The Heterogenous Impacts of Energy Price Changes on Household Expenditure from the Aspect of Different Types of Household in Japan

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1. Introduction

In 2019, the household sector accounts for 19% of Japan's total CO_2 emissions. The household's CO_2 emissions in Japan peaked out in 2012. However, they are not yet on the track of decreasing trend. As one of the measures of mitigating CO_2 emissions in the household sector, expectations are rising about the effects of carbon pricing. When we evaluate the impacts of carbon pricing on energy conservation, price elasticity of energy demand is a key indicator. Some previous papers (Frondel et.al (2019), Chindarkar et.al (2019)) suggest that it is important to consider the differences of price elasticities caused by the household heterogeneity. In this study, therefore, we focus on the income and city size differences as the household heterogeneities concerning to the price elasticity.

Figure 1 shows a recent trend of the total share of energy and transportation expenditure by income category (left, Fig.1-1) and city size category (right, Fig.1-2) based on the Family Income and Expenditure Survey data. The share of energy and transportation expenses such as electricity, LPG, city gas, kerosene, gasoline and transportation service expenses is increasing in low-income households and has recently exceeded 10% of the total expenditure, whereas it is relatively stable at around 8% in high-income households.

Figure 2 shows the percentage of household energy and transportation expenditure over the total household expenditure for the latest 2017. In Japan, the use of public transportation is high among the major developed countries, accordingly, public transportation expenses other than fuel expenses are also analyzed in this study. Regarding the definition, the following are referred to as 'transportation expenses': railroad, bus, taxi, airplane and toll roads. As for the utility costs, the lower the household income, the higher the share of expenditure. It can also be seen that electricity bills account for more than half of the utility bill.

Based on the observations in Figure 1 and 2, it is expected that the impacts of rising energy costs on the household energy consumption and how each fuel is substituted by other energy will be differed by the income category and city size.

In order to evaluate the effects of price changes on energy consumption, the price elasticity of energy demand is often referred. In fact, various estimates have been made on the price elasticity of household energy demand. For instance, a recent analysis of Tanishita (2019) which used the Family Income and Expenditure Survey data estimated the price elasticity of household electricity demand in nine regions nationwide regarding the impacts of the Great East Japan Earthquake. In addition, some previous papers (Frondel et.al (2019), Chindarkar et.al (2019)) suggest that it is important to consider the differences of price elasticities caused by the household heterogeneity. As shown in Fig. 1, it suggests that in order to see the impacts of price change on energy consumption in the household with different income categories in Japan, it is necessary to analyze the whole household consumption expenditure, which includes not only energy but also food, clothing, housing and so on. However in Japan, there is not enough empirical analysis from this point of view.

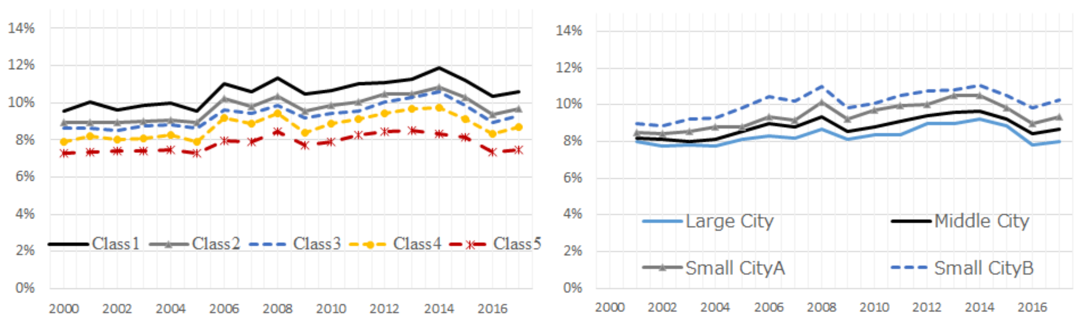

Figure 1 Total share of energy and transportation expenditure
by income category(left, Fig.1-1), city size category(right, Fig.1-2)

