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Fuel Poverty in Summer: An Empirical Analysis Using Microdata for Japan

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Abstract

The term fuel poverty is used to describe households that cannot afford the fuel costs of heating during winters. Fuel poverty is estimated on the basis of European criteria given that winters tend to be severe in Europe. However, it would be inappropriate to apply the same criteria to Asian regions with severe heat levels. Considering fuel poverty in the context of cooling expenses incurred during summers is also necessary. Thus, this study aims to examine potential fuel poverty households in Japan during summer and their occurrence condition using microdata. The estimation results reveal that only 0.93% of the surveyed households report fuel poverty. However, 5.53% poverty households can be classified as fuel poverty households. The results further show that households with elderly couples, particularly those living in old and/or large-floored homes with old room air conditioners, and single parent households are more vulnerable to fuel poverty. This study also conducts a binomial logistic regression analysis to clarify the occurrence condition for fuel poverty households. The findings suggest that elderly households easily fall into fuel poverty because of their low annual income and increased electricity expenditures owing to a rise in the energy amount rate.

Keywords

Energy poverty, summer, elderly person, microdata, low income high costs indicator

1. Introduction

A household is said to be in fuel poverty when it cannot afford the fuel costs of heating during winter because a large portion of their income is spent on energy (e.g. electricity or gas). The 10% indicator—that is, whether 10% or more of household income is spent on energy expenses—is a criterion used to estimate fuel poverty (Boardman, 2010). In addition, the UK government has adopted a low income high costs (LIHC) indicator that combines income thresholds (Hills, 2011). Fuel poverty is considered a problem in Europe and, particularly, in the United Kingdom (Boardman, 2010).

According to Walker et al. (2014a), the elderly are more susceptible to fuel poverty when they live in old and poorly insulated houses, use old and low energy-efficient heaters, and have low income or lack the money to invest in heat insulation and energy-saving heating. This is also true in Japan. As an example of energy consumption in elderly households in Japan, elderly households tend to consume more energy than households with members of other age groups and thus (2017). This issue is also more severe in Japan given that 27.7% of its total population was 65 years and above in 2017, and this rate is expected to increase to 38.4% by 2065 (Japan Cabinet Office, 2018), which is the highest in the world. In Japan, the rate of households with members aged 65 years and above increased from 24.0% in 1980 to 48.4% in 2016. Further, the rate of individuals aged 65 years and above in the poverty group is 19.4% in 2015, which is higher than the OECD's average of 12.5% in 2014 (OECD, 2017). According to a questionnaire survey focusing on people aged 60 and over, 34.8% of respondents answered that they were financially unsettled and worried about their future (Japan Cabinet Office, 2018). This can be explained by the fact that the average income of Japanese households is 5.46 million JPY[1] (51,095 USD), while that of elderly households is as low as 3.08 million JPY (28,823 USD). A reason for the low income of elderly households is that almost of them lives on only social pensions. The employment rate and unemployment rate in Japan were 57.6% and 3.4% in 2015 (Statistics Japan, 2019). If limited to elderly aged 65 and over, these are 21.7% and 2.0%, which is lower than the figures for Japan as a whole. Such information provides us that the majority of elderly do not get wages for employment. In particular, poverty of the elderly has been a severe social problem in Japan, and the solution is urgently needed.

[1] The currency used in the study the Japanese yen (JPY), with USDollars (USD) written in parenthesis. The exchange rate applied was 0.0094 USD = 1 JPY (as of 6 September 2019).

While promoting renewable energy is important for tackling the climate change, the associated increase in cost burden can have a significant impact on the energy tariff of low-income elderly people. Measures supporting the spread of renewable energy such as the feed-in-tariff (FIT) scheme increase economic burdens on households. Japan introduced the FIT scheme in 2009; however, it also raised its electricity tariff from 0.03 JPY/kWh (0.00028 USD/kWh) in 2011 to 2.9 JPY/kWh (0.027 USD/kWh) in 2018, which increased electricity expenditures (Japan Agency for National Resources and Energy, 2019). Asano (2017) predicts that the accumulated electricity tariffs to promote renewable energy will reach 44 trillion JPY (0.41 trillion USD) by 2030. While promoting renewable energy is an important measure to mitigate climate change, welfare policy also required at maintaining and improving the quality of life of elderly people. This kind of promotion of renewable energy might affect impact regarding discussions for potential fuel poverty households in Japan.

As another important discussion, the concept of fuel poverty has been largely based on EU countries given their severe winters. However, Sánchez et al. (2017) states that it is also important to account for fuel poverty resulting from fuel costs to use room air conditioners during summers. Asian regions including Japan experience hot and humid climates in summer. Then, power demand for cooling significantly raises to avoid health problems such as heatstroke. Ono (2013) reports that the number of Japanese patients aged 65 years and above who suffer a heatstroke exponentially increases when the daily maximum temperature is 35°C and more. The Japan Ministry of Environment recommends increasing the temperature of room air conditioners to mitigate climate change. But at the same time, they also suggests using room air conditioners to avoid a heatstroke on extremely hot days. This situation contributes to an increase in both electricity consumption and expenditure (Moore, 2012). Japan has been frequently experiencing intensely hot days of 35°C or more in recent years because of factors such as climate change and the urban heat island phenomenon. In 2018, temperatures reached a record high in the eastern and western regions of Japan, and the number of patients urgently hospitalized owing to a heatstroke was the highest observed in history (Japan Meteorological Agency, 2018; Japan Fire and Disaster Management Agency, 2018). Climate change resulting from human actions should be given the highest priority. However, measures that could harm human health are not preferable. This creates the trade-off problem of implementing measures for climate change mitigation vs. taking action to protect human health. Such a tendency is expected to become more pronounced as climate change intensifies.

