fluctuations in the overall energy demand in regions, according to the compositional effect (arising from the type of energy users) and according to regionally unique factors. This clarifies the dominant factors influencing the total energy demand changes in each region.¹ Additionally, it is possible to investigate the effects of the efficiency measures through the regional effect.

This study aims to analyze the total energy demand changes by Japanese region. The study analyzes the changes according to the national effect, the compositional effect, and the regional effect, by applying dynamic shift-share analysis to the ratio of total energy demand change. Finally, the study clarifies the factors that cause the fluctuations.

Section 2.2 describes how the dynamic shift-share analysis is applied to analyze the regional energy demand, and provides an explanation of the data. Section 2.3 describes the analysis results, while Sect. 2.4 presents the conclusions, and suggests some future research directions.

2.2 Methods

2.2.1 Analytical Framework

First, by applying shift-share analysis to total energy demand changes for user i in region j , it is possible to divide these changes into three components as follows:

$$g(E_{ij}) = g(E) + [g(E_i) - g(E)] + [g(E_{ij}) - g(E_i)], \quad (2.1)$$

where E_{ij} is the energy demand for user i in region j ; E_i is the energy demand ($E_i = \sum_j E_{ij}$) of user i for the entire nation; E is the energy demand ($E = \sum_i E_i$) for the entire nation; and $g(\cdot)$ is a function that expresses the rate of change of each variable. Concretely, the function of energy demand E can be expressed as

$$g(E_t) = \frac{\Delta E_t}{E_t},$$

where t is the time. On the right-hand side of (2.1), the first item is the national effect $g(E)$, the second item is the compositional effect $[g(E_i) - g(E)]$, and the third item is the regional effect $[g(E_{ij}) - g(E_i)]$. The national effect is the rate of change in the national energy demand. If each region has the same rate of change as the rate

¹The energy demand drivers are also related to other issues, such as sociological (household size development, income-related luxury demands), technological advancements, or climate policies. However, to investigate precisely the impact of such issues on changes in energy demand requires an econometric analysis rather than a shift-share analysis. This is because shift-share analysis is only one of the available decomposition methods (Metcalfe 2008).

of change for the entire nation, then the national effect in each region would be that value. The compositional effect shows the degree by which the national energy demand of user i exceeds the rate of change of the national energy demand. This shows the difference in the specific rate of change for user i , and it can be described as a compositional effect that is unique to user i . The regional effect shows the degree that region j 's energy demand of user i exceeds the rate of change of the national energy demand of user i . Because there is a difference between region j and the entire nation with regard to the same user, this is not a user-specific effect; hence, it expresses a regional-specific effect.

The rate of change of the total energy demand by region, can be calculated using the rate of change of the energy demand by user for the region. In other words, the *rate of change of the energy demand of region j* can be calculated from the *rate of change of the energy demand for user i in region j* according to

$$g(E_j) \equiv \sum_i s_{ij} \cdot g(E_{ij}), \quad (2.2)$$

where $s_{ij} = E_{ij}/E_j$. Note that E_j is the energy demand of region j . The question arises of whether to undertake the calculation of s_{ij} at the beginning or the end of the observation period. One proposed solution is the dynamic shift-share analysis mentioned in Sect. 2.1.² Instead of conducting shift-share analysis over a long period, the dynamic version conducts shift-share analysis over a short period in each year, and aggregates the values for each year (Barff and Knight 1988). This study adopts this calculation method, and applies a dynamic shift-share method to the regional energy demand data.

Using (2.1) and (2.2), the rate of change in energy demand for region j can be resolved as

$$g(E_j) = g(E) + \sum_i s_{ij}[g(E_i) - g(E)] + \sum_i s_{ij}[g(E_{ij}) - g(E_i)]. \quad (2.3)$$

On the right-hand side of (2.3), the first term is the national effect $g(E)$, the second term is the compositional effect $\sum_i s_{ij}[g(E_i) - g(E)]$, and the third term is the regional effect $\sum_i s_{ij}[g(E_{ij}) - g(E_i)]$. The national effect is the rate of change in the national energy demand. If each region has the same rate of change as the rate of change for the entire nation, then the national effect in each region would be the rate of change for the entire nation. The compositional effect is the aggregate of the compositional ratio for each user of region j multiplied by the factors specific to user i , and its value depends on the compositional ratio of the users of each region. The regional effect is affected by regionally unique factors that cannot be expressed by national and compositional effects.

²The dynamic approach is a suitable way to address the question of the representational adequacy of continuous time periods by discrete models (Mitchell and Carlson 2005).

Specifically, dynamic shift-share analysis is the equivalent of analyzing the differences in users once the national average trend has been eliminated; and then dividing the components into those that can be explained as such (compositional effects) and those that cannot (regional effects).

2.2.2 Data

The present study undertook dynamic shift-share analysis, using total energy demand data by user, for the 47 Japanese prefectures for the period 1990–2011. We can utilize the data period 1990–2012, but the value for 2012 is removed because it is an estimated value, not an actual value. Using dynamic shift-share analysis, a decomposition analysis was performed on the rate of change in the regional energy demand for the study period. The energy data came from the *Energy Consumption Statistics by Prefecture* (Agency for Natural Resources and Energy, the Ministry of Economy, Trade and Industry). The energy demand data used here relate to the total energy demand, including electricity and gas. However, this is the final energy consumption and does not include primary energy consumption. The energy demand users are the industrial (manufacturing and non-manufacturing) sectors, the ResCom (residential and commercial) sectors, and the transportation sector. The production data are the real gross product, published in the *Annual Report on Prefectural Accounts* (Cabinet Office). The real gross product is value added and includes trades and services.

Table 2.1 re-summarizes the relevant statistics presented in Chap. 1. Comparing the average energy demand for each sector shows a constant high demand level in the manufacturing sector. The average values for the ResCom sectors (residential and commercial) and the transportation sector are relatively small in comparison. During the study period (1990–2011), the manufacturing sector's maximum energy demand was extremely large (1,029,795 TJ in 2000), while its minimum energy demand was relatively small (8,235 TJ in 1990). In other words, there was a significant difference between the maximum and minimum values. Additionally, there was a large variation in the data for each prefecture.

As shown in Chap. 1, in the 1990s, there was an increase in the average annual growth rate of energy demand in most sectors. Energy demand grew at 1.12 % for all sectors, at 0.09 % in the manufacturing sector, and at 2.98 % in the commercial sector. However, in the 2000s, the overall average growth rate fell to -0.55 %, driven mainly by a fall in the manufacturing sector growth rate to -1.45 %. By contrast, energy demand in the commercial and transportation sectors increased to 1.00 and 0.81 %, respectively. These trends reflect the overall energy use trend at the time, specifically a move from the manufacturing sector in the 1990s to the commercial sector throughout the 2000s. Looking at the absolute value of the change, the absolute amount of the energy demand reduction in the manufacturing sector is roughly equal to the increase in the energy demand in the commercial sector.

Table 2.1 Japan's energy demand by sector, and real value added (1990–2011)

	Energy demand (TJ)				Regional gross product (Real value added: Million Yen)			
	All sectors	Industry sector		Manufacturing	ResCom sector		Transportation sector	
		Non-manufacturing			Residential	Commercial		
1990								
Average	244,527	13,270		142,241	34,041	39,599	15,376	9,909,019
Standard deviation	247,976	10,249		183,882	36,560	50,515	12,086	13,927,556
Maximum	1,111,732	60,233		909,773	180,245	296,525	46,492	86,871,666
Minimum	34,509	3,547		8,235	6,416	8,053	3,562	1,925,717
2000								
Average	273,370	11,446		143,552	44,268	53,108	20,996	10,658,548
Standard deviation	273,460	7,930		193,543	46,249	63,634	16,041	14,683,460
Maximum	1,293,160	48,073		1,029,795	222,472	377,043	62,358	93,069,156
Minimum	48,724	3,400		9,434	8,776	11,810	5,262	2,108,983
Annual growth rate (%; 1990–2000)	1.12	–1.47		0.09	2.66	2.98	3.16	0.73
2011								
Average	258,754	10,149		124,003	43,201	58,636	22,765	11,372,417
Standard deviation	252,082	8,098		167,884	45,175	72,779	16,667	15,518,250
Maximum	1,096,462	44,894		829,755	221,439	427,226	66,374	97,824,880
Minimum	48,044	1,833		10,313	8,300	12,291	6,253	1,876,725
(continued)								

(continued)

Table 2.1 (continued)

	Energy demand (TJ)					Regional gross product (Real value added: Million Yen)	
	All sectors	Industry sector		ResCom sector		Transportation sector	
		Non-manufacturing	Manufacturing	Residential	Commercial		
Annual growth rate (%; 2000– 2011)	–0.55	–1.20	–1.45	–0.24	1.00	0.81	0.65
1990–2011							
Average	262,696	11,824	135,589	41,833	52,096	21,354	10,633,278
Standard deviation	259,215	8,684	180,259	43,555	65,180	16,501	14,495,885
Maximum	1,333,681	60,689	1,062,885	232,676	476,685	84,744	101,626,400
Minimum	34,509	1,719	7,630	6,416	8,044	3,562	1,869,686
Annual growth rate (%; 1990– 2011)	0.33	–0.52	–0.22	0.94	1.25	1.50	0.32

Source: Energy Consumption Statistics by Prefecture (METI), Annual Report on Prefectural Accounts (Cabinet Office)

Notes: Japan's 47 prefectures are included in the sample dataset for 1990–2011

Japan's average annual value-added growth rate increased constantly in the 1990s and the 2000s. The growth rate trend represented by the value-added figures, validates the energy intensity (energy demand per value added) trend, this being a rapid drop from the 1990s to the 2000s.

2.3 Results and Discussion

2.3.1 Dynamic Shift-Share Analysis

Table 2.2 gives the factor decomposition results for the three effects on Japan's regional energy demand using Eq. (2.3). Looking at the rate of change in the energy demand, the region with the biggest rate of change was Okinawa, followed by Kita-Kanto, Tohoku, Hokkaido, and then Shikoku (all rural regions). The rates of change for the large metropolitan areas, such as the Greater Tokyo Area, Chubu,

Table 2.2 Factor decomposition of energy demand by Japanese region (1990–2011)

	Rate of change in energy demand (%) (i) + (ii) + (iii)	National effect	Compositional effect	Regional effect
		(i)	(ii)	(iii)
Hokkaido	0.50	0.28	0.29	−0.07
Tohoku	0.65	0.28	0.27	0.09
Kita-Kanto	0.74	0.28	−0.07	0.53
Greater Tokyo Area	0.36	0.28	0.08	0.00
Chubu	0.03	0.28	−0.03	−0.22
Hokuriku	0.29	0.28	0.24	−0.23
Kansai	0.01	0.28	0.09	−0.36
Chugoku	0.19	0.28	−0.42	0.33
Shikoku	0.41	0.28	−0.09	0.22
Kyushu	0.27	0.28	−0.08	0.07
Okinawa	1.22	0.28	0.60	0.34

Notes 1. The rate of change is the annual average (%) for 1990–2011

2. The regions are broken down 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)

Chubu (Nagano, Gifu, Shizuoka, Aichi, Mie)

Hokuriku (Toyama, Ishikawa, Fukui)

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)

and Kansai, were relatively small. The national effect was 0.28 %; thus, the remaining effects (when the national effect was removed from the rate of change for each region) were the compositional and regional effects. In Tohoku and Okinawa, both the compositional and the regional effects led the increase in energy demand. However, in Hokkaido and Hokuiku, while the compositional effect contributed to an increase in energy demand, the regional effect's contribution was negative. Conversely, in Japan's western regions, such as Chugoku, Shikoku, and Kyushu, the regional effect's contribution to the increase in energy demand was larger than that of the compositional effect. The lowering of the energy demand in the large metropolitan areas (excluding the Greater Tokyo Area), such as Chubu and Kansai, was affected appreciably by the regional effects. Particularly, the contributions of these effects were negative for Chubu and Kansai. This reveals that in the large metropolitan areas, the energy demand fell via differences arising from regional-specific factors.

Table 2.3 gives the energy demand decomposition results for Japan's prefectures using dynamic shift-share analysis. The energy demand increase exceeded 1 % in Miyagi, Nara, Tottori, Saga, Kumamoto, Kagoshima, and Okinawa prefectures. Conversely, the rate of change was negative in several prefectures, including Toyama, Shizuoka, Mie, Osaka, Wakayama, Okayama, Hiroshima, and Fukuoka prefectures. A positive sign represents a positive effect on the rate of change in energy demand. A negative sign represents a negative effect on the rate of change in energy demand. The national effect is positive, but is not dominant. It is important to understand the characteristics of each prefecture, in relation to the regional differences arising from the compositional and the regional effects of energy demand. Hence, the prefectures were classified according to four quadrants, formed by the compositional effect on the horizontal axis and the regional effect on the vertical axis (Fig. 2.1).

The compositional and the regional effects are both positive in the first quadrant, this being characteristic of many of the prefectures that are not in large metropolitan areas. In the second quadrant, the compositional effect is negative and the regional effect is positive. Many of the rural prefectures that have an agglomeration of heavy and chemical industries, including petrochemical industrial complexes, are in this quadrant. In the third quadrant, both the compositional and the regional effects are negative. The prefectures of regions that have an agglomeration of processing and assembly industries are in this quadrant. In the fourth quadrant, the compositional effect is positive and the regional effect is negative. Many prefectures that belong to large metropolitan areas with commercial sector agglomeration are in this quadrant. This quadrant also includes some rural prefectures, such as Hokkaido, Toyama, Ishikawa, and Kochi.

These observations show that the positive/negative state of the compositional effect appears to be subject to the agglomeration degree of the manufacturing industries. Further, the positive/negative state of the regional effect seems to be subject to whether the region is a large metropolitan area or a rural region.

Table 2.3 Factor decomposition of Japan's prefectural energy demand (1990–2011)

	Rate of change in energy demand (%) (i) + (ii) + (iii)	National effect (i)	Compositional effect (ii)	Regional effect (iii)
Hokkaido	0.50	0.28	0.29	−0.07
Aomori	0.62	0.28	0.13	0.21
Iwate	0.47	0.28	0.24	−0.05
Miyagi	1.06	0.28	0.38	0.40
Akita	0.97	0.28	0.39	0.29
Yamagata	0.63	0.28	0.50	−0.15
Fukushima	0.58	0.28	0.28	0.02
Ibaraki	0.82	0.28	−0.28	0.83
Tochigi	0.82	0.28	0.16	0.38
Gunma	0.47	0.28	0.20	−0.02
Saitama	0.80	0.28	0.46	0.05
Chiba	0.05	0.28	−0.45	0.22
Tokyo	0.55	0.28	0.89	−0.62
Kanagawa	0.55	0.28	−0.07	0.33
Niigata	0.42	0.28	0.16	−0.02
Toyama	−0.18	0.28	0.00	−0.46
Ishikawa	0.71	0.28	0.53	−0.10
Fukui	0.63	0.28	0.34	0.01
Yamanashi	0.92	0.28	0.49	0.15
Nagano	0.50	0.28	0.40	−0.18
Gifu	0.57	0.28	0.25	0.04
Shizuoka	−0.20	0.28	0.03	−0.52
Aichi	0.16	0.28	−0.01	−0.12
Mie	−0.35	0.28	−0.42	−0.21
Shiga	0.34	0.28	−0.04	0.09
Kyoto	0.66	0.28	0.56	−0.18
Osaka	−0.25	0.28	0.29	−0.83
Hyogo	0.13	0.28	−0.19	0.03
Nara	1.06	0.28	0.60	0.18
Wakayama	−0.30	0.28	−0.37	−0.21
Tottori	1.57	0.28	0.24	1.05
Shimane	0.57	0.28	0.29	0.00
Okayama	−0.06	0.28	−0.60	0.25
Hiroshima	−0.04	0.28	−0.24	−0.09
Yamaguchi	0.87	0.28	−0.53	1.12
Tokushima	0.23	0.28	0.06	−0.11
Kagawa	0.15	0.28	−0.05	−0.08
Ehime	0.69	0.28	−0.22	0.63

(continued)

Table 2.3 (continued)

	Rate of change in energy demand (%) (i) + (ii) + (iii)	National effect	Compositional effect	Regional effect
		(i)	(ii)	(iii)
Kochi	0.36	0.28	0.10	−0.02
Fukuoka	−0.11	0.28	0.04	−0.43
Saga	1.43	0.28	0.38	0.77
Nagasaki	0.44	0.28	0.42	−0.26
Kumamoto	1.25	0.28	0.34	0.63
Oita	0.24	0.28	−0.61	0.57
Miyazaki	0.18	0.28	0.04	−0.14
Kagoshima	1.12	0.28	0.36	0.48
Okinawa	1.22	0.28	0.60	0.34

Note The rate of change is the annual average (%) for 1990–2011

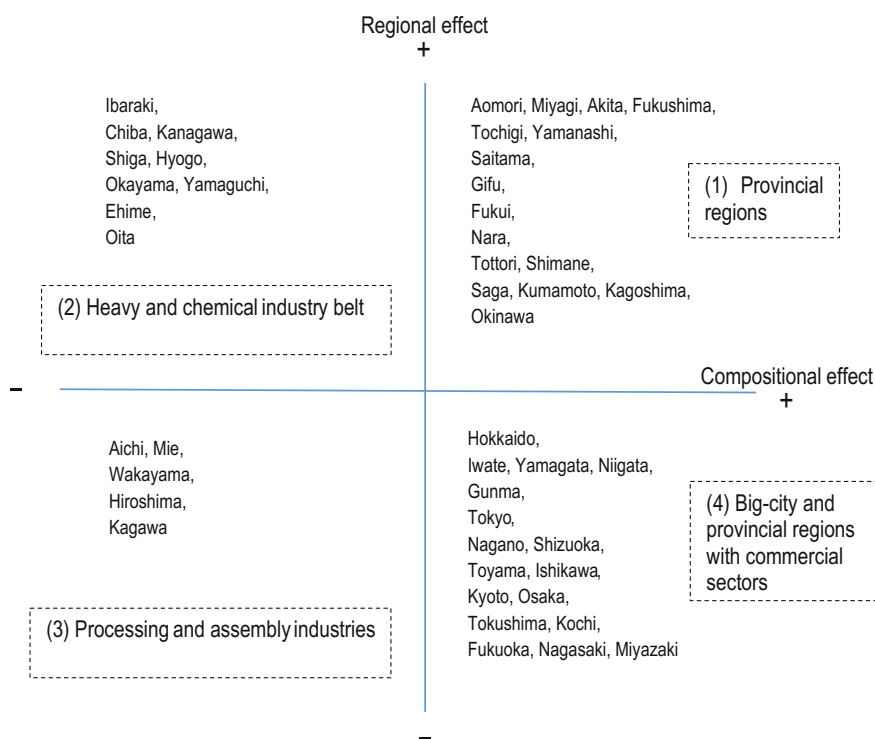


Fig. 2.1 Quadrant classification of Japan's prefectures by compositional effect and regional effects (1990–2011)

2.3.2 Analysis of the Compositional Effect

The dynamic shift-share analysis shows a high correlation between the level of agglomeration of the manufacturing sector and the positive or negative state of the compositional effect. Therefore, it is worth investigating this relationship in more detail. The differences in the compositional effect among the prefectures depend on the users (industrial, ResCom, or transportation sectors) in each prefecture. Here, the study verifies which user has an effect on the compositional effect according to a location quotient described by McCann (2001). A location quotient is usually calculated using the number of employees. The study calculates this location quotient for energy demand. The location quotient (represented by LQ) of the energy demand of user i in region j at time t is given by

$$LQ_{ij,t} = \frac{(E_{ij,t}/N_{j,t}) / (E_{j,t}/N_{j,t})}{(E_{i,t}/N_t) / (E_t/N_t)} = \frac{E_{ij,t}/E_{j,t}}{E_{i,t}/E_t}.$$

The numerator shows the energy demand share of user i in region j . The denominator shows the energy demand share of user i for the entire nation. Accordingly, if the index exceeds one, then the region's energy demand share of user i is higher than that of the entire nation. If the index exceeds one, then the region has a comparative agglomeration of that user.