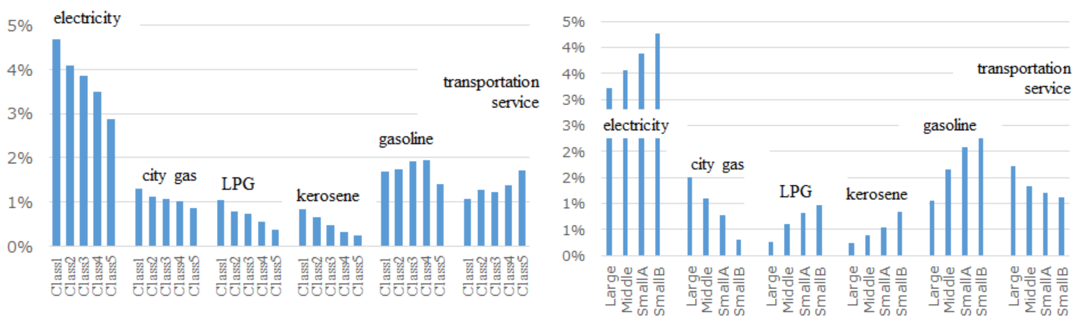

Figure 2 Share of energy and transportation expenditure in the year 2017
by income category(left, Fig2-1), city size category(right, Fig2-2)

Data source: Family Income and Expenditure Survey

In this study, therefore, we focus on the household heterogeneity in Japan, and analyze the impacts of price changes on the household expenses for the different types of household in income category and city size. Our analysis is based on the time series data from the Family Income and Expenditure Survey. The total consumption expenditure of households is divided into the six expenditures of electricity, gas, kerosene, gasoline, transportation expenses, and other expenditures (sum of eating and drinking expenses, clothing expenses, housing expenses, educational and entertainment expenses, etc.).

２．Methodology

2.1 Model

The indirect utility function of representing household consumer takes the form:

$$V = (p, Y) \qquad (1)$$

We model household's whole consumption expenditure including non-energy expenses. We get the following trans-log form:

$$lnV = \alpha_0 + \sum_i \alpha_i \ln(p_i/Y) + (1/2) \sum_i \sum_j \beta_{ij} \ln(p_i/Y) \ln(p_j/Y) \ , \ Y = \sum_i p_i x_i \qquad (2)$$

Where p_i, p_j are the i, j^{th} prices, Y is total consumption value, x_i is the i^{th} consumption volume.

$i, j =$ electricity, LPG, city gas, kerosene, gas oil, transportation service and other consumption

The i^{th} value share w_i can be written as :

$$w_i = (\alpha_i + \sum_j \beta_{ij}\, lnq_j)/(\sum_i \alpha_i + \sum_j \sum_k \beta_{kj}\, lnq_j) \qquad (3)$$

Referring to Kuroda (1989), own-price elasticity and cross-price elasticity are calculated as follows, respectively.

$$\eta_{pii} = -1 + \left(\beta_{ii}/w_i - \sum_j \beta_{ij}\right)/\ (\sum_j \alpha_j + \sum_j \sum_k \beta_{jk}\, ln(p_k/Y)) \tag{4}$$

$$\eta_{pij} = (\beta_{ij}/w_i - \sum_j \beta_{ij})/(\sum_k \alpha_k + \sum_k \sum_l \beta_{kl}\, ln(p_l/Y), \qquad (i \neq j) \tag{5}$$

$$\text{Where} \quad \sum_i w_i = 1,\ \ \sum_i \alpha_i = -1\ ,\ \sum_j \beta_{ij} = 0,\ \ \beta_{ij} = \beta_{ji}$$

Base on the above model, we estimate the price elasticity of energy demand using the aggregated annual data of the Family Income and Expenditure Survey from the year 2001 to 2017.

2.2 Data

Our analysis is based on the Family Income and Expenditure Survey data compiled by the Ministry of Internal Affairs and Communication. In this analysis, we use household income and annual expenditure data by household income category and city size for households of two or more people. The income category is a classification in which households are arranged in order from the one with the lowest annual income, and are divided into five categories. Each category has an equal number of households. They are called the category 1, category 2, category 3, category 4 and category 5, respectively.

The city size is a classification in which households are divided into four categories such as "large city", "middle city", "small city A" and "small city B". "Large city" includes "Government-designated cities" and Tokyo metropolitan Area. "Middle city" includes the cities which have more than 150 thousand population except for "large city". "Small city A" includes the cities whose population is more than 50 thousand and less than 150 thousand. "Small city B" is the cities whose population is less than 50 thousand.

Figure 3 shows the household characteristics of each income category, such as number of household members (Fig.3-1), age of the head of the household (Fig.3-2) and annual household consumption expenditure (Fig.3-3).

We find that the number of household members is gradually decreasing, and the age of the head of the household is increasing, especially in low-income households. Fig.3-3 shows the changes in household consumption expenditure by income category. Household consumption expenditure in the category 5 household is particularly large at more than double the category 1 household. On the contrary the lower the household income, the higher the propensity to consume in household income. In the category1 household, the average propensity to consume in household income is as high as 90% while it drops to 42% in the category 5 household.

