Kiel

Working Papers

Kiel Institute
for the World Economy

Household Formation and Residential Energy Demand: Evidence from Japan

by Carsten Schröder, Katrin Rehdanz, Daiju Narita, Toshihiro Okubo

No. 1836 | April 2013

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

Kiel Working Paper No. 1836 | April 2013

Household Formation and Residential Energy Demand: Evidence from Japan

Carsten Schröder, Katrin Rehdanz, Daiju Narita, Toshihiro Okubo

Abstract:
We use a large household panel for Japan (Keio Household Panel Survey) to estimate household-size economies in energy consumption. The household-size economies we obtain are significant and sizable: the per-capita energy-related spending of a two-adult household is only about two-thirds of the expenditure of a one-adult household. We use the estimates of household-size economies to explore how the demographic trend toward smaller-sized household units changes energy demand in the Japanese household sector. Between 2005 and 2010, for example, average household size in Japan decreased by about five percent. The resulting economy-wide loss in household-size economies increased energy demand in the household sector by about four percent.

Keywords: energy consumption, household-size economies, demographic change, household formation

Carsten Schröder (corresponding author)
University of Kiel
Olshausenstr. 40, 24098 Kiel, Germany
Telephone: +49 431 880-1772
carsten.schroeder@economics.uni-kiel.de

Katrin Rehdanz
University of Kiel and
Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: +49 431 8814-407
E-mail: katrin.rehdanz@ifw-kiel.de

Daiju Narita
Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: +49 431 8814-212
E-mail: daiju.narita@ifw-kiel.de

Toshihiro Okubo
Keio University, Japan
Email: okubo@econ.keio.ac.jp

1 Introduction

Many industrialized countries have implemented energy policies aimed at reducing greenhouse gas (GHG) emissions, and many of these countries promote the efficient use of energy and natural resources via taxes and policies. They promote improvements in the building stock by establishing standards for new buildings and providing subsidies for retrofits of existing houses, they promote the exploitation of renewable energy sources and investments in renewable energy consumption by providing subsidies or levying feed-in tariffs, they promote industrial processes and consumer products that use energy more efficiently, etc. Further, they participate in emissions trading schemes (e.g., the EU-ETS) or use other flexible mechanisms (e.g., the CDM or JI under the Kyoto Protocol) to reduce their GHG emissions.

However, to ensure that these various policies, schemes, and mechanisms are consistent with GHG emission reduction targets, valid projections of future energy use are required,[1] and such projections, in their turn, require information on overall energy use in an economy and on the determinants of demand in economic sectors (especially the industry, transport, and household sectors). In this paper, we set out to improve the validity of such projections by providing a better understanding of energy use and demand in the household sector, as this sector is a key driver of national energy demand in industrialized economies, usually accounting for about 15-25 percent of total energy use.[2] In particular, we explore a linkage that has largely been overlooked in the literature, the nexus between the decrease in average household size and the effect of this decrease on household energy use.[3] Multi-member households usually require less energy per capita than one-member households because the former can benefit from household-size economies. Accordingly, all other things being equal, a decrease in average household size will imply a decrease in household-size economies with regard to energy use and hence higher energy

[1] For Japan, the country we are looking at here, one source of official projections used for policy-making is the Japan Ministry of Economy, Trade and Industry (2008).

[2] According to the U.S. Energy Information Administration, consumption in the household sector in 2010 accounted for 22 percent of total national energy use (based on the physical unit (Btu)). According to the Ministry of Economy, Trade and Industry of Japan, consumption in the household sector in 2010 accounted for 14.4 percent of total national energy use (based on the physical unit (J)). According to Eurostat, consumption in the household sector of EU 27 in 2010 accounted for 26.7 percent of total national energy use (in kg oil equivalents).

[3] Interestingly, other demographic factors such as changes in population size, age structure, or lifestyles are acknowledged to be important determinants and have been addressed in several studies.

demand in the household sector. This being the case, ignoring the trend toward smaller-sized households may lead to erroneous projections of household-sector energy demand.[4]

Surprisingly, the linkage between average household size, household-size economies, and total energy demand has received scant attention in the literature. A number of studies do use household demographics in their attempt to explain household energy demand by employing micro-econometric regression techniques (see, e.g., Ironmonger et al., 1995, Vringer and Blok, 1995, Rehdanz, 2007, Meier and Rehdanz, 2010, and Brounen et al., 2012). However, they either fail to link their estimates to household-size economies or they ignore/overlook the connections between their findings and changes in household composition. Other studies use the well-known IPAT equation[5] or the Kaya Identity,[6] and some of the more recent of them also include demographic factors. However, these studies usually rely on cross-country macro-level data (see O'Neill et al. 2012 for an overview) and cannot isolate household-size economies in energy use from such other determinants of demand as household income. One exception that does use micro-level data is O'Neill and Chen (2002). Their results indicate that household size has a significant effect on US energy demand.

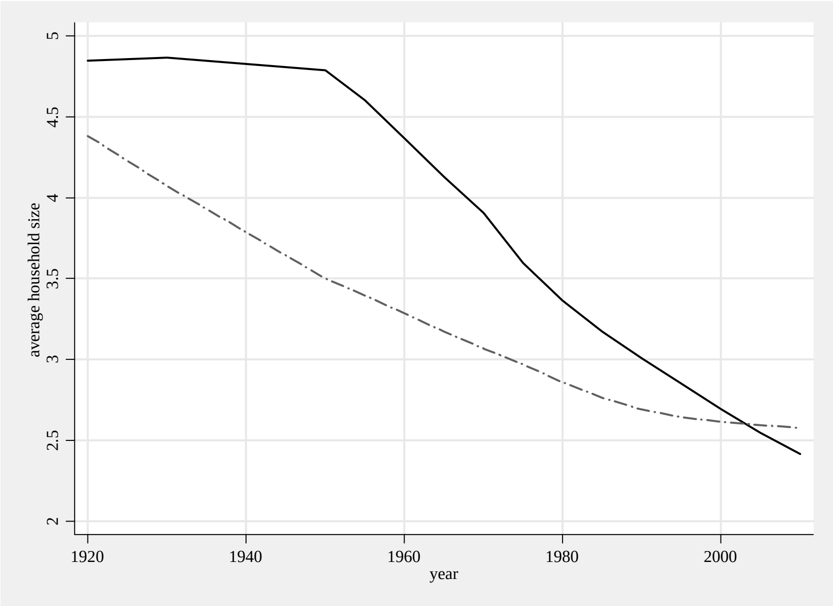
By contrast, the present article quantifies the way in which changes in household size and the share of the population living in households of a particular size alter household energy demand as a result of changes in the economy-wide household-size economies operative in energy use. In doing so, we use micro-level data for a large industrialized country, Japan. In this country, as in many others, we find a long-lasting secular trend towards smaller-sized households. Within less than a century (1920-2010), average household size decreased from more than 4.5 to about 2.5 members (see Figure 1). This trend is also typical of many other industrialized countries, where