Despite the severity of issues discussed in summer, few studies examine fuel poverty in regions with extreme summers. This study aims to estimate potential fuel poverty in summer in Japan. In particular, this study focuses on the elderly people to reveal the degree of their potential fuel poverty. This study also discusses the occurrence condition for these households using microdata from the National Survey of Family Income and Expenditure. A detailed analysis using the microdata will provide in-depth information on each household and individual. This study provide fundamental information how national and local governments should treat the potential fuel poverty in summer from the viewpoint of climate change mitigation and health problems in summer.

Numerous studies have been conducted on fuel poverty to estimate potential fuel poverty households in, for example, Atsalis et al. (2016), Chapman et al. (2012), Elsberg et al. (2016), Okushima (2016) and Simoes et al. (2016) estimates national and/or regional potential fuel poverty using national statistics. Fabbri (2015) introduces a fuel poverty risk index to evaluate building energy performance that influences required energy consumption. März (2018) visualizes vulnerability dimensions (heating burden, soci-economic and building vulnerability) for fuel poverty using geographic information system and multi-criteria decision analysis. Fargallo et al. (2018) predict future fuel poverty risks associated with climate change. Fahmy et al. (2011) and Walker et al. (2014b) estimate potential fuel poverty households by conducting regression and other criteria analyses. Studies analysing the characteristics of and factors contributing to fuel poverty households focus on the effects of the national economy (Simshauser et al., 2011; Dagoumas and Kitsiosc, 2015); the health risks of fuel poverty households (Shortta and Rugkåsa, 2007; Lacroix and Chaton, 2015; Sharpe et al., 2015; Chard and Walker, 2016); and the influence of social conditions, residential area, and energy supply (Walker, 2008; O'Sullivan et al., 2011; Thomson and Snell, 2013; Roberts et al., 2015). Price et al. (2012) examine statistics on fuel poverty and confirm that factors such as income, prepaid electricity rates, and family composition significantly impact fuel poverty.

Sánchez et al. (2017), in a study closely related to the present research, advocate the importance of considering fuel poverty in countries with extreme summers and analyse the criteria for fuel poverty on the basis of temperature thresholds in Spain. However, the exact number of households in fuel poverty during summer remains unclear. Okushima (2016) estimates potential fuel poverty households in Japan using microdata from the National Survey of Family Income and Expenditure. However, since the survey period is limited to the summer and fall, Okushima combined multiple statistics to obtain annual data. However, combining the original statistics with multiple statistics increases the potential for errors. This further hinders the ability to appropriately estimate the number of fuel poverty households. Thus, this study uses data from the national survey to estimate the rate of potential fuel poverty households only in the summer.

2. Materials and methods

The National Survey of Family Income and Expenditure is conducted every five years to capture household assets such as income and expenditure, savings and liabilities, possession of consumer durable goods, and housing and residential land (Japan Ministry of Internal Affairs and Communications, 2017). The survey aims to comprehensively grasp the structure of households from the viewpoints of income, consumption, and assets. This survey also reports detailed data including age of household head, number of households, and annual income and expenditure.

This study uses microdata for FY1989[2], FY1994, FY1999, and FY2004 since these are the latest available data released in March 2019 for the National Survey of Family Income and Expenditure. The microdata are classified into those for single households and households with two or more members. The FY2004 survey reports 3,936

[2] FY refers to the Japanese fiscal year. For example, FY1989 starts in April 1989 and ends in March 1990.

single households and 43,861 households with two or more members. The survey is conducted for two months (October–November) for single households and three months (September–November) for households with two or more members. Thus, researchers conducting an annual analysis combine the microdata with other statistics. But this operation might decrease their accuracy of estimation. Meanwhile, room air conditioners are generally used from July to September, except in certain regions of Japan. Since the electricity bill for August is usually generated in the following month, microdata for households with two or more members can be used to examine electricity expenditures for cooling during August–September. Using the microdata, this study attempts to clarify the actual situation of fuel poverty in Japan during summers. However, note that the latest available microdata are those for FY2004 released in February 2019.

As mentioned above, expenditure on electricity in summer is not available, and single households were excluded in this study. However, analysing single households is extremely important for the purpose of this study, and it is a future issue.

2.1 Calculating the rate of potential fuel poverty households

This study estimates the ratio of electricity expenditure to annual income for each surveyed household using equation (1). Next, the rate of potential fuel poverty households is determined on the basis of the LIHC indicator (Hills, 2011). Figure 1 is a conceptual diagram of the LIHC indicator. Hills (2011) indicates that households are defined as fuel poor where their household income is low and where their required energy spending in order to achieve an adequate standard of warmth is above a specified threshold. In this study, the energy cost threshold was to 10% indicator (Walker et al, 2014b) that many literatures adopt this indicator. The income threshold was adopted to set to 60% of the median household annual income in EU countries (Poverty and Social Exclusion, 2016) because there is no similar thinking in Japan. In this study, 10% indicator is adopted as the energy cost threshold, and households meeting the above income threshold are regarded as potential fuel poverty households. However, this study calculates 10% indicator in summer, and annual data is not available for the data limitation of the microdata. Therefore, the 10% indicator in this study was calculated by dividing expenditure on electricity into income in summer to estimate the potential fuel poverty households in summer (see equation (1))

$$10\%\ \text{indicator} = \frac{\text{Expenditure in summer}}{\text{Income in summer}}. \quad (1)$$

This study focuses on electricity costs rather than energy costs, because the source of power for room air conditioners in Japanese households is electricity. This is because while electricity, gas and kerosene are mainly used as energy sources for heating and cooling in Japan, energy sources for home cooling equipment are limited to electricity.