Figure 4 shows the household characteristics of each city size category, such as number of household members (Fig.4-1), age of the head of the household (Fig.4-2) and annual household consumption expenditure (Fig.4-3).

Compared to Figure 3, the differences among city categories are relatively small. However, also in Figure 4, the number of household members decreases gradually and the age of householder steadily increases. Fig.4-3 shows that household consumption expenditure in the large city is bigger than that in the small city.

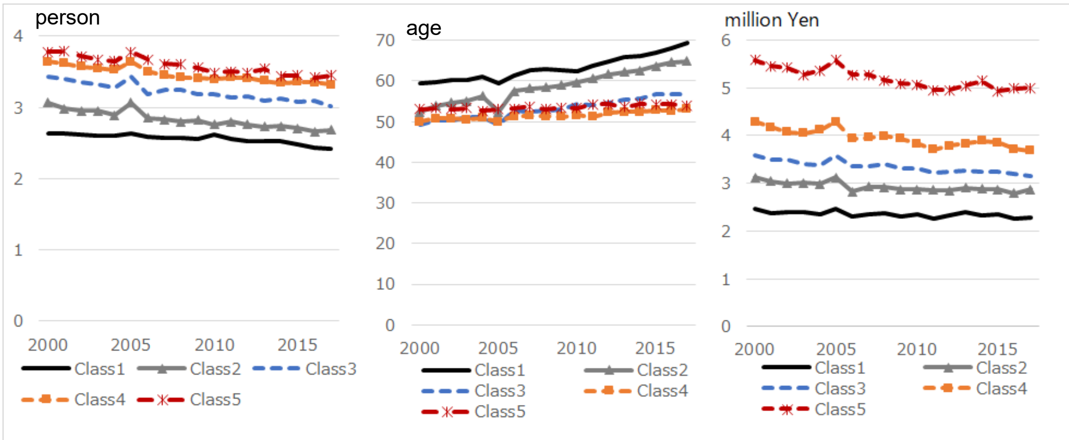

Figure 3 Household size(left, Fig.3-1), age of householder(center, Fig.3-2), annual household consumption expenditure(right, Fig.3-3) in each income category

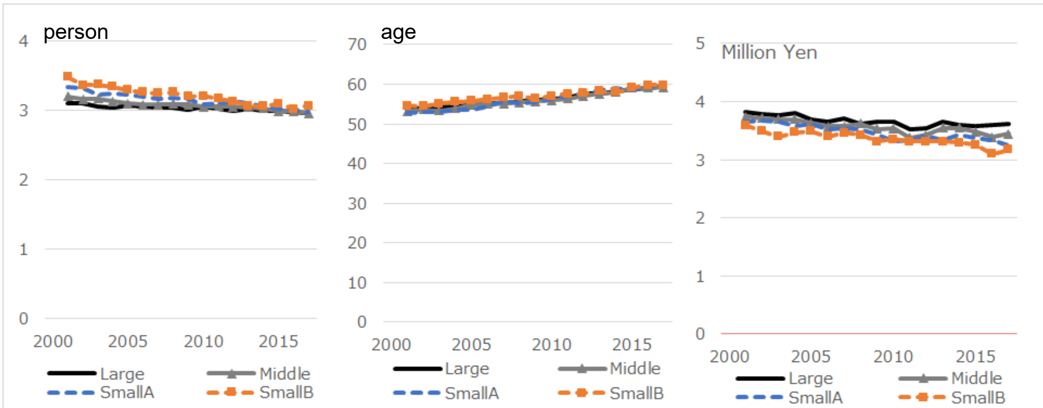

Figure 4 Household size(left, Fig.4-1), age of householder(center, Fig.4-2), annual household consumption expenditure(right, Fig.4-3) in each city size category

Data source: Family Income and Expenditure Survey

As for the household consumption expenditure items, our analysis covers energy expenses, transportation service expenses and the other expenses. Energy expenses include electricity, LPG, city gas, kerosene, gasoline. Transportation expenses include railroad, bus, taxi, aviation and toll road. Other consumption expenditures include food and beverages, clothing, housing, education and recreational and all other items.

In the Family Income and Expenditure Survey, although the unit price of purchase is also listed for some items but not for all items. Therefore, for the price data, we use data of the national average of Consumer Price Index for each item.