[4] The present article, however, focuses on the direct connection between forgone intra-household sharing potentials due to the trend towards smaller-sized household units and energy demand in the household sector. Demographic change may, of course, have other long-lasting implications for the whole economy, and these will again re-echo in aggregate energy demand. For example, demographic change may impact economic growth (see, for example, Prskawetz et al. (2007) for an analysis of EU countries), the financial viability of social security systems (e.g., Gruber and Wise (1998)), labor and capital markets (e.g., Poterba (2001)), cross-border capital flows (e.g., Higgins (1998)), the sharing of GDP between working-age and retiree populations (e.g., Disney (2007) and Razin et al. (2002)), income and wealth distribution (e.g., Pestieau (1989)), households' consumption patterns (e.g., Pollak and Wales (1981) and numerous follow-up studies), etc.

[5] IPAT describes the environmental impact (I) of human activities as the product of: population size (P), affluence (A), and technology (T).

[6] The Kaya Identity explains annual carbon emissions as the product of population size, per capita income, energy intensity, and carbon intensity.

average households consist of two to three members. Household size in the United States, for example, has also decreased since the end of the 18th century, with the one-generation household again becoming the norm (see Figure 1).



Note. Data from the Statistics Bureau of Japan (census data) and the U.S. Census Bureau. Solid line: Japan. Dashed-dotted line: US.

Figure 1. Average household size in Japan and in the US

We proceed in three stages. First, we use a household panel dataset to estimate household-size economies in energy use. This enables us to control for effects that cannot be observed or measured directly or that change over the observation period but not across household units (e.g., policy reforms). Second, we use census data to derive how population shares living in various household types change over time. Third, we combine the results of these two steps to explore how changes in population shares have affected the total amount of energy used in the household sector.

We identify significant household-size economies and show that the trend towards smaller-sized households has a substantial effect on energy demand in the Japanese household sector. The five percent decrease in average household size between 2005 and 2010, for example, increased energy demand in the household sector by about four percent.

The remainder of the article proceeds as follows. Section 2 introduces the concepts and procedures related to the identification of household-size economies in energy use. Section 3 describes the data and its preparation. Section 4 sets out the estimates derived from a regression analysis. Section 5 assesses the effect of the secular trend towards smaller-sized households on energy demand in Japan's household sector. Section 6 concludes.

2 Household-size Economies: Definition and Identification

Members of households with more than one member can share household goods, such as vehicles, appliances, and housing, and thus benefit from household-size economies. Household-size economies are also likely to exist in energy use (see Elsner (2001) and Deaton and Paxson (1998)).[7]

In the literature, household-size economies in overall consumption are frequently assessed by using general equivalence scales, S. Such scales are indicators of differences in material needs between households of various size or composition. Usually, they use a one-member household as a so-called reference household, r, whose material needs are normalized to one. Equivalence scales for households other than the one-member households, for example, a household consisting of a couple with a child, show how material needs change as further members join the household. For a given household size, the smaller the scale value the higher the suggested level of household-size economies in overall consumption. The most commonly used general equivalence scale is the OECD equivalence scale (see OECD (2011)). This scale assigns a weight of 1.0 for the one-member reference household and an additional weight of 0.5 for each additional adult and 0.3 for each child. Accordingly, the equivalence scale for a household with one adult and one child is 1.3, and 2.1 for a two adult household with two children.

We use the OECD equivalence scale in identifying total household expenditure so as to ensure the same living standard across different household types, say types j and k: $exp^j/S^j = exp^k/S^k = exp^*$, where exp^* denotes equivalent expenditures. Further, we let energy expenditures, $energy$, depend on total household expenditures and household composition, d, i.e., $energy = energy(exp, d)$. Household composition, for example, can be captured by the

[7] Several studies are indeed backed up by empirical support, including Ironmonger et al. (1995) for Australia; Vringer and Blok (1995) for the Netherlands; Leach (1987) for South Asia.

total number of household members, n, or by the number of adults and children, n_A and n_C. A multi-member household, j, benefits from household-size economies in the use of energy if

$$(1)\quad \frac{energy(exp^j, d^j)}{energy(exp^r, d^r)} < \frac{n^j}{n^r} = \frac{n^j}{1}\ for\ n^j > n^r, and\ with\ exp^j/S^j = exp^k/S^k = exp^*.$$

Of course, many other general equivalence scales have been suggested in the literature.[8] It appears that the choice of the general equivalence scale affects the expenditure levels yielding the same living standard, i.e. the same equivalent expenditures, exp^*. Accordingly, the determination of household-size economies is sensitive to the general equivalence scale that is used. However, we would like to expressly point out that our use of the OECD scale to identify household-size economies in energy use makes no difference to our answer to the question of how the demographic trend toward smaller-sized household units changes energy demand in the household sector over time. This is because the change in energy demand does not depend on identifying an identical living standard across household types, exp^*. Instead, it derives from estimates of the expenditure functions $(energy(exp^j, d^j))$ together with census data on population characteristics.

3 Database and Working Sample

We use the Keio Household Panel Survey (KHPS), which is a Japanese household panel conducted by Keio University. The first wave of KHPS was conducted in year 2004 and covered 4,005 households; the most recent wave was conducted in 2012. The usual sample size ranges between 3,000 and 3,500 households. [9]

The KHPS provides information on various aspects of the participating households. It provides, for example, comprehensive information on household composition, income, expenses, assets, employment, school attendance, and lifestyle. Crucially for our analysis, it provides detailed information on the composition of participating households, on their total expenditures and aggregate expenditures on electricity, gas, water, and sewage, and on their non-aggregate

[8] Schröder (2009) and Lewbel and Pendakur (2007) provide a review of the literature on equivalence scales.
[9] On aspects of representativeness of data, see Kimura (2005). For sample attrition in KHPS, see Miyauchi et al. (2006), McKenzie et al. (2007), and Naoi (2008).

expenditures on electricity and gas only for 2004 and 2005.[10] Although the aggregate expenditures also include money spent on water and sewage, we will refer to these expenditures as energy-related expenditures.[11]

In preparing our working sample, we excluded from all KHPS waves those households for which the relevant information for our analysis is lacking. Further, to prevent outliers from biasing our estimates, we discarded the one percent of the households with the lowest and highest total expenditures and energy-related expenditures.