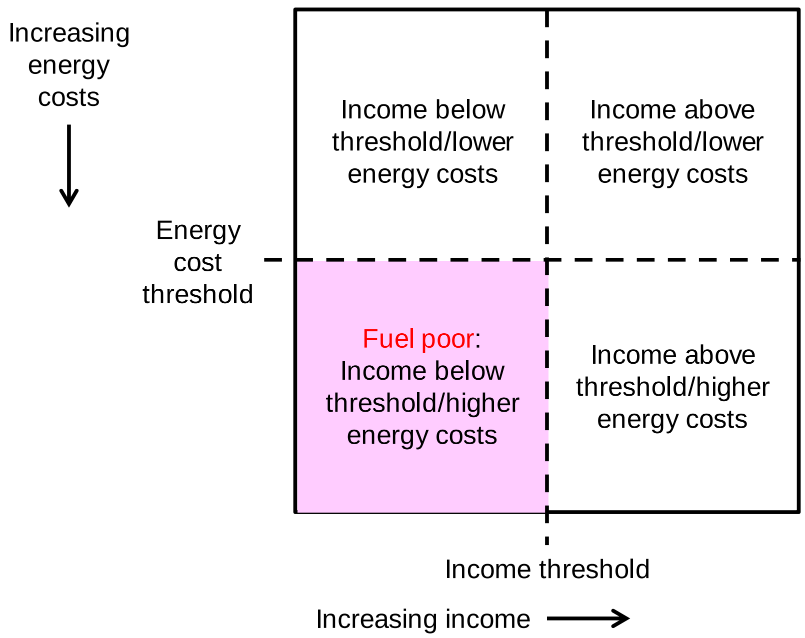


Figure 1 LIHC indicator (Hills, 2011)

2.2 Analysing the characteristics of fuel poverty households

This study examines the difference between fuel poverty and non-fuel poverty households and the characteristics of the former by combining the estimated rate of potential fuel poverty households with other parameters in the microdata (Table 1). Poverty households are said to have income less than half of the median of equivalent disposable income (Japan Ministry of Internal Affairs and Communications, 2017).

Equivalent disposable income is calculated as annual disposable income, excluding household annual income from the annual equivalent of non-consumption expenditure, divided by the square root of the number of household members. Accordingly, elderly couple households, single parent households, or households receiving public assistance are hypothesized as being vulnerable to fuel poverty and are verified using statistical analyses. Following the verification, a regression formula is created to clarify factors contributing to fuel poverty. This formula allows for a simulation to elucidate the occurrence condition for fuel poverty and the factors that render a household more vulnerable.

Table 1 Variables used in the cross-sectional analysis

Household information	Number of household members	
	Total floor space	
	Type of dwelling houses*1	
	Age of household head	
	Quantities of cars possessed	
Receipts	Income	
	Receipts other than income	
	Carry-over from previous month	
Expenditure	Living expenditure	Food
		Housing
		Water & sewerage charge
		Electricity

	Gas
	Other fuel & light
	Furniture & household utensils
	Clothes & footwear
	Medical care
	Transportation & communication
	Education
	Recreational services
	Miscellaneous
Non-living expenditure	Direct taxes
	Disbursements other than expenditure*2
	Carry-over to next month
Quantities of room air conditioners possessed	Total
	Bought within 1 year
	Bought 1~5 years
	Bought 5 years or more

*1: Detached houses and apartments. *2: Insurance premium payments, savings, etc.

2.3 Sensitivity analysis

This study conducts a simulation using the regression formula to determine the factors contributing to fuel poverty. In particular, it investigates the mechanism for fuel poverty in the context of elderly households.

3. Results and discussions

3.1 Presence of fuel poverty

Table 2 shows the temporal changes in the rate of potential fuel poverty households. The income threshold in FY2004 is 3,540,000 JPY (33,127 USD). Poverty and potential fuel poverty households was counted households that overlaps poverty households and potential fuel poverty households. Of the total sample for FY2004, 0.93% accounts for fuel poverty households. If only the 10% indicator were considered, the potential fuel poverty increases up to 3.2%. This rate is similar to rate estimated for FY1989 and FY1994. For FY1999, this rate is 2.46%, although this can be attributed to the rising unemployment rate caused by the 1997 Asian financial crisis. The annual rate of poor households is about 8%. In FY2004, 5.53% of poverty households are fuel poverty households, which is considerably higher than the rate of fuel poverty households in the total sampled households. This result suggests that poor households can easily fall into fuel poverty.

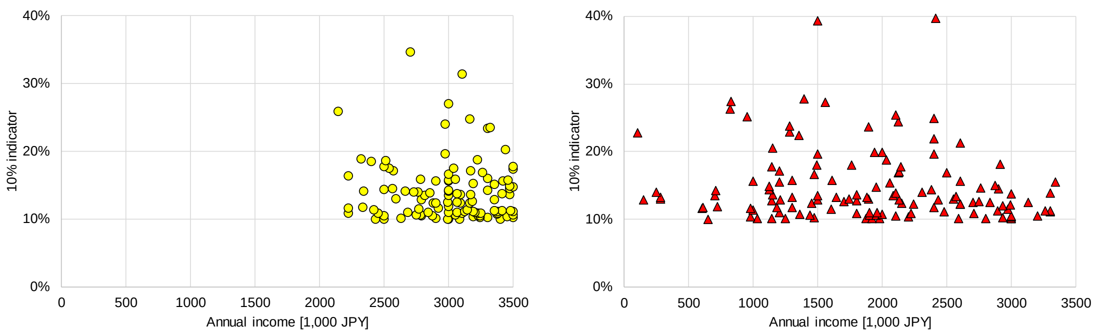
Table 2 Temporal changes in potential fuel poverty households

