Kochi University of Technology

Social Design Engineering Series *SDES-2017-7*

Demographic effects on residential electricity and city gas consumption in aging society of Japan

Toru Ota
Toho Gas Corporation

Makoto Kakinaka
Graduate School for International Development and Cooperation, Hiroshima University

Koji Kotani
School of Economics and Management, Kochi University of Technology
Research Center for Future Design, Kochi University of Technology

2nd June, 2017

School of Economics and Management
Research Center for Future Design
Kochi University of Technology

Demographic effects on residential electricity and city gas consumption in aging society of Japan

Toru Ota[*] Makoto Kakinaka[†] Koji Kotani[‡,§,¶,‖,**]

May 31, 2017

Abstract

Japan has been confronted with two demographic forces, declining fertility rates and lengthening life spans, which give rise to the rising ratio of the elderly (aging society), the decline in population and the prevalence of nuclear families. This study empirically analyzes demographic effects on residential electricity and city gas consumption in Japan. Our analysis presents the following main results. First, the aging of the society decreases the electricity demand but increases the city gas demand. Second, the shrink of population with the prevalence of nuclear families increases the electricity demand but decreases the city gas demand. The direction of the demand for each alternative depends on the balancing of the first and second effects. Third, the analysis also shows clear results about the own- and cross-price effects. Ongoing energy market reforms targeting price reduction would increase the energy demand with the possible substitutability between the two energy sources. Our case study of Japan is also applicable to other countries that will, have just started to, experience the similar demographic pattern of the aging society with energy market deregulation.

Key Words: Demographic changes; aging society; energy markets; electricity and city gas demands

[*]Toho Gas Corporation

[†]Graduate School for International Development and Cooperation, Hiroshima University, 1-5-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8529, Japan (e-mail: kakinaka@hiroshima-u.ac.jp)

[‡]Research Center for Future Design, Kochi University of Technology

[§]School of Economics and Management, Kochi University of Technology

[¶]Urban Institute, Kyusyu University

[‖]College of Business, Rikkyo University

[**]Corresponding author, E-mail: kojikotani757@gmail.com

Contents

Nomenclature

EUIL Electric Utility Industry Law

GEU General Electricity Utilities

IPP Independent power producer

JPEX Japan Electric Power Exchange

PPS Power producer and supplier

UN United Nations

1 Introduction

Japan has been facing important demographic issues of the aging of society with the decline in birth rates (see, e.g., Muramatsu and Akiyama, 2011). According to the Statistics Bureau of the Ministry of Internal Affairs and Communication, the proportion of the Japanese population aged 65 or above has reached $25.97\,\%$, while that of aged 14 or below has declined to $12.77\,\%$ in 2014. Although most developed countries have experienced the aging of society, its speed in Japan has been tremendous, currently with the highest proportion of elderly citizens in the world. The "super-aged society" in Japan originates from continuous declines in the fertility and marriage rates with long life expectancy, associated with changes of norms and development of medical technology (figure 1). In addition, the number of households has outgrown with the decline in the average number of members within a household, and the majority of households would be elderly (figure 2). The trend of aged society is expected to continue in the future. The Statistics Bureau now estimates that $31.60\,\%$ of the population will be aged 65 or above, while only $10.32\,\%$ will be aged 14 or below in 2030. The government has recently attempted to respond to demographic concerns, such as possible shortage of labor force and pension system sustainability, and to introduce various public policies to restore the fertility rate and encourage the elderly to stay in work.

[Figure 1 about here.]

[Figure 2 about here.]

Demographic changes affect various macroeconomic conditions. Recent researches have contributed to understanding possible links between demographic and environmental processes in the field of environmental demography. One crucial issue among them is a possible effect on residential energy demand, since demographic features of the aged society, such as fewer household members and free-time-rich living environments, could affect consumption patterns for households (Yamasaki and Tominaga, 1997). For example, an ageing society inspires a large proportion of households to spend more time at home, rather than on activities outside, due to old people's preference on the sedentary life style. In addition, recent natural disaster, the Great East Japan Earthquake and tsunami in 2011, brought about huge natural disaster, which killed over 20,000 people and devastated social assets mainly in the Tohoku region. Radioactive pollution associated with the destruction of the nuclear power plants in Fukushima has made the public to realize crucial concerns of risks relying much on nuclear energy and has thus stimulated intense discussions on energy policies. The government authority has introduced various policy measures, including liberalization in pursuit of competitive environments, and has also attempted to set the future plans related to the long-run power supply configuration, i.e., the balancing among electricity, city gas, and other energy resources, with the consideration of various aspects, such as the energy efficiency and patterns of energy demand in the aged society. Thus, the examination on patterns of the residential demand for each energy resource under the ongoing aging of the society is required to plan and adopt appropriate energy policies.

There have existed many empirical studies on the roles of demographic factors, such as the population, age structure, household size, and urbanization, on energy and/or environmental issues (see Liddle, 2014, for a review of the demographic effects).[1] Among them, some works discuss the effects of demographic changes, particularly in age structure, on energy consumption. For instance, as macro-level and cross-country analyses, York (2007a) examines the demographic effects in 14 EU countries and presents that an increase in the proportion of the elderly is associated with increased energy consumption. The study of York (2007b) over 14 Asian countries shows that the proportion of the population in the productive age range has the positive effect on energy use. In addition, Liddle and Lung (2010) suggest the U-shaped lifecycle with respect to energy intensity in OECD countries by showing the relatively energy intensive lifestyle during the early adulthood and retirement-age periods and the relatively energy non-intensive lifestyle during the middle-age period. Liddle (2011) also shows the U-shaped effect of age structure on residential electricity consumption over 22 OECD countries in the sense of the positive impact for the young and the old cohorts and the negative impact for the middle. Moreover, as micro-level analyses, mainly at the household level, some studies have recently analyzed the effects of demographic factors on energy consumption and have argued that

[1]See, e.g., Dietz and Rosa (1997), Yamasaki and Tominaga (1997), O'Neill and Chen (2002), Shi (2003), Cole and Neumayer (2004), Fan et al. (2006), Martinez-Zarzoso et al. (2007), Roberts (2008), York (2008), Kronenberg (2009), Jorgenson and Clark (2010), Jorgenson et al. (2010), Poumanyvong and Kaneko (2010), Martinez-Zarzoso and Maruotti (2011), Fang et al. (2012), Jorgenson and Clark (2012), Okada (2012), Zhu et al. (2012), Knight et al. (2013), Liddle (2013) and Honjo and Fujii (2014)

different micro-demographic processes could cause various patterns of residential energy consumption (see, e.g., Pachauri, 2004, Brounen et al., 2012, Jingchao and Kotani, 2012, Fu et al., 2014, Valenzuela et al., 2014, Elnakat et al., 2016).

Concerning the case of Japan, few empirical studies have focused on the demographic effects on energy issues with the consideration of the rapid aging of the society, although there is a lot of literature on energy policy issues related to energy production and consumption in Japan (Takase and Suzuki, 2011, Lu et al., 2016). As an initial study on the demographic effects in Japan, Yamasaki and Tominaga (1997) discuss the evolution of the aging society and its effects on residential energy demand in Japan by examining possible factors which determine energy demand of elderly households and predicting future residential energy consumption. However, their study remains at summarizing current aging trends of demography and energy use but does not employ empirical analysis in a scientific manner. Differently from the previous studies, our study attempts to analyze the demographic effects on residential energy consumption by employing econometric methods with the panel data at the prefecture level.[2] In addition, this paper intends to evaluate the demographic effects on the demands for two main energy sources in Japan, electricity and city gas, taking into account their substitutability in the energy markets.

The Agency of Natural Resources and Energy of Japan reports that the proportions of electricity and city gas to the total residential energy consumption amount to $50.6\,\%$ and $20.7\,\%$ in 2011, respectively. These two crucial energy industries are currently in the final process of liberalization whose objective is to ensure not only fair treatment of all entrants into the markets but also the stable supply of electricity and city gas. The Great East Japan Earthquake and resulting tsunami in 2011, which severely damaged the Fukushima Daiichi nuclear power plant, has casted a significant reconsideration of the national energy strategy, including market structures of the electricity and city gas industries (see, e.g., McLellan et al., 2013, Kuramochi, 2015). Thus, the novelty of our study would be to attempt to empirically examine the roles of ongoing demographic issues related to the aging of the society in determining the residential energy demands for the two crucial sources, electricity and city gas. The analysis on such an issue must be significant and important to understand current and future paths of energy demands

[2] Relevant studies may include the work of Honjo and Fujii (2014) that evaluate the impacts of demographic, meteorological, and economic changes on emissions by examining household emissions in the 47 prefectures of Japan.

and to design sound energy policy in Japan.