Altogether, our unbalanced working sample comprises 21,470 observations from 5,152 household units. Table 1 gives the sample sizes by wave and household type. Altogether, eight household types are distinguished that will also be used later in the econometric analysis: childless adult ($A1C0$); one adult with at least one child ($A1C1^+$); two adults without children ($A2C0$); two adults with one child ($A2C1$); two adults with at least two children ($A1C2^+$); three or more adults without children ($A3^+C0$); three or more adults with one child ($A3^+C1$); three or more adults with at least two children ($A3^+C2^+$). Most households in our database are adult-only households. For example, from a total of 2,897 household units in 2010, more than 62 percent (1,817) come under the heading childless households (with one, two, or three and more adults). Except for single-parent households, the number of observations by household type and year usually exceeds 100, which should be sufficiently large to guarantee sensible estimates.

Table 1. Number of observations by wave and household type

Wave	$A1C0$	$A1C1^+$	$A2C0$	$A2C1$	$A2C2^+$	$A3C0$	$A3C1$	$A3C2^+$	All types
2004	273	39	637	261	482	1062	238	245	3237
2005	213	39	552	228	447	930	208	205	2822
2006	197	34	513	182	422	858	201	185	2592
2007	273	52	763	234	596	1145	250	264	3577
2008	244	48	738	224	541	1039	228	229	3291
2009	238	40	693	218	490	962	211	202	3054
2010	233	27	684	208	456	900	213	176	2897
Sum	1671	279	4580	1555	3434	6896	1549	1506	21470
%	7.78	1.30	21.33	7.24	15.99	32.12	7.21	7.01	7.78

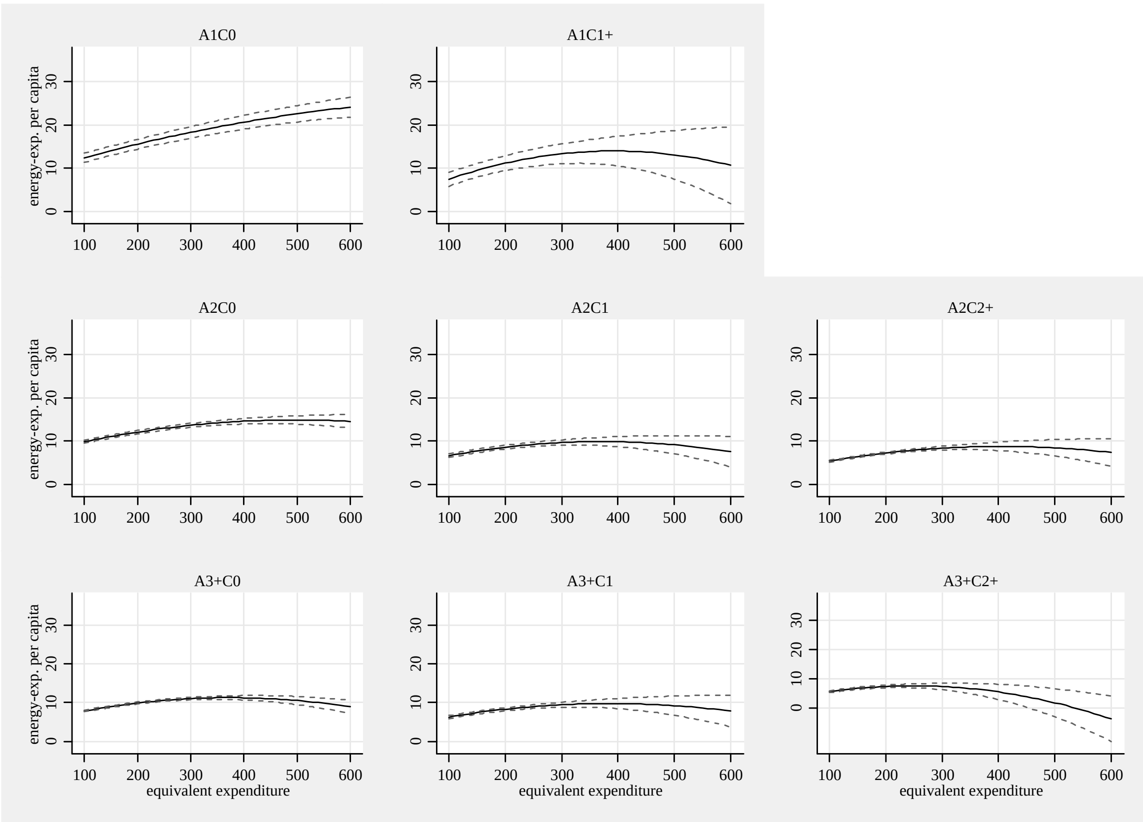
Note. Own calculations.
Database. KHPS 2004-2010.

[10] The data reflects monthly expenditure for one month, which is January in all cases.
[11] Household expenditures on water and sewage are usually small.

4 Results

4.1 Per-capita energy-related expenditures by household type

This section provides some initial descriptive statistics on the relationships between energy-related expenditures, household type, and total expenditures. For each household type introduced in Section 3, Figure 2 shows the relationship between per-capita energy-related expenditures and equivalent total expenditures (total expenditures divided by the OECD scale). Each household type is depicted in a separate graph. A graph provides the predicted per-capita energy-related expenditures and its 95 percent confidence interval from a linear regression with equivalent total expenditure and squared equivalent total expenditure as explanatory variables.[12] Expenditures are given in 1,000 Japanese Yen (JPY) per month at 2010 prices.[13]



Note. Own computations. Database is KHPS 2010. Dashed lines indicate 95 percent confidence intervals.

Figure 2. Energy-related expenditures per capita in different household types

[12] The regression includes year dummies to control for period effects. The estimates refer to period 2010.

[13] On 3 January 2013 the price of 1 US$ in JPY is 88.25.

The relationship between per-capita energy-related expenditures and equivalent total expenditures is positive but weak, indicating that energy has the characteristics of a necessity good that cannot readily be replaced by other goods.

Fixing a particular level of equivalent total expenditure and then comparing the corresponding per-capita energy-related expenditures across household types gives us an initial idea of the role of household-size economies in the use of energy. Take, for example, the childless single adult household type ($A1C0$) with an equivalent income of 400,000 JPY as a benchmark. The respective energy-related expenditure is about 20,210 JPY. With the same equivalent income, a childless two-adult household ($A2C0$) spends only about 14,480 JPY per capita on energy, a childless three-adult household ($A3^{+}C0$) 11,295 JPY (-28 percent). Fixing the number of household members and equivalent income sheds light on the different roles of adults and children for energy expenditures. The graphs suggest that energy-related expenditures are smaller for children than for adults. For example, consider again an equivalent income of 400,000 JPY. The energy-related expenditures of a childless three-adult household ($A3^{+}C0$) are 11,295 JPY per capita and only 9,986 JPY for a two-adult household with one child ($A2C1$; -12 percent). It is 9,877 JPY for a three-adult household with one child ($A3^{+}C1$; -13 percent) and only 8,813 for a two-adult household with two children (or more) ($A2C2^{+}$; -22 percent). The next section contains formal statistical tests on these and other relationships.