Table 2.4 gives the correlation coefficient between the compositional effect and the location quotient, calculated for 1990 ($t = 1990$). The results show a negative trend for the compositional effect when a region specializes in manufacturing, particularly for the chemical, chemical textile, and pulp and paper sectors, and the iron and steel, non-ferrous metal, and cement and ceramics sectors. Meanwhile, the results also show a positive trend for the compositional effect for regions that specialize in the ResCom sector, such as residential and commercial sectors; and for the transportation sector, centered on passenger vehicles.

The following observations are made from checking the location quotient of the energy demand by user for the five highest-ranking prefectures and the five lowest-ranking prefectures, with respect to the rate of change by compositional effect. For the highest-ranking prefectures, the location quotient for the residential, commercial, and transportation sectors was more than one, and high. In contrast, the location quotient of the heavy and chemical industries (particularly the chemical, chemical textile, and pulp and paper industry, and the iron and steel, non-ferrous metal, and cement and ceramics industry), is close to zero, and extremely low. For the lowest-ranking prefectures, this relationship is reversed.

In other words, in prefectures that specialize in civil activities (including the residential and commercial sectors and the transportation sector), the rate of increase in energy demand is large. Meanwhile, in prefectures that specialize in heavy and chemical industries, a negative rate of change is observed for energy demand by way of the compositional effect.

Table 2.4 Factor decomposition of the compositional effect in Japan, by sector and prefecture

	Industrial sector				ResCom sector				Transportation sector					
	Non-manufacturing		Manufacturing		Machinery	Commercial and others			Public services	Commercial services	Retail services	Cars		
	Agriculture, forestry and fishery	Construction and mining	Chemical, chemical textile, pulp and paper	Iron and steel, non-ferrous metals, cement and ceramics		Water supply, sewage and waste disposal	Trade and finance services							
Correlation coefficient between the composition effect and location quotient	0.21	0.89	-0.74	-0.69	0.16	0.95			0.79	0.86	0.87	0.93	0.94	0.81
	Five top-ranking prefectures in compositional effect: location quotient													
Tokyo	0.06	2.35	0.04	0.10	0.59	1.90			2.69	3.18	2.47	2.69	2.62	1.07
Oknawa	1.66	1.66	0.01	0.25	0.00	1.69			1.66	1.66	1.68	1.66	1.66	2.47
Nara	0.65	1.93	0.02	0.01	0.96	2.06			1.87	1.35	1.93	1.49	1.55	2.07
Kyoto	0.30	1.25	0.16	0.28	1.86	1.82			2.06	2.05	1.88	1.76	1.80	1.25
Ishikawa	2.14	1.55	0.09	0.07	1.27	1.74			0.87	1.68	1.48	1.70	1.72	2.23
Five bottom-ranking prefectures in compositional effect: location quotient														
Mie	1.11	0.52	2.84	0.19	0.98	0.44			0.38	0.30	0.41	0.41	0.42	0.68
Chiba	0.24	0.50	2.29	1.25	0.18	0.47			0.66	0.31	0.45	0.36	0.36	0.47
Yamaguchi	0.63	0.38	2.35	1.16	0.30	0.39			0.34	0.29	0.32	0.38	0.39	0.51
Okayama	0.18	0.28	2.15	1.61	0.43	0.27			0.21	0.23	0.20	0.27	0.27	0.33
Oita	0.82	0.30	1.77	2.08	0.17	0.24			0.06	0.19	0.27	0.25	0.26	0.39

Notes Location quotient is the value of 1990 (t = 1990)

2.3.3 Analysis of the Regional Effect

The differences in the compositional effect rely on differences in the specialization of the energy user of each prefecture. The differences in the regional effect rely on the differences in the regionally unique characteristics of each of the prefecture's energy users. The results of dynamic shift-share analysis show a high correlation between the positive or negative state of the regional (large metropolitan area versus rural) effect, and it is worth investigating this relationship in greater detail. To gain a more detailed understanding, the portion of the regional effect $\sum_i s_{ij} [g(E_{ij}) - g(E_i)]$ in (2.3) is resolved into the degree of energy intensity and the real gross product (value added).³

First, the region's energy consumption for each user can be resolved with approximate equations using the formula

$$g(E_{ij}) = g(E_{ij}/Y_j) + g(Y_j), \quad (2.4)$$

where Y_j is the real gross product of region j and E_{ij}/Y_j is the energy intensity of user i in region j . Moreover, the nation's energy consumption for each user can be resolved with approximate equations using the formula

$$g(E_i) = g(E_i/Y) + g(Y), \quad (2.5)$$

where Y is the national gross product, and E_i/Y is the national energy intensity for user i . Substituting (2.4) and (2.5) into the regional effect portion of (2.3) yields

$$\sum_i s_{ij} [g(E_{ij}) - g(E_i)] = \sum_i s_{ij} [g(E_{ij}/Y_j) - g(E_i/Y)] + [g(Y_j) - g(Y)]. \quad (2.6)$$

The regional effect is expressed as the sum of the change of energy intensity and regional gross product, specifically, as follows:

$$\text{Energy-intensity effect: } \sum_i s_{ij} [g(E_{ij}/Y_j) - g(E_i/Y)]$$

$$\text{Production effect: } [g(Y_j) - g(Y)]$$

Table 2.5 gives the results of the decomposition using (2.6). The regional effect is not attributable to an energy user composition; therefore, it is difficult to discuss the regional effect contributions that give rise to energy intensity and production activity as a trend of the compositional difference by user. Therefore, this study considers the breakdown of the factor analysis results for both the top-ranking and the bottom-ranking prefectures, in terms of the rate of change attributable to the regional effect.

³There is a method of dividing to identify the finer factors. However, the calculation becomes inflationary. This study is simplified to the two factors that seem dominant.

Table 2.5 Factor decomposition of the regional effect in Japan

	Regional effect	Energy-intensity effect	Production effect
Hokkaido	-0.07	0.18	-0.27
Aomori	0.21	0.10	0.15
Iwate	-0.05	0.08	-0.12
Miyagi	0.40	0.66	-0.27
Akita	0.29	0.66	-0.35
Yamagata	-0.15	0.14	-0.26
Fukushima	0.02	0.40	-0.35
Ibaraki	0.83	0.43	0.48
Tochigi	0.38	0.27	0.14
Gunma	-0.02	-0.24	0.25
Saitama	0.05	-0.18	0.23
Chiba	0.22	0.07	0.17
Tokyo	-0.62	-0.53	-0.09
Kanagawa	0.33	0.43	-0.06
Niigata	-0.02	-0.12	0.10
Toyama	-0.46	-0.33	-0.10
Ishikawa	-0.10	0.27	-0.37
Fukui	0.01	-0.24	0.26
Yamanashi	0.15	0.12	0.07
Nagano	-0.18	-0.33	0.17
Gifu	0.04	0.08	-0.03
Shizuoka	-0.52	-0.82	0.37
Aichi	-0.12	-0.34	0.31
Mie	-0.21	-0.76	0.60
Shiga	0.09	-0.59	0.70
Kyoto	-0.18	-0.27	0.11
Osaka	-0.83	-0.13	-0.68
Hyogo	0.03	0.41	-0.36
Nara	0.18	0.41	-0.24
Wakayama	-0.21	-0.59	0.42
Tottori	1.05	1.80	-0.74
Shimane	0.00	-0.08	0.06
Okayama	0.25	0.03	0.28
Hiroshima	-0.09	-0.01	-0.02
Yamaguchi	1.12	0.90	0.25
Tokushima	-0.11	-0.75	0.64
Kagawa	-0.08	-0.25	0.19
Ehime	0.63	0.26	0.40
Kochi	-0.02	0.46	-0.50
Fukuoka	-0.43	-0.79	0.35

(continued)

Table 2.5 (continued)

	Regional effect	Energy-intensity effect	Production effect
Saga	0.77	0.55	0.23
Nagasaki	-0.26	-0.46	0.19
Kumamoto	0.63	0.62	0.04
Oita	0.57	0.30	0.33
Miyazaki	-0.14	-0.43	0.27
Kagoshima	0.48	0.16	0.29
Okinawa	0.34	-0.27	0.60

The top-ranking prefectures in terms of the rate of change attributable to the regional effect are in rural regions; i.e., Yamaguchi prefecture, followed by Tottori, Ibaraki, Saga, and Ehime prefectures. An observable characteristic of these regions is that, except for Tottori prefecture, both the energy-intensity and the production effects contribute positively. For the 10 top-ranking prefectures, both of these factors contribute positively to the regional effect, and no notable differences in the size of this contribution are observed. Meanwhile, the bottom-ranking prefectures are those in the large metropolitan areas, with Osaka at the very bottom, followed by Tokyo, Shizuoka, Toyama, and Fukuoka prefectures. An observable characteristic of these regions is that the energy-intensity effects are all negative. Moreover, there is a tendency for the size of these effects to exceed the production effect. Therefore, it is highly possible that the rate of change in the regional effect is negative mainly owing to a declining energy-intensity effect. Note that the energy-intensity effect for the 10 bottom-ranking prefectures is negative.

Accordingly, the results obtained suggest that it is possible to explain the differences between large metropolitan areas and rural regions, which are expressed as the regional differences of the regional effect; i.e., differences not in the production effect, but in the energy-intensity effect. Last, the correlation coefficient between the regional effect and the energy-intensity effect is 0.76, and that between the regional effect and the production effect is 0.08. This shows that the correlation coefficient between the regional effect and the energy-intensity effect is relatively high, compared with that between the regional effect and production effect.

2.4 Conclusions

To clarify which factors determine the fluctuations in the regional energy demand in Japan, this study applied dynamic shift-share analysis to the fluctuations in regional energy demand. The results show that although there is a positive contribution from the national effect, it is not dominant. Further, the positive and the negative fluctuations in regional energy demands are determined by both compositional and regional effects.

The study found that the compositional effect contributes most to energy demand growth in the prefectures that specialize in the ResCom and transportation sectors. Further, the compositional effect does not contribute to energy demand growth in the prefectures that specialize in the heavy and chemical industries of the manufacturing sector. Moreover, the study found that among the regional effects, the improvement in energy intensity through energy conservation (which is promoted mainly in large metropolitan areas), contributes to constraining the energy demand. For example, because of improved energy intensity, the energy demand declined in Mie, Wakayama, Osaka, Shizuoka, Toyama, Fukuoka, and Hiroshima prefectures. That is, the regional effects in large metropolitan areas are comparable, and differ significantly from rural regions in terms of energy demand. This study attributes this observation to the promotion of energy conservation in large metropolitan areas. Future research could investigate differences between rural and urban areas in Japan that might prove to be causal to the statistical data used in this analysis.

The study concludes that the findings are reasonable, as the dynamic shift-share-analysis focuses on the rate of change. The study expected that the compositional effect—expressing the degree by which the national energy demand from each energy user exceeds the rate of change of the national energy demand—would be low in the manufacturing industry, because energy demand changes mainly arise from efficiency efforts in this sector. The study also verifies that the agglomeration of industry reinforces this effect (Otsuka et al. 2014; Otsuka and Goto 2015). The study results are fully consistent with these insights.

The finding that the compositional and the regional effects are relevant to energy demand changes shows that having a mixture of industry and ResCom sector businesses in a region potentially flattens out the fluctuations in energy demand changes. This suggests that when moderating the change of regional energy demand, it is important to diversify the industrial structure in each region. This finding should make an important contribution to strategizing Japan's national energy master plan. This result suggests that it is necessary to take into account the differences between the energy users and the regions to investigate the future trends of energy demand in Japan accurately.

Compared with static shift-share analysis, dynamic shift-share analysis accounts for the time variation of the industrial structure. In other words, dynamic shift-share analysis does not assume a time-fixed structure in energy demand, to enable the factor decomposition of continuous changes in energy demand. That is, using dynamic shift-share analysis can alleviate a static shift-share analysis problem: the potential over- or underestimation of the energy change rate. Therefore, when evaluating the fluctuations in energy demand, the Japanese Government should adopt a dynamic approach to capture the fluctuation of energy demand on a dynamic basis, rather than fixing the observation period in a two-point static approach. However, to assess the dynamic structure on the energy demand in detail, it is necessary to decompose further the regional differences in energy demand by energy user. This is a topic for future research on energy demand forecasting.

References

- Artige, L., and L.V. Neuss. 2014. A new shift-share method. *Growth Change* 45(4): 667–683.
- Barff, R.A., and P.L. Knight III. 1988. Dynamic shift-share analysis. *Growth Change* 19(2): 1–10.
- Bernstein M.A., Fonkych K, Loeb S., and D.S. Loughran. 2003. State-level changes in energy intensity and their national implications. Rand Corp.
- Dawson, J.A. 1982. Shift-share analysis: A bibliographic review of technique and applications. (No. 949). Vance Bibliographies, Monticello.
- Dunn, E.S. 1960. A statistical and analytical technique for regional analysis. *Papers in Regional Science* 6(1): 97–112.
- Dinc, M., and K.E. Haynes. 1999. Source of regional inefficiency: An integrated shift-share, data envelopment analysis and input-output approach. *The Annals of Regional Science* 33(4): 469–489.
- Esteban-Marquillas, J.M. 1972. A reinterpretation of shift-share analysis. *Regional Science and Urban Economics* 2(3): 249–255.
- Haynes, K.E., and M. Dinc. 1997. Productivity change in manufacturing regions: A multifactor/shift-share approach. *Growth Change* 28(2): 201–221.
- Haynes, K.E., and Z.B. Machunda. 1987. Considerations in extending shift-share analysis: Note. *Growth Change* 18(2): 69–78.
- Hirobe, T. 2015. Economic shift-share effects and spatial agglomeration regarding inter-regional disparities of labour market in the USA. *Regional Science Policy & Practice* 7(3): 103–117.
- Knudsen, D.C., and R.A. Barff. 1991. Shift-share analysis as a linear model. *Environment and Planning A* 23(3): 421–431.
- Kobayashi, N. 2004. Industrial structure and manufacturing growth during Japan's bubble and post-bubble economics. *Regional Studies* 38(4): 429–444.
- Markusen, A.R., H. Nooponen, and K. Driessen. 1991. International trade, productivity, and US regional job growth: A shift-share interpretation. *International Regional Science Review* 14(1): 15–39.
- Marquez, M.A., J. Ramajo, and G.J.D. Hewings. 2009. Incorporating sectoral structure into shift-share analysis. *Growth Change* 40(4): 594–618.
- McCann, P. 2001. *Urban and regional economics*. New York: Oxford University Press.
- Metcalf, G.E. 2008. An empirical analysis of energy intensity and its determinants at the state level. *The Energy Journal* 29(3): 1–26.
- Ministry of Economy, Trade and Industry (METI), Agency for Natural Resources and Energy. 2015. Outline of the FY2014 Annual Report on Energy (Energy White Paper 2015). http://www.meti.go.jp/english/report/downloadfiles/2015_outline.pdf. Accessed 16 March 2016.
- Mitchell, W., and E. Carlson. 2005. Exploring employment growth disparities across metropolitan and regional Australia. *Australasian Journal of Regional Studies* 11(1): 25–40.
- Nissan, E., and G. Carter. 1994. An extension to the shift-share technique for predicting and evaluating changes in employment growth. *Journal of Regional Analysis and Policy* 24(2): 49–67.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2014. Energy efficiency and agglomeration economies: The case of Japanese manufacturing industries. *Regional Science Policy & Practice* 6(2): 195–212.
- Otsuka, A., and M. Goto. 2015. Estimation and determinants of energy efficiency in Japanese regional economies. *Regional Science Policy & Practice* 7(2): 89–101.
- Raupach-Sumiya, J., H. Matsubara, A. Prahl, A. Aretz, and S. Salecki. 2015. Regional economic effects of renewable energies—comparing Germany and Japan. *Energy, Sustainability and Society* 5(10): 1–17. doi:10.1186/s13705-015-0036-x.
- Shi, C., J. Zhang, Y. Yang, and Z. Zhang. 2007. Shift-share analysis on international tourism competitiveness: A case of Jiangsu province. *Chinese Geographical Science* 17(2): 173–178.

Chapter 3

Energy Efficiency and Productivity

Abstract Along with various environmental concerns, Japan has an important policy issue arising from the development of its economy, which is how simultaneously to attain regional economic growth and energy efficiency. This study examined the impacts of agglomeration economies on energy efficiency of Japanese manufacturing industries. Using a prefecture-level panel data set from the *Energy Consumption Statistics by Prefecture*, this study reveals the following three empirical findings. First, productivity growth has improved energy efficiency, but not vice versa. Second, agglomeration economies, which are a driving force for productivity growth, have improved the energy efficiency of Japanese manufacturing industries. Finally, by agglomerating similar industries, localization economies are effective in improving energy efficiency in rural areas. The third finding is consistent with many previous studies claiming that agglomeration economies based on localization occur for many medium-sized cities. The result implies that an important policy direction for Japan will be to formulate medium-sized cities in rural areas than large metropolitan cities in terms of improving the energy efficiency of manufacturing industries.

Keywords Energy efficiency · Productivity · Agglomeration economies · Japanese manufacturing industries

3.1 Introduction

One of the most important policy issues in Japan is how to find a way to reduce the amount of CO₂ emissions by improving energy efficiency, while simultaneously achieving economic growth. Since the two energy crises in the 1970s, manufacturers within the industrial sector have consumed a vast amount of energy in Japan. They now have to improve the level of their energy conservation efforts under

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severe environmental regulations. Manufacturing industry is indeed important for the overall Japanese economy. However, because of several social-economic factors (e.g., globalization of the economy, excessive over-evaluation of the currency, and environmental regulations), Japanese manufacturing industries have lost their competitiveness in our modern global market. As a result, their underperformance has negatively influenced Japanese regional economic growth.

To take the next step in exploring the issue from an energy policy perspective, this study needs to investigate the relationship between productivity improvement and energy efficiency, both of which are important components for the future growth of the Japanese economy under various environmental constraints. Clarifying the policy implications of these issues is the purpose of this study.

Industrial agglomeration is well known to be very important in improving industrial productivity. Economic benefits produced from agglomeration economies have been discussed for over a century, starting from the original work of Marshall (1890). In the context of agglomeration economies, cost savings and productivity gains can be obtained by spatially concentrating the various industries into several groups. Such effects of agglomeration economies are categorized into “localization economies” and “urbanization economies” (McCann 2001). The input-output ties in a given industry group determine both localization economies and agglomeration economies, which are usually characterized as geographic concentration of companies in that industry. The geographical proximity allows these companies to share facilities and services and to reduce transportation and transaction costs. This type of company clustering in the same industry indicates that the overall productivity of an industry becomes higher than that of the other type of industry structure in which companies are geographically dispersed. The industrial clusters, usually characterized by localization economies, are often found in medium-sized rural areas, such as a company town, production district, or oil/chemical complex. Thus, the rural areas need to specialize in a certain industry to obtain an economic benefit from localization economies. They also need to maintain an appropriate scale to avoid uneconomical factors such as congestion and skyrocketing land prices, which often occur with an increase in the size of each area.

In contrast, urbanization economies belong to agglomeration economies that occur between different industries. Urbanization economies are created by geographical ties between wide varieties of economic interactions in different industries, which originate from the diversity of an industrial structure (Jacobs 1969). For example, many companies cluster together to enjoy their economies of scale in modern cities. Production activities of these companies require a number of facilities and services, such as an infrastructure for transportation within a city, an organized large-scale labor market, and labor forces characterized by a wide variety of skills, social overhead capital, and government services. Companies also need to outsource legal and commercial services, such as those provided by lawyers, accountants, consultants, shipping agents, and financial institutions. It is also necessary for urbanization economies to develop cultural/recreational facilities and activities to attract highly skilled managers and workers. The urbanization economies need organizations that are willing to invest in the research and development of new

products and production processes (e.g., so-called “venture capital”). Even though their activities are not directly related to the industries that benefit from the localization economies, they are clustered together to provide companies and workers with various important services. Thus, the area size benefiting from urbanization economies is larger than that of localization economies. The clustering effort in urbanization economies reflects the feasibility of a massive regional market.

As discussed above, this study can easily argue that the agglomeration economies that serve to improve industrial productivity are also important for strengthening competitive advantages in the worldwide market; see Eberts and McMillen (1999), Rosenthal and Strange (2004), Otsuka et al. (2010), Otsuka and Goto (2015a, b), and Combes and Gobillon (2015). Unfortunately, no previous studies have explored the influence of agglomeration economies on energy efficiency, although this relationship has become more important than before, with the increasing emphasis on the development of sustainable societies.