Our empirical study employs the panel data analysis with the prefecture-level data of residential electricity and city gas consumption and several demographic variables, which capture the aging of the society in Japan, during the five periods (every five years from 1990 to 2010). The results related to demographic effects first present that the aging of the society, or a rise in the proportion of the elderly, would decrease the electricity demand but increase the city gas demand. In addition, the shrink of population with the prevalence of nuclear families increases the electricity demand but decreases the city gas demand. The direction of the total effect of demographic changes on the demand for each alternative depends on the balancing of the first and second effects.

Concerning non-demographic effects, our analysis presents important implications about the ongoing deregulation processes of the energy markets. The result observes that a reduction in electricity price would increase the electricity demand, but it would not affect the city gas demand significantly. On the other hand, a reduction in city gas price would increase the city gas demand, but it would decrease the electricity demand due to the substitution effect. Our empirical results of demographic and non-demographic effects would provide some important implications about future directions of energy policy in Japans electricity and city gas markets. Moreover, the empirical findings are also applicable to other countries that will, have just started to, experience the similar demographic pattern of the aging society with energy market deregulation.

2 Demographic changes and energy industries in Japan

This section first provides a brief overview of the aging of society with low fertility in Japan and its demographic conditions. Then we explain Japans energy markets by focusing on the two major industries, electricity and city gas industries.

2.1 Demographic changes in Japan

The United Nations (UN) defines an aging society as the one where more than $7\,\%$ of the population is over the age of 65, and it also defines populations with more than $20\,\%$ elderly as a “super-aged” society. Aging is not only a developed country problem, but many emerging markets have already been classified as an aging country. It should be emphasized that the pace of aging population in some emerging countries is more rapid than in developed countries. In Japan, the proportion of the elderly aged 65 or above has reached 26 % in 2014 (Statistics Bureau of the Ministry of Internal Affairs and Communication) with its highest fraction all over the world, which implies that Japan has already reached a zone far beyond "super-aged" society. The aging trend is expected to continue, so that the proportion of the elderly will reach 30 % by 2025 and almost 40 % by 2060, which no country has ever experienced in our human history.

Population aging is accompanied with the shrinkage of the total population and labor force, which would cause various economic and social problems, such as the pulling-down of potential economic growth rate, large burdens on the social security system, elderly poverty, and elderly health care including dementia. For instance, a decline in labor force will bring about the contraction of national production and income, as well as possibly the productivity low-down and the losing of international competitiveness. In addition, increased social security costs have been a major force to recent large fiscal deficit in Japan. Moreover, elderly poverty and health care have recently become important social problems in Japan.

Traditional social norm in Japan required a familys eldest (or elder) son and his wife to take a kind of responsibility in providing care for his parents. However, such traditional norm has diminished, as the economy has developed with increased number of nuclear families. Recently, some surveys show that elderly people in Japan tend to feel more socially isolated than in other advanced countries. Moreover, the 2011 Great East Japan Earthquake caused the issue of aging to receive more attention from the public and policymakers. Since the Tohoku regions, where social infrastructure was seriously destroyed by the earthquake and tsunami, have long faced various social problems associated with depopulation, low birth rate, longevity, and hollowing-out of industry, the issue of aging has further attracted remarkable attention in the whole regions, especially in rural regions, which calls for prompt and effective public policies.

It has been widely acknowledged that the aging of society is caused by two main demographic factors: increasing longevity and declining fertility rate (see various reports on the aging of society published by the Cabinet Office of the Government of Japan). Since the end of World War II, the improvement of living environments and dietary life and the progress of medical technology have decreased mortality for all generations and thus have increased longevity. An increase in longevity has raised the average age of the population, so that the population of the elderly has increased substantially. In addition, it is also known that low fertility or birth rate in Japan mainly originates from a rise in the percentage of unmarried people, advancing of late marriage and late birth, and the low average number of births for each household. This trend could be caused by changes in the traditional sense of values about human life, including increased burdens of childcare, difficulty in managing to balance work and childcare, high education costs, and well-educated womens social advancement (see, e.g., Retherford et al., 2001, Narayan and Peng, 2007, Boling, 2008). A decline in fertility generally has reduced the numbers of babies as well as the population of younger people.

The heavy demographic issues of the aging society with low fertility have generated a wide range of social and economic problems, including the sustainability of the social security system, which creates huge challenges for the Japanese economy. To solve them, Japan requires new public policies and social support network system at both the macro- and micro-levels (see, e.g., Muramatsu and Akiyama, 2011). Indeed, the central and local governments have attempted to solve such demographic problems by developing a series of public policies to increase fertility and to keep the total population and the labor force. These public policies include the encouragement of women and elderly to engage in the labor force and the provision of incentives for family formation, such as establishment of enough nursery centers, reduction in burdens for childcare, childcare allowance and non-financial compensations for families with children, exemption of tuition fees for public high school, and even public provision of match-making marriage services.

2.2 Energy industries in Japan

Figure 3 shows the total population and residential energy consumption in Japan during the period from 1965 to 2010. It appears that the growth of residential consumption dominated the population growth during the economic growth period until the early 1990s, but both residential consumption and the population has peaked out or remained at certain levels since 2000s. Figure 4 presents consumption of the two main sources, electricity and city gas, in the residential sector. The electricity consumption has increased steadily. On the other hand, the city gas consumption increased along with the population growth until the mid 2000s, but since then it has peaked out or remained at a certain level. The rise in the electricity consumption is much larger than that in the city gas consumption.

[Figure 3 about here.]

[Figure 4 about here.]

2.3 Electricity industry

The electricity industry is characterized as a natural monopoly. The market structure of the electricity industry in Japan used to follow regional monopolies without new entries under the regulation, so that competition did not exist among them. Ten vertically integrated electric power companies, or General Electricity Utilities (GEU), have covered operations from generation to retail supply. Regulatory reforms in the electricity industry started in 1995 with the amendment of the Electric Utility Industry Law (EUIL), which intended to introduce partial competition in the power-generation sector (see, e.g., Nakano and Managi, 2008, Goto and Sueyoshi, 2009, various documents published by the Ministry of Economy, Trade, and Industry and the Agency for Natural Resources and Energy). This reform enabled new entrants to enter the power-generating markets by allowing electric power companies to buy electricity from outside sources, such as firms in-house generators that generated more electricity than they needed and independent power producers (IPPs), and by introducing the competitive tendering system with simplified approval conditions. In addition, the government also introduced yardstick regulation as a form of incentive regulation to encourage competition in the market.

The subsequent amendment of the EUIL in 1999 has introduced partial liberalization in retail markets since 2000. This liberalization allowed electricity companies to compete to customers using more than $2000\,\mathrm{kW}$ of electricity, which accounted for almost $30\,\%$ of the total electricity supply, with deregulation on prices for the large customers and transmission lines for access by third parties. This amendment enabled power producer and supplier (PPS) to enter the market. Since then, the retail market has gradually been deregulated from large customers to smaller ones. The amendments of the EUIL have liberalized the eligibility to be lowered to 500 kW in 2004 and to 50 kW in 2005. In addition, Japan Electric Power Exchange (JEPX) was established as a wholesale power exchange. Moreover, the government has improved regulation of third party access to grid lines and has introduced accounting separation of transmission and distribution sectors. Due to a series of reforms, almost all customers, except for households, are free to choose their electricity suppliers from incumbents and new entrants.

2.4 City gas industry

Similarly to the electricity industry, the government has implemented a series of regulatory reforms on the city gas industry to secure the stable supply of natural gas, suppress gas prices, and expand gas choice for consumers and business opportunities as well as uses for natural gas. The Gas Business Act was established in 1925, and the present Gas Business Act was reorganized in 1954 after World War II. In contrast to only ten electric power utilities in the electricity market, there are 209 city gas companies or utilities in 2013, 13 % of which are owned by local governments. The deregulation of the city gas industry started in 1995 (see, e.g., Takahashi, 2006). The regulatory reform abolished regulations on market entry and gas rates for the supply of gas to large-volume gas users with at least 2 million cubic meters under annual contracts. The subsequent regulatory reform in 1999 expanded the scope of liberalization of the city gas retail market by covering gas users with an annual contracted volume of at least 1 million cubic meters, with deregulation on gas rates. In addition, the transportation service was passed into low, which required four major city gas companies to prepare consignment supply agreements.

Further deregulation was adopted in 2004, so that the scope of liberalization was extended to gas users with an annual contracted volume of at least 500 thousand cubic meters, which would approximately to the volume consumed by medium-sized factories. The transportation service was also extended to all domestic natural gas suppliers thacityed gas pipelines and electric power companies, although certain conditions were required. Liberalization in 2007 extended the scope of eligibility to gas users with an annual contracted volume of at least 100 thousand cubic meters with deregulations on various operations including the transportation service. Such a series of regulatory reforms toward liberalization have intensified competition in the city gas market, although the role of new entrants is still relatively small. As of 2012, the gas supply by new entrants has reached approximately 15 % of the deregulated portion of the supply in the city gas market, where the electricity supply of PPS is less than 4 % of the deregulated portion of the supply the electricity market. Although the city gas market has been under the liberalization process, new entry has been limited to mainly entities that own sources of gas, such as electric power companies, oil companies, and trading companies (Takahashi, 2006).