4.2 Household-size economies in energy-related expenditures

4.2.1 Specification of regressions

Because our analysis builds on panel data, we can account for individual heterogeneity across household units, i.e., for various unobservable characteristics such as intra-household decision processes or the intra-household-production technology in use.

The two basic techniques for analyzing panel data are fixed and random effects. The central distinction between the fixed-effects and the random-effects model is “whether the unobserved individual effect embodies elements that are correlated with the regressors” (Green, 2003, p. 183). If the error terms are correlated, then the fixed-effects model is not suitable since inferences may not be correct. We have used Hausman tests to see whether the fixed effects are correlated with the regressors. All test statistics advocate the use of the fixed-effects model. We have also tested to establish whether time fixed effects are needed in the fixed-effects model. Joint tests to analyze whether the dummies for all years are jointly equal to zero are rejected for all regression specifications. Accordingly, the regressions always include period dummies, DP.

Our regression analysis builds on three functional forms. The first functional form is

$$(2) \quad energy_{i,t} = \sum_{n=1}^{N} \hat{\alpha}^n \, DN_{i,t}^n + \hat{\beta} \, exp_{i,t} + \sum_{t=2005}^{P} \pi_t \, DP_t + \boldsymbol{\varphi X_{i,t}} + u_i + \varepsilon_{i,t}.$$

In equation (2) $DN_{i,t}^n$ are dummy variables. $DN_{i,t}^n = 1$ if the number of household members is n or larger, otherwise zero. For example, if the household size of household i in period t is $n = 3$, then $DN_{i,t}^1 = DN_{i,t}^2 = DN_{i,t}^3 = 1$. The respective regression coefficients indicate how energy-related expenditures change with every additional household member. The second variable is total household expenditures, $exp_{i,t}$. Thus the corresponding regression coefficient captures how energy-related expenditures change with total household expenditures. The terms DP_t denote period dummies. Because the observation period comprises seven years, we have included six period dummies. The corresponding coefficients capture period effects. The vector $\boldsymbol{X_{i,t}}$ represents other independent variables observed at household level, e.g., type and age of housing or interactions between demographic characteristics and total expenditure. We use u_i to denote the individual fixed effect and $\varepsilon_{i,t}$ to denote the error term.

Ignoring period effects and the role of the independent variables contained in $\boldsymbol{X_{i,t}}$, energy-related household-size economies for household type j relative to the one-member reference household, r, evaluated at equivalent expenditures exp^*, are given by,

$$(2^{HSE}) \quad \widehat{HSE}_J = 1 - \frac{\frac{\widehat{energy}_J}{n_j}}{\frac{\widehat{energy}_r}{n_r}} = 1 - \frac{\frac{\widehat{energy}_J}{n_j}}{\frac{\widehat{energy}_r}{1}} = \frac{\frac{\sum_{n=1}^{n_j} \hat{\alpha}^n D^n + \hat{\beta}\frac{exp_j}{S_j}}{n_j}}{\hat{\alpha}^1 + \hat{\beta}\frac{exp_r}{S_r}} \text{ with } \frac{exp_j}{S_j} = \frac{exp_r}{S_r} = \frac{exp_r}{1} = exp^*.$$

The second functional form capturing differences in energy expenditures between adults and children is

$$(3)\quad energy_{i,t} = \sum_{n_A=1}^{N_A} \hat{\alpha}^{n_A}\, DA_{i,t}^{n_A} + \sum_{n_C=1}^{N_C} \hat{\gamma}^{nc}\, DC_{i,t}^{nc} + \hat{\beta}\, exp_{i,t} + \boldsymbol{\varphi X_{i,t}} + u_i + \varepsilon_{i,t}.$$

According to equation (3) the terms $DA_{i,t}^{n_A}$ and $DC_{i,t}^{n_C}$ are dummy variables for each adult and for each child in a household unit. For example, in a two-adult household with one child we have $DA_{i,t}^1 = DA_{i,t}^2 = DC_{i,t}^1 = 1$. The associated regression coefficients $\hat{\alpha}^{n_A}$ and $\hat{\alpha}^{n_C}$ reveal how the presence of each adult and each child influences households' energy expenditures.

The third functional form capturing differences in energy expenditures by household type, as defined by the numbers of adults and children, is

$$(4)\quad energy_{i,t} = \sum_{type} \hat{\alpha}^{type}\, DT_{i,t}^{type} + \hat{\beta}\, exp_{i,t} + \sum_{p=2005}^{P} \pi_p\, DP_p + \boldsymbol{\varphi X_{i,t}} + u_i + \varepsilon_{i,t}.$$

The term $DT_{i,t}^{type}$ is a dummy variable indicating whether household i in period t belongs to households with a particular demographic composition, $type$. The types are the same as those introduced in Section 2. The regression coefficients $\hat{\alpha}^{type}$ distinguish energy-related expenditures across types. For specifications (3) and (4), energy-related household-size economies can again be derived analogously to equation (2^{HSE}).

To check for robustness, we fitted functional forms (2), (3), and (4) using different sets of variables contained in the vector $\boldsymbol{X_{i,t}}$. In the baseline specification (S1) $\boldsymbol{X_{i,t}}$ is empty. In the second specification (S2), the vector $\boldsymbol{X_{i,t}}$ comprises interactions between the demographic dummy variables and total expenditures. The regression coefficients pertaining to the interactions indicate how the role of demographic characteristics for energy-related expenditures changes with total expenditures.

4.2.2 Expenditure patterns for energy: estimates from fixed effects

Results from fixed-effects regressions are summarized in Tables 2, 4, and 6. Complementary test statistics on the equality of demography-related regression coefficients appear in Tables 3, 5, and 7. The upper panel of the regression tables shows the coefficient estimates and the respective robust standard errors (to deal with heteroskedasticity), while the bottom panel contains the following summary statistics: (a) the number of observations (N); (b) the Fstatistic to see whether all the coefficients in the model are different from zero; (c) the fraction of variance due to fixed effects (the intra-class correlation), ρ; (d) the amount of variance of the dependent variable explained by the independent variables, $R^2_{overall}$, as well as the R square within and between classes, R^2_{within} and $R^2_{between}$.