The remainder of this study is organized as follows: Sect. 3.2 reviews and discusses the literature; from this background, the study prepares two hypotheses to be examined. Section 3.3 describes the empirical analysis undertaken to clarify the relationship between productivity and energy efficiency, as summarized in the first hypothesis. Section 3.4 discusses determinants of energy efficiency and then provides an industrial data set and its related descriptive statistics. This section also describes a regression model to test the second hypothesis, in which this study examines the relationship between agglomeration economies and energy efficiency. Section 3.5 summarizes the empirical results obtained in this study. Section 3.6 concludes this study with suggested future extensions.

3.2 Literature Review and Hypotheses

To maintain a competitive advantage in the modern global market and meet the standards required by environmental regulations, industries need to invest significantly in research and development to increase their productivity (Seo 2013). When they are spatially agglomerated, it is easier for a specific company that develops technological knowledge to share information with other companies through face-to-face communication and the transfer of workers’ knowledge among companies. Thus, agglomeration economies can play an important role in improving industrial productivity as a whole by creating and transferring technological knowledge (Fujita and Thisse 2002). According to Tveteras and Battese (2006) and Yamamura and Shin (2007), localization economies improve productivity by creating opportunities for companies to imitate technological knowledge within the same industry, while urbanization economies improved productivity by creating new technological knowledge and facilitating knowledge spillovers among different industries.

Meanwhile, technological innovations, arising under environmental regulations, have often been associated with the construction of energy-efficient production systems. Porter and Van der Linde (1995) argued that efforts to improve the

productivity of an entire manufacturing process under environmental regulation resulted in energy efficiency as well as major improvements in productivity. The existence of such a positive relationship between environmental regulation and productivity is popularly called the Porter hypothesis.

Beside the Porter hypothesis, other studies supported a further business implication in that improvements in productivity decreased the amount of energy inputs, therefore increasing the level of energy efficiency. For example, Boyd and Pang (2000) indicated that productivity improvement had a direct linkage with enhancing energy efficiency. Their claim was that energy efficiency played an important role in productivity improvement. Until recently, most studies implicitly assumed such a relationship between energy efficiency and productivity. However, there was very limited quantitative verification of causality between the two production factors.

To overcome this gap in the research, this study applies an econometric approach to the data set on Japan's manufacturing industry so that we can investigate empirically the relationship between improvements in productivity and energy efficiency. This study is the first research effort to examine empirically the hypothesis depicted as Hypothesis (1) at the top of Fig. 3.1.

In addition to the first hypothesis, there is a straightforward expectation that agglomeration economies have a direct connection with improvements in energy efficiency, as depicted in Fig. 3.1. This is the second hypothesis, or Hypothesis (2), in this study. In fact, it was recently noted that urban agglomeration had a positive effect on energy efficiency in the residential, commercial, and transportation sectors (Newman and Kenworthy 1989; Bento and Cropper 2005; Brownstine and Golob 2009; Karathodorou et al. 2010; Su 2011; Morikawa 2012, etc.). These studies used the level of population density as a variable to demonstrate agglomeration and revealed that there was a strong negative correlation between population density and energy consumption. This finding implied that the urban structural conditions

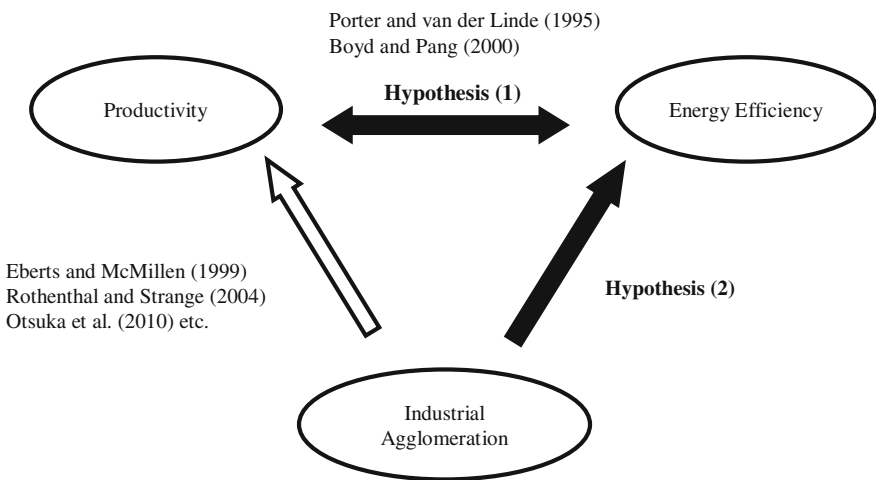


Fig. 3.1 Hypotheses to be examined

represented by greater population density increased energy efficiency. However, these studies did not consider the effect of technological innovations arising from agglomeration, as discussed in industrial agglomeration debates. This study therefore needs to examine the relationship between agglomeration in an industrial sector and its energy consumption. Indeed, there is no clear understanding about how industrial agglomeration influences energy efficiency through the establishment of a cluster. Thus, it is important for us to examine this relationship to understand economic and/or geographical factors that influence energy efficiency.

In examining the industrial sector, this study focuses particularly on Japanese manufacturing industries, because they are important not only for overall economic growth in Japan, but also for its regional economies. Thus, this study is concerned with examining empirically whether agglomeration economies in Japanese manufacturing industry have a direct linkage to energy efficiency. This relationship is visually summarized in Fig. 3.1.

3.3 Relationship Between Productivity and Energy Efficiency

In this study, productivity is defined by Total Factor Productivity (TFP). TFP, often referred to as “multi-factor productivity,” is an economic factor that accounts for the proportion of output that is not explained by the traditionally measured inputs of labor and capital. If all inputs are incorporated in the TFP measurement, it then represents a measure of an economy’s long-term technological change or technological dynamism. In measuring TFP, this study considers the following Cobb-Douglas production function:

$$\ln TFP_{jt} = \ln y_{jt} - \alpha_{jt} \ln L_{jt} - (1 - \alpha_{jt}) \ln \lambda_t K_{jt}.$$

Here, the variable y is the real Gross Regional Product (GRP), L is a labor input (calculated by multiplying the number of employees by working hours per capita), K is capital stock, λ is the working rate of capital, and α is labor’s relative cost share. Subscript j represents j -th region and t represents t -th time period, respectively.

Meanwhile, energy efficiency (*ENERGY*), defined as the ratio of energy consumption to the production amount of GRP, is often used as a standard index to indicate energy efficiency in energy policy. If the index decreases, then the energy consumption per unit of GRP decreases, so that energy efficiency improves. Conversely, if the index increases, then the energy efficiency decreases. This index has been used in the International Energy Association’s report (IEA 2009) on the energy policies of the G8 countries. Therefore, this study uses this index to measure energy efficiency by following the definition of the IEA.

To examine the first hypothesis, let us consider the relationship between TFP and energy efficiency within a time horizon. To consider a time trend in this study, we compute the average value of TFP and that of energy efficiency for Japanese

manufacturing industry in 47 prefectures. Figure 3.2 depicts these average trends. As depicted on the left-hand side of Fig. 3.2, the TFP had a rising trend, but the energy efficiency maintained a downward trend during the observed annual periods from 1990 to 2008. In particular, energy efficiency gradually decreased in the 1990s, then decreased considerably from 2002 to 2008. The relationship between TFP and energy efficiency is visually clear when both factors are plotted as shown in the right-hand graph of Fig. 3.2, where TFP is displayed on the horizontal axis and energy efficiency on the vertical axis. As depicted in Fig. 3.2, the relationship between TFP and energy efficiency exhibited a downward path. On average, therefore, a negative relationship existed over time between energy efficiency and the TFP. Here, it is important to add that the decreasing trend of energy intensity implies the improvement of energy efficiency. The result implies that the improvement in energy efficiency has been accompanied by TFP growth.

Previous research has argued that improvements in productivity contribute towards enhancing energy efficiency. This study examines the relationship empirically by using the Granger causality test (Granger 1969). The Granger causality test is a statistical hypothesis test to examine whether a certain time series variable is useful to forecast another variable. That is, “a time series X Granger causes Y ” if a series of statistical tests confirm that the values of X provide statistically significant information about future values of Y .

In verifying causality, this study needs first to confirm whether the data set is stationary or not by using the DF-GLS (Dickey-Fuller GLS) test. The test results are summarized in Table 3.1. The DF-GLS test performs a modified Dickey-Fuller t test for a unit root in which the series is transformed by a generalized least-squares regression (Dickey and Fuller 1979). The results indicate that for each of the lag orders related to the variables for both energy efficiency and TFP, the unit root exists at a significance level where the null hypothesis cannot be rejected. Since a unit root exists for the two variables, this study needs to examine difference series, so that the stationarity of the data set can be confirmed. The tests, based upon difference series, are summarized in Table 3.1.

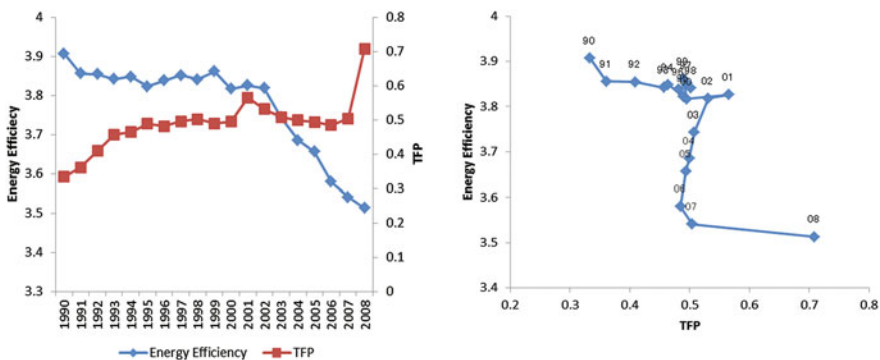


Fig. 3.2 Trends in energy efficiency and total factor productivity

Table 3.1 Dickey-Fuller GLS test: DF-GLS

Lag	DF-GLS tau Test Statistic		1 % Critical Value	5 % Critical Value	10 % Critical Value
	ENERGY	TFP			
7	-2.844	-1.185	-3.77	-4.929	-3.642
6	-2.225	-0.655	-3.77	-3.828	-2.861
5	-2.243	-1.134	-3.77	-3.218	-2.467
4	-2.198	-1.826	-3.77	-2.989	-2.368
3	-2.434	-2.075	-3.77	-3.03	-2.474
2	-1.17	-1.955	-3.77	-3.229	-2.692
1	-0.734	-2.266	-3.77	-3.476	-2.932

This study also applies the Granger test by using a vector auto regressive (VAR) model on the following two variables:

$$y_t = \alpha_1 + \lambda_{11}y_{t-1} + \cdots + \lambda_{1p}y_{t-p} + \beta_{11}x_{t-1} + \cdots + \beta_{1p}x_{t-p} + u_{1t}, \text{ and}$$

$$x_t = \alpha_2 + \lambda_{21}y_{t-1} + \cdots + \lambda_{2p}y_{t-p} + \beta_{21}x_{t-1} + \cdots + \beta_{2p}x_{t-p} + u_{2t},$$

where the variable y expresses the energy efficiency, x expresses the TFP for each difference series, and u represents white noise. The fourth lag order model is selected when the test statistics are calculated by using the econometric software STATA version 13 (see Table 3.2).

Table 3.3 exhibits the results of the Granger causality test. In particular, the numerical values in this table exhibit the results of Wald test statistics. The test confirms that the effect of TFP on energy efficiency is significant at the 1 % significance level, but no significant effect is observed in the opposite direction from energy efficiency to TFP. Thus, causality is established in the direction from TFP to energy efficiency (*ENERGY*) and not vice versa. Therefore, this study confirms that the hypothesis proposed in previous research is statistically applicable to the data set used in this study. The statistical test and the observation of the averaged data on prefectures indicate the validity of the assumption that TFP is a factor to improve energy efficiency.

Table 3.2 Lag-order selection statistics for VARs

Lag	FPE	AIC	HQIC	SBIC
0	4.20E-06	-6.70804	-6.71649	-6.61675
1	4.90E-06	-6.55655	-6.5819	-6.28267
2	6.20E-06	-6.37665	-6.4189	-5.92018
3	8.40E-06	-6.21006	-6.26922	-5.57101
4	3.00E-06	-7.53408	-7.61014	-6.71243

(a) FPE: Final Prediction Error

(b) AIC: Akaike's Information Criterion

(c) SBIC: Schwarz's Bayesian Information Criterion

(d) HQIC: Hannan and Quinn Information Criterion

Table 3.3 Granger causality
Wald tests

	chi2	Prob > chi2
From TFP to ENERGY	71.621	0
From ENERGY to TFP	2.7478	0.601

(a) chi2 stands for a chi-squared value

(b) Prob stands for a probability

3.4 Data and Empirical Model

3.4.1 Determinants of Energy Efficiency

Section 3.3 indicated, through statistical tests, that there was an influence from productivity to energy efficiency as discussed by the first hypothesis (i.e., relationship between productivity and energy efficiency). In addition to this hypothesis, the present study needs to examine the second hypothesis: whether industrial agglomeration affects energy efficiency. To examine the second hypothesis, we need to examine the relationship between energy efficiency and agglomeration economies, both of which are important in improving productivity. This study uses the location quotient (LQ) as an index to demonstrate localization economies. The LQ was used in the research of Glaeser et al. (1992), which analyzed agglomeration economies as a variable for localization.

The variable LQ for industry i in location j is defined 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 is the production share of industry i nationwide. If the magnitude of LQ exceeds unity, then the region has a high production share of industry i , compared with other regions in a nation. In such a case, the particular industry is characterized as a core industry, indicating its concentration in a specific area.

This study also uses the Glaeser Index (GI) as an index to indicate urbanization economies. The GI is defined as the fraction of the region's employment that uses the largest five industries other than the main industry (Glaeser et al. 1992). The diversity of a given industrial structure increases if the value of the index decreases. A major factor underlying urbanization economies is the diversity of industrial structures (Fujita and Thisse 2002). According to Glaeser et al. (1992), the GI is considered as the best indicator for representing such diversity. Therefore, this study uses the GI to analyze urbanization economies. Meanwhile, the Hirschman-Herfindahl Index (HHI) is also often used as an indicator of industrial diversity (Capello and Nijkamp 2009). However, it is known that the GI is usually highly correlated with the HHI. Indeed, the correlation between these indexes, calculated by using the two-digit industry classification in 2005, was 0.96 and was

statistically significant at the 1 % significance level. This result suggested that there was a correlation between the GI index and the HHI index. Since a lower HHI index indicates higher diversity, this study may repeat the previous proposition that the diversity of the industrial structure increases as the GI value decreases. As a result of such validity assessments, this study can use the GI as a variable to represent the diversity of an industrial structure.

In addition to specifying variables for representing agglomeration economies, this study uses several socioeconomic variables to explain differences in energy efficiency. This study follows the research of Metcalf (2008) regarding the selection of socioeconomic variables, with an exception of agglomeration economies. First, the capital-labor ratio (KL) is incorporated in this study. The numerator represents capital and the denominator is labor. This indicator represents the capital intensity of industries. The ratio provides information on how much capital concentration/density influences differences in energy efficiency. Thompson and Taylor (1995) and Metcalf (2008) revealed that capital and energy have a substitution relationship over both the short run and long run. Meanwhile, Antweiler et al. (2001) concluded that capital and pollution were positively correlated.

This study considers the implicit impact of vintage of capital stock on energy efficiency. Infrequent replacement investments in capital stock may lead to low energy efficiency in a local industry. On the other hand, local industry with frequent replacement investments of capital stock may hold energy efficient capital stock, resulting in higher energy efficiency of the industry. To measure this vintage effect, this study considers the investment rate of capital stock per year, which is defined as the rate of investment in capital stock (IK).

The study also incorporates a temperature data set to consider the influence of temperature changes on production activities. Heating degree days ($WARM$) and cooling degree days ($COOL$) are considered in this study. The population tends to concentrate in areas with suitable temperature conditions. The above indexes are considered to control and measure the impact of temperature on energy consumption in previous studies. For example, Metcalf and Hassett (1999) and Reiss and White (2008) have used indexes of warm and cool days to analyze energy consumption in a household sector. Finally, this study considers a time trend ($TREND$) variable to explain the annual changes in energy efficiency over time.

3.4.2 Data Sources and Descriptive Statistics

This study analyzes manufacturers in the following industrial sectors across 47 prefectures, in Japan: Chemical, Chemical Textile, Pulp and Paper ($CHEMI$); Iron and Steel, Non-ferrous metal, Cement and Ceramics ($IRON$); and Machinery (MAN). Figures from manufacturing sectors have only been published in official statistics. This study analyzes these three sectors, in addition to the overall manufacturing sector. The share of final energy consumption for the $CHEMI$ sector in the whole manufacturing industry is 45 %, followed by 32 % of the $IRON$ sector.

These two industrial sectors are extremely energy-intensive. On the other hand, the final energy consumption ratio of the machinery sector is as low as 3 %. The observed annual periods for this study were from 1990 to 2008. The data set consists of annual panel data for each prefecture.

This study obtains the final energy consumption data set for the industry sectors from METI's (Ministry of Economy, Trade and Industry's) *Energy Consumption Statistics by Prefecture*. A data set regarding the amount of production, which is the denominator to calculate energy efficiency, is based on an actual production value from economic activity that is obtained from the *Annual Report on Prefectural Accounts* report issued by the Japanese Cabinet office. The rest of the socioeconomic data set is mainly obtained from the *CRIEPI Regional Database* (Central Research Institute of Electric Power Industry). This study also uses a data set indicating heating degree days and cooling degree days from National Meteorological Agency data. The number of heating degree days in an annual period is the cumulative difference of temperatures between 14 °C and the average temperature on each day in an annual period whose average temperature drops below 14 °C. In a similar manner, the number of cooling degree days in an annual period is the cumulative difference of temperatures between 22 °C and the average temperature on each day in one year whose average temperature goes above 24 °C. Since a temperature data set is obtained from meteorological centers located in each city, prefectural temperature data are equivalent to the prefectural capital data.

Tables 3.4 and 3.5 present the descriptive statistics of the data used in this study. The energy efficiency in Table 3.4 indicates that the average for manufacturers was 62.082 GJ/million yen, based on all samples; while being 247.146 GJ/million yen for *CHEMI* and 166.037 GJ/million yen for *IRON*. Both these averages far exceeded that of the overall manufacturing sector, implying that they were extremely low in terms of energy efficiency. On the other hand, *MAN* showed a low average of 5.320 GJ/million yen, indicating that the sector was energy efficient. When examining changes over time, the manufacturing sector exhibited a significant improvement in energy efficiency between 1990 (72.001 GJ/million yen) and 2008 (47.184 GJ/million yen), a reduction of 34 % during the observed period. From the definition of the energy efficiency variable, the decrease indicated an improvement in energy efficiency. In the same period, *IRON* also improved energy efficiency. In contrast, *CHEMI*'s energy use increased 24 % from 225.484 GJ/million yen in 1990 to 279.244 GJ/million yen in 2008.