３． Results

3.1 Estimation of expenditure share function

We estimate the expenditure share function using the equation (3) for each of the seven expenditure of electricity, LPG, city gas, kerosene, gasoline, transportation expenses and other consumption by income category and city size.

As the sum of expenditure shares is $\sum w_i = 1$, we estimate simultaneously the six share functions excluding one (other consumption) of each income category or city size using the method of Zellner's Seemingly Unrelated Regressions (SUR).

Estimated results are shown in Table 1. In the table, the numbers come after the name of parameter such as α and β denote items of expenditure. Each item of i, j = 1, 2, ... ,6 indicates in order 1: electricity, 2: LPG, 3: city gas, 4: kerosene, 5: gasoline and 6: transport service, respectively.

The bottom part of Table 1 shows the coefficients of determination that indicates the explanatory power of the estimated share function. Regarding electricity and gasoline, the explanatory power is relatively high at around 0.8 to 0.9 for all income categories and city sizes. On the other hand, the explanatory power of LPG in most categories is relatively low and that of City Gas in "Small City B" is the lowest. One possible reason is that LPG is mainly used in the suburbs and rural areas where do not have gas pipeline infrastructure in Japan. In the category 5 household, the explanatory value of kerosene is also small. This is because kerosene is mainly used for heating especially in the rural areas where household income is relatively low.

3.2 Estimation of Price Elasticities

Table 2 and 3 show the own-price elasticity and cross-price elasticity which are calculated using the estimated model parameters. In those tables, the elasticity values are shown by the groups of each characteristic of goods, divided into "electricity, LPG, city gas, kerosene", "gasoline, transportation expenses", and "other consumption".

Although the model estimation period is from the year 2000 to 2017, each value in Table 2-3 represents the average of the years 2010 through 2017 in order to focus more on the latest information. Since this period includes the Great East Japan Earthquake, it is necessary to be a little cautious to the fact that we may overestimate the price elasticity values for electricity demand.

3.2.1 Own-Price Elasticity

In tables 2 and 3, bold numbers show the own-price elasticities which are derived from the equation (4). Most of the estimated own-price elasticities are negative which is expected theoretically,

Table 1. The estimated parameters of share function in household expenditure

		Category1	**Category2**	**Category3**	**Category4**	**Category5**
Estimated Parameter	α1	-0.048**	-0.042**	-0.040**	-0.036**	-0.031**
	α2	-0.011**	-0.009**	-0.008**	-0.006**	-0.004**
	α3	-0.015**	-0.014**	-0.013**	-0.012**	-0.011**
	α4	-0.009**	-0.007**	-0.006**	-0.005**	-0.004**
	α5	-0.019**	-0.019**	-0.021**	-0.021**	-0.017**
	α6	-0.012**	-0.013**	-0.013**	-0.014**	-0.016**
	β11	-0.031**	-0.030**	-0.026**	-0.023**	-0.011**
	β12	-0.015**	-0.008**	-0.008**	-0.003**	0.000
	β13	0.004*	0.001	0.000	0.000	-0.007**
	β14	-0.002	-0.005**	-0.004**	-0.003	-0.004**
	β15	0.003	0.004	0.004	0.001	0.006**
	β16	-0.010**	-0.010**	-0.009*	-0.011**	-0.012**
	β22	0.015**	0.014**	0.009**	0.005**	0.006**
	β23	-0.005**	-0.005**	-0.001	-0.003**	-0.003**
	β24	0.001	-0.004**	0.002	0.002	0.001
	β25	-0.004	0.005	-0.005*	-0.003	-0.002
	β26	0.029**	0.011**	0.017**	0.022**	0.007*
	β33	-0.014**	-0.013**	-0.011**	-0.008**	-0.006**
	β34	0.001	0.006**	0.001	0.001	0.003**
	β35	0.001	-0.008**	-0.001	-0.001	-0.004
	β36	-0.004	0.002	-0.007*	0.001	0.009**
	β44	-0.004	0.000	-0.004*	0.001	0.001
	β45	-0.004	-0.008*	0.001	-0.008**	-0.006*
	β46	-0.005	0.003	0.001	-0.002	0.001
	β55	0.029	-0.002	-0.018**	-0.005	-0.002
	β56	-0.014	-0.006	-0.001	-0.002	-0.005
	β66	0.001	0.017	-0.005	-0.026	-0.008
R^2	electricity	0.96	0.94	0.97	0.95	0.91
	LPG	0.39	0.58	0.58	0.75	0.79
	City Gas	0.85	0.78	0.85	0.87	0.67
	kerosene	0.84	0.60	0.64	0.46	0.20
	gasoline	0.78	0.88	0.86	0.86	0.75
	transport	0.88	0.87	0.84	0.82	0.57