Table 2 contains the results from equation (2) (the number-of-members functional form). We comment on the basic specification (S1) first. The regression constant (the coefficient $\hat{\alpha}^1$ from equation (2)) and the coefficient for energy-related expenditures describe the energy-related expenditures of the one-member household. Apparently, energy-related expenditures are rather inelastic: when total expenditures increase by 100 JPY, only 1.3 JPY are related to energy.[14] This finding supports our preliminary conclusion from Figure 2 that energy is a necessity good. Compared to the one-member household, further members joining the household unit make for higher energy-related expenditures. This can be seen from the positive coefficients for the DN dummy variables. However, energy-related expenditures stop rising with the sixth household member. More members than that do not change energy-related expenditures. It is also interesting to note that the second household member increases expenditures by a smaller amount than the first, the third by a smaller amount than the second, and so on. For example, the coefficient pertaining to the second member (4.67) (third member (2.77)) is only about one third (one fifth) of the first (13.78). These figures indicate substantial household-size economies that are also increasing in the number of household members.

In addition to the basic specification, specification (S2) also includes interaction terms between the demographic dummy variables and total expenditures. The respective regression coefficients are all insignificant, suggesting that an additional household member raises energy-related expenditure by the same absolute amount for both rich and poor households. This implies that multi-member households with low total expenditures (income) spend a higher fraction of their available resources on energy than multi-member households with high total expenditures (income). Combined with the low elasticity between energy-related expenditures and total

[14] We have also tested more flexible specifications for the relationships between energy-related expenditures and total expenditures. For example, we have included higher polynomials of total expenditures. However, the associated regression coefficients usually turned out to be insignificant.

expenditures, this means that in households with meager material resources and many members energy accounts for the highest expenditure share. Accordingly, these households are the ones most seriously affected by rising energy prices.[15]

Table 2. Energy-related expenditures by household size: estimates from fixed effects

Specification	(1)		(2)	
DN^2	4.665***	(0.578)	5.284***	(0.871)
DN^3	2.769***	(0.328)	2.170***	(0.595)
DN^4	2.681***	(0.318)	2.382***	(0.593)
DN^5	1.539***	(0.442)	2.010*	(0.876)
DN^6	1.940**	(0.654)	1.063	(1.445)
DN^7	1.018	(0.982)	-0.609	(2.135)
DN^8	-0.864	(1.634)	1.130	(3.809)
DN^9	2.265	(4.870)	-13.219	(9.156)
DN^{10+}	6.879	(7.997)	27.412	(18.686)
exp	0.013***	(0.001)	0.013***	(0.003)
DP_{2004}	reference		reference	
DP_{2005}	-0.062	(0.215)	-0.065	(0.215)
DP_{2006}	1.203***	(0.226)	1.199***	(0.226)
DP_{2007}	0.299	(0.220)	0.294	(0.220)
DP_{2008}	1.465***	(0.226)	1.451***	(0.226)
DP_{2009}	2.515***	(0.234)	2.496***	(0.234)
DP_{2010}	1.311***	(0.236)	1.287***	(0.236)
$exp \times DN^2$			-0.002	(0.003)
$exp \times DN^3$			0.002	(0.002)
$exp \times DN^4$			0.001	(0.002)
$exp \times DN^5$			-0.001	(0.002)
$exp \times DN^6$			0.002	(0.004)
$exp \times DN^7$			0.005	(0.006)
$exp \times DN^8$			-0.006	(0.011)
$exp \times DN^9$			0.047	(0.027)
$exp \times DN^{10}$			-0.059	(0.037)
$constant$	13.781***	(0.611)	13.800***	(0.811)
N	21,470		21,470	
$F\ statistic$	50.90		34.31	
ρ	0.627		0.627	
R^2_{within}	0.0744		0.0754	
$R^2_{between}$	0.282		0.284	
$R^2_{overall}$	0.220		0.221	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. $F\ statistic$ is the test whether all the coefficients in the model are different from zero. ρ is the intra-class correlation.
Database. KHPS 2004-2010.

Based on specification (2), we have tested for differences in the regression coefficients for the demographic dummy variables. For example, we have investigated whether the regression

[15] This holds under the assumption that direct price elasticities are not too different across household types.

coefficient related to the dummy for the one-member household, $\hat{\alpha}^1$, differs statistically from the coefficient that relates to the two-member household, $\hat{\alpha}^2$, whether $\hat{\alpha}^2$ differs statistically from $\hat{\alpha}^3$, and so forth. The test statistics are summarized in Table 3. They indicate a significant drop in energy-related consumption (rising household-size economies) for each additional household member up to a household size of three. For larger households, the $\hat{\alpha}^{\cdot}$ coefficients do not differ statistically.

Table 3. Wald tests on equality of household-size coefficients for energy

$\hat{\alpha}^{N1} = \hat{\alpha}^{N2}$		$\hat{\alpha}^{N2} = \hat{\alpha}^{N3}$		$\hat{\alpha}^{N3} = \hat{\alpha}^{N4}$		$\hat{\alpha}^{N4} = \hat{\alpha}^{N5}$		$\hat{\alpha}^{N5} = \hat{\alpha}^{N6}$		$\hat{\alpha}^{N6} = \hat{\alpha}^{N7}$	
$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$Fstat.$
0.000	65.655	0.007	7.194	0.859	0.032	0.046	3.991	0.643	0.215	0.476	0.509

Note. Own calculations. Tests rely on coefficients from specification (1) in Table 2.
Database. KHPS 2004-2010.

Table 4 shows the results from equation (3) (functional form distinguishing between adults and children). The regression results convey three general messages. First, one additional adult increases energy-related expenditures more than an additional child. Second, in terms of energy-related expenditures, a second adult is less costly than the first, a third is less costly than the second, and so forth, while the costs for the first, second, and third child do not differ systematically. These conclusions are supported by the formal statistical tests shown in Table 5. Interactions between total expenditures and demographics are again insignificant or small, and the general relationships between household composition and energy-related expenditures are robust across the regression specifications.