Looking now at agglomeration economies, the LQ was 1.029 on average in the manufacturing sector. Being greater than unity, this indicated that many regions in Japan specialized in manufacturing. Furthermore, the LQ increased from 1990 to 2008, implying an increase in agglomeration among similar industries. In various industries including *CHEMI*, *IRON*, and *MAN*, the average LQ over all samples exceeded unity, and these measures increased each year. Meanwhile, the GI decreased during the observation period, which was inconsistent with the LQ. The GI in 1990 was 0.338 on average, but it dropped to 0.321 in 2008, indicating that diversification has progressed nationwide in Japan's industrial structure. Thus,

Table 3.4 Descriptive statistics

		ENERGY (GJ per million yen)				LQ			GI (share)	
		Manufacturing				Manufacturing				
		Chemical, chemical textile, pulp and paper (CHEMI)	Iron and steel, non-ferrous metal, cement and ceramics (IRON)	Machinery (MAN)		Chemical, chemical textile, pulp and paper (CHEMI)	Iron and steel, non-ferrous metal, cement and ceramics (IRON)	Machinery (MAN)		
1990	Average	72.001	225.484	188.766	8.557	0.984	0.986	1.044	0.900	0.338
	Standard deviation	73.514	297.848	196.368	9.275	0.360	0.797	0.677	0.568	0.042
	Maximum	373.346	1326.228	781.784	59.741	1.915	4.047	2.677	2.460	0.420
	Minimum	9.939	2.610	5.197	0.000	0.233	0.055	0.292	0.007	0.253
2000	Average	64.267	242.659	155.548	3.895	1.042	1.047	1.093	1.027	0.331
	Standard deviation	63.249	382.494	173.255	2.760	0.369	0.906	0.676	0.579	0.038
	Maximum	272.602	2089.242	729.857	16.411	1.954	4.895	2.706	2.391	0.405
	Minimum	10.532	0.000	0.499	0.000	0.271	0.053	0.283	0.018	0.247
2008	Average	47.184	279.244	167.137	2.483	1.059	1.088	1.124	1.136	0.321
	Standard deviation	43.737	685.758	200.413	1.881	0.364	1.065	0.788	0.579	0.036
	Maximum	187.686	4032.789	811.404	7.978	1.802	5.195	3.201	2.467	0.391
	Minimum	3.922	0.000	0.000	0.000	0.220	0.045	0.239	0.012	0.253
Full-sample	Average	62.082	247.146	166.037	5.320	1.029	1.033	1.091	1.014	0.333
	Standard deviation	61.752	525.749	178.118	5.435	0.367	0.894	0.705	0.565	0.039
	Maximum	373.346	11059.129	910.027	59.741	1.982	5.327	4.053	2.881	0.420
	Minimum	3.922	0.000	0.000	0.000	0.219	0.021	0.239	0.005	0.247

Table 3.5 Descriptive statistics

		KL (million per capita)				IK		WARM (degree days)	COOL (degree days)			
		Manufacturing				Manufacturing						
		Chemical, chemical textile, pulp and paper (CHEMI)	Iron and steel, non-ferrous metal, cement and ceramics (IRON)	Machinery (MAN)	Chemical, chemical textile, pulp and paper (CHEMI)	Iron and steel, non-ferrous metal, cement and ceramics (IRON)	Machinery (MAN)					
1990	Average	16.690	43.249	38.448	12.733	0.112	0.099	0.090	0.159	1033	408	
	Standard deviation	7.119	22.912	25.070	4.471	0.021	0.030	0.026	0.042	435	168	
	Maximum	39.039	97.822	122.349	23.883	0.154	0.214	0.154	0.254	2479	922	
	Minimum	7.465	8.024	11.369	2.011	0.066	0.044	0.033	0.042	2	18	
2000	Average	27.734	65.136	62.818	21.246	0.069	0.064	0.058	0.100	1121	405	
	Standard deviation	10.106	33.081	38.052	6.068	0.017	0.021	0.040	0.035	563	152	
	Maximum	60.954	148.268	191.233	33.957	0.115	0.134	0.289	0.205	3054	918	
	Minimum	12.336	12.494	18.620	5.519	0.045	0.027	0.023	0.049	1	28	
2008	Average	36.647	87.617	84.332	26.340	0.089	0.081	0.070	0.131	1025	365	
	Standard deviation	11.573	79.240	42.588	7.790	0.021	0.039	0.027	0.048	502	186	
	Maximum	66.178	540.293	200.295	43.869	0.145	0.204	0.148	0.270	2583	1047	
	Minimum	15.124	14.750	18.393	5.668	0.058	0.030	0.024	0.018	30	4	
											(continued)	

(continued)

Table 3.5 (continued)

		KL (million per capita)				IK			WARM (degree days)		COOL (degree days)
		Manufacturing				Manufacturing			Machinery (MAN)		
Full-sample	Average	26.629	63.560	59.914	20.251	0.076	0.073	0.061	0.108	1082	357
	Standard deviation	11.444	41.137	37.691	7.172	0.024	0.036	0.030	0.047	501	181
	Maximum	70.340	540.293	218.555	43.869	0.241	0.370	0.296	0.489	3054	1251
	Minimum	7.465	8.024	11.369	1.907	0.030	0.016	0.014	0.011	0	0

the agglomeration of diverse industries became important over this period, and this study may consider that industrial agglomeration has increased during the period observed.

The capital-labor ratio is regarded as a socioeconomic variable outside agglomeration economies. The average capital-labor ratio of the entire manufacturing industry sector was 26.629. In contrast, compared with the overall manufacturing industry ratio, the average capital-labor ratios over the sample of the *CHEMI* and *IRON* industries were higher at 63.560 and 59.914, respectively. Thus, these industries were capital-intensive. Another contrast existed in *MAN*, where the capital-labor ratio was characterized at a low value of 20.251. In observing the sequential changes over all industries from 1990 through 2008, there was an increase in capital efficiency. This was due to advances in mechanization in the production process. Finally, the investment-capital ratio of the entire manufacturing industry was 0.076, with a small variation within each industry. This possibly indicated the upgrading of production facilities. All these variables were standardized by the method in which the average value was subtracted from the raw data and divided by a standard deviation.

3.4.3 Empirical Model

Using the data set described in Sect. 3.4.2, this study examines the impact of agglomeration economies on energy efficiency. The model used in this study is specified as follows:

$$\ln(ENERGY_{jt}) = \beta_1 \ln(LQ_{jt}) + \beta_2 \ln(GI_{jt}) + \beta_3 \ln(KL_{jt}) + \beta_4 \ln(IK_{jt}) + \beta_5 WARM_{jt} + \beta_6 COOL_{jt} + \beta_7 TREND + \alpha_j + u_{jt}. \quad (1.1)$$

The main variables in the model are expressed by logarithmic values. The subscript j is the j -th region ($j = 1, \dots, J$) and t is time ($t = 1, \dots, T$). The equation is used for each industry i ($i = 1, \dots, I$). *ENERGY* is energy efficiency, so indicating the amount of final energy consumption per unit production. *LQ* is the location quotient. *GI* is the Glaeser Index. Both *LQ* and *GI* are variables that represent agglomeration economies. *KL* represents the capital-labor ratio obtained via dividing capital stock by the number of employees. *IK* is an investment-capital ratio obtained via dividing capital expenditures by private sector capital stock. *WARM* are heating degree days and *COOL* are cooling degree days. *TREND* is a time trend. A random error term is provided by u .

The α and β are unknown parameters to be estimated by the proposed regression model. To utilize panel data characteristic of the observed data set, this study applies the panel data estimation to Eq. (1.1) related to each industry. The subscript j of α expresses the individual effect for each prefecture. The expected signs of β_1 and β_2 are negative and positive, respectively, when the agglomeration economy improves energy efficiency. The parameter β_3 is negative in sign when capital and

energy consumption are negatively correlated. In contrast, when capital and energy consumption are positively correlated, it becomes positive. This study expects that the parameter β_4 is negative in sign, because new capital investment needs to improve energy efficiency. In addition, since energy efficiency is expected to improve over time, β_7 , which is the parameter of a time trend variable, is negative in sign. In contrast, if the opposite is true, then it has a positive sign.

3.5 Empirical Results

Table 3.6 shows the resulting parameter estimates. This study uses two models: Models 1 and 2. The first model uses limited explanatory variables on industrial agglomeration, and the second model incorporates all the variables for socioeconomic factors. The F-test is used to confirm whether the individual effect actually exists or not by examining the null hypothesis that no individual effect exists in all industries. In addition, the Hausman test rejects the null hypothesis that the observed individual effect is a random effect at the 1 % level of significance. Thus, the results in Table 3.6 can be considered as those from the fixed-effect model. Furthermore, this study incorporates a time-trend variable to examine whether an annual effect exists or not.

Manufacturing sector: First, this study pays attention to the manufacturing sector. The results of Models 1 and 2 indicate that agglomeration economies lead to the improvement of energy efficiency. Because the explanatory variables and dependent variable are expressed by logarithmic expressions, the parameter estimates (β_1 to β_4) represent the elasticity of each explanatory variable in relation to the dependent variable, namely the energy efficiency. Thus, the degree of influence of a given explanatory variable on the energy efficiency becomes large when the absolute value of each parameter estimate is large. The estimated elasticity indicates that LQ exceeds GI in its impact on energy efficiency. In particular, the effect of LQ is large in Model 1, since the estimated parameter of LQ is -0.4813 , while that of GI is 0.3084 . This indicates that same-industry clusters, or localization economies, make a greater contribution to increases in energy efficiency than do the different-industry clusters, or urbanization economies, in the manufacturing sector as a whole. Furthermore, although GI is not significant in Model 2, it may effectively influence energy efficiency. The parameter estimate of the capital-labor ratio KL is positive in sign, indicating that capital and energy consumption have a complementary relationship. The parameter estimate of the investment-capital ratio IK is negative in sign, as originally expected in this study. The time trend is also negative in its sign, indicating that a positive trend exists in energy efficiency. However, the effect is not large, because the parameter estimate is small.

CHEMI: The effect of LQ is larger than the effect of GI in this industry. LQ is negative, as originally expected in this study. The parameter estimates are almost at the same level as those of the overall manufacturing sector. However, they indicate that the effect of agglomeration economies on energy efficiency is relatively large in

Table 3.6 Estimation results

	Model 1	Model 2
Manufacturing		
$\ln(LQ)$	-0.4813*** (0.0322)	-0.4782*** (0.0270)
$\ln(GI)$	0.3084*** (0.0230)	0.0191 (0.0235)
$\ln(KL)$		0.3642*** (0.0315)
$\ln(IK)$		-0.0359*** (0.0056)
<i>Warm</i>		-0.0291 (0.0228)
<i>Cool</i>		0.0322*** (0.0106)
<i>Trend</i>		-0.0583*** (0.0035)
F test	736.5400***	261.0300***
Hausman test	19.8500***	96.0620***
Adjusted R ²	0.9754	0.9844
Chemical, chemical textile, pulp and paper (CHEMI)		
$\ln(LQ)$	-0.4682*** (0.0692)	-0.4475*** (0.0668)
$\ln(GI)$	0.2404*** (0.0709)	-0.2802*** (0.0883)
$\ln(KL)$		0.2414*** (0.0768)
$\ln(IK)$		-0.0230 (0.0177)
<i>Warm</i>		-0.0161 (0.0841)
<i>Cool</i>		-0.0045 (0.0403)
<i>Trend</i>		-0.0466*** (0.0055)
F test	46.6560***	34.4270***
Hausman test	43.8580***	38.6690***
Adjusted R ²	0.7535	0.7768
Iron and steel, non-ferrous metal, cement and ceramics (IRON)		
$\ln(LQ)$	-0.4829*** (0.0697)	-0.4924*** (0.0637)

(continued)

Table 3.6 (continued)

	Model 1	Model 2
$\ln(GI)$	0.3831*** (0.0772)	0.1728** (0.0909)
$\ln(KL)$		-0.9379*** (0.0803)
$\ln(IK)$		0.0301 (0.0199)
<i>Warm</i>		0.1369 (0.0880)
<i>Cool</i>		-0.0521 (0.0420)
<i>Trend</i>		0.0580*** (0.0076)
F test	40.6600***	41.5910***
Hausman test	53.8460***	164.6400***
Adjusted R ²	0.7104	0.7583
Machinery (MAN)		
$\ln(LQ)$	-0.2665*** (0.0498)	-0.1104** (0.0494)
$\ln(GI)$	0.5907*** (0.0541)	0.1412** (0.0614)
$\ln(KL)$		-0.0078 (0.0432)
$\ln(IK)$		-0.0112 (0.0137)
<i>Warm</i>		0.1100* (0.0583)
<i>Cool</i>		-0.0329 (0.0275)
<i>Trend</i>		-0.0336*** (0.0045)
F test	64.6830***	54.7390***
Hausman test	134.5900***	93.1910***
Adjusted R ²	0.8741	0.8962

(a) A standard deviation is listed within parentheses. ***, **, and * indicate significance at the 1, 5, and 10 % levels, respectively

the *CHEMI* sector. Furthermore, *GI* is not robust, because the sign changes between Models 1 and 2. The capital-labor ratio is positive in sign, as found in the overall manufacturing sector. The result suggests that capital and energy consumption have a complementary relationship. The time trend is negative in sign.

IRON: The parameter estimates for *LQ* and *GI* are negative and positive in their signs, respectively. *LQ* and *GI* are statistically significant at the 1 % significant

level. The large parameter estimate on LQ indicates that this industry is characterized by the effect of the same-industry cluster, or localization economies, on energy efficiency. Furthermore, the capital-labor ratio, having a negative sign, indicates that capital and energy consumption have a relationship that is different from the overall manufacturing sector. The time trend term is positive in the sign of its parameter estimate, differing in this respect from the overall manufacturing sector. However, the impact is not large in its magnitude.

MAN: The estimates for LQ and GI are negative and positive in their signs, respectively. Both are statistically significant. The effect of GI is larger than that of LQ , indicating that *MAN* may have a considerable benefit from industry diversification or urbanization economies. Although the time trend is also negative, the effect is limited.

In drawing conclusions from the computational results obtained, it is important to note that localization economies are found in all industries within the manufacturing sector. The urbanization economies are also important, but their effects are not robust on *CHEMI*. Meanwhile, the effect of urbanization economies is influential on *IRON* and *MAN*. The rationale for such a difference exists in the business characteristics of different industries; that is, the linkages between industries are different for each sector. The data set, found in the *2005 Input-Output Tables* (Ministry of Internal Affairs and Communications), indicates that the input ratio from other industries into the manufacturing sector was 38 % on average. The ratio was much higher in *CHEMI* (46 %), *IRON* (62 %), and *MAN* (51 %). These ratios suggest that the individual industries in the manufacturing sector, as examined in this study, are characterized by connections or linkages with other industries. Thus, the industries located in an area with a diverse industrial structure are likely to gain economic benefits, under the effect of improved productivity created through business between different industries. Such are typical benefits from urbanization economies.

A contribution of this study is to identify the extent to which the agglomeration economies assist in improving the energy efficiency of an industry. This study identifies three empirical findings:

First, Table 3.7 exhibits a level of contribution (as an annual rate expressed as a percentage) by which the agglomeration economies change the status of energy efficiency. This study computes the status change by applying the parameter estimates in Table 3.2 to Eq. (1.1). The level of contribution of localization economies on the manufacturing sector as a whole had a national average of -0.359 %, while the level of contribution of urbanization economies had a national average of -0.051 %. This indicates that the effect of urbanization economies was not significant for the overall manufacturing sector. In other words, the effect of localization economies was relatively large in the overall manufacturing sector.

Second, the level of contribution of localization economies was the highest in Kyushu with a magnitude of -1.610 %. Tohoku was high at -1.280 % as well. In contrast, the levels of contribution of localization economies in areas with large populations, such as the Greater Tokyo Area and Kansai, were positive, so reducing energy efficiency. This was because the manufacturing sector's share of economic

Table 3.7 Contribution of industrial agglomeration effects to energy efficiency in 1990–2008 (annual % rate)

	Manufacturing			Chemical, chemical textile, pulp and paper (CHEMI)		Iron and steel, non-ferrous metal, cement and ceramics (IRON)		Machinery (MAN)	
	Localization economies	Urbanization economies		Localization economies	Urbanization economies	Localization economies	Urbanization economies	Localization economies	Urbanization economies
Hokkaido	-0.347	-0.078		1.344	1.136	-0.252	-0.701	-0.520	-0.573
Tohoku	-1.280	-0.083		-0.814	1.208	-1.466	-0.745	-0.289	-0.609
Kita-Kanto	-0.495	-0.078		-1.041	1.146	-0.990	-0.707	-0.050	-0.578
Greater Tokyo Area	1.018	-0.027		-0.001	0.402	0.241	-0.248	0.269	-0.203
Chubu	-0.412	-0.015		0.043	0.220	0.117	-0.136	-0.124	-0.111
Hokuriku	-0.202	-0.096		-1.363	1.405	-0.760	-0.867	-0.283	-0.709
Kansai	0.046	0.005		0.007	-0.069	-0.454	0.042	0.025	0.035
Chugoku	-0.521	-0.033		2.032	0.476	1.079	-0.293	-0.358	-0.240
Shikoku	-0.517	-0.024		-0.738	0.358	1.069	-0.221	-0.319	-0.181
Kyushu	-1.610	-0.042		0.432	0.619	-0.007	-0.382	-0.562	-0.312
Okinawa	0.376	-0.085		-1.029	1.250	0.568	-0.771	-0.441	-0.630
Average	-0.359	-0.051		-0.103	0.741	-0.078	-0.457	-0.241	-0.374

(a) The relationships between the prefectures and regions are as follows: Hokkaido (Hokkaido), Tohoku (including Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima and Niigata), Kita-Kanto (including Ibaragi, Tochigi, Gunma and Yamanashi), Greater Tokyo Area (including Saitama, Chiba, Tokyo and Kanagawa), Hokuriku (including Toyama, Ishikawa and Fukui), Chubu (including Nagano, Gifu, Shizuoka, Aichi and Mie), Kansai (including Shiga, Kyoto, Osaka, Hyogo, Nara and Wakayama), Chugoku (including Tottori, Shimane, Okayama, Hiroshima and Yamaguchi), Shikoku (including Tokushima, Kagawa, Ehime and Kochi), Kyushu (including Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki and Kagoshima) and Okinawa (Okinawa)

(b) The table lists regions based upon their geological locations from north to south in Japan. Each region (including prefectures) can be considered a regional economic unit where several prefectures (i.e., administrative units) locate near and link together from social and economic perspectives

activities decreased during the observed period in these areas. On the other hand, the reduced value of the GI indicated that urbanization economies were improving energy efficiency in the Greater Tokyo Area, including Saitama, Chiba, Tokyo, and Kanagawa prefectures. These results implied that localization economies functioned to improve energy efficiency in Japanese rural areas, because more manufacturing businesses were established within the rural areas. Meanwhile, the urbanization economies presumably played an important role in improving energy efficiency in the Greater Tokyo Area as a result of the increased concentration of various industries.

Finally, individual industries were all characterized by a low level of contribution by localization economies, being below the level of the manufacturing sector as a whole. Although promoting same-industry clusters among industries helped in improving energy efficiency, the level of improvement was limited in its magnitude. The inter-regional comparison showed that localization economies were important in rural areas, as found in the overall manufacturing sector. In particular, *IRON* had a large magnitude in Tohoku at -1.466% , while *MAN* displayed a large magnitude in Kyushu at -0.562% . According to *Nihon Keizai Shimbun* (a Japanese leading economic newspaper), the results seen in Tohoku were due to the increased establishment of iron and steel companies during the periods observed. Meanwhile, in Kyushu, the level of contribution by localization economies increased because the establishment of automobile companies increased during the period observed. *IRON* and *MAN* were characterized by a high level of contribution from urbanization economies, compared with localization economies. These results indicated that the effect of urbanization economies was also important in the rural areas, unlike the manufacturing sector as a whole. Consequently, the fact that *IRON* and *MAN* industries have diversified industrial structures in the rural areas, but not in the Greater Tokyo Area (including large cities like Tokyo), leads these areas to improve energy efficiency through a higher level of contribution by urbanization economies.

3.6 Conclusions and Policy Implications

This study investigated the relationships among industrial agglomeration, productivity, and energy efficiency in Japanese manufacturing industry. The study found that a causal relationship existed between productivity, measured by TFP, and energy efficiency. A detailed investigation of such relationships revealed that productivity growth improved energy efficiency, but not vice versa. The result implies that improvements in productivity lead to the enhancement of energy efficiency. Since improvement in productivity is a major component of economic growth, the implication is that economic prosperity is associated with environmental protection via efficient energy use in Japan's manufacturing industry.

Next, this study focused on agglomeration economies, as an important component of improving productivity, and directly analyzed the relationship between agglomeration economies and energy efficiency. Since previous studies did not

directly examine this relationship, but rather examined the effect indirectly through productivity, this study was the first effort that focused upon the direct linkage between these factors. The empirical results obtained in this study clearly indicated that agglomeration economies led to a high level of energy efficiency. The degree of elasticity implied that same-industry clusters, represented by the location quotient, contributed to improve energy efficiency in the overall manufacturing sector and the *CHEMI* industry. Meanwhile, the two industries *IRON* and *MAN* had a different pattern in that the diversification of industrial structure also contributed to increase the status of energy efficiency. Such different effects of agglomeration economics were attributed to different industry linkages in Japan.