	FY1989	FY1994	FY1999	FY2004
Sampled households	44,537	44,687	44,540	43,861

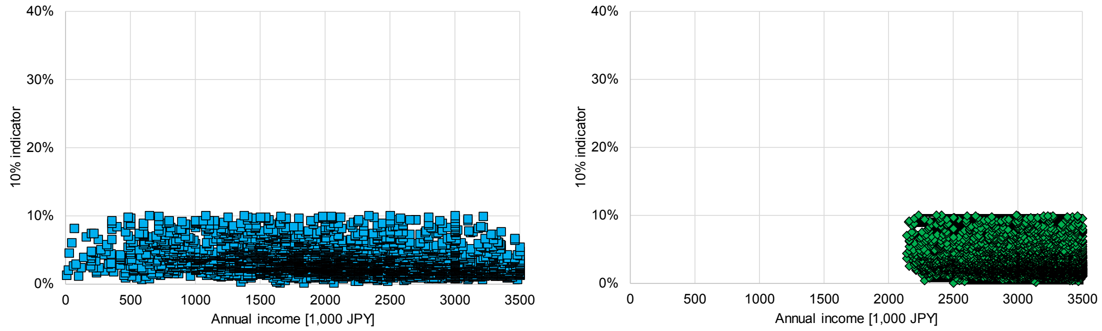
Poverty households	3,422	3,655	3,805	3,798
(%)	(7.68%)	(8.18%)	(8.54%)	(8.66%)
Potential fuel poverty households	537	506	1,094	409
(%)	(1.21%)	(1.13%)	(2.46%)	(0.93%)
Poverty and potential fuel poverty households	119	143	275	210
(%)	(3.48%)	(3.91%)	(7.23%)	(5.53%)

Previous studies have largely estimated the rate of fuel poverty households in the context of winter, and thus conducting a comparative analysis for the present findings is difficult. Nevertheless, this study attempts to determine the validity of the results for potential fuel poverty households. Okushima (2016) conducts a survey in Japan and estimates fuel poverty households at 8.4%. Of the total energy consumption by Japanese households, heating accounts for 24.1% and cooling for 2.3% (Japan Agency for National Resources and Energy, 2018). This is because heating equipment is limited to room air conditioners and electric fans that run on electricity, whereas heating is obtained from multiple equipment such as room air conditioners and electric heaters that have various sources of energy such as electricity and gas. Moreover, a combination of heating equipment is used during the winter, contributing to the large difference between heating and cooling. The estimated difference is similar between this and Okushima's study, and thus the findings of this research are judged to have some relevance.

Figure 2 illustrates the relationship between annual income and the 10% indicator. Here, the sampled households are classified into four types: poverty, fuel poverty, poverty and fuel poverty, and miscellaneous. Annual incomes higher than the income threshold (X axis) are excluded. The results reveal that poverty households have annual incomes lower than the income threshold, and for a majority of these households, the income is less than the 10% indicator. By contrast, the income of fuel poverty households exceeds the 10% indicator, and the income levels for half of these households overlap with those of poverty households.



(1) Fuel poverty households (2) Poverty and fuel poverty households



(3) Poverty households (4) Miscellaneous households

Figure 2 Relationship between annual income and the 10% indicator (FY2004 microdata)

Figure 3 shows the relationship between expenditure on electricity in summer/Income in summer and the class of annual income. Figure 4 also shows number of fuel poverty households and the class of annual income. The average age of the household head is generally higher for fuel poverty households than others. In other words, there is a high rate of elderly persons in fuel poverty households. This finding is further supported by the fact that among the 409 fuel poverty households reported in FY2004, 47.7% had household heads aged 65 years and above. The data also reveal households with an annual income higher than the 10% indicator at 20 million JPY (187,160 USD) or more; these households are possibly energy wasters.

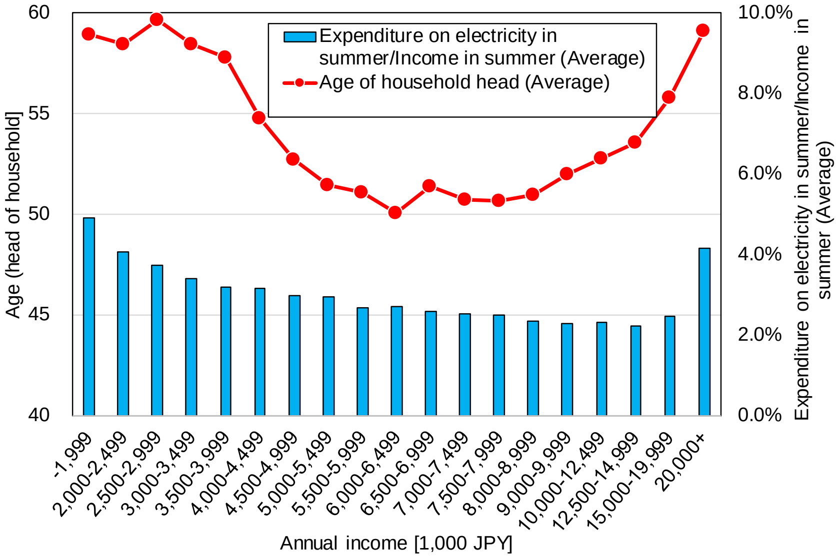


Figure 3 Expenditure on electricity in summer/Income in summer considering the class of annual income (FY2004 microdata)

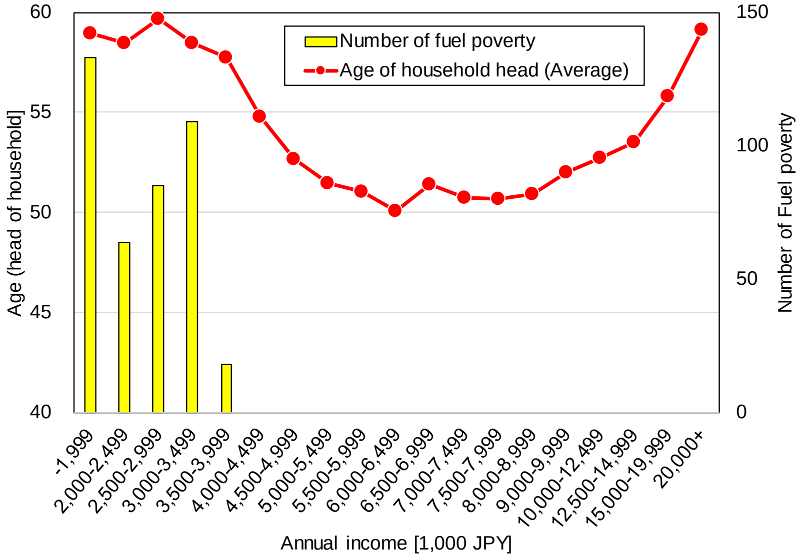


Figure 4 Number of fuel poverty households considering the class of annual income (FY2004 microdata)