Table 4. Energy-related expenditures by adults and children: estimates from fixed effects

Specification	(1)		(2)	
DA^2	4.487***	(0.480)	5.668***	(0.767)
DA^3	2.728***	(0.310)	1.525**	(0.571)
DA^4	2.545***	(0.358)	2.334***	(0.700)
DC^1	1.652***	(0.394)	1.946**	(0.702)
DC^2	1.999***	(0.375)	0.499	(0.781)
DC^3	1.533*	(0.610)	2.770*	(1.105)
exp	0.013***	(0.001)	0.014***	(0.003)
DP_{2004}	reference		reference	
DP_{2005}	-0.077	(0.215)	-0.076	(0.215)
DP_{2006}	1.158***	(0.227)	1.154***	(0.227)
DP_{2007}	0.234	(0.221)	0.228	(0.221)
DP_{2008}	1.376***	(0.227)	1.381***	(0.227)
DP_{2009}	2.420***	(0.235)	2.405***	(0.235)
DP_{2010}	1.181***	(0.238)	1.171***	(0.238)
$exp \times DA^2$			-0.005	(0.003)
$exp \times DA^3$			0.004*	(0.002)
$exp \times DA^4$			0.001	(0.002)
$exp \times DC^1$			-0.001	(0.002)
$exp \times DC^2$			0.005*	(0.002)
$exp \times DC^3$			-0.004	(0.003)
$constant$	14.625***	(0.550)	14.347***	(0.746)
N	21,470		21,470	
$F\ statistic$	58.28		41.56	
ρ	0.625		0.625	
R^2_{within}	0.0712		0.0724	
$R^2_{between}$	0.304		0.303	
$R^2_{overall}$	0.234		0.234	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. $F\ statistic$ is the test whether all the coefficients in the model are different from zero. ρ is the intra-class correlation.
Database. KHPS 2004-2010.

Table 5. Wald tests on equality of coefficients for adults and children for energy

$\hat{\alpha}^{A1} = \hat{\alpha}^{A2}$		$\hat{\alpha}^{A2} = \hat{\alpha}^{A3}$		$\hat{\alpha}^{C1} = \hat{\alpha}^{C2}$		$\hat{\alpha}^{C2} = \hat{\alpha}^{C3}$	
$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$
0.000	111.603	0.003	8.968	0.562	0.337	0.526	0.403

Note. Own calculations. Tests rely on coefficients from specification (1) in Table 4.
Database. KHPS 2004-2010.

Finally, Table 6 contains the results from equation (4) (functional form distinguishing by type of household), while Table 7 summarizes formal tests for the equality of regression coefficients. The results clearly indicate that energy expenditures are usually driven by the presence of adult household members. For a fixed number of adults, children tend to have little effect on the household-type-related coefficients. The only exception is the one-adult household with children.

Here we find a prominent rise in energy expenditures due to the presence of children. Tests on the differences between child-related energy expenditures in one-, two-, and three-adult households are provided in Table 7. For the first child, energy-related expenditures are significantly higher in one-adult than in two- or three-adult households. In two- and three-adult households, differences in energy-related expenditure caused by children are insignificant (5 percent level).

Table 6. Energy-related expenditures by household type: estimates from fixed effects

Specification	(1)		(2)	
DT^2 (A1C1$^+$)	5.787***	(1.004)	3.673*	(1.660)
DT^3(A2C0)	5.002***	(0.586)	5.521***	(0.885)
DT^4(A2C1)	7.039***	(0.726)	8.125***	(1.121)
DT^5(A2C2$^+$)	9.562***	(0.722)	9.989***	(1.024)
DT^6(A3$^+$C0)	8.885***	(0.650)	8.364***	(0.942)
DT^7(A3$^+$C1)	10.079***	(0.736)	10.038***	(1.217)
DT^8(A3$^+$C2$^+$)	11.253***	(0.836)	8.787***	(1.392)
exp	0.013***	(0.001)	0.013***	(0.003)
DP_{2004}	reference		reference	
DP_{2005}	-0.086	(0.216)	-0.080	(0.216)
DP_{2006}	1.105***	(0.228)	1.097***	(0.228)
DP_{2007}	0.177	(0.222)	0.175	(0.222)
DP_{2008}	1.322***	(0.228)	1.325***	(0.228)
DP_{2009}	2.347***	(0.235)	2.333***	(0.235)
DP_{2010}	1.108***	(0.239)	1.100***	(0.239)
$exp \times DT^2$			0.008	(0.006)
$exp \times DT^3$			-0.002	(0.003)
$exp \times DT^4$			-0.004	(0.004)
$exp \times DT^5$			-0.001	(0.003)
$exp \times DT^6$			0.002	(0.003)
$exp \times DT^7$			0.000	(0.004)
$exp \times DT^8$			0.007	(0.004)
$constant$	14.196***	(0.615)	14.359***	(0.812)
N	21,470		21,470	
$F\ statistic$	53.60		37.04	
ρ	0.631		0.631	
R^2_{within}	0.0671		0.0686	
$R^2_{between}$	0.283		0.282	
$R^2_{overall}$	0.217		0.216	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. $F\ statistic$ is the test whether all the coefficients in the model are different from zero. ρ is the intra-class correlation.
Database. KHPS 2004-2010.

Table 7. Wald tests on equality of coefficients for household types for energy

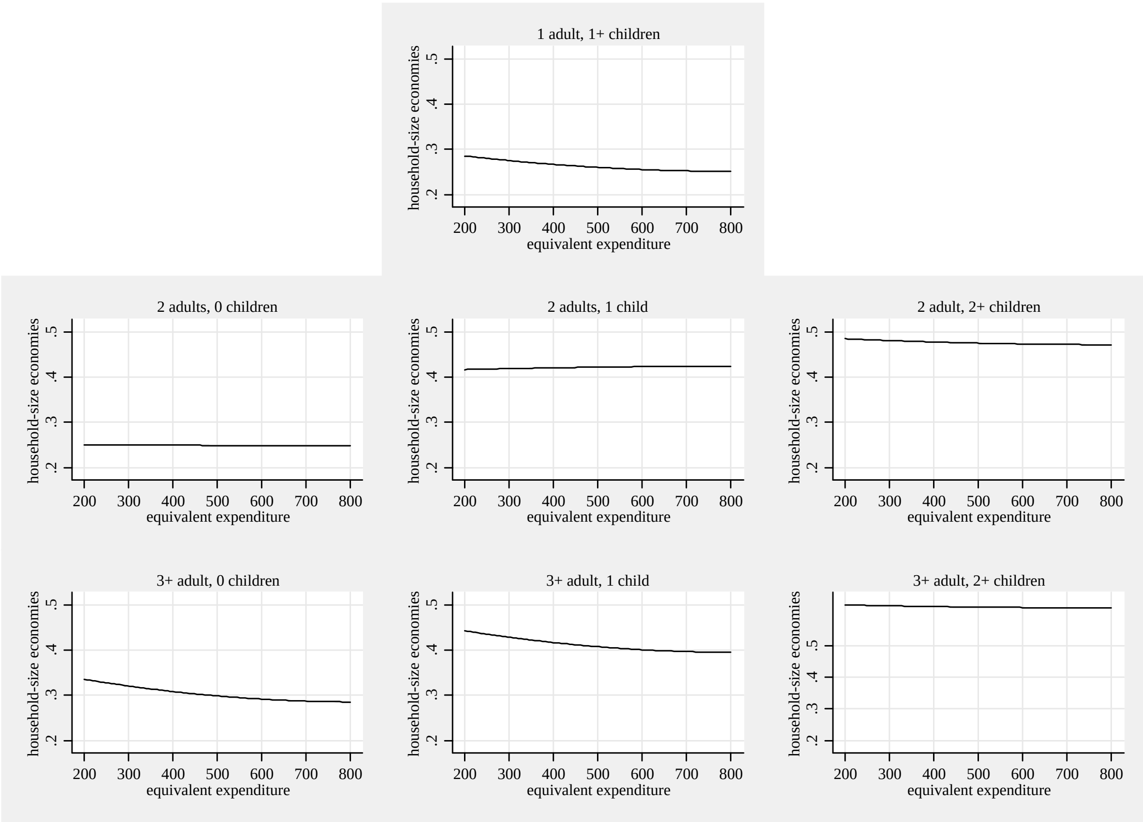
$\hat{\alpha}^{A1C1^+} = \hat{\alpha}^{A2C1} - \hat{\alpha}^{A2C0}$		$\hat{\alpha}^{A1C1+} = \hat{\alpha}^{A3C1} - \hat{\alpha}^{A3C0}$		$\hat{\alpha}^{A2C1} - \hat{\alpha}^{A2C0} = \hat{\alpha}^{A3C1} - \hat{\alpha}^{A3C0}$		$\hat{\alpha}^{A2C2^+} - \hat{\alpha}^{A2C1} = \hat{\alpha}^{A3C2^+} - \hat{\alpha}^{A2C1}$	
$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$	$Prob > F$	$F\ stat.$
0.000	14.154	0.000	19.225	0.163	1.944	0.055	3.689