The results obtained in this study indicated that the degree of the effect of localization economies exceeded that of the urbanization economies for the overall manufacturing sector and the *CHEMI* industry. However, this study found that the contribution of localization economies from same-industry clusters was large in rural areas, but this contribution was limited in large cities. Thus, the establishment of a same-industry cluster was effective in improving energy efficiency in the overall manufacturing sector and the *CHEMI* industry in the rural areas. Moreover, the contribution of urbanization economies was relatively large for the *IRON* and *MAN* industries.

Finally, this study recommends the development of medium-sized cities, such as company towns and production areas, to achieve a high level of energy efficiency for the overall manufacturing sector. This implies that regional policies to form compact cities and to promote smart communities are effective for improving energy efficiency for the overall manufacturing sector in rural areas. Such policies are consistent with the Japanese government's regional reconstruction plan after the Great East Japan Earthquake in 2011. Since the effect of localization economies is particularly large for the *CHEMI* industry, this study recommends that the formation of oil and chemical complexes in rural areas becomes an important industrial policy for improving energy efficiency in Japan. Meanwhile, the effect of urbanization economies is large for the *IRON* and *MAN* industries, creating cities with diverse industries that assist companies in the various industries to reduce fixed costs and improve their energy efficiency.

In conclusion, it is hoped that this study makes a contribution toward regional science and energy policy.

References

- Antweiler, W., B.R. Copeland, and M.S. Taylor. 2001. Is free trade good for the environment? *American Economic Review* 91: 877–908.
- Bento, A.M., and M.L. Cropper. 2005. The effects of urban spatial structure on travel demand in the United States. *The Review of Economics and Statistics* 87(3): 466–478.
- Boyd, G.A., and J.X. Pang. 2000. Estimating the linkage between energy efficiency and productivity. *Energy Policy* 28: 289–296.

- Brownstine, D., and T.F. Golob. 2009. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* 65(1): 91–98.
- Capello, R., and P. Nijkamp. 2009. *Handbook of regional growth and development theories*. Cheltenham: Edward Elgar.
- Combes, P.P., and L. Gobillon. 2015. The empirics of agglomeration economies. In *Handbook of regional and urban economics*, vol. 5A, eds. G. Duranton, J.V. Henderson, and W. Strange, pp 247–348. Amsterdam: Elsevier.
- Dickey, D.A., and W.A. Fuller. 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74: 427–431.
- Eberts, R., and D. McMillen. 1999. Agglomeration economies and urban public infrastructure. In *Handbook of regional and urban economics*, vol. III, eds. P.C. Cheshire, and E.S. Mills. New York: North Holland.
- Fujita, M., and J. Thisse. 2002. *The economics of agglomeration: Cities, industrial location and regional growth*. Cambridge: Cambridge University Press.
- Glaeser, E.L., H.D. Kallal, J.A. Scheinkman, and A. Shleifer. 1992. Growth in cities. *Journal of Political Economy* 100: 1126–1152.
- Granger, C.W.J. 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* 37: 424–438.
- IEA. 2009. *Progress with implementing energy efficiency policies in the G8*. International Energy Agency Paper.
- Jacobs, J. 1969. *The economy of cities*. New York: Vintage Books.
- Karathodorou, N., D.J. Graham, and R.B. Noland. 2010. Estimating the effect of urban density on fuel demand. *Energy Economics* 32(1): 86–92.
- Marshall, A. 1890. *Principles of economics*. London: Macmillan.
- McCann, P. 2001. *Urban and regional economics*. New York: Oxford University Press.
- Metcalf, G.E. 2008. An empirical analysis of energy intensity and its determinants at the state level. *The Energy Journal* 29(3): 1–26.
- Metcalf, G.E., and K.A. Hassett. 1999. Measuring the energy savings from home improvement investment: Evidence from monthly billing data. *The Review of Economics and Statistics* 81: 516–528.
- Morikawa, M. 2012. Population density and efficiency in energy consumption: An empirical analysis of service establishments. *Energy Economics* 34: 1617–1622.
- Newman, P.W.G., and J.R. Kenworthy. 1989. Gasoline consumption and cities. *Journal of the American Planning Association* 55(1): 24–37.
- Otsuka, A., and M. Goto. 2015a. Regional policy and the productive efficiency of Japanese industries. *Regional Studies* 49(4): 518–531.
- Otsuka, A., and M. Goto. 2015b. Agglomeration economies in Japanese industries: The Solow residual approach. *The Annals of Regional Science* 54(2): 401–416.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2010. Industrial agglomeration effects in Japan: Productive efficiency, market access, and public fiscal transfer. *Papers in Regional Science* 89(4): 819–839.
- Porter, M.E., and C. Van der Linde. 1995. Toward a new conception of the environment competitiveness relationship. *Journal of Economic Perspectives* 9: 97–118.
- Reiss, P.C., and M.W. White. 2008. What changes energy consumption? Prices and public pressures. *RAND Journal of Economics* 39: 636–663.
- Rosenthal, S., and W. Strange. 2004. Evidence on the nature and sources of agglomeration economies. In *Handbook of regional and urban economics*, vol. 4, ed. J.V. Henderson, and J.F. Thisse. Amsterdam: Elsevier.
- Seo, S.N. 2013. Economics of global warming as a global public good: Private incentives and smart adaptations. *Regional Science Policy & Practice* 5(1): 83–95.
- Su, Q. 2011. The effect of population density, road network density, and congestion on household gasoline consumption in U.S. urban areas. *Energy Economics* 33(3): 445–452.
- Thompson, P., and T.G. Taylor. 1995. The capital-energy substitutability debate. *The Review of Economics and Statistics* 77: 565–569.

- Tveteras, R., and G.E. Battese. 2006. Agglomeration externalities, productivity, and technical inefficiency. *Journal of Regional Science* 46: 605–625.
- Yamamura, E., and I. Shin. 2007. Dynamics of agglomeration economies and regional industrial structure: The case of the assembly industry of the Greater Tokyo region, 1960–2000. *Structural Change and Economic Dynamics* 18: 483–499.

Chapter 4

Determinants of Energy Efficiency: Stochastic Frontier Analysis

Abstract In response to increased environmental constraints, it has become an important policy issue for Japan to improve energy efficiency for the future, along with the growth of regional economies. This study uses a stochastic frontier model to estimate the energy demand function and analyze the levels and determinants of energy efficiency. The empirical analysis, conducted by using data from 47 prefectures in Japan, revealed the following four findings. First, the proposed energy efficiency measure (calculated using the stochastic frontier model) is found valid, as its ranking is highly correlated with that of energy intensity. Second, increasing population density is effective in improving energy efficiency. Third, improving regional accessibility by developing a highway network helps to improve energy efficiency in Japan. Fourth, the level of energy efficiency is deteriorating in areas where raw material industries are clustered. These results indicate that the means to increasing both economic productivity and environmental efficiency are to implement a regional decentralization policy by creating major urban areas across the nation and expand a wide-area transportation network to link these areas. In addition, the promotion of technological innovations through appropriate environmental regulations is important to advance such regional policies.

Keywords Energy efficiency · Energy intensity · Population density · Accessibility · Japanese regional analysis

4.1 Introduction

Given the increased environmental constraints, it is an important policy issue for Japan to improve energy efficiency and suppress CO₂ emissions as regional economies grow. In response to the Kyoto Protocol, which Japan adopted in 1997 and ratified in 2005, various environmental data, associated with the development

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of environment-related legal systems, are becoming available. Hopefully, the results of studies using these data will lead to better energy and environmental policies and regional economic development, in order to create a low-carbon society.

In this context, it is necessary for us to measure energy efficiency indicators and analyze their determinants in order to formulate energy and environmental policies in Japan (EIA 1995). However, while energy efficiency indicators have been measured recently with country-level data using stochastic frontier analysis (SFA) and data envelopment analysis (DEA), no measurement has been made at the prefectural level in Japan. In addition, most previous studies have focused on the scores of the energy efficiency indicators and have not fully analyzed the determinants.

Meanwhile, in terms of strategies to grow regional economies, the importance of forming compact cities has come under the spotlight in Japan, from both economic and environmental perspectives. Therefore, it is necessary to verify whether a compact city policy, aiming to shift from centralized to decentralized cities, would really be effective in terms of overall energy conservation in a given region. At the same time, developing road networks, which are essential for building an optimal city system under the current national land structure, could increase energy conservation by shortening inter-regional distances and improving transportation efficiency. Thus, it is also necessary to examine the effects of such developments on energy conservation. Furthermore, it is necessary to examine impacts of the industrial structure on the level of energy efficiency, because the shift from an energy-intensive industrial structure to an energy-saving one may be effective in improving regional energy efficiency.

To address these issues, this study looks at prefectures of Japan with the following aims: (1) To measure energy efficiency based on the SFA method. Since the International Energy Agency (IEA) uses energy intensity (energy consumption divided by GDP) as a proxy indicator for energy efficiency, this study examines the validity of the proposed energy efficiency indicator by comparing it with the energy intensity. (2) The study defines a “compact city” as a city with densely inhabited districts (DIDs); and examines whether a compact city positively affects the improvement of energy efficiency. The study also empirically analyzes whether (3) improved accessibility through development of a highway network between cities has a positive impact on energy efficiency, and (4) to what extent a cluster of energy-intensive, raw material industries reduce regional energy efficiency. In particular, although the budget for highway construction was reduced during the observation period, the study examines the extent to which the development of a highway network contributed to energy conservation at the prefectural level, and then provides suggestions regarding future development of regional policy.

The rest of this study is organized as follows. This study review previous studies on energy efficiency in Sect. 4.2. Here, we mainly look at studies that applied SFA to examine energy efficiency, as well as previous studies on population density, a factor that has drawn attention as a means to improve energy efficiency. In Sect. 4.3, the study present a framework for empirical analysis and describe the

model used in this study. Section 4.4 describes the data used for the analysis and Sect. 4.5 provides the results of the empirical analysis. Section 4.6 presents the conclusion and policy implications.

4.2 Previous Studies

SFA is a type of frontier analysis that can be applied to the measurement of energy efficiency. The basic idea of this method is first to estimate the efficiency frontier and then measure the level of energy efficiency of prefectures in Japan by calculating the relative distance between the actual data points and the frontier. SFA is a parametric approach that separates stochastic noise from inefficiency. Since this method has a strong analytical capability applied to assessing the score of energy efficiency, SFA has been used by many researchers to measure the levels of energy efficiency for all industries.

For example, Feijoo et al. (2002) measured the energy efficiency of industries in Spain, and concluded that energy policy and regulation reduced CO₂ emissions. Buck and Young (2007) measured the energy efficiency of commercial buildings in Canada. They concluded that commercial buildings in Canada are highly energy efficient, and that the building ownership and the economic activities of the building are the main factors affecting energy efficiency. Boyd (2008) analyzed the energy efficiency of wet corn milling plants and argued that the advantage of using the SFA to measure energy efficiency is that it is possible to avoid issues regarding the definition of energy intensity. Further, Boyd et al. (2008) used SFA in order to estimate the factory-level energy efficiency of the manufacturing sector in the United States. Aranda-Uson et al. (2012) analyzed the energy efficiency in four industries—food, drink and tobacco manufacturing, textiles, chemicals, and non-metallic mineral products—in Spain, and measured the energy efficiency scores. As a result, it became clear that the total energy consumption of these four industries could be reduced by about 20 %. Filippini and Hunt (2011) measured the energy efficiency of 29 OECD countries, between 1978 and 2006. In addition, Filippini and Hunt (2012) used state-level data from the United States between 1995 and 2007, and measured the energy consumption and energy efficiency of the residential sector. The analyses of Filippini and Hunt (2011, 2012) concluded that there was no correlation between energy efficiency levels measured by SFA and energy intensity, so energy intensity is not an appropriate proxy for the level of energy efficiency. Lin and Yang (2013) measured the energy efficiency of the thermal power industry in China and Lin and Wang (2014) measured the energy efficiency of the iron and steel industry in China. Both studies showed that the energy efficiency was relatively improved in the industry.

This series of previous studies focused on measuring the energy efficiency score using the SFA method. Therefore, while the energy efficiency levels in industries of various countries and regions have been measured so far, there are not enough empirical analyses that examine the factors that determine the level of energy

efficiency. One of the few exceptions for this is Otsuka et al. (2014), who indicated that agglomeration economies affected the level of energy efficiency of the regional economy.

The concept of agglomeration economies is important when we examine the advantages of compact cities—urban structures in which the population is clustered in particular areas—which have drawn attention in recent years. Indeed, many previous studies have shown that an urban structure with a high density increases energy efficiency.

Specifically, Newman and Kenworthy (1989) were the first to study such a relationship between energy efficiency and urban structures. Newman and Kenworthy (1989) used data from 32 cities across the world in 1980, and looked at population density as a scale of urban structure. They found that there was a negative relationship between population density and per-capita gasoline consumption. Bento and Cropper (2005) used data from 114 U.S. cities in 1990 and examined whether urban structure and public transportation have an influence on the choice of transportation for commuting and car mileage at the household level. They demonstrated that the probability of driving to work becomes lower when population centrality and rail miles are higher, and road density is lower. They also showed that population centrality, job-housing balance, city shape, and road density all have significant effects on annual household vehicle miles travelled, which increases energy consumption. Brownstine and Golob (2009) used data for the state of California and analyzed the relationships between residential density, private vehicle usage, and private vehicle fuel consumption. The study demonstrates that population density has a direct effect on vehicle usage, and that both private vehicle usage and population density affect fuel consumption. Karathodorou et al. (2010) used cross-sectional data from 84 cities around the world to show how population density affects the demand for automobile fuel. In addition, they estimated the elasticity of fuel demand relative to population density. They concluded that the propensity to walk or ride a bicycle increases in high-density cities, because transportation distances are shorter; and that per-capita fuel consumption decreases, because public transportation can substitute for the use of private vehicles. Su (2011) demonstrated how urban structures affected household gasoline consumption across 50 cities in the United States. The study considered traffic congestion and highway density as part of the urban structure, and showed that population density negatively affected household gasoline consumption. Morikawa (2012) looked at the commercial sector in Japan and examined the effect of population density on energy efficiency. He demonstrated that the energy efficiency improved by about 12 % when the population density doubled.

As described above, previous studies that analyzed the relationship between urban structure and energy consumption found that there was a strong positive correlation between population density and energy consumption. It suggests that the urban structure, as represented by population density, increases energy efficiency.

Taking note of the contributions of the previous studies, this study will extend them by using SFA not only to evaluate the levels of energy efficiency, but also to analyze the factors that affect energy efficiency, which provides us with new

insights into the improvement of energy efficiency. In doing so, we will specifically examine urban structure, accessibility, and industrial structure as determinants of energy efficiency.

4.3 Analysis Method

This study will follow Filippini and Hunt (2011, 2012) regarding the analytical method, and assume that there is an aggregate energy demand function F at the prefectural level in Japan, as shown below.

$$E_{jt} = F(Y_{jt}, P_t, POP_{jt}, A_{jt}, CDD_{jt}, HDD_{jt}, ISH_{jt}, SSH_{jt}, EF_{jt}), \quad (4.1)$$

where subscript j represents the j th region and t represents the t th time period. E is the final energy consumption, Y is the real gross regional product (GRP), P is the real price of energy, POP is the population, and A is the living and nonliving floor area, while CDD and HDD are cooling degree days and heating degree days, respectively. The CDD and the HDD represent air temperature factors. ISH and SSH represent the share of industrial sector and the share of commercial sector in the GRP, respectively. EF is the level of unobservable, underlying energy efficiency.

“Underlying energy efficiency” includes effects of various factors that vary by region. For example, they include local government regulations, differences in social environments, differences in industrial structure, and differences in culture, life style, and values. Here, when the underlying energy efficiency is low, it means that there is a waste of energy. Since the aggregated energy efficiency that is linked to manufacturing equipment and production processes cannot be observed directly when using the aggregated energy data by region, this underlying energy efficiency must be determined by estimation. Thus, this study uses SFA to estimate the level of the underlying energy efficiency, because SFA identifies the best practice in energy usage as a benchmark.

Since SFA usually measures the economic performance of a production process, it is based on production theory applied to an econometric approach for the efficiency measurement. Therefore, the application is generally based on the idea that the frontier function will provide the maximum output level or the minimum cost level feasible to the production entity. In the case of the cost function, the frontier represents the minimum level of feasible cost to produce a given level of output. The same idea can be applied to the energy demand function, that is, when the output under a production activity is given, the difference between the observed energy demand and the minimized energy demand will represent inefficiency. Specifically, in the case of the aggregate energy demand function used here, the frontier provides the minimum level of energy usage that the economy requires for production activity to achieve a given level of output. In other words, estimating the frontier function for energy demand will enable us to estimate the baseline energy

demand, which reflects effectively managed energy usage in production processes in regions, achieved by means such as utilizing highly efficient equipment. This frontier approach enables us to assess whether a given region is located on the frontier. If a given region is not on the frontier, the distance from the frontier represents the energy consumption over the baseline demand, and becomes an indicator representing energy inefficiency.

The approach used in this study (SFA) adopts a distribution assumption proposed by Aigner et al. (1977). That is, the level of energy efficiency for the regional economy can be approximated by a one-sided, non-negative error term. Therefore, this study assume that the log-log functional form of Eq. (4.1) can be defined as follows:

$$\ln E_{jt} = \alpha + \alpha_Y \ln Y_{jt} + \alpha_P \ln P_t + \alpha_{POP} \ln POP_{jt} + \alpha_A \ln A_{jt} + \alpha_{CDD} \ln CDD_{jt} + \alpha_{HDD} \ln HDD_{jt} + \alpha_{ISH} \ln ISH_{jt} + \alpha_{SSH} \ln SSH_{jt} + v_{jt} + u_{jt}, \quad (4.2)$$

where α represents an estimated parameter. The error term $(v_{jt} + u_{jt})$ consists of two parts: the random error term v_{jt} and the inefficiency-related error term u_{jt} (Fig. 4.1). It is assumed that v_{jt} has a distribution of $N(0, \sigma^2)$, and is independent of u_{jt} as well as all explanatory variables; while u_{jt} is a non-negative stochastic variable, and is assumed to have a distribution of $N(\mu, \sigma_u^2)$. The value of u_{jt} indicates the level of efficiency of underlying energy usage under Eq. (4.1), which is interpreted as an indicator of energy inefficiency (waste of energy).

Improvement of energy efficiency is explained through multiple theories in this study, because this occurs not only through technological and organizational factors affecting energy demand, but also through social innovations in the production and consumption of energy services.

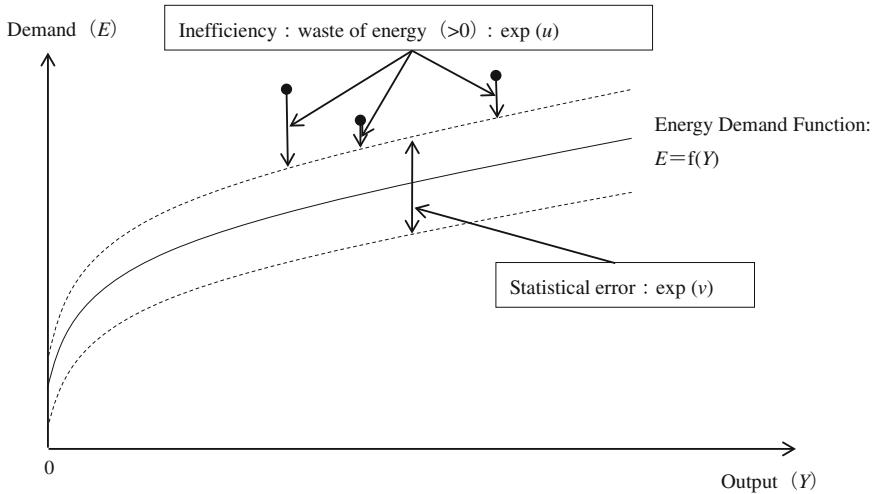


Fig. 4.1 Stochastic energy demand frontier function

In this study, the mean energy efficiency μ is defined by the following equation:

$$\mu_{jt} = \beta_0 + \beta_{DENS} \ln DENS_{jt} + \beta_{ACC} \ln ACC_{jt} + \beta_{MSH} \ln MSH_{jt}, \quad (4.3)$$

where β represents an estimated parameter. *DENS* is the population density in the DID, and *ACC* is an indicator of market access. A DID is a district defined by the census of Japan for statistical purposes. In principle, the DID is defined when basic units of area with population density of 4000 or more people per square kilometer are adjacent to each other and form a district with more than 5000 people. However, basic units, such as airports, seaports, industrial zones, and parks that have strong urban characteristics, are included as DIDs even if their population density is low. In a narrow sense, DIDs are indicators to express the scale of divisions in urban and rural areas, as well as urban districts in a city. Therefore, compared with normal population density, DID population density more clearly represents population agglomeration in a city. The market access indicator is introduced to consider regional accessibility. *ACC* is defined by the following equation:

$$ACC_{jt} \equiv \sum_{k \neq j} \left[\left(d_{jkt}^{-1} / \sum_{k \neq j} d_{jkt}^{-1} \right) \cdot Q_{kt} \right],$$

where d_{jk} is the minimum time for travel (travel cost) between regions j and k . Gross regional output Q_k represents the size of the regional market. From the definition, this indicator represents the level of market access considering not only the market size, but also the economic cost to access the market. *MSH*, the share of material industry with regard to GRP in the manufacturing industry, is a variable incorporated into the equation to control for the effects of industrial structure.