3.2 Fuel poverty households and their expenditure

This subsection examines the characteristics of fuel poverty households from the viewpoint of expenditure. Table 3 presents the difference in expenditures between fuel poverty and non-fuel poverty households. The results highlight expenditure items dominating households' total expenditure. Rates that are underlined denote greater differences between the two household types. The results for the difference in population mean for each expenditure item is shown by t value and p value. The t value tests whether expenditures between fuel poverty and non-fuel poverty households has difference or not. If the t value exceeds 2, significant at the 5% level of the test is satisfied. The p value also means that whether null hypothesis is correct or alternative hypothesis is correct. In this case, the null hypothesis means that there is no difference in expenditures between fuel poverty and non-fuel poverty households, and the alternate hypothesis means that there is difference in expenditures between fuel poverty and non-fuel poverty households. The results indicate that the p value all exceeded 2 and the p value is significant at the 5% level (except for gas, whose results are significant at the 1% level) for both household types.

Table 3 Difference in expenditure between fuel poverty and non-fuel poverty households (FY2004 microdata)

		Fuel poverty households		Non-fuel poverty households		*t*-value	*p*-value
		JPY (USD)	Ratio	JPY (USD)	Ratio		
Expenditure		122,691 (1,148)	100%	681,749 (6380)	100%	-	-
Living expenditure	Food	43,515 (407)	35.5%	71,261 (667)	10.5%	28.41	*p<0.01***
	Housing	4,389 (41)	3.6%	18,223 (171)	2.7%	8.05	*p<0.01***
	Water & sewerage charge	3,840 (36)	3.1%	5,106 (48)	0.7%	7.86	*p<0.01***
	Electricity	11,731 (110)	9.6%	9,324 (87)	1.4%	19.29	*p<0.01***
	Gas	4,606 (43)	3.8%	4,287 (40)	0.6%	2.43	1.54×10^{-2}*
	Other fuel & light	1,613 (15)	1.3%	954 (9)	0.1%	3.08	*p<0.01***
	Furniture & household utensils	3,960 (37)	3.2%	10,055 (94)	1.5%	17.87	*p<0.01***
	Clothes & footwear	3,415 (32)	2.8%	13,511 (126)	2.0%	29.78	*p<0.01***
	Medical care	5,084 (48)	4.1%	13,114 (123)	1.9%	17.02	*p<0.01***
	Transportation & communication	13,931 (130)	11.4%	43,984 (412)	6.5%	32.16	*p<0.01***
	Education	1,693 (16)	1.4%	15,459 (145)	2.3%	17.63	*p<0.01***
	Recreational services	9,176 (86)	7.5%	31,281 (293)	4.6%	36.05	*p<0.01***
	Miscellaneous	6,354 (59)	5.2%	22,123 (207)	3.2%	30.17	*p<0.01***
Non-living expenditure	Direct taxes	126 (1)	0.1%	18,351 (172)	2.7%	130.56	*p<0.01***
	Disbursements other than expenditure*1	5,608 (52)	4.6%	340,749 (3,189)	50.0%	169.23	*p<0.01***
	Carry-over to next month	3,651 (34)	3.0%	63,966 (599)	9.4%	61.39	*p<0.01***

*: $p<0.05$ **: $p<0.01$. *1: Insurance premium payments, savings, etc.

Expenditure items that reported particularly large differences include food, electricity, gas, other fuel and lights, and disbursements other than expenditure for both fuel and non-fuel poverty households. Fuel poverty households spend 7% of food expenditure on eating out, whereas non-fuel poverty ones spend 17%, indicating that the former are more likely to eat at home than the latter. This also suggests that fuel poverty households spend more on energy (i.e. electricity, gas, and other fuel and light) for not only cooling but also cooking. Disbursements other than expenditure include insurance premium payments and savings. Related spending is less for fuel poverty households than non-fuel poverty ones. In FY2004, the disposable income for fuel poverty households and non-fuel poverty ones was 2,330,492 JPY (21,809 USD) and 6,173,247 JPY (57,769 USD). Given their limited disposable income, fuel poverty households are reluctant to spend on insurance premium payments and savings. This trend suggests that a majority of fuel poverty households overlap with poverty households.

3.3 Vulnerability of households to fuel poverty

This study further examines households highly vulnerable to fuel poverty among those that have elderly couples, are run by single parents, and receive public assistance. To do so, it creates a correlation matrix to identify such households on the basis of the household heads' age, annual income, number of households, and quantity of room air conditioners. Table 4 shows the results for the correlation matrix. The cells to the upper right of the diagonal of the correlation matrix indicate correlation coefficients and those to the lower left denote *p*-values from the test for no correlation with the parent correlation coefficient. The row and column numbers match. Results based on the factors with significant *p*-values are as follows.