Note. Own calculations. Tests rely on coefficients from specification (1) in Table 6.
Database. KHPS 2004-2010.

4.2.3 Household-size economies for energy

As seen in equation (2^{HSE}), household-size economies can be derived by comparing predictions about the energy-related expenditures of a type j household and a one-member reference household evaluated against the same equivalent total expenditure. Because equivalent total expenditures are based on the OECD equivalence scale that distinguishes between adults and children, estimates of household-size economies will rely on the third functional form equation (4) that distinguishes household types by the numbers of adults and children in them.

In Figure 3 our results are summarized in eight separate graphs, one graph per household type excluding the one-member reference type. A graph provides household-size economies evaluated at different levels of equivalent expenditures. In sum, household-size economies play a significant role in households' energy consumption. As an example, a childless two-adult household's per-capita spending on energy is about 33 percent lower than the spending of a childless one-adult household with the same equivalent total expenditure. Adding further members leads to a further increase of household-size economies. Comparing household-size economies at different equivalent expenditure levels, relationships differ across household types. Household-size economies are near-constant for the $A2C0$ and the $A2C2^+$ types. They decrease in equivalent total expenditures for the $A1C1^+$ and for the three-adult household types but increase for the $A2C1$ household.



Note. Own computations. Database is KHPS.

Figure 3. Household-size economies for energy

4.3 Household-size economies for gas and electricity

So far, our analysis has focused on household-size economies in energy-related expenditures. In our database, energy-related expenditures comprise expenditures related to the commodities gas, electricity, water, and sewage. Of course, this does not exclude the eventuality that household-size economies may differ for the four commodities. The 2004 and 2005 KHPS waves enable us to take a more detailed view. These two waves list expenditures on gas and electricity as separate categories in addition to energy-related expenditures. We use this information to identify differences in household-size economies between electricity and gas. Unfortunately, our investigation builds on a rather short time window (waves 2004-5), within which demographic characteristics are invariant for the vast majority of households. This means that the role of demographics in a fixed-effects model would be absorbed in the fixed effects. For this reason, we have decided to estimate a random effects model that allows for the inclusion of time-invariant variables.[16]

The KHPS waves 2004 and 2005 also encompass a broader set of variables possibly affecting energy demand. Notably the endowment of households with the following electrical devices is given: air conditioning, fridges, washing machines, televisions, and computers. Further, two variables are included that may help explain gas consumption: age and type of building.

For both electricity and gas, we have run random-effects models using the functional forms from equations (2), (3), and (4). For each of the three functional forms, we have also chosen the same specifications regarding the conditioning variables as in the fixed-effects estimations.[17] In addition, we have used a third specification (S3) to further expand the set of conditioning variables. In the case of electricity expenditures, the third specification also controls for household equipment with electrical devices (see last paragraph). In the case of gas expenditures, it also controls for age and type of building.

The results of the analysis are assembled in Tables 8-10 for electricity and in Tables 11-13 for gas. As for energy, the formal tests on the equality of coefficients related to household composition are shown in separate tables (Tables 14-16). In general, the results for the two sub-aggregates electricity and water are consistent with our findings for aggregate energy. In accordance with the regressions from the number-of-members functional form (equation (2)), adding further members to the household unit increases expenditures on both electricity and gas, as is the case with general energy expenditures. Further, the second household member again increases expenditures on both electricity and gas by a smaller amount than the first, the third by a smaller amount than the second, and so forth. As in the findings for energy, the regressions distinguishing between adults and children indicate that children are less costly than adults. Finally, for the regressions distinguishing between different household types, we again find no systematic differences between children in one-, two-, and three-adult households.

[16] A non-negligible fraction (about 3.5 percent) report zero expenditures for gas. For this reason, we have also estimated a left-censored random-effects tobit model. The tobit estimates turned out to be consistent with those from the baseline random-effects model. For reasons of comparability of the regression estimates for energy-, electricity-, and gas-related expenditures, we have elected here to report the results from the baseline random-effects model. The results from the random-effects tobit model can be provided upon request.

[17] One exception concerns the household-size specification (eq. 2). Because the number of households with nine or more members is rather small, these are included in the category ‘8+ members.’