3 Empirical analysis

City gas and electricity are major fuels for households in Japan. According to the Agency for Natural Resources and Energy, city gas and electricity serve 20.7 % and 50.6 % of total residential energy consumption as of 2011, respectively. This section discusses how demographic factors relate to residential demands for city gas and electricity in Japan by conducting empirical analysis with the prefecture-level panel data covering 47 prefectures every 5 years during the period from 1990 to 2000.

3.1 Methodology and data

To discuss the role of demographic factors in determining households demand for city gas and electricity at the prefecture level, we consider four main demographic factors which characterize the aged society in Japan. The first is the proportion of the elderly, which is defined as the population aged 65 or above. The second is the population, and the third is the average number of household members. The last factor is the total fertility rate, which is captured by the average number of children born to a woman over the female population. These four factors closely reflect the central issues on the aging of the society and the shrinkage of the population with the decline in the birth rate in Japan. To examine the demographic effects, this study estimates the following two equations (the electricity and city gas equations), each of which electricity consumption and city gas consumption as the dependent variable:

$$QE_{it} = \alpha_0 + \alpha_1 ELD_{it} + \alpha_2 POP_{it} + \alpha_3 POH_{it} + \alpha_4 TFR_{it} + \sum_k \gamma_k X_{kit} + \epsilon_{it},$$

$$OG_{it} = \beta_0 + \beta_1 ELD_{it} + \beta_2 POP_{it} + \beta_3 POH_{it} + \alpha_4 TFR_{it} + \sum_k \eta_k X_{kit} + \varepsilon_{it},$$

where QE_{it} and OG_{it} are the logs of electricity and gas consumption (terajoul (TJ)) in prefecture i at year t, respectively; $ELD_{it}, POP_{it}, POH_{it}$ and TFR_{it} are the proportion of the elderly, the log of the total population, the average number of household members, and the total fertility rate, respectively; X_{kit}s are other control variables that are expected to affect electricity consumption and city gas consumption; and ϵ_{it} and ε_{it} are error terms. Table 1 summarizes all the definitions of variables used in the analysis. Figures 5 to 8 illustrate the proportion of the elderly, the log of the total population, the average number of household members, and the total fertility rate for each prefecture in 2010, respectively.

[Table 1 about here.]

[Figure 5 about here.]

[Figure 6 about here.]

[Figure 7 about here.]

[Figure 8 about here.]

Our empirical models include the proportion of the elderly (or the population aged 65 or above) to the total population (ELD_{it}) at the prefecture level, which can be considered as a direct measure of the aging of each prefecture. In addition, we include the log of the total population (POP_{it}) at the prefecture level to capture the effects of the population size and the concentration of economic and social activities in the economy. Moreover, this study considers the average number of family members (POH_{it}) to evaluate the increasing importance on a small-sized family or a nuclear family, which is a family group consisting of a pair of adults (or the elderly) and their children, in the society of Japan. Furthermore, the total fertility rate (TFR_{it}) is included to examine the role of the recent declining trend of the number of children and infants. As other control variables, this study incorporates some of non-demographic variables into our models. Our models include the logs of electricity and gas prices at the prefecture level (PE_{it} and PG_{it}), so that the coefficients of PE_{it} and PG_{it} in the electricity (city gas) equation measure the own- and cross-price (cross- and own-price) elasticities, respectively. The cross-price elasticity captures the substitutability or complementarity of electricity and city gas consumptions. In addition, the models include the log of per capita gross prefectural product (INC_{it}) to capture the income level at the prefecture level. Moreover, we include the time dummies to control for the time-specific effects to partly account for unobserved heterogeneity.

The panel data at the prefecture level consists of five periods (every five years from 1990 to 2010, i.e., 1990, 1995, 2000, 2005, and 2010). Table 1 exhibits the definitions of variables used in this study. The data of electricity and gas consumptions (TJ) in the residential sector is obtained from the Energy Consumption Statistics of the Research Institute of Economy, Trade and Industry, and the data of nominal gross prefectural product (million yen) is taken from the Economic and Social Research Institute. Concerning the price information, the data of average prices of electricity and city gas at the prefecture level is collected from annual reports on the retail price survey of the Statistic Bureau, the Ministry of Internal Affairs and Communications. Since there does not exist the data of average prices at the prefecture level, we use the information in each prefectural capital as a reference. Although we admit that the price schemes of electricity and city gas are generally complicated, we take the price of electricity in the first energy charges from 1 to $120\,\mathrm{kW\,h}$ and the price of city gas per $1465.12\,\mathrm{M\,J}$ as the average prices of electricity and city gas, respectively. Regarding the demographic data, we obtain the population data, including the population of aged 65 or above and the total fertility rate, and the household data from the census reports and annual reports on the population estimates of the Statistics Bureau, the Ministry of Internal Affairs and Communications. The population density is calculated by the total population per square kilometer of land area, which is taken from the prefectural area survey of the Ministry of Land, Infrastructure, Transport and Tourism.

Tables 2 and 3 report the summary of statistics and the correlation matrix of variables used in our empirical analysis. The correlation matrix shows that among our four important demographic variables, the proportion of the elderly (ELD_{it}) is negatively correlated with the electricity consumption (QE_{it}) and the city gas consumption (QG_{it}), so that the recent issue of the aged society with the high proportion of the elderly in Japan is associated with the decreased demands for electricity and city gas. The matrix also presents that the average number of household members (POH_{it}) and the total fertility rate (TFR_{it}) are also negatively correlated with the electricity and city gas consumptions, so that the spread of the small-sized family and the low total fertility rate in the aged society are associated with the increased demands for electricity and city gas. In addition, the population (POP_{it}) are positively correlated with the electricity and city gas consumptions, so that the large population increases electricity and city gas demands. Regarding non-demographic variables, the electricity and city gas consumptions are negatively correlated with their own price as well as other energy price (PE_{it} and PG_{it}) which appears to imply that electricity and city gas are ordinary goods and complements. Moreover, the electricity and city gas consumptions are positively correlated with the income level (INC_{it}), and they are negatively correlated with the average number of household members (POH_{it}). It should be noticed that the correlation analysis simply presents the statistical association between two variables, and thus more careful examination should be required to analyze the roles of demographic and non-demographic factors in relating to the energy demand.

[Table 2 about here.]

[Table 3 about here.]

This study empirically evaluates the demographic effects on residential electricity and city gas consumption by applying fixed effects (FE) and Prais-Winsten (PW) methods. We first apply the FE estimation, since our sample may face the heterogeneity problem so that the OLS estimation could suffer from heterogeneity bias with a common constant term. The Wooldridge tests for autocorrelation in panel data (Wooldridge, 2010) suggest that our FE estimation could suffer from serial correlation. In addition, the modified Wald statistic for groupwise heteroskedasticity in the residuals of a fixed effects model observes the presence of heteroscedasticity in our FE estimation (Greene, 2011). These results imply that the estimated results of the FE estimation could suffer from the biased problem. Thus, we conduct the PW estimation with panel-corrected standard errors to control for serial correlation of type AR(1), heteroskedascity, and cross-panel correlation.

3.2 Results

This subsection presents the estimated results and their implications on how demographic factors relate to electricity and city gas consumptions in Japan. In this study, our empirical models include four demographic variables, the proportion of the elderly (ELD_{it}), the population (POP_{it}), the average number of household members (POH_{it}), and the total fertility rate (TFR_{it}), which captures the ongoing issue in the aged society of Japan.

3.2.1 Demographic effects

Table 4 presents the estimated results of the electricity and city gas consumption equations by applying the fixed effects (FE) and Prais-Winsten (PW) methods. First, the results show that the coefficients on the proportion of the elderly (ELD_{it}) are significantly negative in the electricity consumption equation, irrespective of the choice of methods, while they are significantly positive in the city gas consumption equation although less clear results under the FE method. The effects of the aged society show the different direction between the electricity and city gas consumptions. Prefectures with the high proportion of the elderly face the relatively small electricity demand and large city gas demand, while those with the low proportion of the elderly face the relatively large electricity demand and small city gas demand. The coefficients on ELD_{it} in the electricity consumption equation are estimated at around $-1.1 \sim -1.0$, and those in the city gas consumption equation are estimated at around $1.6 \sim 1.7$. This implies that an $1\,\%$ rise in the proportion of the elderly would result in an $1.0 \sim 1.1\,\%$ decline in the electricity consumption and an $1.6 \sim 1.7\,\%$ increase in the city gas consumption. Our results showing different directions for electricity and city gas demands would explain the insignificant effect of age structure in many of macro-level empirical studies, as mentioned in the survey study of Liddle (2014). Once we consider the disaggregated level, i.e., electricity and city gas demands, our results could provide a clear picture of the demographic effects.

[Table 4 about here.]