		Large City	Middle City	Small CityA	Small CityB
Estimated Parameter	α1	-0.036**	-0.037**	-0.041**	-0.043**
	α2	-0.003**	-0.006**	-0.009**	-0.013**
	α3	-0.019**	-0.013**	-0.009**	-0.004**
	α4	-0.003**	-0.004**	-0.006**	-0.010**
	α5	-0.011**	-0.018**	-0.022**	-0.027**
	α6	-0.017**	-0.013**	-0.013**	-0.011**
	β11	-0.023**	-0.021**	-0.020**	-0.023**
	β12	0.000	0.005**	0.003	0.003
	β13	-0.002	-0.006	-0.02**	-0.010**
	β14	-0.005**	-0.008**	-0.01**	-0.01**
	β15	0.005	0.016**	0.02**	0.02**
	β16	-0.021**	-0.034**	-0.04**	-0.02**
	β22	-0.002	-0.004**	0.003	-0.003
	β23	-0.004**	-0.002	0.005**	-0.002
	β24	0.001	-0.002*	0.002	0.002
	β25	-0.001	0.003	-0.010**	-0.002
	β26	0.000	-0.001	0.010**	-0.003
	β33	-0.015**	-0.008**	-0.001	0.001
	β34	0.004**	0.007**	0.01**	0.001
	β35	-0.004	-0.009**	-0.01**	-0.002
	β36	0.014**	0.017**	0.01**	0.012**
	β44	-0.002*	-0.002	-0.005	0.001
	β45	-0.002	-0.004	-0.005	-0.015**
	β46	0.016**	0.013**	0.007*	0.009**
	β55	0.000*	-0.013**	-0.013	0.000
	β56	-0.015**	-0.023**	-0.014**	-0.018**
	β66	0.004**	0.078**	0.041**	0.034**
R^2	electricity	0.88	0.91	0.82	0.84
	LPG	0.29	0.82	0.63	0.27
	City Gas	0.78	0.56	0.71	0.12
	kerosene	0.74	0.71	0.68	0.60
	gasoline	0.87	0.95	0.87	0.86
	transport	0.75	0.80	0.78	0.42

Note: **, * denote statistical significance at 5% and 10%, respectively.

except for the elasticity of transport expenditure in the category1 and category3 households.

As for the impacts of income differences on the price elasticities, our results show that the own-price elasticities of electricity, city gas, kerosene and gasoline are larger in the category 5 households than in the category 1 households. This means that the higher the household income the more elastic the demand is. The higher own-price elasticities in the high-income households means that energy conservation is easier in those households because they can afford to invest in energy efficient appliances. On the other hand, lower own-price elasticities in the low-income households means that the rise of energy prices increases household energy expenditure burdens more severely.

As for the impacts of city size differences on the price elasticities, we find that the own-price elasticities of small cities are larger than those of large cities. Because in a small city, average house size is larger and transportation tends to depend more on automobiles. This implies that the households in a small city have more energy appliances and automobiles. Therefore, they have more chances to buy new

Table 2. The price elasticities of energy demand in the different income category household

Category1									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.32**	0.32	-0.09	0.04	Gasoline	**-0.54**	-0.24	other	**-0.92**
LPG	1.31	**-2.32**	0.46	-0.09	transport	-0.40	**0.89**		
City Gas	-0.29	0.36	**-0.05**	-0.06					
kerosene	0.23	-0.12	-0.10	**-0.50**					

Category2									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.26**	0.20	-0.03	0.12	gasoline	**-0.90**	0.29	other	**-0.94**
LPG	0.93	**-2.60**	0.59	0.48	transport	0.44	**-2.34**		
City Gas	-0.09	0.40	**-0.03**	-0.46					
kerosene	0.72	0.64	-0.89	**-1.06**					

Category3									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.32**	0.21	-0.01	0.11	gasoline	**-0.14**	0.07	other	**-0.91**
LPG	1.00	**-2.14**	0.09	-0.21	transport	0.12	**-0.63**		
City Gas	-0.03	0.06	**-0.04**	-0.13					
kerosene	0.78	-0.33	-0.29	**-0.18**					

Category4									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.34**	0.10	-0.01	0.08	gasoline	**-0.78**	0.09	other	**-0.92**
LPG	0.53	**-1.76**	0.45	-0.25	transport	0.14	**0.96**		
City Gas	-0.02	0.25	**-0.31**	-0.08					
kerosene	0.62	-0.38	-0.21	**-1.27**					

Category5									
	electricity	LPG	City Gas	kerosene		gasoline	transport		Other
electricity	**-0.62**	-0.01	0.23	0.15	gasoline	**-0.90**	0.32	Other	**-0.94**
LPG	-0.05	**-2.39**	0.75	-0.20	transport	0.32	**-0.51**		
City Gas	0.68	0.33	**-0.43**	-0.33					
kerosene	1.44	-0.28	-1.05	**-1.37**					

appliances and cars, which are more energy efficient.