Here, ES_{jt} shows the level of inefficiency with a lower limit of 1 (Coelli 1996).

$$ES_{jt} = E(\exp(u_{jt}) \mid v_{jt} + u_{jt}), \quad 1 \leq ES_{jt} < \infty$$

When the inefficiency term shows improved efficiency, β is negative. For example, if we anticipate wasteful energy use in decentralized cities, energy efficiency might improve if the population is clustered in certain areas and a compact city is formed. In other words, we expect that energy efficiency increases as the population density increases. In addition, energy usage is probably wasteful in regions with poor distribution systems. Once the travel time to other regions is lowered through the development of a highway network, energy efficiency might improve. In other words, we can expect higher energy efficiency in regions with better market access. If these assumptions are valid, the coefficients of *DENS* and *ACC* should be negative.

On the other hand, since material industries such as “chemicals, chemical textiles, pulp and paper,” and “iron and steel, non-ferrous metals, cement, and ceramics” generally have a high energy intensity (Table 4.1), energy efficiency is expected to be low in areas where these industries are clustered. Thus, the coefficient of *MSH* should be positive.

4.4 Data

This study uses a data set consisting of panel data from 47 prefectures in Japan ($j = 1-47$), for the period between 1991 and 2007 ($t = 1991-2007$).

The final energy consumption by prefecture (E) is obtained from the *Energy Consumption Statistics by Prefecture* (Agency for Natural Resources and Energy, the Ministry of Economy, Trade and Industry). The real prefectural gross output by region (Y) is obtained from the *Annual Report on Prefectural Accounts* (Cabinet Office). The real energy price index (period 2005 = 100) (P) is based on the Corporate Goods Price Index (energy goods) data, published by the Bank of Japan. The POP data are from the *Basic Resident Register Population* (Statistics Bureau, Ministry of Internal Affairs and Communications). Building floor area by region (A) is from the *Building Stock Statistics* (Ministry of Land, Infrastructure, Transport and Tourism). CDD and HDD are data from prefectural capitals and meteorological observation points; CDD is the cumulative difference in temperatures between 22 °C and the average temperature for those days over a one-year period that are higher than 24 °C, while HDD is the cumulative difference in temperatures between 14 °C and the average temperature of those days over a one-year period that are below 14 °C. The shares of value added of the industrial and commercial sectors (ISH , SSH) are both based on data in the *Annual Report on Prefectural Accounts* (Cabinet Office). $DENS$ data are from census data and the production output (Q) required for the ACC is from the *Annual Report on Prefectural Accounts* (Cabinet Office). MSH data are sourced from the *Annual Report on Prefectural Accounts* (Cabinet Office).

Table 4.1 Energy intensity

Sector		FY2009
Total final energy consumption	GJ/million yen	22.5
Non-manufacturing	GJ/million yen	14.9
Manufacturing	GJ/million yen	49.1
Chemicals, chemical textiles, pulp and paper	GJ/million yen	220.5
Iron and steel, non-ferrous metals, cement, and ceramics	GJ/million yen	273.0
Machinery	GJ/million yen	2.9
Residential	GJ/person	15.7
Commercial and others	GJ/million yen	6.6
Transportation	GJ/person	9.4

Note These values were calculated from statistics in the Energy Consumption Statistics by Prefecture (METI) and the Annual Report on Prefectural Accounts (Cabinet Office).

Table 4.2 Descriptive statistics

Description	Variable	Mean	Std. Dev.	Maximum	Minimum
Energy consumption (TJ)	<i>E</i>	263,962	260,516	1,333,681	36,419
GRP (million yen)	<i>Y</i>	10,367,535	13,941,227	100,931,767	1,877,135
Real price of energy (2005 = 100)	<i>P</i>	109	5	116	101
Population	<i>POP</i>	2,671,595	2,436,815	12,361,736	606,695
Floor Area (ten thousand m ²)	<i>A</i>	358	327	1919	57
Cooling degree day	<i>CDD</i>	387	160	678	0
Heating degree day	<i>HDD</i>	1009	367	2769	561
Share of industrial sector (%)	<i>ISH</i>	31	7	53	12
Share of commercial sector (%)	<i>SSH</i>	62	6	83	42
DID population density (person/km ²)	<i>DENS</i>	5533	1517	11,526	3417
Market access index (million yen)	<i>ACC</i>	23,025,629	5,412,122	39,549,680	13,864,119
Share of material industry (%)	<i>MSH</i>	23	10	68	1

Table 4.2 describes the basic statistics of the data used in this study. To conduct the estimation, all the data are normalized by subtracting the mean from the raw data and dividing the result by the standard deviation.

4.5 Empirical Analysis

Table 4.3 shows the estimation results of the energy demand frontier function. Model A does not contain time dummies in an error term to represent inefficiency, while Model B accounts for time dummies. The results show that the estimated coefficients in both models have expected signs and almost all variables are statistically significant. There is very little difference in the size of the estimated coefficients, regardless of inclusion of time dummies, so that the results are consistent between the two models.

Since the models consist of log-log variables, the estimated coefficients can be interpreted as elasticity on energy consumption. The estimated income elasticity is 0.3 and price elasticity is 0.1, that is, income elasticity is higher than price elasticity. The elasticity of population size is relatively large, at 0.4, suggesting that the energy

Table 4.3 Estimation Results

	Model A		Model B	
	Coefficient	Standard-error	Coefficient	Standard-error
Constant (α)	-0.482**	(0.009)	-0.482**	(0.009)
αY	0.338**	(0.027)	0.332**	(0.029)
αP	-0.061**	(0.007)	-0.064**	(0.007)
αPOP	0.428**	(0.036)	0.420**	(0.039)
αA	0.105**	(0.032)	0.119**	(0.037)
αCDD	-0.015	(0.009)	-0.018	(0.009)
αHDD	0.058**	(0.011)	0.059**	(0.012)
αISH	0.160**	(0.022)	0.160**	(0.022)
αSSH	0.068**	(0.021)	0.069**	(0.021)
Constant (β_0)	0.003*	(0.069)	-0.014*	(0.247)
$\beta DENS$	-0.107**	(0.039)	-0.095**	(0.041)
βACC	-0.171**	(0.041)	-0.179**	(0.043)
βMSH	0.560**	(0.025)	0.585**	(0.030)
Time dummies	No		Yes	
Sigma-squared	0.264**	(0.028)	0.264**	(0.030)
Gamma	0.991**	(0.002)	0.991**	(0.002)

Note The symbols ** and * indicate significance at the 1 % and the 5 % levels, respectively

demand will increase by about 4 % when the population increases by 10 %. The elasticity of building floor area is about 0.1, which is small compared with that of the population size. It means that the energy demand will increase by 1 % when the floor area increases by 10 %. As for temperature variables, the coefficient of *CDD* is not statistically significant. Meanwhile, the coefficient of *HDD* is significant, but small compared with the other variables. Therefore, we can say that the air temperature factors do not have a large effect on the overall energy demand. In terms of the effect of the economic structure on energy demand, the estimated coefficient for the industrial sector is about 0.2, while it is around half this—about 0.1—for the commercial sector. In other words, the industrial sector, centered on the manufacturing industry, has a relatively large effect in increasing the energy demand compared with the commercial sector centered on service industries.

Next, we will check the results of the estimated coefficients that explain energy efficiency. Both *DENS* and *ACC* are negative, as expected. This indicates that the higher the *DENS* becomes, the higher the energy efficiency will be. This result is consistent with previous studies. The results also suggest that the larger the *ACC* indicator becomes, the higher the energy efficiency will be. The estimated coefficient of the *ACC* indicator is higher than the estimated coefficient of *DENS* in both

Models A and B. This implies that the development of a distribution network, associated with the construction of highway network linking the regions, would increase energy efficiency more than an increase in *DENS* would.

Meanwhile, the industrial structure variable is positive, as expected. This indicates that the energy efficiency decreases in areas with a higher ratio of materials industries. The real data also confirm that energy efficiency is low in two industries, “chemicals, chemical textiles, pulp and paper” and “iron and steel, non-ferrous metals, cement, and ceramics,” which are categorized among materials industries (Table 4.1). The data show that the level of energy intensity in 2009 for all sectors was 22.5 GJ/million yen, while it was far higher at 220.5 GJ/million yen for “chemicals, chemical textiles, pulp and paper” and 273.0 GJ/million yen for “iron and steel, non-ferrous metals, cement, and ceramics.” Since the high level of energy intensity means that the energy efficiency is low or inferior, these two are energy-inefficient sectors. In other words, this means the overall energy efficiency level in a region is low when energy-inefficient material industries account for a higher percentage of the economy as a whole; the results of the estimation also reflect this characteristic of industrial structure.

Table 4.4 shows the basic statistics of energy efficiency in each region obtained from the estimation results. There is no significant difference in the energy efficiency scores measured in Models A and B. The score of 1 represents the status of full efficiency, and energy efficiency declines as the score increases from 1. The mean in efficiency scores is 1.8 and the median is about 1.4. Given that the largest score was at 7.2 and the smallest score was almost 1.2, we can see that there is a large regional gap in energy efficiency scores.

In order to examine the effectiveness of the energy efficiency indicator measured by the SFA, energy intensity—final energy consumption divided by GRP used as a proxy indicator of energy efficiency—was calculated to perform a rank correlation test between the energy efficiency indicator and energy intensity. Table 4.5 shows the results. The results of Spearman’s rank correlation test show that there is a correlation between them at the 1 % significance level, in both Models A and B.

Table 4.4 Energy efficiency score

	Model A	Model B
Mean	1.84	1.84
Median	1.37	1.38
Maximum	7.17	7.23
Minimum	1.02	1.02
Std. Dev.	1.19	1.20

Table 4.5 Spearman’s rank correlation (ρ)

		p-value
Model A	0.905	2.20E-16
Model B	0.900	2.20E-16

Therefore, it has become clear that the ranking of the energy efficiency indicator measured by the SFA is similar to that of the energy intensity, and that the characteristics of each indicator are similar. The results indicate that the energy efficiency measured in this study is effective as an indicator of energy efficiency.

Now, we examine the regional distribution of the energy efficiency indicator. Table 4.6 shows the mean and ranking of the energy efficiency score of each prefecture. There is no large ranking variation between Models A and B. Besides the Greater Tokyo Area, including the Tokyo and Saitama Prefectures, the highly ranked areas are Nara, Nagano, Yamanashi, Yamagata, Ishikawa, and Kyoto Prefectures. In these areas, the population is concentrated in DIDs, indicating strong agglomeration economies. This is consistent with Otsuka et al. (2010) and Otsuka and Goto (2015b), who demonstrated that the economic effect of agglomeration is large in these areas. At the same time, the efficiency of goods distribution is also high in these areas due to their well-developed highway network; therefore, the energy efficiency is expected to be high. In contrast, energy efficiency is extremely low in the Oita, Okayama, Yamaguchi, Chiba, Mie, and Ibaraki Prefectures. What is common among these areas is the presence of oil sector and chemical complexes. This means that there are many energy-inefficient industries located in these areas, such as “chemicals, chemical textiles, pulp and paper” and “iron and steel, non-ferrous metals, cement, and ceramics.” Meanwhile, it is true that those industries have played an important role in increasing the productivity of industries in Japan. For example, Otsuka and Goto (2015a) showed that these industries have attained high level of productivity through the economies of agglomeration. However, from the viewpoint of energy efficiency, such improved productivity does not always accompany improved energy efficiency for those industries; in fact, the improved productivity is offset by lower energy efficiency. It could imply that there are constraints on improving energy efficiency for these industries that originate from technological characteristics. Therefore, while the advancement of waste heat utilization at industrial complexes among plants is a solution for higher energy efficiency, it is not sufficient. These industries need to improve their energy efficiency through further technological innovation.

Table 4.7 displays the mean energy efficiency score in the 1990s and 2000s in Model A. The results demonstrate the following two points. First, it does not seem that the mean scores vary widely over the period in areas where energy efficiency is high. In other words, areas that are already energy efficient have been maintaining a high standard over time. Second, the mean scores are increasing from the 1990s to the 2000s in areas with low energy efficiency, indicating that their energy efficiency has been deteriorating. Therefore, it suggests that in order to increase the overall energy efficiency in Japan, it is necessary to apply appropriate environmental regulations and regional policies to the areas where the score deteriorates over the period, and implement policies to increase energy efficiency by encouraging production process management and technological innovation.

Table 4.6 Average energy efficiency scores and ranking

	Model A		Model B	
	Efficiency score	Rank	Efficiency score	Rank
Hokkaido	1.37	24	1.35	23
Aomori	1.79	33	1.77	33
Iwate	1.28	16	1.28	16
Miyagi	1.31	18	1.30	18
Akita	1.23	14	1.23	14
Yamagata	1.08	7	1.08	5
Fukushima	1.14	10	1.13	10
Ibaraki	2.92	42	2.93	42
Tochigi	1.17	11	1.17	11
Gunma	1.13	9	1.13	9
Saitama	1.08	4	1.08	4
Chiba	4.12	44	4.12	44
Tokyo	1.08	5	1.08	7
Kanagawa	1.86	35	1.86	35
Niigata	1.38	25	1.38	25
Toyama	1.56	30	1.55	30
Ishikawa	1.08	8	1.08	6
Fukui	1.32	19	1.32	19
Yamanashi	1.07	3	1.07	3
Nagano	1.06	2	1.06	2
Gifu	1.19	13	1.19	13
Shizuoka	1.32	20	1.33	20
Aichi	1.43	27	1.43	27
Mie	3.07	43	3.07	43
Shiga	1.39	26	1.39	26
Kyoto	1.08	6	1.09	8
Osaka	1.49	28	1.49	28
Hyogo	1.83	34	1.83	34
Nara	1.05	1	1.05	1
Wakayama	2.25	39	2.26	39
Tottori	1.51	29	1.52	29
Shimane	1.34	21	1.35	21
Okayama	5.43	46	5.44	46
Hiroshima	2.73	41	2.74	41
Yamaguchi	4.75	45	4.77	45
Tokushima	1.61	31	1.61	31
Kagawa	1.87	36	1.87	36
Ehime	2.30	40	2.31	40
Kochi	2.03	38	2.03	38

(continued)

Table 4.6 (continued)

	Model A		Model B	
	Efficiency score	Rank	Efficiency score	Rank
Fukuoka	1.98	37	1.98	37
Saga	1.17	12	1.17	12
Nagasaki	1.29	17	1.30	17
Kumamoto	1.26	15	1.27	15
Oita	6.76	47	6.80	47
Miyazaki	1.68	32	1.68	32
Kagoshima	1.36	23	1.37	24
Okinawa	1.34	22	1.35	22

Table 4.7 Average Energy Scores over Time

	Model A		Model B	
	1991–1999	2000–2007	1991–1999	2000–2007
Hokkaido	1.32	1.43	1.30	1.41
Aomori	1.71	1.87	1.70	1.86
Iwate	1.30	1.27	1.29	1.26
Miyagi	1.25	1.38	1.24	1.37
Akita	1.14	1.34	1.14	1.33
Yamagata	1.08	1.09	1.07	1.09
Fukushima	1.15	1.13	1.14	1.13
Ibaraki	2.89	2.96	2.89	2.97
Tochigi	1.16	1.17	1.16	1.17
Gunma	1.15	1.10	1.15	1.11
Saitama	1.08	1.08	1.08	1.08
Chiba	3.87	4.40	3.88	4.40
Tokyo	1.05	1.11	1.06	1.12
Kanagawa	1.85	1.87	1.86	1.87
Niigata	1.38	1.39	1.37	1.38
Toyama	1.62	1.49	1.61	1.48
Ishikawa	1.09	1.08	1.08	1.08
Fukui	1.30	1.34	1.30	1.34
Yamanashi	1.06	1.07	1.06	1.07
Nagano	1.06	1.05	1.06	1.05
Gifu	1.20	1.19	1.20	1.19
Shizuoka	1.40	1.23	1.41	1.23
Aichi	1.47	1.38	1.48	1.38
Mie	3.34	2.77	3.34	2.77
Shiga	1.55	1.21	1.55	1.21
Kyoto	1.09	1.07	1.10	1.07

(continued)

Table 4.7 (continued)

	Model A		Model B	
	1991–1999	2000–2007	1991–1999	2000–2007
Osaka	1.51	1.46	1.52	1.47
Hyogo	1.79	1.87	1.79	1.88
Nara	1.03	1.07	1.03	1.08
Wakayama	2.29	2.20	2.29	2.22
Tottori	1.42	1.62	1.43	1.62
Shimane	1.34	1.34	1.35	1.34
Okayama	5.28	5.59	5.30	5.61
Hiroshima	2.67	2.80	2.68	2.81
Yamaguchi	4.38	5.16	4.40	5.19
Tokushima	1.61	1.61	1.61	1.61
Kagawa	1.82	1.92	1.82	1.92
Ehime	2.22	2.39	2.23	2.40
Kochi	2.00	2.05	2.01	2.06
Fukuoka	2.05	1.91	2.05	1.91
Saga	1.11	1.23	1.11	1.24
Nagasaki	1.27	1.32	1.27	1.32
Kumamoto	1.24	1.28	1.25	1.29
Oita	6.75	6.78	6.79	6.81
Miyazaki	1.65	1.71	1.65	1.72
Kagoshima	1.33	1.40	1.34	1.40
Okinawa	1.26	1.44	1.26	1.44

4.6 Conclusions and Policy Implications

This study attempted to measure the underlying energy efficiency of 47 prefectures in Japan by combining an energy demand model and a stochastic frontier approach. To our knowledge, this study is the first research effort to apply this approach to prefectures in Japan and examine its practicality in obtaining policy implications. In determining energy demand, the study controlled output, price, population, floor area, temperature, and industrial structure to derive energy efficiency. The proposed estimates of energy efficiency in this study are a good proxy to the underlying energy efficiency with greater accuracy compared with the energy intensity variable, because the latter tends to be influenced by the industrial structure, while the effect is controlled in derivation of energy efficiency.

This analysis demonstrated the following four findings. First, the proposed measure of energy efficiency is effective in measuring the underlying energy efficiency in the case of Japanese prefectures, given the high correlation of the rankings between the estimated energy efficiency measure and energy intensity. Second, this study reconfirmed the importance of population density in improving energy

efficiency. Estimation results of this study suggest that the presence of DIDTs and the formation of compact cities will contribute to energy conservation. Third, developing transportation networks and shortening travel time to other regions would enhance the ability of distribution systems and lead to regional energy conservation. Fourth, the analysis showed that energy efficiency is lower in areas where materials industries are clustered. This suggests the need for implementing appropriate environmental regulations and regional policies in areas where oil and chemical complexes are located, which is expected to advance production process management and technological innovation to improve energy efficiency.

To conclude, it is suggested that forming compact cities in prefectural areas and linking cities by highways to establish city systems (national land structure) are very effective ways to improve the energy efficiency of regional economies. These policies will also increase environmental efficiency while increasing the productivity of regional economies. The results of this study indicate that it is important to develop decentralized national land through multi-polar interventions and promote wide-area transportation networks to achieve both increased productivity and environmental efficiency.