Possible explanation about the positive effect on the city gas demand and the negative effect on the electricity demand could be related to the differences in the lifestyle between the young and the elderly (see Yamasaki and Tominaga, 1997, for the details of residential energy demand in the aging society of Japan). Compared with the young, the elderly is generally characterized by the free-time-rich lifestyle so that they tend to stay home longer. This lifestyle of the elderly would increase residential energy use associated with home appliances. In Japan, a large portion of appliances that are required for the daily life at home may consist of gas using appliances, such as heaters, gas cooking appliances, and hot-water suppliers in kitchens and bathrooms, although all-electrified houses have recently been prevailed mainly for newly constructed houses and apartments. The large length of home occupancy for the elderly implies the positive association of the aged society with the city gas demand. In addition, elderly people are often likely to prefer gas using appliances due to their familiarity with how to use them and their sense of some difficulty in using electricity using appliances often attached with many new functions. Moreover, young people tend to use various kinds of electrical equipment and components and electrical circuit games, which would increase the electricity demand for the young. In contrast, old people are likely to limit the use of appliances on products, mainly gas-using appliances, which would increase the city gas demand for the elderly. The above arguments suggest that the young people tend to have relatively large electricity demand, while the elderly people tend to have relatively large city gas demand. Thus, the intensified aging of the society would decrease the electricity consumption but increase the city gas consumption.

Second, the estimated results present that, given the household size fixed, the coefficients on the population (POP_{it}) are significantly positive in both the electricity and city gas consumption equations, so that prefectures with large population tend to have large residential energy demand. However, the values of the estimated coefficients on POP_{it} differ remarkably between the electricity and city gas consumptions, such that the coefficients in the electricity consumption equation are more than five times larger than those in the city gas consumption equation. Given the household size fixed, the estimated elasticity of the electricity demand in response to a change in the population is around 0.3, while those of the city gas demand is around $1.7 \sim 1.8$. The interpretation of this outcome would be relevant to the features of each energy business and the population density that is associated with the population in the region. Electricity business covers most of lands in Japan. On the other hand, city gas business concentrates on urban areas. Since the investment to install and expand the distribution network of the gas pipeline is costly and, in some cases, technically quite difficult, especially in rural areas, city gas companies tend to prioritize to bury pipelines in areas with the large population. An increase in the population enhances peoples choice of energy sources, which would enable people to choose city gas use. Thus, the city gas consumption is more sensitive to the population size than the electricity consumption. Moreover, given that the electricity consumption is nearly twice as large as the city gas consumption in 2010 (see figure 4), the population elasticity of energy demand is estimated at around 0.8, which is close to the empirical result of South and East Asia in York (2007b).

Third, concerning the effect of the average number of persons per household (POH_{it}), the analysis observes that the coefficients on POH_{it} is significantly negative in the electricity consumption equation, while those in the city gas consumption equation is insignificant. Given the population fixed, the elasticity of the electricity demand in response to the average number of household members is estimated at approximately -0.31. In general, as the family size is larger, energy efficiency per household improves due to the prevention of the duplication of the use of appliances in the same household. Thus, residential energy use is expected to be negatively associated with the average number of persons per household. Our estimated results suggest that the aforementioned arguments are crucial for the use of electricity, but not for the use of city gas. Assuming the fixed population, the prevalence of nuclear families increases the electricity demand.

The previous discussions about the effects of changes in population and the average household size (number of household members) are based on the presumption that the household size and population are exogenously fixed, respectively. Noting that the average household size is calculated by dividing population by the number of households, one can also estimate the effect of a population change on energy consumption, as the number of households fixed, by differentiating the two terms, POP_{it} ($=$ $\ln$[population]) and POH_{it} ($= \frac{\text{population}}{\text{number of households}}$) with respect to POP_{it}. This would reflect the current situation of the aging society in Japan, since the death of the elderly implies the decline in population as well as the possible decline in the household size. Currently, in Japan, many old people live together with their spouse, not with their children, particularly after their children become an adult. Once their spouse passes away, they tend to live alone.[3] Thus, the effect of a decline in population (perhaps the elderly population) on energy consumption can be decomposed into the two sub-effects, direct effect and indirect effect through the decline in the household size.

Our estimation suggests that a 1 percent increase in the population decreases the electricity demand

[3]Furthermore, the elderly who lives alone faces issues about "solitary death" or death at home without anyone knowing, which has recently become serious social problems in Japan.

by $0.56 \sim 0.58$ %, given that the household size is equal to its sample average of 2.88.[4] In contrast, a $1\,\%$ percent increase in the population increases the city gas demand by $1.74\,\%$, given that the coefficient on the household size is insignificant. The results confirm that the shrink of population mainly associated with the death of the elderly, along with the decline in the household size (perhaps an increase in the number of the elderly who lives alone), increases the electricity demand, but decreases the city gas demand. Regarding the total fertility rate (TFR_{it}) as a final demographic factor in this study, the coefficients on TFR_{it} are insignificant for all models, so that the electricity and city gas demands are generally insensitive to the total fertility rate.

3.2.2 Other control variables

Concerning other control variables that are not directly related to demographic factors, the estimated results show that the coefficients on the income level (INC_{it}), which is measured by per capita gross prefectural product, in the electricity consumption equation are significantly positive for the PW estimation, although less significant results for the FE estimation, and those in the city gas consumption equation are insignificant for both estimation methods. Energy consumption tends to increases along with a rise in the income level. However, our results imply that the income effect is significant only on the electricity demand but not on the city gas demand. In general, a large portion of gas using home appliances can be classified into indispensable equipment for daily life, while electricity using appliances include indispensable equipment as well as a variety of appliances for entertainment and luxury life. High-income people tend to consume electricity using appliances to enjoy their luxury life. Thus, prefectures with the high income end up with the relatively large electricity demand.

The analysis also presents some clear evidences of the own- and cross-price effects on the electricity and city gas demands in Japan. The estimated results of the electricity consumption equation show that

[4] For the FE estimation result of the electricity consumption equation, differentiating QE_{it} with respect to POP_{it} yields

$$\frac{\partial QE_{it}}{\partial POP_{it}} = 0.320 - 0.307 \times \frac{1}{HH} \times \frac{\partial POPL_{it}}{HH_{it}} = 0.320 - 0.307 \times \frac{POPL_{it}}{HH_{it}}$$

where $POPL_{it}$, POP_{it} and HH_{it} are the population, the log of the population and the number of households, respectively. By using the sample average of household size or the average number of persons per household of 2.878 (see table 2), we can derive

$$\frac{\partial QE_{it}}{\partial POP_{it}} = 0.320 - 0.307 \times 2.878 = -0.583.$$

the coefficients on its own price (PE_{it}) and city gas price (PG_{it}) are significantly negative and positive, respectively, irrespective of the model choice. The electricity demand is reduced by a rise in its own price, but it is increased by a rise in city gas price. This analysis supports the conventional argument of the negative own-price effect and the positive cross-price effect associated with the substitutability of two goods in the sense that the electricity consumption is substituted for the city gas consumption when city gas price goes up. The results present that the own- and cross-price elasticities of the electricity demand are estimated at around $-0.38 \sim -0.32$ and $0.09 \sim 0.13$, respectively.

On the other hand, the empirical analysis of the city gas consumption equation illustrates that the coefficients on its own price (PG_{it}) are significantly negative, irrespective of the model choice, but those on electricity price (PE_{it}) are insignificant. The city gas demand is reduced by a rise in its own price, but it is insensitive to a change in electricity price. In contrast to the case where the electricity demand shows the substitutability with the city gas consumption, the estimated results present that the city gas consumption tends to be less substituted for the electricity consumption even when electricity price goes up. Possible justification may include that the product variety of electricity using appliances are much larger than that of gas using appliances. Electricity using appliances can be substituted for a larger portion of gas using appliances, but gas using appliances cannot be substituted for a large portion of electricity using appliances. Thus, the electricity consumption equation shows the significantly positive cross-price effect, but the city gas consumption equation fails to present the clear evidence supportive of the cross-price effect. The results show that the own-price elasticity of the city gas demand is estimated at around $-0.24 \sim -0.23$, which is smaller than the estimated own-price elasticity of the electricity demand.

3.2.3 Discussion

The previous subsections have examined how the electricity and city gas consumptions relate to demographic factors, some of which reflect the aged society of Japan, and other non-demographic factors, such as the income level and electricity and city gas prices at the prefecture level. Based on our empirical findings, this subsection attempts to discuss current and future pictures of the energy demand in relation to the ongoing aging of the society in Japan. The main issues of the aged society in Japan, most of which are and will be shared by other developed and emerging countries, are on the increase in the proportion of the elderly (ELD_{it}), the decline in the population (POP_{it}), the small size of the number of household members (POH_{it}), and the low level of the total fertility rate (TFR_{it}). In addition, the central authority has attempted to liberalize energy markets by removing barriers in vertical integration and to create a comprehensive and competitive energy markets in Japan (see, e.g., Takase and Suzuki, 2011). Possible benefits from such liberalization may include the promotion of innovation with different services and development of revolutionary technology for energy-related firms and the expansion of energy choices with low and stable energy prices for consumers.