3.2.2 Cross-Price Elasticity

In tables 2 and 3, the non-bold numbers show cross-price elasticities derived from the equation (5). In those tables, the number in each cell indicates the change in demand for the row-wise items relative to the price change for the column-wise items.

As for the impacts of the income difference, our results show that the impact of price increase of kerosene on the electricity demand in high-income households is larger than in low-income households. It means that when the price of kerosene increases, switching the heating energy from kerosene to electricity is easier in high-income households than low-income households.

If we compare table 2 and table 3, cross-price elasticities between gasoline and transportation services are very different from each other. Those values of table 3 are mostly larger than those of table 2. This means that the city size is a very important factor when we discuss the consumer's choice of transportation. In table 3, we can also find that compared to the large cities, in the small cities, the price increase of transportation services induces less demand increase of gasoline. The share of the private car in the total transportation means is already high enough in small cities. This might squeeze potential for shift

Table 3. The Price Elasticities of Energy Demand in the Different Types of the Household

Large City									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.31**	0.01	0.05	0.16	gasoline	**-0.46**	2.62	other	**-0.96**
LPG	0.11	**-0.30**	1.48	-0.48	transport	1.72	**-5.23**		
City Gas	0.09	0.23	**-0.15**	-0.22					
kerosene	1.89	-0.48	-1.44	**-0.16**					

Middle City									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.29**	-0.08	-0.02	0.23	gasoline	**-0.38**	1.18	other	**-0.97**
LPG	-0.44	**-0.20**	0.05	0.21	transport	1.66	**-5.45**		
City Gas	-0.06	0.02	**-0.08**	-0.35					
kerosene	1.88	0.32	-1.05	**-0.73**					

Small CityA									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.47**	-0.09	0.46	0.22	gasoline	**-0.46**	0.59	other	**-0.92**
LPG	-0.36	**-1.31**	-0.56	-0.18	transport	1.15	**-4.38**		
City Gas	2.10	-0.66	**-0.89**	-0.66					
kerosene	1.42	-0.29	-0.93	**-0.19**					

Small CityB									
	electricity	LPG	City Gas	kerosene		gasoline	transport		other
electricity	**-0.44**	-0.07	0.25	0.16	gasoline	**-1.01**	0.65	other	**-0.92**
LPG	-0.22	**-0.75**	0.15	-0.15	transport	1.82	**-4.35**		
City Gas	3.51	0.68	**-1.45**	-0.49					
kerosene	0.66	-0.19	-0.15	**-1.13**					

from public transportations to private cars.

4. Conclusion

We find the price elasticities vary according to the household income level and the size of the city where households are located. Our results suggest that energy pricing policy should be carefully designed considering the heterogenous response of different types of household. This suggests that rise of energy price is quite regressive in the household sector.

The higher own-price elasticities in the high-income households mean that energy conservation is easier in high-income households because they are affordable to invest energy efficient appliances. On the other hand, lower own-price elasticities in the low-income households mean that the rise of energy price increases household's energy expenditure burden more severely.

The price elasticities of households in a small city are bigger than those of households in a large city. Because in a small city where is generally located in a suburban area, average house size is larger and transportation tends to depend more on automobile rather than public transportation. This implies that the households in a small city use more energy appliances and automobiles. This also suggests rising price stimulates such household to replace less energy efficient appliances to energy efficient ones. This result is consistent with the study for India presented by Chindarkar (2019). As for the study for developed country, Bernstein and Griffin (2006) found the regional differences of price elasticity of residential electricity demand. In their study, elasticity of the southeastern region where the air-conditioning load is increasing rapidly is bigger than those of other regions.

Our analysis results that in order to evaluate the impacts of energy price change on energy consumption in the household, it is important to take into account differences of household characteristics especially income level and location. Furthermore, the impacts of differences in the regional climate on the price elasticity is one of our future research topics.

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