References

- Aigner, D.J., C.A.K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function model. *Journal of Econometrics* 6: 21–37.
- Aranda-Uson, A., G. Ferreira, M.D. Mainar-Toledo, S. Scarpellini, and E. Liera. 2012. Energy consumption analysis of Spanish food and drink, textile, chemical and non-metallic mineral products sectors. *Energy* 42: 477–485.
- Bento, A.M., and M.L. Cropper. 2005. The effects of urban spatial structure on travel demand in the United States. *The Review of Economics and Statistics* 87(3): 466–478.
- Boyd, G.A. 2008. Estimating plant level energy efficiency with a stochastic frontier. *The Energy Journal* 29: 23–43.
- Boyd, G., E. Dutrow, and W. Tunnessen. 2008. The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use. *Journal of Cleaner Production* 16(6): 709–715.
- Brownstine, D., and T.F. Golob. 2009. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* 65(1): 91–98.
- Buck, J., and D. Young. 2007. The potential for energy efficiency gains in the Canadian commercial building sector. *Energy* 32: 1769–1780.
- Coelli, T. 1996. A guide to FRONTIER version 4.1: A computer program for stochastic frontier production and cost function estimation. CEPA Working Papers (University of New England, NSW, Australia), #96/07.
- EIA. 1995. Measuring energy efficiency in the United States' economy: A beginning. Energy Information Administration, DOE/EIA-0555(95)/2, Washington, DC, USA.
- Feijoo, M.L., J.F. Franco, and J.M. Hernandez. 2002. Global warming and the energy efficiency of Spanish industry. *Energy Economics* 24: 405–423.
- Filippini, M., and L.C. Hunt. 2011. Energy demand and energy efficiency in the OECD Countries: A stochastic demand frontier approach. *The Energy Journal* 32: 59–79.
- Filippini, M., and L.C. Hunt. 2012. U.S. residential energy demand and energy efficiency: A stochastic demand frontier approach. *Energy Economics* 34: 1484–1491.

- Karathodorou, N., D.J. Graham, and R.B. Noland. 2010. Estimating the effect of urban density on fuel demand. *Energy Economics* 32(1): 86–92.
- Lin, B.Q., and L.S. Yang. 2013. The potential estimation and factor analysis of China's energy conservation on thermal power industry. *Energy Policy* 62: 354–362.
- Lin, B., and X. Wang. 2014. Exploring energy efficiency in China's iron and steel industry: A stochastic frontier approach. *Energy Policy* 72: 87–96.
- Otsuka, A., and M. Goto. 2015a. Regional policy and the productive efficiency of Japanese industries. *Regional Studies* 49(4): 518–531.
- Otsuka, A., and M. Goto. 2015b. Agglomeration economies in Japanese industries: The Solow residual approach. *The Annals of Regional Science* 54(2): 401–416.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2010. Industrial agglomeration effects in Japan: Productive efficiency, market access, and public fiscal transfer. *Papers in Regional Science* 89(4): 819–839.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2014. Energy efficiency and agglomeration economies: The case of Japanese manufacturing industries. *Regional Science Policy & Practice* 6(2): 195–212.
- Morikawa, M. 2012. Population density and efficiency in energy consumption: An empirical analysis of service establishments. *Energy Economics* 34: 1617–1622.
- Newman, P.W.G., and J.R. Kenworthy. 1989. Gasoline consumption and cities. *Journal of the American Planning Association* 55(1): 24–37.
- Su, Q. 2011. The effect of population density, road network density, and congestion on household gasoline consumption in U.S. urban areas. *Energy Economics* 33(3): 445–452.

Chapter 5

Residential Energy Demand and Energy Efficiency

Abstract Based on the rapid increase in residential energy demand, the question of how to raise energy efficiency in the residential sector, while controlling overall demand, is an important policy issue for Japan. In this study, the stochastic frontier model is used to estimate the energy demand function in the residential sector and to analyze the energy efficiency levels and their factors. From the results of the empirical analysis based on regional data in Japan, the following three points were clarified. First, the energy efficiency levels calculated using the stochastic frontier model were highly correlated with the energy intensity levels and are effective as an index expressing energy efficiency. Second, raising the regions' electrification rates is an effective way of improving energy efficiency in the residential sector. Third, increasing the regions' population densities is also an effective way of improving energy efficiency in the residential sector. These findings suggest that not only will implementing policies to advance electrification contribute greatly to improving environmental efficiency in the residential sector, but also that realizing decentralized, multi-polar national spatial developments may improve environmental efficiency and stimulate regional economies.

Keywords Energy efficiency · Energy intensity · Residential sector · Electrification rate · Population density · Japanese regional analysis

5.1 Introduction

Energy consumption in Japan's residential sector is influenced by changes to the social structure, such as changes to the lifestyles of citizens as they pursue greater convenience and comfort in their lives, and also by an increase in the number of households; and consumption has risen significantly alongside the growth in individual consumption. With energy consumption in the residential sector in 1973 set as 100, by 2011 this value had risen to 208.9, meaning energy consumption was more than two times that at the time of the first oil shock. Therefore, promoting energy conservation in the residential sector has become a pressing issue and the

Japanese government has implemented a variety of measures to achieve this aim (Japan's Energy White Paper 2015).

Energy consumption in the residential sector is greatly affected by the energy intensity, defined as energy consumption per household. When examining energy intensity, we see that its growth rate has been slowed by the improved energy consumption efficiency of consumer electronic devices used in residences. Despite this, overall energy consumption is trending upwards, along with the shift to the larger sizes and wider diversities of these devices. Therefore, the question of whether it is possible to raise energy consumption efficiency to an extent greater than the spread of consumer electronics has now become a policy issue.

However, energy intensity is not deemed to be suitable as an index expressing energy efficiency (EIA 1995, 2013; IEA 2009), because this measure depends upon a variety of social and environmental factors. Therefore, many researchers have attempted other energy efficiency index measurements. In recent years, energy efficiency index measurements have been carried out using stochastic frontier analysis (SFA) and data envelopment analysis (DEA), using data from various countries; but the majority of these studies focused only on scores from the energy efficiency index and did not fully analyze their underlying factors. Therefore in this study, the energy efficiency index proposed by Otsuka and Goto (2015a) is utilized, the levels of residential energy consumption efficiency are measured, and their factors analyzed.

Up to 1965, which is around the start of Japan's period of high economic growth, coal constituted more than one third of the energy consumption in the residential sector. It was subsequently replaced by kerosene, and by 1973, coal provided only around 6 % of residential energy. During that period, kerosene, electric power, and gas (city gas and LP gas) each had around a one-third share of energy consumption, but after that, electric power's share increased greatly, due to the spread of new consumer electronic devices and as these devices became larger in size and multi-functional in design. In recent years, all-electric homes have become widespread, and by 2011, electric power's share of residential energy had reached 50.6 %. Approximately 40 % of electric power is used for refrigerators, lighting, TVs, and air conditioning. For devices that consume a lot of energy, it is necessary to verify whether the various measures implemented by the government to improve energy conservation have succeeded. In other words, verifying whether electrification has improved energy efficiency is important for the formulation of energy policy. At the same time, within the growth strategies for regional economies in Japan, the importance of forming compact cities has been advocated for both their economic and their environmental advantages. There is therefore a need to verify whether a compact-city policy that aims to transition from decentralized cities to centralized cities is also effective for energy conservation in Japan's residential sector.

Taking into account the problems described above, this study, in targeting Japan's prefectures, takes the following steps: (1) an attempt is made to measure residential energy efficiency values based on the SFA method. As the IEA uses energy intensity (energy/household) as the representative index for energy efficiency, the effectiveness of the measurement index in this study is examined from

the viewpoint of whether or not there is a correlation between the energy efficiency index values measured in this study and energy intensity. After doing this, (2) the issue of whether electrification improves energy efficiency in residential sector is verified. At the same time, (3) whether “compact cities”—defined as cities with a densely inhabited district (DID)—improve energy efficiency in residential sectors, is also verified.

Below, in Sect. 5.2, the existing research on energy efficiency is reviewed. This is mainly an overview of previous studies that used SFA. In Sect. 5.3, the framework for the empirical analysis is presented and the model employed in this study is described. In Sect. 5.4, the data used for the analysis are described. In Sect. 5.5, the results of the empirical analysis are presented. In Sect. 5.6, the conclusion and policy implications are outlined.

5.2 Previous Studies

In order to estimate the energy efficiency level, it is possible to use both parametric and non-parametric frontier approaches (Murillo-Zamorano 2004; Shui et al. 2015). In the non-parametric methods, such as data envelopment analysis (DEA), the frontier function is considered to be the decision function of a number of variables and no specific functional form is assumed. The parametric methods, such as stochastic frontier analysis (SFA), are based on econometric models and therefore require a specific functional form.

DEA, which is representative of the non-parametric approach, is a method of estimating the production frontier non-parametrically. Since Charnes et al. (1978), a body of theoretical and applied research on DEA has been accumulated by many researchers and it is one of the most effective tools for measuring the management efficiency of decision-making units (DMUs), such as companies. This method does not assume a specific function type for the production function and estimates the production frontier using linear programming. The production frontier is the envelope (surface) connecting, from their respective planes, a sample of those companies that are the most efficient. If a company is on this frontier, it has an efficiency of 1, and if it is not on the frontier, the degree to which it is inefficient is determined by its distance from the frontier.

A merit of DEA is that it does not require in advance a specific production function type or information on the distribution of technical inefficiency. At the same time, in order to be able to explicitly derive the efficiency of individual companies, DEA also has the advantage of easily being able to consider the presence of multiple products and multiple input goods.

However, there are a number of problems with DEA. First, as statistical errors are not normally considered with this method, it does not consider errors in the specification of the production frontier; that is to say, it is not possible to introduce all of the explanatory variables into the estimation formula, so it does not consider the errors that occur from this absence of various elements within its formulation. In

addition, let us consider the case of a sample that has particularly high observed values (abnormal values) for productivity, compared with the other samples. In this case, as a deviation from the frontier is not allowed in a negative direction from the definition of the production frontier, the production frontier is determined so as to include these observed values as a technically complete and efficient sample. As a result, the reliability of the statistics may be greatly impaired. Next, DEA is good at measuring relative efficiency from a comparison with a reference set that is close to the DMU that is the subject of evaluation. Conversely, in the event that a comparison with the entire sample is difficult, for example when the efficiency value is evaluated to be 1 (the most efficient), it is not easy to compare the relative merits and demerits between the samples. While on the one hand, it is possible to measure the relative efficiency of one economic unit compared with other economic units, on the other hand, it may not be possible to carry out the type of comparisons in which one supposes a combination of theoretically achievable inputs and outputs other than the reference set. Further, since DEA is a non-parametric method, verifying hypotheses statistically is difficult.

Stochastic frontier analysis, which is representative of the parametric approach, assumes a specific function type for the production frontier and is a method of estimating the production frontier parametrically.

SFA has merit, for example, in cases where particularly high observed values (abnormal values) for productivity are obtained compared with other samples; the stochastic production frontier can absorb a significant part of the impact of these abnormal values symmetrically in the error term. Therefore, the problem of the instability of the estimates of the production function arising from the presence of abnormal values in the direction of high productivity can be avoided.

On the other hand, however, a disadvantage in obtaining estimates using SFA is that it is necessary to have a priori assumptions with regard to the distribution of technical inefficiency. Usually, distributions such as a half-normal distribution, exponential distribution, or gamma distribution are assumed. However, there may be no theoretical economic grounds to necessitate the selection of a particular distribution type. Even using the same data set, the shape of the estimated production frontier will be different depending on the selection of the assumed distributions, so the method has the disadvantage that these estimated values for technical inefficiency will be different. Further, correspondence is not easily achieved when there are multiple production goods; and above all, it is necessary to assume in advance the production function type.

In order to model the energy demand function for Japan's regions, this study use SFA to process the statistical noise in the data. Data used in this study are mainly official processing figures. Therefore, the data may have some noise. The study can handle this noise through the use of SFA; processing this statistical noise would be impossible if DEA was used.

The basic idea in SFA is first to estimate the efficiency frontier, and then, based on this, to measure efficiency by calculating the relative distances from the actual data points to the frontier. As this method has a high discrimination capability with regard to the evaluation of energy efficiency values, SFA has been used by many

researchers to measure energy efficiency levels in industry as a whole and also in specific industries (Feijoo et al. 2002; Buck and Young 2007; Boyd 2008; Boyd et al. 2008; Aranda-Uson et al. 2012; Filippini and Hunt 2011, 2012; Lin and Yang 2013, 2014; Filippini and Lin 2016).

In previous studies relating to SFA, the focus was placed on measuring energy efficiency values based on the SFA method. On the one hand, the energy efficiency levels of various countries, regions, and industries have been extensively measured; on the other hand, while there have been some empirical analyses that considered individual factors that determine energy efficiency levels, such as Otsuka et al. (2014) and Otsuka and Goto (2015a), this cannot be said to have been carried out sufficiently.

Otsuka et al. (2014) and Otsuka and Goto (2015a) pointed to the existence of agglomeration economies as an element determining energy efficiency levels. With regard to the effects of agglomeration economies, in recent years the focus has been placed on urban structures that concentrate the population in a specific region (compact cities), and many previous studies have indicated that an urban structure expressing a high population density is an element behind increased energy efficiency (Newman and Kenworthy 1989; Bento and Cropper 2005; Brownstine and Golob 2009; Karathodorou et al. 2010; Morikawa 2012). The main previous studies that analyzed the relationship between urban structures and energy consumption showed a strong association between population density and energy efficiency. In other words, they suggest that an urban structure expressing a higher population density increases energy efficiency.

In contrast to the previous research described above, this study applies SFA not only to evaluate energy efficiency in the residential sector, but also to analyze the factors that affect it, and to obtain new findings on improving energy efficiency in the residential sector. To do this, electrification and urban structures will be investigated as the specific factors.

5.3 Analysis Method

In this study, in accordance with Otsuka and Goto (2015a), the aggregate energy demand function F described below is assumed to be present at the level of Japan's prefectures.

$$E_{jt} = F(Y_{jt}, P_t, N_{jt}, A_{jt}, U_{jt}, CDD_{jt}, HDD_{jt}, CE_{jt}). \quad (5.1)$$

Here, j represents the regions and t is the time. E is final energy consumption in residential sector, Y is real prefectural income (real income), P is the residential sector's real energy price, N is the number of households, A is the residential floor area, U is the urbanization rate, CDD is cooling degree day, which represents the element of weather in terms of higher temperatures than average, and HDD is heating degree day, which represents lower than normal temperatures.

Unfortunately, since the energy efficiency level cannot normally be observed directly in economic systems, we need to estimate it. As previously stated, in this study, in accordance with the approach taken in Otsuka and Goto (2015a), the energy efficiency levels in Japan's regions are estimated using the stochastic frontier demand function. The stochastic frontier function generally measures economic performance in the production process. Therefore, it has been applied to production theory using an econometric approach.

In general, the frontier function is based on the principle that it gives the maximum output level or the lowest cost level that can be achieved by a given production unit. In the case of the cost function, the frontier expresses the minimum level of costs that can be achieved for a given output. The case of the energy demand function can be considered in the same way. In other words, in the event that the output from a certain production activity is a given, the difference between the observed energy demand amount and the minimized demand amount expresses the technical inefficiency. More specifically, in the case of the aggregate energy demand function used here, the frontier gives the minimum level of energy that is required for the production activity in the economy in order to achieve the given level of produced goods. That is to say, by estimating the energy demand frontier function, it becomes possible to estimate the energy demand baseline that reflects the energy demand of regions that are efficiently managing energy usage in the production process, by using highly efficient equipment and other means. This frontier approach makes it possible to judge whether or not a certain region is on the frontier. If a region is not on the frontier, then an index expresses so-called energy inefficiency, with the region's distance from the frontier representing that portion of its energy consumption that exceeds the baseline demand.

The SFA approach used in this study is based on the assumption that the distribution of the energy efficiency level of the economy as a whole can be approximated by the error term of a one-sided, non-negative term (Otsuka and Goto 2015a) by adopting the stochastic frontier function approach proposed by Aigner et al. (1977). Therefore, it is assumed that the log-log function type of Eq. (5.1) can be defined as follows.

$$\ln E_{jt} = \alpha + \alpha_Y \ln Y_{jt} + \alpha_P \ln P_t + \alpha_N \ln N_{jt} + \alpha_A \ln A_{jt} + \alpha_U \ln U_{jt} + \alpha_{CDD} \ln CDD_{jt} + \alpha_{HDD} \ln HDD_{jt} + v_{jt} + u_{jt}. \quad (5.2)$$

Here, α is the estimated parameter. The error term ($v_{jt} + u_{jt}$) is composed of two parts: the random error term v_{jt} and the inefficiency-related error term u_{jt} , where v_{jt} has the distribution $N(0, \sigma^2)$ and is assumed to be independent from u_{jt} and all of the explanatory variables, and u_{jt} is the non-negative stochastic variable and has an assumed distribution of $N(\mu, \sigma_u^2)$. The term u_{jt} expresses the efficiency of the energy level CE in (1) interpreted as an index of energy inefficiency (wasted energy consumption).

In addition to improving energy efficiency through technical factors related to energy demand and organizational factors, other approaches promote social

innovation in the production and consumption of energy services. In terms of the analysis, a number of such routes can be captured and assessed.

In this study, the energy efficiency average μ is formulated as follows:

$$\mu_{jt} = \beta_0 + \beta_{DENS} \ln DENS_{jt} + \beta_E \ln Electricity_{jt}. \quad (5.3)$$

Here, β is the estimated parameter. *DENS* is the densely inhabited district (DID) population density, and *Electricity* is the electrification rate. DIDs are districts set for statistical purposes in Japan's Population Census. They are defined as districts containing basic unit blocks with a population density of 4000 or more per square kilometer, such districts being adjacent to each other in a municipality; and districts consisting of the above adjacent basic unit blocks whose population is 5000 or more. However, basic unit blocks with a strong urban aspect, such as airports, ports, industrial zones, and parks, are included as DIDs even if they have a low population density. DIDs are used for the division between urban regions and rural regions and as an index showing the scale of a city in the narrow sense. Accordingly, the DID population density is interpreted as strongly expressing the degree of population density in urban areas, when compared with normal population density. The electrification rate is introduced to ascertain the extent of each region's electrification.

Here, CE_{jt} , which shows the inefficiency level, takes a non-negative value with 1 as the lower limit (Coelli 1996).

$$CE_{jt} = E(\exp(u_{jt}) \mid v_{jt} + u_{jt}), 1 \leq CE_{jt} < \infty.$$

In the event of an improvement to efficiency through the element of the inefficiency term, the sign of β will be negative. For example, there is considered to be waste in energy usage in decentralized cities. Therefore, if the population can be concentrated into specific areas and compact cities formed and developed, energy efficiency is likely to improve; in other words, it is anticipated that the greater the population density, the higher the energy efficiency. There is also thought to be waste in energy usage in regions with poor electrification rates. Regions using coal and kerosene emit more carbon dioxide than regions that use electricity. If the amount of electricity the former use is increased by progressing electrification, the energy efficiency in their residential sectors is also likely to improve. Therefore, the coefficient values of *DENS* and *Electricity* are expected to be negative.

5.4 Data

This study is based upon a panel data set of Japan's 47 prefectures ($j = 1-47$) from 1991 to 2007 ($t = 1991-2007$).

Each prefecture's residential sector final energy consumption (E) is obtained from data in the *Energy Consumption Statistics by Prefecture* (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry). Each region's real prefectural income (Y) is obtained from data in the *Annual Report on Prefectural Accounts* (Cabinet Office). The residential sector real energy price index (2005 = 100) (P) is from IEA data. The number of households (N) is from data on the number of households in the *Basic Resident Register* (Statistics Bureau, Ministry of Internal Affairs and Communications). For each region's building floor area (A), data from the *Building Stock Statistics* (Ministry of Land, Infrastructure and Transport) is used. The urbanization rate (U) is the ratio of the DID population to the total population. The total population was obtained from the *Basic Resident Register Populations* (Statistics Bureau, Ministry of Internal Affairs and Communications) and the DID populations from the *Population Census* (Statistics Bureau, Ministry of Internal Affairs and Communications). The cooling degree days (CDD) and heating degree days (HDD) are from data on the prefectural capitals and from temperature observation points, with cooling degree days being the sum of the difference between the average temperature on days where it exceeded 24 and 22 °C, and heating degree days being the sum of the difference between the average temperature on days when it was below 14 and 14 °C. The DID population density ($DENS$) is from Population Census data, while electricity energy consumption, which provides data necessary to calculate the electrification rates (*Electricity*), and total energy consumption, is obtained from data in the *Energy Consumption Statistics by Prefecture* (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry).