In connection with social issues associated with ongoing Japan's aged society, our empirical analysis could deduce the following implications about the electricity and city gas demands. First, the negative aging effect on the electricity demand and the positive aging effect on the city gas demand in our empirical results suggest that as the aged society prevails, the electricity demand would decrease but the city gas demand would increase. Second, the empirical analysis has presented the positive effect of the population on both the electricity and city gas consumptions, with the latter effect more intensified, given the number of persons per household per household exogenously fixed. Third, our results have also shown the significantly negative association of the family size with the electricity demand but the insignificant association with the city gas demand, given the population exogenously fixed.

Fourth, assuming that the number of household is exogenously fixed, the effect of a decline in population (perhaps the elderly population) on energy consumption can be decomposed into the two sub-effects, direct effect and indirect effect through the decline in the household size. The assumption might reflect current trend of the aging society in Japan, where the death of the elderly reduces the population as well as downsizes the household size. The estimation results confirm that given the number of households exogenously fixed, the shrink of population mainly associated with the death of the elderly, along with the decline in the household size (perhaps an increase in the number of the elderly who lives alone), increases the electricity demand, but decreases the city gas demand. The indirect effect through the decline in the household size dominates the indirect effect for the electricity demand, while the direct effect dominates the indirect effect for the city gas demand. Fifth, current low level of the total fertility rate in Japan, as the last demographic factor in our models, appears not to affect energy demand significantly.

The ongoing energy market reforms toward liberalization will bring about various impacts on economic activities, such as production and consumption, in Japan. Although there are a lot of discussion about the effects of policy reform on energy prices, most of the public expect that deregulation, including removals of barrier to new entry, stimulates competition among energy suppliers, which would reduce energy prices and increase the variety of services for consumers. The estimated price effects in our analysis suggest that the reduction in electricity price, perhaps associated with intense competition, would increase the electricity demand, but it would not affect the city gas demand significantly. On the other hand, our empirical results illustrate that the reduction in city gas price would increase the city gas demand, but it would also decrease the electricity demand due to the substitution effect.

4 Conclusion

Japan has been facing crucial demographic issues of the aging population with the low fertility. In addition, the recent huge earthquake in the Tohoku region of Japan and the subsequent event of the destruction of nuclear power plants in Fukushima have shed light on fundamental policy issues of energy mix and its sustainability in Japan. Among various energy-related issues, this study has analyzed the effects of demographic and non-demographic factors on electricity and city gas consumption in the residential sector by using the panel data at the prefecture level. Our empirical analysis has shown the clear evidence of different demographic effects on the electricity and city gas demands, which would provide important implications for energy policy formulation as well as corporate strategy of energy-related companies under the ongoing aging of the society in Japan.

The results have presented the following important effects. First, the aging of the society decreases the electricity demand but increases the city gas demand. Second, the shrink of population with the prevalence of nuclear families increases the electricity demand but decreases the city gas demand. The direction of the demand for each alternative depends on the balancing of the first and second effects. Third, the analysis also shows clear results about the own- and cross-price effects. Ongoing energy market reforms targeting price reduction would increase the energy demand with the possible substitutability between the two energy sources. Our case study of Japan is also applicable to other countries that will, have just started to, experience the similar demographic pattern of the aging society with energy market deregulation.

This study has not explicitly examined the linkage of demographic changes with environmental issues. However, since environmental pollution reflects energy consumption crucially, our results of energy consumption have also provided some implications about environmental protection arguments. Although in the Kyoto Protocol Japan agreed to target the reduction of national greenhouse emissions per year by 6 percent from the level in the base year (1990) during the first commitment period of 2008-2012, Japan's CO_2 emissions have exceeded the level in the base year 1990. Possible reasons include the unsatisfactory performance in the household sector, which has been, and will be, closely related to demographic changes. During this period, CO_2 emissions in the household sector increased from the level in the base year, while those in the industrial sector decreased (Honjo and Fujii, 2014). In addition, the shutdown of nuclear power plants after the 2011 earthquake and tsunami have enforced Japans energy supply to shift from nuclear power generation as clean energy to fossil fuel power generation with large emissions. To mitigate this problem, natural gas has received attention as clean energy. Thus, our study on demographic effects on residential electricity and city gas demands would also help policymakers plan energy policy that balances between environmental protection and sustainable energy supply under the aging of the society.

Acknowledgments

The authors thank anonymous referees, Kenta Tanaka and Hiroaki Miyamoto for their helpful comments, advice and support.

5 Bibliography

Boling, P. (2008). Demography, culture, and policy: Understanding Japan's low fertility. *Population and development review*, 34(2):307–326.

Brounen, D., Kok, N., and Quigley, J. (2012). Residential energy use and conservation: Economics and demographics. *European economic review*, 56:931–945. World Bank policy research working paper 6589.

Cole, M. A. and Neumayer, E. (2004). Examining the impact of demographic factors on air pollution. *Population and environment*, 26:5–21.

Dietz, T. and Rosa, E. A. (1997). Effects of population and affluence on CO_2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, 94:175–179.

Elnakat, A., Gomez, J. D., and Booth, N. (2016). A zip code study of socioeconomic, demographic, and household gendered influence on the residential energy sector. *Energy reports*, 2:21–27.

Fan, Y., Liu, L., Wu, G., and Wei, Y. (2006). Analyzing impact factors of CO_2 emissions using the STIRPAT model. *Environmental impact assessment review*, 26:377–395.

Fang, W. S., Miller, S. M., and Yeh, C. (2012). The effect of ESCOs on energy use. *Energy policy*, 51:558–568.

Fu, C., Wang, W., and Tang, J. (2014). Exploring the sensitivity of residential energy consumption in China: Implications from a micro-demographic analysis. *Energy research and social science*, 2:1–11.

Goto, M. and Sueyoshi, T. (2009). Productivity growth and deregulation of Japanese electricity distribution. *Energy policy*, 37:3130–3138.

Greene, W. H. (2011). *Ecnometric analysis*. Prentice hall.

Honjo, K. and Fujii, M. (2014). Impacts of demographic, meteorological, and economic cchange on household CO_2 emissions in the 47 prefectures of Japan. *Regional science policy and practice*, 6:13–30.

Jingchao, Z. and Kotani, K. (2012). The determinants of household energy demand in rural Beijing: Can environmentally friendly technologies be effective? *Energy economics*, 34:381–388.

Jorgenson, A. and Clark, B. (2012). Are the economy and the environment decoupling? A comparative international study, 1960-2005. *American journal of sociology*, 118:1–44.

Jorgenson, A., Rice, J., and Clark, B. (2010). Cities, slums and energy consumption in less developed countries. *Organization and environment*, 23:189–204.

Jorgenson, A. K. and Clark, B. (2010). Assessing the temporal stability of the population/environment relationship in comparative perspective: A cross-national panel study of carbon dioxide emissions, 1960–2005. *Population and environment*, 32:27–41.

Knight, K. W., Rosa, E. A., and Schor, J. B. (2013). Could working less reduce pressures on the environment? A cross-national panel analysis of OECD countries, 1970-2007. *Global environmental change*, 23:691–700.

Kronenberg, T. (2009). The impact of demographic change on energy use and greenhouse gas emissions in Germany. *Ecological economics*, 68:2637–2645.

Kuramochi, T. (2015). Review of energy and climate policy developments in Japan before and after Fukushima. *Renewable and sustainable energy reviews*, 43:1320 – 1332.

Liddle, B. (2011). Consumption-driven environmental impact and age structure change in OECD countries: A cointegration-STIRPAT analysis. *Demographic research*, 24:749–770.

Liddle, B. (2013). Population, affluence, and environmental impact across development: Evidence from panel cointegration modeling. *Environmental modelling and software*, 40:255–266.

Liddle, B. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: Evidence from macro-level, cross-country analyses. *Population and environment*, 35:286–304.

Liddle, B. and Lung, S. (2010). Age-structure, urbanization, and climate change in developed countries: Revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Population and environment*, 31:317–343.

Lu, H., Lin, B., Campbell, D. E., Sagisaka, M., and Ren, H. (2016). Interactions among energy consumption, economic development and greenhouse gas emissions in Japan after world war II. *Renewable and sustainable energy reviews*, 54:1060–1072.

Martinez-Zarzoso, I., Bengochea-Morancho, A., and Morales-Lage, R. (2007). The impact of population on CO_2 emissions: Evidence from European countries. *Environmental and resource economics*, 38:497–512.

Martinez-Zarzoso, I. and Maruotti, A. (2011). The impact of urbanization on CO_2 emissions: Evidence from developing countries. *Ecological economics*, 70:1344–1353.