Table 4 Correlation matrix (FY2004 microdata)

(1) Total floor space	(2) Elderly couple households	(3) Single parent households	(4) Households receiving public assistance	(5) Combination of (2) and (4)	(6) Combination of (3) and (4)	(7) Annual income	(8) 10% indicator	(9) Number of fuel poverty households	(10) Expenditure on electricity	(11) Quantity of air conditioners	(12) Bought within 1 year' to 'Within the past year	(13)

First, total floor area is negatively correlated with households that have a single parent and receive public assistance but positively correlated with households with elderly couples. In addition, total floor area is positively correlated with the 10% indicator, presence of fuel poverty households, expenditure (electricity), and quantity of room air conditioners. Second, the 10% indicator is positively correlated with households that have a single parent or receive public assistance. Third, there is a significant relationship between fuel poverty households and households with elderly couples and single parents. In other words, these household types are highly vulnerable to fuel poverty. The finding that households with single parents are strongly affected by fuel poverty is consistent with Okushima’s conclusion (2016). On the other hand, there is no correlation between households receiving public assistance and fuel poverty households.

Finally, expenditure (electricity) is negatively correlated with households with elderly couples and single parents and those receiving public assistance. At the same time, the 10% indicator is higher for these households. The 10% indicator is positively correlated with quantity of room air conditioners and assets for the past five years or more. On the other hand, the number of bought over a certain period shows a decreasing trend. Room air conditioners bought five years or more are also positively correlated with fuel poverty households. These results suggest that fuel poverty households that report a high rate for the 10% indicators possibly have old room air conditioners.

This study focuses on households with elderly couples given their expected increase in the future. It also tests for differences in the population average between households with elderly couples and miscellaneous households. Table 5 presents the results. The larger differences in each item between elderly and miscellaneous households are denoted by underlined values. All items are significant at the 1% level. The results suggest that compared with miscellaneous households, elderly couples live in wider and older houses. This trend is generally related to their life events. For instance, in Japan, it is common to get married and build a large house when a child is born. The children eventually move out of the house in search of employment or after marriage, while the parents continue to live in the same home, which eventually becomes a large space for just two people. Moreover, such older houses have poor insulation and tend to consume more energy.

Table 5 Difference between elderly and miscellaneous households (FY2004 microdata)

	Elderly households	Miscellaneous households	*t*-value	*p*-value
Sampled households	5,126	38,735	-	-

Total floor area (m^2)	122	118	5.83	*p<0.0**
Years after construction	39.88	31.37	16.21	*p<0.01*
Age of household head	73.47	51.1	291.60	*p<0.01*
Annual income in 1,000 JPY (1,000USD)	4,530 (42.39)	7,030 (65.79)	67.88	*p<0.01*
10% indicator	3.4%	2.8%	25.14	*p<0.01*
Fuel poverty household	1.9%	0.8%	5.73	*P<0.01*
Expenditure on electricity (JPY)	7,932	9,534	26.38	*p<0.01*
Quantity of room air conditioners (items)	2.46	2.74	10.13	*p<0.01*
Past 5 years or more (items)	2.06	2.20	4.29	*p<0.01*

Both households possess almost the same quantity of room air conditioners, many of which are old conditioners that have low energy-saving performance and increase electricity expenditures. These conditions are particularly detrimental in homes with poor insulation.

3.4 Sensitivity analysis

To clarify the occurrence condition for fuel poverty households, a sensitivity analysis was conducted. In this study, a regression analysis was conducted to estimate potential fuel poverty households for the elderly persons' households using the following binomial logistic regression:

$$\log\left[\frac{\pi(Y=1)}{1-\pi(Y=1)}\right] = b_0 + b_1x_1 + b_2x_2 + \cdots + b_px_p \qquad (2)$$

where Y is the explanatory variable, x_p is the explanatory variable, b_p is the partial regression coefficient, b_0 is a constant, and p is the number of explanatory variables.

Microdata for FY1989, FY1994, FY1999, and FY2004 was utilized for the analysis. The total number of sample households is 177,625 across the four waves. Then, the valid sample comprises 169,451 households because invalid data of 8,174 households contained missing data. Fuel poverty households was set as the explained variable. This variable varies from 1 (if households are in fuel poverty) to 0 (if households are in non-fuel poverty). The explanatory variables are total floor area, age of household head, annual income, energy amount rate, expenditure on electricity and temperature. Total floor area, age of household head, annual income are considered to significantly impact fuel poverty households. Energy amount rate was added to measure the impact on fuel poverty households because variations in the rate could cause those in carbon pricing (e.g. electricity tariff). The energy amount rate is converted as per the FY2015 standard using the consumer price index; accordingly, the rate is 27.72 JPY/kWh (0.26 USD/kWh) for FY1989, 25.28 JPY/kWh (0.24 USD/kWh) for FY1994, 23.08 JPY/kWh (0.22 USD/kWh) for FY1999, and 21.73 JPY/kWh (0.20 USD/kWh) for FY2004 (Federation of Electric

Power Companies of Japan, 2018; Statistics Japan, 2017). Temperature added to clarify the relationship between the potential fuel poverty and temperature in summer.

Regression analysis results was described as following formula. These explanatory variables and constraint were significant at the 1% level, although temperature was excluded because the *p-value* was not significant.

$$\log\left[\frac{\pi(Y=1)}{1-\pi(Y=1)}\right] = 0.23x_1 + 0.00084x_2 + 0.020x_3 - 0.0058x_4 + 0.00017x_5 - 10.31 \quad (3)$$

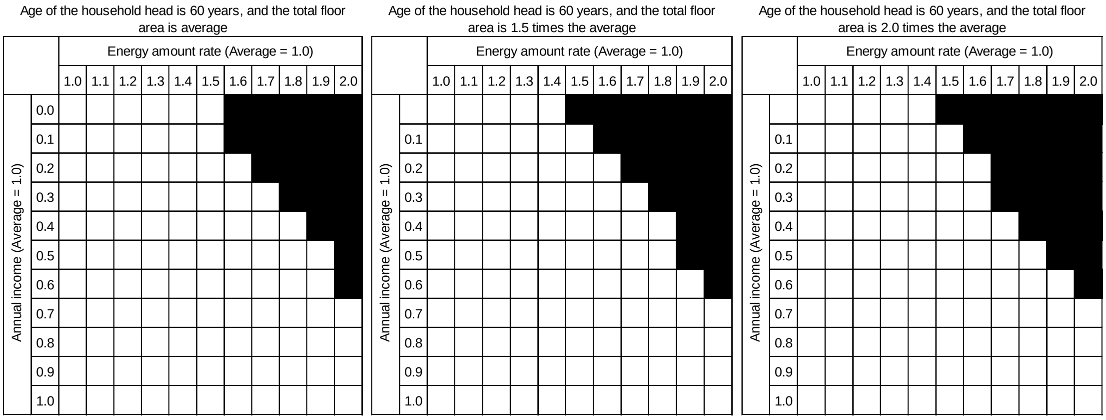
x_1: Energy amount rate (JPY/kWh), x_2: Total floor area (m^2), x_3: Age of household heads, x_4: Annual income (1,000 JPY) and x_5: Expenditure on electricity (JPY).