Table 5.1 shows the descriptive statistics. For the estimations, the data were standardized by subtracting the average from the original data and dividing by the standard deviation.

Table 5.1 Descriptive statistics

Description	Variable	Mean	Std. Dev.	Maximum	Minimum
Residential energy consumption (TJ)	E	41,879	43,456	232,000	6,783
Real income (million yen)	Y	7,911,391	10,588,221	76,311,078	1,512,781
Real price of residential energy (2005 = 100)	P	95	6	105	87
Number of household	N	994,869	1,032,668	6,060,432	188,931
Floor area (ten thousand m ²)	A	274	257	1,453	36
Index of urbanization (%)	U	50	19	100	24
Cooling degree day	CDD	360	175	1,186	0
Heating degree day	HDD	1,106	474	2,769	0
DID population density (person/km ²)	$DENS$	5,533	1,517	11,526	3,417
Electrification rate (%)	<i>Electricity</i>	48	9	68	22

5.5 Empirical Analysis

Table 5.2 shows the results of the estimates of the frontier demand function. Model A does not consider the time dummy in the error term, while Model B does consider the time dummy. In both of the models, the signs of the estimated coefficients were as expected, and practically all of the variables were statistically significant.

As it is a log-log variable, the estimated coefficient can be interpreted as elasticity. The estimated income elasticity was 0.384 and price elasticity was -0.040 , so income elasticity exceeded price elasticity. As only the time dummy was considered in the estimates, no major differences were seen in the sizes of the estimated coefficients and the results were stable. The elasticity of the number of households was comparatively large, at 0.554. This suggests that if the number of households increases by 10 %, energy demand will rise by about 5 %. The elasticity of the building floor area was in the region of -0.024 , which was small compared with the number of households and was not significant. The elasticity of the urbanization rate was significant at 0.058. This means that if urbanization progresses by 10 %, energy demand will increase by 0.58 %. For the temperature variables, while on the one hand the cooling degree day was not statistically significant, on the other hand the coefficient parameter of the heating degree day was small. Therefore, it can be said that the air temperature factor does not have a major impact on overall residential energy demand.

Table 5.2 Estimation results

	Model A			Model B		
	Coefficient		Standard error	Coefficient		Standard error
Constant (α)	-0.169	**	(0.018)	-0.157	**	(0.018)
αY	0.384	**	(0.019)	0.394	**	(0.018)
αP	-0.040	**	(0.004)	-0.040	**	(0.003)
αN	0.554	**	(0.020)	0.543	**	(0.019)
αA	-0.024		(0.015)	-0.022		(0.015)
αU	0.058	**	(0.008)	0.060	**	(0.008)
αCDD	0.004		(0.005)	0.006		(0.005)
αHDD	0.032	**	(0.005)	0.034	**	(0.004)
Constant (β_0)	0.126	**	(0.022)	0.117	**	(0.022)
$\beta DENS$	-0.023	**	(0.007)	-0.028	**	(0.007)
βE	-0.217	**	(0.007)	-0.206	**	(0.008)
Time dummies	No			Yes		
Sigma-squared	0.011	**	(0.001)	0.011	**	(0.001)
Gamma	0.469	**	(0.118)	0.375	**	(0.127)

Note The symbols ** and * indicate significance at the 1 and 5 % levels, respectively

Next, we will confirm the estimation results for the coefficients that explain energy efficiency. The signs of both the population density and electrification rate variables were negative, as expected. This shows that as population density becomes greater, energy efficiency increases. This result is consistent with the findings of previous research. The results also showed that energy efficiency improves with higher electrification rates. In both Models A and B, the estimated coefficient for the electrification rate greatly exceeded that for the population density. This signifies that the effects on energy efficiency of the rise in the electrification rate, which has occurred through the replacement of gas with electric power and the introduction and spread of consumer electronics, is greater than the effects of population density.

Table 5.3 shows the energy efficiency scores for each region obtained from the results of the estimates. There were no major differences in the energy efficiency scores measured using Model A and Model B. An efficiency score of 1 is the most efficient, and the more the score exceeds 1, the lower the energy efficiency level. The average was 1.21 and the median score was 1.09. The largest score was 2.39 and the smallest 1.01, from which we understand that there are regional differences in the energy efficiency scores.

Next, in order to verify the effectiveness of the energy efficiency index measured using SFA, energy intensity is calculated by dividing residential final energy consumption by the number of households and performing a rank correlation test on the results. Table 5.4 shows these results. In both Models A and B, the results of Spearman’s rank correlation test were found to be significant at the 1 % level. Therefore, it was clarified that the ranking in the energy efficiency index measured using SFA is close to the ranking of energy intensity that is used as the representative index of energy efficiency, and that the characteristics of these indexes are similar. This shows the validity of the energy efficiency index measured in this study as an index expressing energy efficiency.

Next, we will consider regional patterns in the energy efficiency index for the residential sector. Table 5.5 shows each prefecture’s average energy efficiency scores and ranking. No major changes in ranking were seen between Model A and Model B. The high-ranking regions included Shiga Prefecture, Wakayama

Table 5.3 Energy efficiency score

	Model A	Model B
Mean	1.21	1.19
Median	1.09	1.07
Maximum	2.39	2.41
Minimum	1.01	1.01
Std. Dev.	0.26	0.26

Table 5.4 Spearman’s rank correlation (ρ)

		<i>p</i> -value
Model A	0.666	2.20E-16
Model B	0.619	2.20E-16

Table 5.5 Average energy efficiency scores and ranking

	Model A		Model B	
	Efficiency score	Rank	Efficiency score	Rank
Hokkaido	2.10	47	2.11	47
Aomori	1.82	46	1.80	46
Iwate	1.71	43	1.70	44
Miyagi	1.50	40	1.49	40
Akita	1.77	45	1.75	45
Yamagata	1.65	41	1.62	41
Fukushima	1.67	42	1.64	42
Ibaraki	1.08	23	1.07	22
Tochigi	1.05	7	1.04	8
Gunma	1.08	21	1.06	16
Saitama	1.20	35	1.17	34
Chiba	1.34	39	1.31	39
Tokyo	1.06	14	1.05	12
Kanagawa	1.24	37	1.19	37
Niigata	1.72	44	1.69	43
Toyama	1.27	38	1.24	38
Ishikawa	1.20	34	1.18	35
Fukui	1.22	36	1.19	36
Yamanashi	1.04	4	1.03	4
Nagano	1.13	31	1.10	31
Gifu	1.06	15	1.05	10
Shizuoka	1.09	24	1.07	20
Aichi	1.13	32	1.10	32
Mie	1.09	27	1.07	25
Shiga	1.02	1	1.02	2
Kyoto	1.07	18	1.06	19
Osaka	1.15	33	1.12	33
Hyogo	1.11	29	1.09	29
Nara	1.11	28	1.08	28
Wakayama	1.02	2	1.02	1
Tottori	1.07	19	1.06	18
Shimane	1.09	26	1.08	27
Okayama	1.08	22	1.06	17
Hiroshima	1.08	20	1.07	21
Yamaguchi	1.12	30	1.10	30
Tokushima	1.06	11	1.04	9
Kagawa	1.06	12	1.04	7
Ehime	1.06	9	1.05	11
Kochi	1.04	5	1.04	5

(continued)

Table 5.5 (continued)

	Model A		Model B	
	Efficiency score	Rank	Efficiency score	Rank
Fukuoka	1.09	25	1.08	26
Saga	1.06	13	1.05	13
Nagasaki	1.07	17	1.07	24
Kumamoto	1.05	8	1.05	14
Oita	1.04	6	1.04	6
Miyazaki	1.06	10	1.06	15
Kagoshima	1.06	16	1.07	23
Okinawa	1.03	3	1.02	3

Prefecture, Okinawa Prefecture, Yamanashi Prefecture, and Kochi Prefecture. All of these regions are located in West Japan, where electrification has progressed. In contrast, Hokkaido had the worst efficiency, while efficiency was also poor in each of the Tohoku prefectures, including Aomori. One factor that may lie behind this is that within the heating demand in these regions, there is a lot of demand for coal and gas, and electrification has not progressed. On the other hand, Tokyo, in which the population is concentrated, had a high efficiency score. In Tokyo, the population is concentrated into DIDs and there appears to be a high level of agglomeration economies. Otsuka et al. (2010) and Otsuka and Goto (2015b) verified that the effects of agglomeration economies are high in this region. It is estimated that energy efficiency is high from population concentrations as typified by the extreme concentration in Tokyo.

Table 5.6 shows the average scores for energy efficiency in the 1990s and 2000s in Model A. The following two points are characteristic of these results. The first point is that in regions with high energy efficiency, changes to the average scores were not observed to a great extent. In other words, regions where energy efficiency is already high are maintaining these high levels. The second point is that in low energy efficiency regions, the average score improved greatly from the 1990s to the 2000s, indicating that their energy efficiency is improving. Therefore, the results suggest that in Japan’s regions, the low energy efficiency regions are catching up to the high energy efficiency regions, and through this catch-up process, nationwide energy efficiency is improving.

Figure 5.1 shows the relationships between the regions’ electrification rate averages and their energy efficiency average scores. Taken as a whole, a downward-sloping relationship can be seen. The electrification rate rose rapidly from the 1990s to the 2000s. This rise in the electrification rate encouraged improvements in the regions’ energy efficiency, greatly increasing the energy efficiency levels. In other words, the rise in the electrification rate is estimated to have contributed significantly to the rise in energy efficiency.

Table 5.6 Average energy scores over time

	Model A		Model B	
	1991–1999	2000–2007	1991–1999	2000–2007
Hokkaido	2.23	1.94	2.25	1.95
Aomori	1.85	1.79	1.84	1.76
Iwate	1.73	1.69	1.73	1.67
Miyagi	1.52	1.49	1.51	1.47
Akita	1.77	1.76	1.77	1.74
Yamagata	1.66	1.63	1.64	1.60
Fukushima	1.66	1.68	1.64	1.64
Ibaraki	1.09	1.08	1.07	1.06
Tochigi	1.05	1.04	1.05	1.04
Gunma	1.08	1.07	1.06	1.05
Saitama	1.22	1.18	1.18	1.15
Chiba	1.36	1.33	1.33	1.29
Tokyo	1.08	1.04	1.07	1.04
Kanagawa	1.25	1.22	1.21	1.18
Niigata	1.84	1.60	1.80	1.56
Toyama	1.33	1.20	1.30	1.16
Ishikawa	1.25	1.14	1.24	1.12
Fukui	1.27	1.16	1.24	1.12
Yamanashi	1.04	1.04	1.03	1.03
Nagano	1.14	1.11	1.12	1.09
Gifu	1.07	1.06	1.05	1.04
Shizuoka	1.11	1.06	1.09	1.05
Aichi	1.15	1.11	1.12	1.08
Mie	1.11	1.07	1.09	1.05
Shiga	1.02	1.02	1.02	1.02
Kyoto	1.09	1.06	1.08	1.05
Osaka	1.18	1.13	1.14	1.09
Hyogo	1.11	1.10	1.10	1.08
Nara	1.12	1.09	1.10	1.07
Wakayama	1.02	1.02	1.02	1.01
Tottori	1.09	1.06	1.08	1.05
Shimane	1.11	1.07	1.10	1.06
Okayama	1.09	1.06	1.07	1.05
Hiroshima	1.10	1.05	1.09	1.04
Yamaguchi	1.15	1.08	1.13	1.06
Tokushima	1.06	1.05	1.05	1.04
Kagawa	1.05	1.06	1.04	1.04
Ehime	1.06	1.05	1.05	1.04
Kochi	1.04	1.04	1.04	1.04
Fukuoka	1.12	1.06	1.10	1.05
Saga	1.07	1.05	1.07	1.04

(continued)

Table 5.6 (continued)

	Model A		Model B	
	1991–1999	2000–2007	1991–1999	2000–2007
Nagasaki	1.09	1.05	1.09	1.05
Kumamoto	1.07	1.03	1.07	1.03
Oita	1.05	1.03	1.05	1.03
Miyazaki	1.07	1.04	1.07	1.04
Kagoshima	1.09	1.04	1.10	1.04
Okinawa	1.03	1.02	1.03	1.02

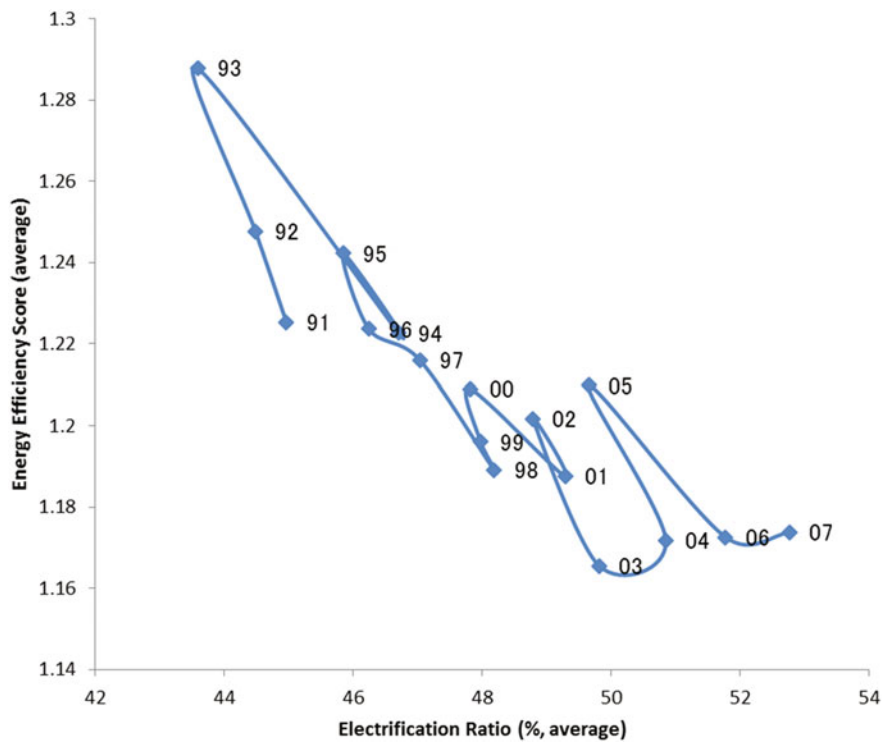


Fig. 5.1 Relationship between electrification ratio and energy efficiency score (regional average)

5.6 Conclusions and Policy Implications

In this study, energy efficiency levels in the residential sector were measured using a combination of an energy demand model and stochastic frontier model, based on data on Japan’s 47 prefectures. To the best of our knowledge, this is the first measurement of the energy efficiency levels of the residential sector in Japan’s

prefectures. For the specification of energy demand, each of production and prices, the number of households, floor area, urbanization, and temperature were controlled for in order to derive energy efficiency. Energy intensity, which is used as an energy efficiency index proxy variable, tends to be dependent on the economic and social structure of the region, so the fact that these influences were controlled for in this study when deriving the energy efficiency values can be said to result in a superior index that is more accurate.

From the results of this analysis, the following three points were clarified. First, in the case of Japan, the energy efficiency index ranking was correlated with the energy intensity ranking, which indicates the effectiveness of the energy efficiency index that this study employed. Second, the importance of population density for energy efficiency was reconfirmed. The findings suggested that the presence of DIDs and the formation of compact cities as defined in this study is the key to energy saving in residential sector. Third, promoting electrification in the residential sector and raising the regions' electrification rates also appear to result in energy savings.

In conclusion, together with the formation of compact cities in the regions, establishing an appropriate competitive environment and promoting electrification would seem to be extremely effective ways of improving energy efficiency in the residential sector. These policies will raise the productivity of regional economies as well as increase environmental efficiency. The results of this analysis showed that, in terms of the keys to achieving both higher productivity and improved environmental efficiency, promoting electrification and realizing decentralized, multipolar national spatial developments are vital steps.

References

- Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry. 2015. FY 2014 Annual Report on Energy (Energy White Paper 2015).
- Aigner, D.J., C.A.K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function model. *Journal of Econometrics* 6: 21–37.
- Aranda-Uson, A., G. Ferreira, M.D. Mainar-Toledo, S. Scarpellini, and E. Liera. 2012. Energy consumption analysis of Spanish food and drink, textile, chemical and non-metallic mineral products sectors. *Energy* 42: 477–485.
- Bento, A.M., and M.L. Cropper. 2005. The effects of urban spatial structure on travel demand in the United States. *The Review of Economics and Statistics* 87(3): 466–478.
- Boyd, G.A. 2008. Estimating plant level energy efficiency with a stochastic frontier. *The Energy Journal* 29: 23–43.
- Boyd, G., E. Dutrow, and W. Tunnessen. 2008. The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use. *Journal of Cleaner Production* 16(6): 709–715.
- Brownstine, D., and T.F. Golob. 2009. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* 65(1): 91–98.
- Buck, J., and D. Young. 2007. The potential for energy efficiency gains in the Canadian commercial building sector. *Energy* 32: 1769–1780.

- Charnes, A., W.W. Cooper, and E. Rhodes. 1978. Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research* 2(6): 429–444.
- Coelli, T. 1996. A guide to FRONTIER Version 4.1: a computer program for stochastic frontier production and cost function estimation. CEPA Working Papers. NSW, Australia: University of New England, #96/07.
- EIA. 1995. *Measuring energy efficiency in the United States' economy: a beginning*. Washington, DC, USA: Energy Information Administration. DOE/EIA-0555(95)/2
- EIA. 2013. *International energy outlook 2013*. U.S. Energy Information Administration.
- Feijoo, M.L., et al. 2002. Global warming and the energy efficiency of Spanish industry. *Energy Economics* 24: 405–423.
- Filippini, M., and L.C. Hunt. 2011. Energy demand and energy efficiency in the OECD countries: a stochastic demand frontier approach. *The Energy Journal* 32: 59–79.
- Filippini, M., and L.C. Hunt. 2012. U.S. residential energy demand and energy efficiency: a stochastic demand frontier approach. *Energy Economics* 34: 1484–1491.
- Filippini, M., and B. Lin. 2016. Estimation of the energy efficiency in Chinese provinces. *Energy Efficiency*. doi:[10.1007/s12053-016-9425-z](https://doi.org/10.1007/s12053-016-9425-z).
- IEA. 2009. Progress with implementing energy efficiency policies in the G8. International Energy Agency Paper.
- Karathodorou, N., D.J. Graham, and R.B. Noland. 2010. Estimating the effect of urban density on fuel demand. *Energy Economics* 32(1): 86–92.
- Lin, B.Q., and L.S. Yang. 2013. The potential estimation and factor analysis of China's energy conservation on thermal power industry. *Energy Policy* 62: 354–362.
- Lin, B., and X. Wang. 2014. Exploring energy efficiency in China's iron and steel industry: a stochastic frontier approach. *Energy Policy* 72: 87–96.
- Morikawa, M. 2012. Population density and efficiency in energy consumption: an empirical analysis of service establishments. *Energy Economics* 34: 1617–1622.
- Murillo-Zamorano, L.R. 2004. Economic efficiency and frontier techniques. *Journal of economic Surveys* 18(1): 33–77.
- Newman, P.W.G., and J.R. Kenworthy. 1989. Gasoline consumption and cities. *Journal of the American Planning Association* 55(1): 24–37.
- Otsuka, A., and M. Goto. 2015a. Estimation and determinants of energy efficiency in Japanese regional economies. *Regional Science Policy & Practice*. 7(2): 89–101.
- Otsuka, A., and M. Goto. 2015b. Agglomeration economies in Japanese industries: the Solow residual approach. *The Annals of Regional Science* 54(2): 401–416.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2010. Industrial agglomeration effects in Japan: Productive efficiency, market access, and public fiscal transfer. *Papers in Regional Science* 89(4): 819–839.
- Otsuka, A., M. Goto, and T. Sueyoshi. 2014. Energy efficiency and agglomeration economies: the case of Japanese manufacturing industries. *Regional Science Policy & Practice* 6(2): 195–212.
- Shui, H., X. Jin, and J. Ni. 2015. Manufacturing productivity and energy efficiency: a stochastic efficiency frontier analysis. *International Journal of Energy Research* 39(12): 1649–1663.