McLellan, B. C., Zhang, Q., Utama, N. A., Farzaneh, H., and Ishihara, K. N. (2013). Analysis of Japan's post-Fukushima energy strategy. *Energy strategy reviews*, 2:190–198.

Muramatsu, N. and Akiyama, H. (2011). Japan: Super-aging society preparing for the future. *Gerontologist*, 4:425–432.

Nakano, M. and Managi, S. (2008). Regulatory rreform and productivity: An empirical analysis of the Japanese electricity industry. *Energy policy*, 36:201–209.

Narayan, P. K. and Peng, X. (2007). Japan's fertility transition: Empirical evidence from the bounds testing approach to cointegration. *Japan and the world economy*, 19:263–278.

Okada, A. (2012). Is an increased elderly population related to decreased CO_2 emissions from road transportation? *Energy policy*, 45:286 – 292.

O'Neill, B. C. and Chen, B. S. (2002). Demographic determinants of household energy use in the United States. *Population and development review*, 28:53–88.

Pachauri, S. (2004). An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. *Energy policy*, 32:1723–1735.

Poumanyvong, P. and Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis. *Ecological economics*, 70:434–444.

Retherford, R. D., Ogawa, N., and Matsukura, R. (2001). Late marriage and less marriage in Japan. *Population and development review*, 27:65–102.

Roberts, S. (2008). Demographic, energy and our homes. *Energy policy*, 36:4630–4632.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975-1996: Evidence from pooled cross-country data. *Ecological economics*, 44:29–42.

Takahashi, H. (2006). Regulatory reform in the city gas industry and competition between energy companies. Technical report, Japan gas association.

Takase, K. and Suzuki, T. (2011). The japanese energy sector: Current situation, and future paths. *Energy policy*, 39:6731–6744.

Valenzuela, C., Valencia, A., White, S., Jordan, J. A., Cano, S., Keating, J., Nagorski, J., and Potter, L. B. (2014). An analysis of monthly household energy consumption among single-family residences in Texas, 2010. *Energy policy*, 69:263–272.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT Press.

Yamasaki, E. and Tominaga, N. (1997). Evolution of an aging socieity and effect on residential energy demand. *Energy policy*, 25:903–912.

York, R. (2007a). Demographic trends and energy consumption in European union nations, 1960-2025. *Social science research*, 36:855–872.

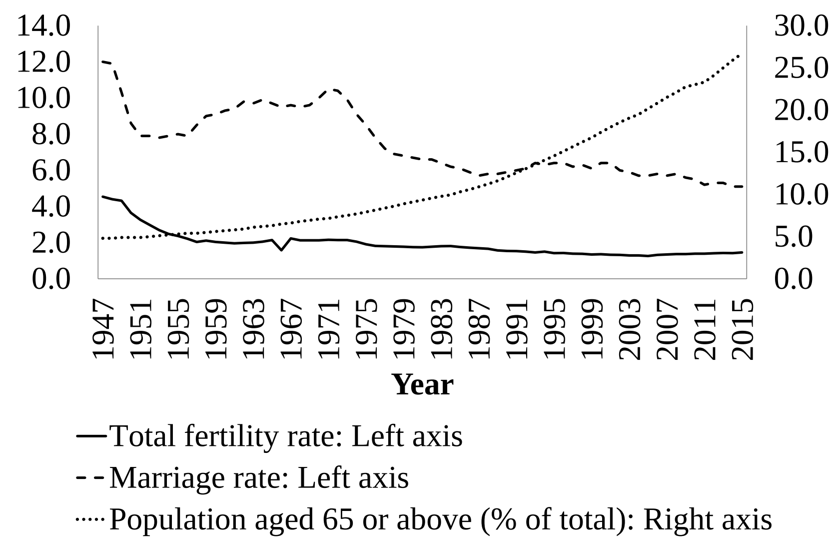
York, R. (2007b). Structural influences on energy production in south and east Asia. *Sociological forum*, 22:532–554.

York, R. (2008). Decarbonization in former Soviet republics, 1992-2000: The ecological consequences of demodernization. *Social problems*, 55:370–390.

Zhu, H., You, W., and Zeng, Z. (2012). Urbanization and CO_2 emissions: A semi-parametric panel data analysis. *Economics letters*, 117:848–850.

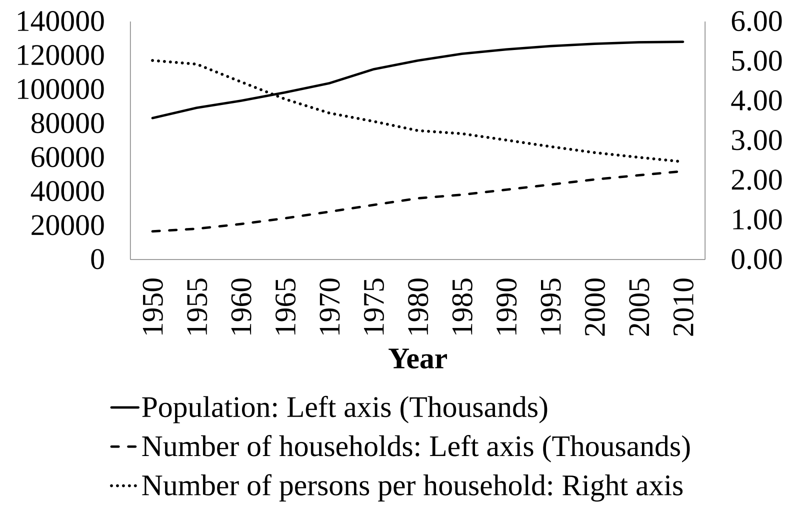
List of Figures

Figure 1: Demographic changes in Japan[5]



Total fertility rate is the average number of children that would be born to a woman over her lifetime, which is multiplied by 1000. Marriage rate is annual number in notification of marriage per total population, which is multiplied by 1000. Population aged 65 or above (% of total) is the percentage of the population aged 65 or above to the total population. The data is taken from Statistics Bureau, Ministry of Internal Affairs and Communications.

Figure 2: Population, the number of households and number of persons per household in Japan



The data is taken from Statistics Bureau, Ministry of Internal Affairs and Communications.

Figure 3: Residential energy consumption and population in Japan.

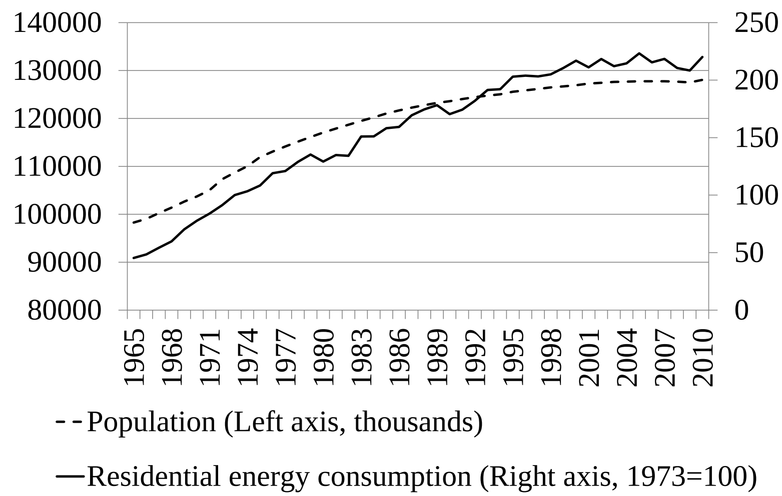


Figure 4: Electricity and city gas consumption (Unit: 10 power 18 J) for the residential sector in Japan

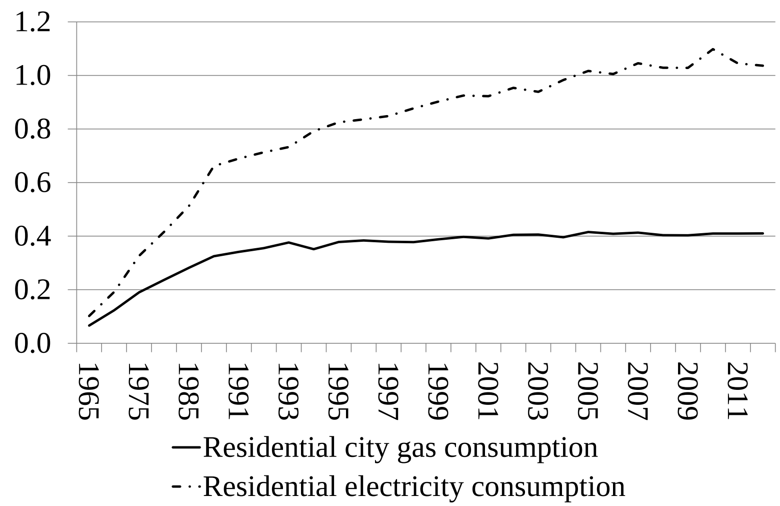


Figure 5: Proportion of the population aged 65 or above for each prefecture in 2010, Japan