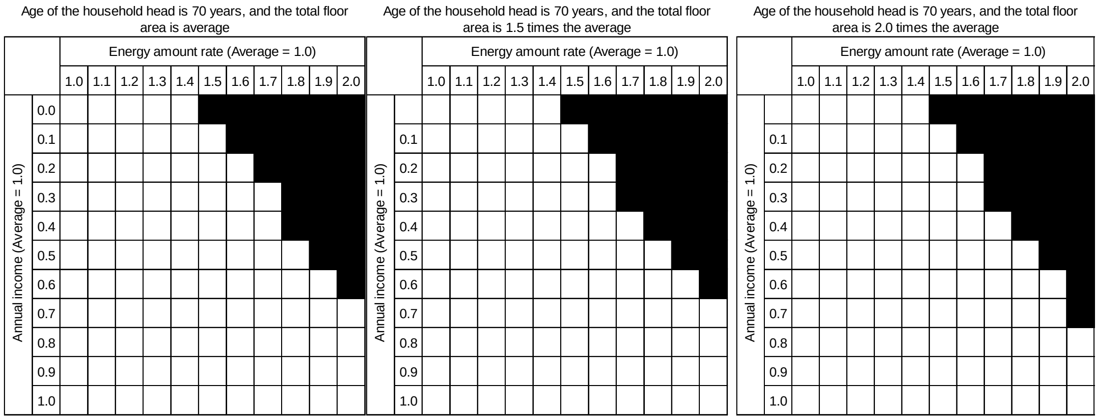
Nagelkerke's R^2, denoting the correlation coefficient for the binomial logistic regression, reports a low value of 0.286. However, all explanatory variables are significant at the 1% level in terms of the *p*-value, and regression coefficients are selected for the regression equation. In terms of the explanatory variables, annual income negatively impacts fuel poverty, whereas all other factors have a positive influence.

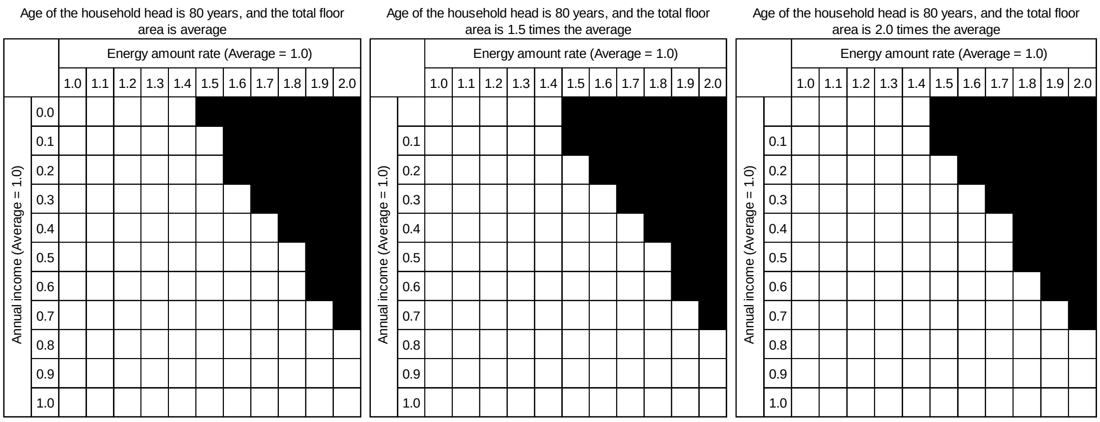
Next, a simulation was performed using the aforementioned regression formula. In this simulation, age of household heads changed from 60 years old to 70, 80, and 90 years old. Total floor area was also changed from the average for the sampled households to 1.5 times and twice the average. Annual income changes from 0% to 100% in 10% increments. Energy amount rate also increases from 110% to 200% in 10%

increments. It is assumed that expenditure on electricity varies with changes in the energy amount rate. Given the aforementioned changes in the explanatory variables, 12 patterns were derived for the simulation. The source of the explanatory value to be changed is the average value for FY2004 microdata: energy amount rate is 21.73 JPY/kWh, total floor area is 118.4 m^2, age of household head is 53.7 years, annual income is 6,740,000 JPY (63,073 USD), and expenditure on electricity is 9,346 JPY (87.46 USD).

Figure 5 shows the simulation results. For each pattern, vertical lines represent the difference in results owing to changes in the age of the household head. Horizontal lines denote the difference in results owing to changes in total floor area. For example, the result on the upper left indicates that household heads are 60 years old and the total floor area is average. On the lower right, the results suggest that household heads' age is 90 years and the total floor area is twice the average. When the rate of the age of household head and the rate of the annual income cross dotted black, it is considered that the fuel poor household has occurred.