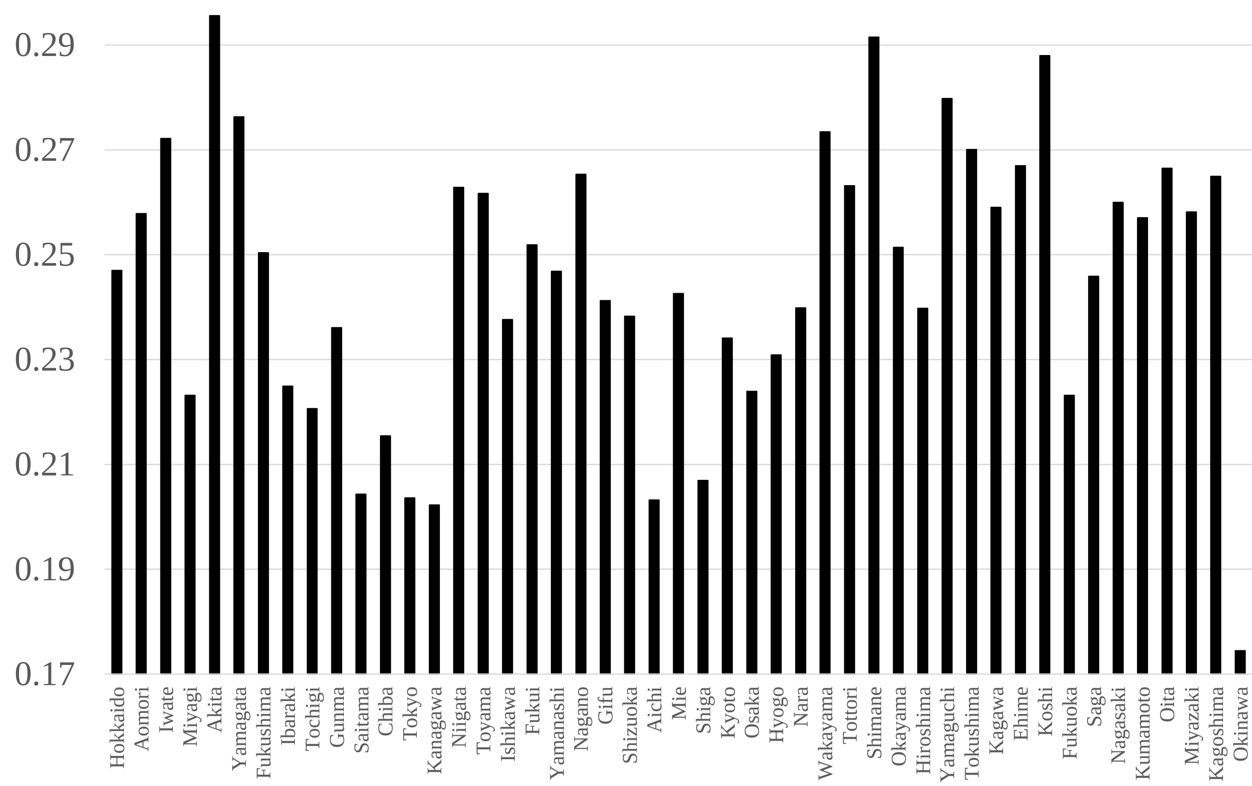


Figure 6: Logarithm of the population for each prefecture in 2010, Japan

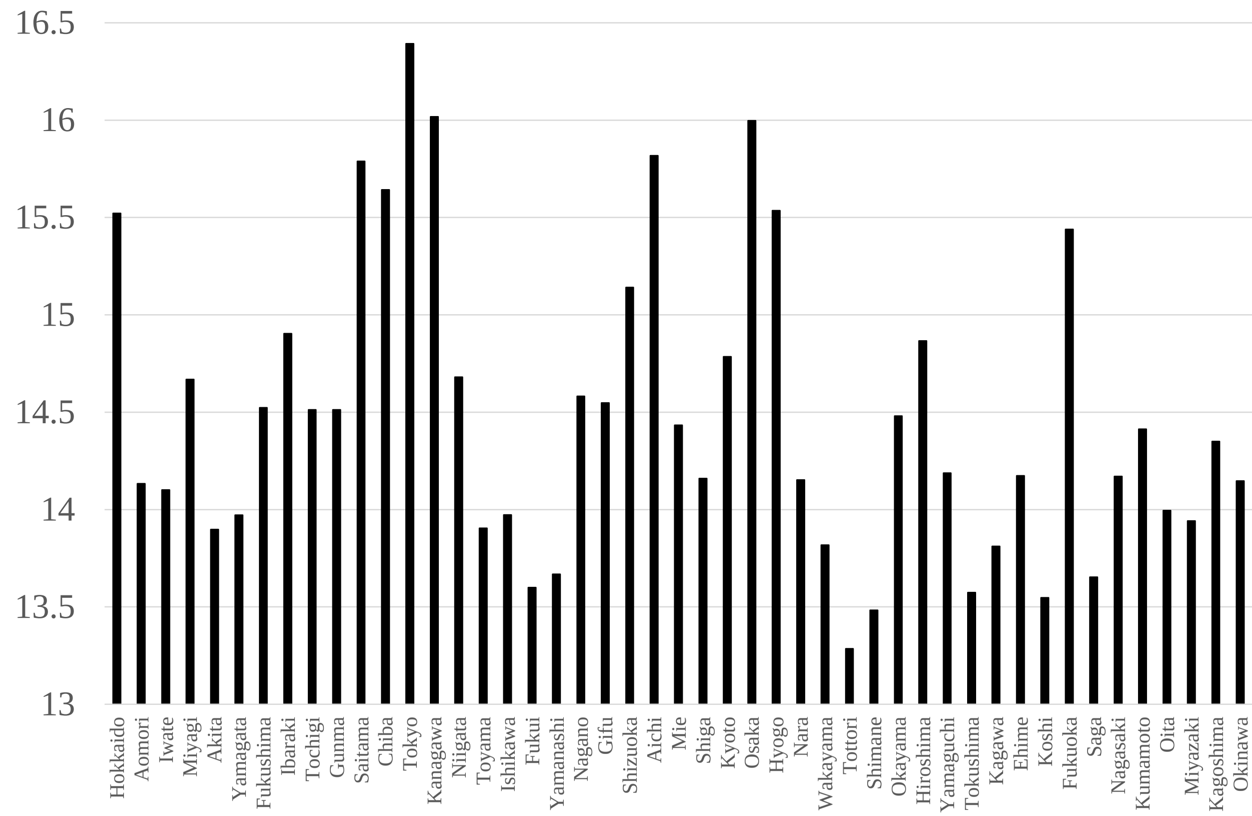


Figure 7: Average number of household members for each preferecture in 2010, Japan