Age of the household head is 60 years, and the total floor area is average
Age of the household head is 60 years, and the total floor area is 1.5 times the average
Age of the household head is 60 years, and the total floor area is 2.0 times the average
Energy amount rate (Average = 1.0)
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Annual income (Average = 1.0)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0


Age of the household head is 70 years, and the total floor area is average
Age of the household head is 70 years, and the total floor area is 1.5 times the average
Age of the household head is 70 years, and the total floor area is 2.0 times the average
Energy amount rate (Average = 1.0)
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Annual income (Average = 1.0)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0


Age of the household head is 80 years, and the total floor area is average
Age of the household head is 80 years, and the total floor area is 1.5 times the average
Age of the household head is 80 years, and the total floor area is 2.0 times the average
Energy amount rate (Average = 1.0)
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Annual income (Average = 1.0)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

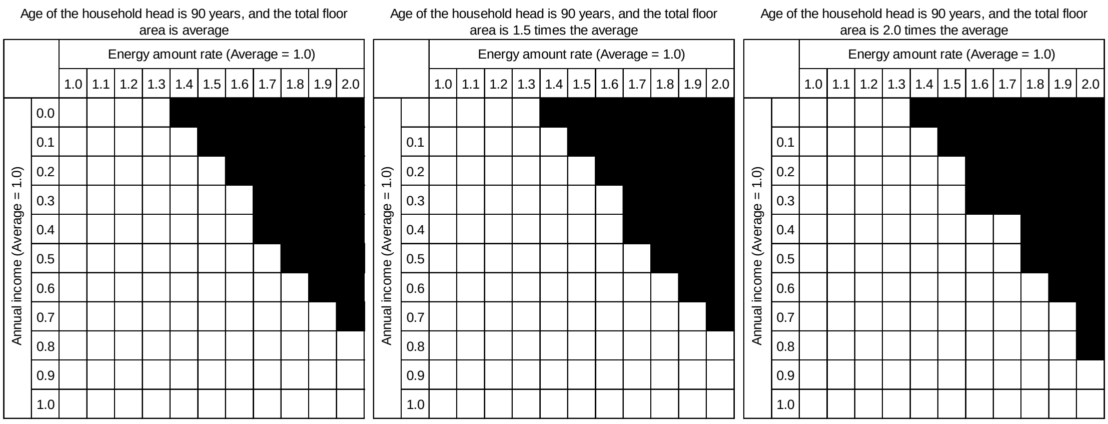

Age of the household head is 90 years, and the total floor area is average
Age of the household head is 90 years, and the total floor area is 1.5 times the average
Age of the household head is 90 years, and the total floor area is 2.0 times the average
Energy amount rate (Average = 1.0)
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Annual income (Average = 1.0)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Figure 5 Simulation results

As results of the simulation, households whose total floor area is average and heads are 60 years old tend to be the potential fuel poverty when energy amount rate is 160% or higher than the average and annual income is 60% or lower than the average. In this study, the width of energy amount rate and annual income that the potential fuel poverty is occurred is called as vulnerability. This vulnerability gradually increases with a rise in household heads' age. For instance, households whose head is 90 years tend to be the potential fuel poverty when energy amount rate is 140% or greater than the average and annual income is 70% or lower than the average. As another result, a majority of the elderly households spend from their pension and have annual incomes that are considerably lower than those of younger generations. Energy amount rate could rise as a result of increased carbon pricing (e.g. electricity tariffs) to promote renewable energy. However, possibility of elderly households increased up to criteria of the fuel poverty when the energy amount rate was risen. This result indicates that they might be more vulnerable to fuel poverty when carbon pricing increases. In addition, large total floor area increases energy amount rate and decreases annual income. In other words, elderly people in large homes are more vulnerable to fuel poverty.

4. Conclusions

This study estimates the number of Japanese households vulnerable to fuel poverty during summers using microdata. It focuses on elderly households and examines the occurrence condition for fuel poverty households by performing a simulation. The findings obtained from the study are as follows.

1) The estimation results using FY2004 microdata from the National Survey of Family Income and Expenditure reveal that 0.93% of the sampled households are potential fuel poverty households. Among the poverty households, 5.53% are fuel poverty households. Fuel poverty households tend to spend more on food and energy than non-fuel poverty households. Further, they have low annual income, savings, and insurance.

2) This study analyses whether households that have elderly couples, are run by single parents, or receive public assistance are more vulnerable to fuel poverty. The results reveal that elderly and single parent households are highly vulnerable. In the case of the elderly households, living in old and large houses and possessing old room air conditioners are key factors contributing to their vulnerability to fuel poverty.

3) A regression analysis is conducted to clarify the occurrence condition for fuel poverty households. More specifically, it examines for the presence of fuel poverty considering the age of household heads, total floor area, expenditure on electricity, annual income, and energy amount rate. The results reveal that changes in total floor area and energy amount rate increase potential fuel poverty households, particularly if they have lower annual income and older household heads. Further, a rise in energy amount rate as a result of carbon pricing (e.g. electricity tariff) is a significant factor contributing to elderly households' vulnerability to fuel poverty.

It can be concluded that fuel poverty in summer is extremely low compared with that observed in winter. However, the ratio of fuel poverty households to poverty households is not negligible. In addition, elderly households account for a higher number of poverty households compared with those of other generations. This suggests elderly households are more vulnerable to fuel poverty. About 58% of electricity consumption at 2:00 PM in the summer can be attributed to the use of room air conditioners (Cool share committee, 2018). Room air conditioners are desirable to avoid a heatstroke. On the other hand, fuel costs have been on the rise as a result of carbon pricing such as electricity tariff. This tendency increases elderly households' vulnerability to fuel poverty on an annual basis. Thus, urgent measures are needed to tackle these issues during the summer.

In this study, a commonly used 10% indicator is used as an indicator for estimating the potential fuel poverty households. However, it is necessary to consider whether to use this indicator. Because the 10% indicator is proposed in Europe and is particularly targeted in winter. Therefore, setting the cost threshold to 10% in countries with hot and humid climate zones such as Asia including Japan might not be appropriate. Further study is needed to discuss what percentage is appropriate taking into account Asian housing construction and poverty situation.

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