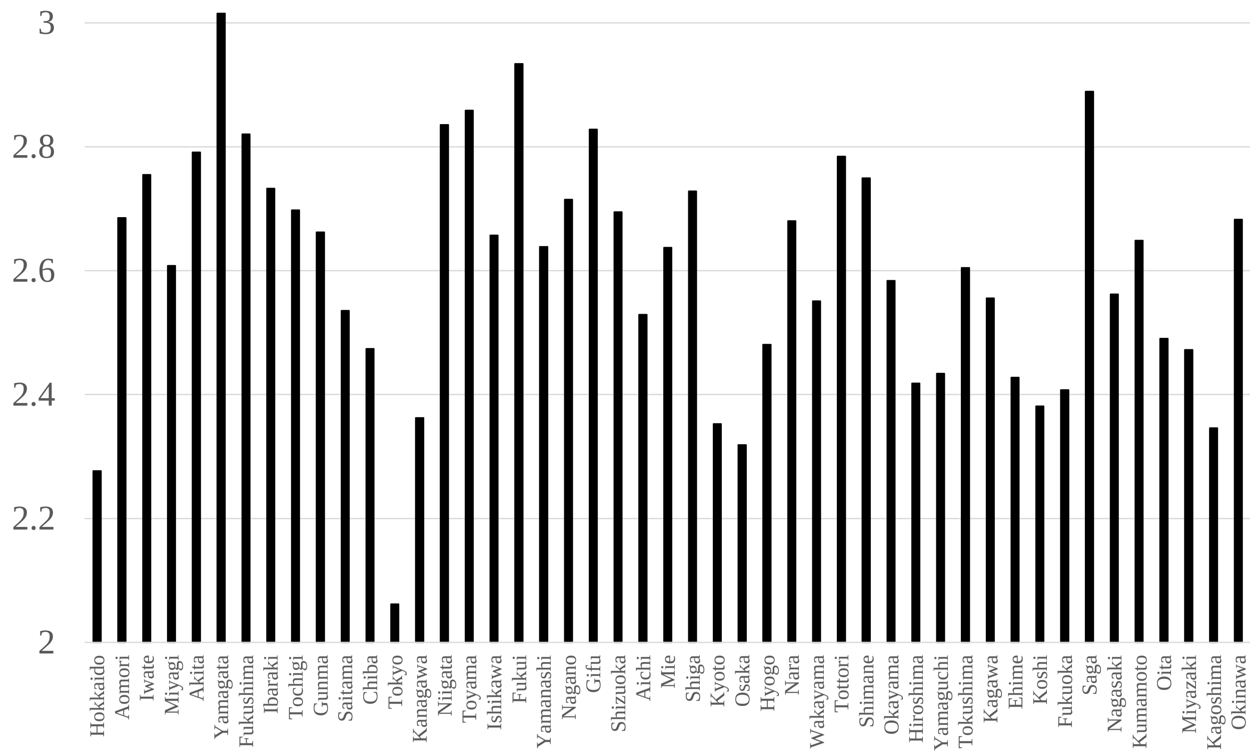
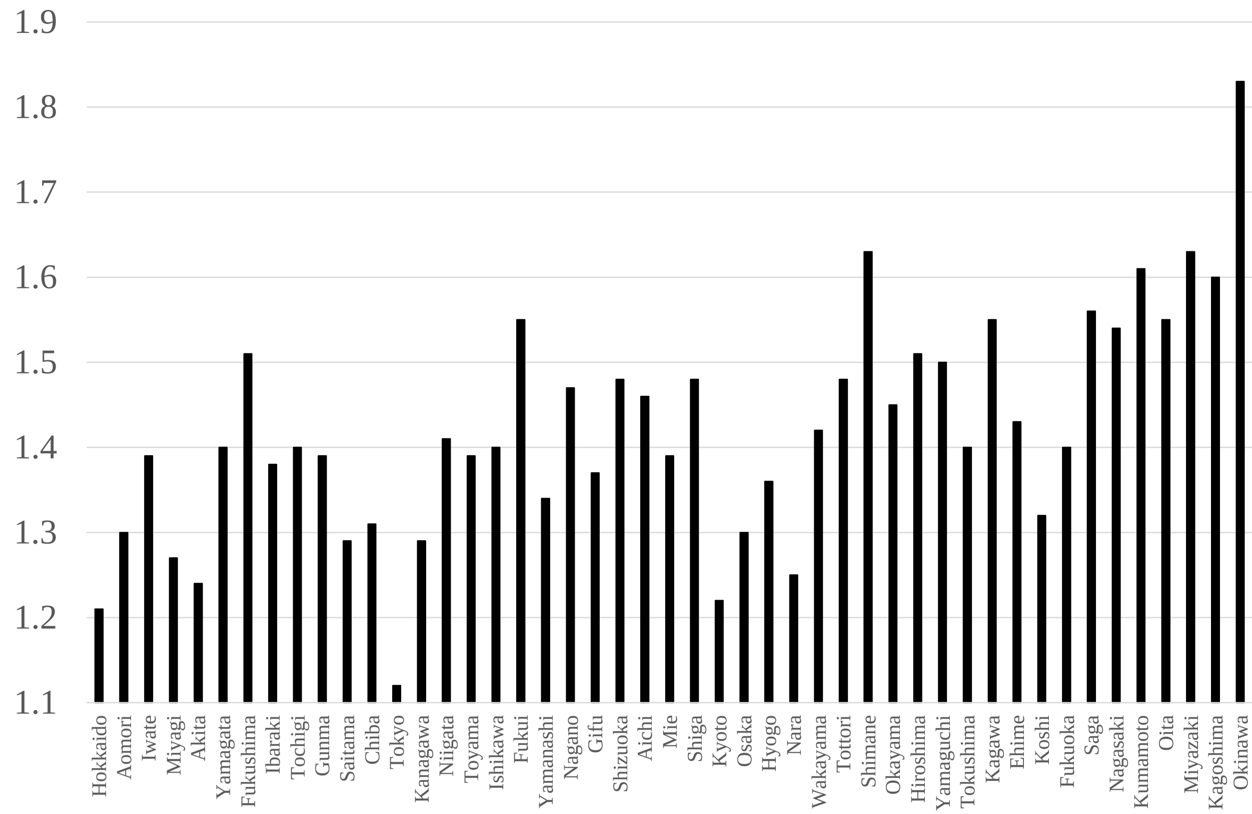


Figure 8: Total fertility rate for each preferecture in 2010, Japan



List of Tables

Table 1: Definitions of variables (Subscripts i and t in each variable represent prefectures and years, respectively)

Variable	Definition
Dependent variable	
OE_{it}	Log of residential electricity consumption
OG_{it}	Log of residential town gas consumption
Independent variable	
ELD_{it}	Proportion of the elderly (people aged 65 or above) to total population
TFR_{it}	Total fertility rate (the average number of children born to a woman)
PE_{it}	Log of electricity price in the first energy charges from 1 to $12\,\mathrm{kW\,h}$
PG_{it}	Log of gas price per $1465.12\,\mathrm{M\,J}$
POP_{it}	Log of population
INC_{it}	Log of per capita gross prefectural product
POH_{it}	Number of person per household

Table 2: Summary statistics (Observations = 235)

	Mean	SD[1]	Min	Max
QE_{it}	9.509	0.781	7.902	11.681
QG_{it}	7.794	1.487	5.603	11.423
ELD_{it}	0.191	0.047	0.083	0.296
TFR_{it}	1.478	0.156	1.000	1.950
PE_{it}	2.868	0.094	2.726	3.075
PG_{it}	8.656	0.169	8.341	9.054
POP_{it}	14.496	0.736	13.286	16.393
INC_{it}	1.248	0.174	0.851	1.993
POH_{it}	2.878	0.303	2.062	3.695

[1] "SD" stands for standard deviation.

Table 3: Correlation matrix

	QE_{it}	QG_{it}	ELD_{it}	TFR_{it}	PE_{it}	PG_{it}	POP_{it}	INC_{it}	POH_{it}
QE_{it}	1.000								
QG_{it}	0.901	1.000							
ELD_{it}	−0.202	−0.356	1.000						
TFR_{it}	−0.656	−0.573	−0.237	1.000					
PE_{it}	−0.299	−0.166	−0.540	0.476	1.000				
PG_{it}	−0.280	−0.476	0.406	0.202	−0.022	1.000			
POP_{it}	0.933	0.936	−0.406	−0.513	−0.175	−0.360	1.000		
INC_{it}	0.497	0.471	−0.009	−0.425	−0.240	−0.221	0.437	1.000	
POH_{it}	−0.563	−0.371	−0.466	0.679	0.397	−0.171	−0.383	−0.275	1.000

Table 4: Estimation results (Observations = 235)

Variable	Electricity consumption (QE_{it})				Town gas consumption (QG_{it})			
	FE		PW		FE		PW	
ELD_{it}	−1.126***	−1.038**	−1.063***	−0.995***	1.779	1.705	1.671**	1.615**
	(0.547)	(0.467)	(0.306)	(0.262)	(1.640)	(1.654)	(0.841)	(0.814)
TFR_{it}	0.009	−0.080	0.009	0.069	−0.059	−0.011	−0.052	−0.018
	(0.0048)	(0.054)	(0.058)	(0.047)	(0.148)	(0.166)	(0.104)	(0.123)
PE_{it}	−0.322***	−0.367***	−0.313***	−0.350***	0.102	0.079	0.060	0.044
	(0.100)	(0.087)	(0.085)	(0.100)	(0.248)	(0.268)	(0.137)	(0.131)
PG_{it}	0.127**	0.106**	0.117***	0.092**	−0.234*	−0.240*	−0.234***	−0.240***
	(0.055)	(0.045)	(0.035)	(0.038)	(0.137)	(0.142)	(0.065)	(0.064)
POP_{it}	0.323***	0.320**	0.326***	0.318***	1.857***	1.744***	1.832***	1.735***
	(0.128)	(0.144)	(0.066)	(0.080)	(0.297)	(0.340)	(0.149)	(0.171)
INC_{it}	-	0.092	-	−0.090*	-	−0.106	-	−0.093
		(0.082)		(0.036)		(0.170)		(0.077)
POH_{it}	-	−0.307***	-	−0.313***	-	−0.080	-	−0.058
		(0.085)		(0.045)		(0.273)		(0.085)
Constant	5.099***	6.014**	4.646***	7.280***	−17.719***	−15.670***	−17.031***	−15.091***
	(1.915)	(2.268)	(1.014)	(1.413)	(4.400)	(5.518)	(2.031)	(3.143)
R-squared	0.9877	0.9898	0.9995	0.9997	0.6881	0.6894	0.9986	0.9986
Wald stats[1]	3.3×10^4***	3.9×10^3***	-	-	1.3×10^4	1.6×10^4	-	-
AC[2]	57.01***	65.87***	-	-	61.42***	62.19***	-	-

***, ** and * significant at 1 %, 5 % and 10 % levels, respectively.

[1] "Wald stats" stand for modified Wald statistics.

[2] "AC" stands for autocorrelation.