Table 8. Electricity-related expenditures by household-size: estimates from random effects

Specification	(1)		(2)		(3)	
DN^2	3.269***	(0.305)	2.521**	(0.813)	2.200**	(0.816)
DN^3	0.990***	(0.258)	1.518*	(0.734)	1.083	(0.720)
DN^4	0.688**	(0.252)	0.711	(0.617)	0.512	(0.608)
DN^5	1.424***	(0.348)	1.178	(0.778)	0.858	(0.790)
DN^6	1.525**	(0.534)	0.991	(1.368)	0.567	(1.508)
DN^7	1.658	(0.885)	-0.262	(1.958)	-1.340	(2.297)
DN^8	0.897	(1.776)	6.293*	(3.017)	5.973	(3.277)
exp	0.012***	(0.001)	0.009**	(0.003)	0.009**	(0.003)
DP_{2004}	reference		reference		reference	
DP_{2005}	0.207	(0.116)	0.201	(0.116)	-0.838***	(0.123)
$exp \times DN^2$			0.004	(0.004)	0.001	(0.004)
$exp \times DN^3$			-0.002	(0.003)	-0.002	(0.003)
$exp \times DN^4$			-0.000	(0.002)	0.000	(0.002)
$exp \times DN^5$			0.001	(0.002)	0.001	(0.002)
$exp \times DN^6$			0.002	(0.004)	0.002	(0.004)
$exp \times DN^7$			0.006	(0.006)	0.008	(0.007)
$exp \times DN^8$			-0.016*	(0.007)	-0.020*	(0.008)
$\#Aircon$					0.545***	(0.057)
$\#Fridge$					1.055***	(0.274)
$\#Wash.mach.$					-0.246	(0.325)
$\#TV$					0.627***	(0.093)
$\#PC$					0.259*	(0.107)
$constant$	3.908***	(0.284)	4.329***	(0.556)	2.113**	(0.653)
N	6,111		6,111		5,724	
ρ	0.636		0.635		0.597	
R^2_{within}	0.0338		0.0343		0.0455	
$R^2_{between}$	0.210		0.213		0.310	
$R^2_{overall}$	0.188		0.191		0.288	
χ^2	896.0		927.2		1330.8	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero. *Database*. KHPS 2004-2005.

Table 9. Electricity-related expenditures by adults and children: estimates from random effects

Specification	(1)		(2)		(3)	
DA^2	1.543***	(0.307)	2.444**	(0.753)	2.023**	(0.722)
DA^3	2.243***	(0.228)	2.424***	(0.626)	1.820**	(0.634)
DA^4	2.236***	(0.285)	2.048**	(0.674)	1.502*	(0.689)
DC^1	-0.536*	(0.268)	-0.708	(0.682)	-0.965	(0.677)
DC^2	0.338	(0.298)	0.388	(0.793)	0.502	(0.784)
DC^3	1.068*	(0.444)	0.950	(0.965)	0.580	(0.983)
exp	0.012***	(0.001)	0.015***	(0.003)	0.012***	(0.003)
DP_{2004}	reference		reference		reference	
DP_{2005}	0.191	(0.117)	0.188	(0.117)	-0.806***	(0.125)
$exp \times DA^2$			-0.004	(0.003)	-0.003	(0.003)
$exp \times DA^3$			-0.001	(0.002)	-0.001	(0.002)
$exp \times DA^4$			0.001	(0.002)	0.001	(0.002)
$exp \times DC^1$			0.001	(0.002)	0.002	(0.002)
$exp \times DC^2$			-0.000	(0.003)	-0.001	(0.003)
$exp \times DC^3$			0.000	(0.003)	0.001	(0.003)
$\#Aircon$					0.556***	(0.059)
$\#Fridge$					0.973***	(0.276)
$\#Wash.mach.$					-0.166	(0.323)
$\#TV$					0.545***	(0.096)
$\#PC$					0.264*	(0.109)
$constant$	5.521***	(0.315)	4.757***	(0.619)	2.714***	(0.644)
N	6,111		6,111		5,724	
ρ	0.624		0.623		0.587	
R^2_{within}	0.0269		0.0273		0.0391	
$R^2_{between}$	0.237		0.238		0.321	
$R^2_{overall}$	0.210		0.211		0.298	
χ^2	757.2		791.8		1197.4	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero.
Database. KHPS 2004-2005.

Table 10. Electricity-related expenditures by household type: estimates from random effects

Specification	(1)		(2)		(3)	
DT^2 (A1C1$^+$)	2.396**	(0.765)	2.054	(1.630)	2.302	(1.52)
DT^3(A2C0)	3.374***	(0.306)	2.667**	(0.821)	2.329**	(2.83)
DT^4(A2C1)	2.308***	(0.369)	2.101*	(0.907)	1.389	(1.57)
DT^5(A2C2$^+$)	3.086***	(0.334)	2.991***	(0.772)	2.591***	(3.31)
DT^6(A3$^+$C0)	6.361***	(0.330)	6.088***	(0.703)	4.991***	(6.81)
DT^7(A3$^+$C1)	6.225***	(0.449)	6.209***	(1.124)	4.919***	(4.24)
DT^8(A3$^+$C2$^+$)	6.894***	(0.427)	5.509***	(0.945)	3.905***	(3.84)
exp	0.012***	(0.001)	0.009**	(0.003)	0.010**	(3.11)
DP_{2004}	reference		reference		reference	
DP_{2005}	0.181	(0.117)	0.178	(0.117)	-0.811***	(-6.53)
$exp \times DT^2$			0.002	(0.007)	-0.001	(-0.10)
$exp \times DT^3$			0.003	(0.004)	0.001	(0.20)
$exp \times DT^4$			0.001	(0.004)	0.001	(0.25)
$exp \times DT^5$			0.001	(0.004)	-0.001	(-0.16)
$exp \times DT^6$			0.002	(0.003)	-0.001	(-0.27)
$exp \times DT^7$			0.001	(0.004)	-0.000	(-0.03)
$exp \times DT^8$			0.005	(0.004)	0.004	(0.87)
$\#Aircon$					0.535***	(9.28)
$\#Fridge$					1.001***	(3.63)
$\#Wash.mach.$					-0.126	(-0.39)
$\#TV$					0.564***	(5.87)
$\#PC$					0.297**	(2.77)
$constant$	3.995***	(0.282)	4.392***	(0.558)	2.137**	(3.26)
N	6,111		6,111		5,724	
ρ	0.625		0.625		0.592	
R^2_{within}	0.0282		0.0293		0.0426	
$R^2_{between}$	0.237		0.237		0.317	
$R^2_{overall}$	0.210		0.210		0.295	
χ^2	982.2		1018.6		1428.3	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero.
Database. KHPS 2004-2005.

Table 11. Gas-related expenditures by household size: estimates from random effects

Specification	(1)		(2)		(3)	
DN^2	1.355***	(0.256)	1.251*	(0.557)	1.196*	(0.589)
DN^3	0.646**	(0.218)	0.743	(0.453)	0.648	(0.460)
DN^4	0.903***	(0.206)	0.467	(0.459)	0.413	(0.464)
DN^5	-0.113	(0.300)	0.445	(0.617)	0.505	(0.628)
DN^6	0.247	(0.425)	0.562	(0.876)	0.631	(0.889)
DN^7	-0.761	(0.663)	-0.369	(1.238)	-0.375	(1.254)
DN^8	0.540	(1.473)	0.107	(3.867)	-0.215	(3.931)
exp	0.006***	(0.001)	0.005*	(0.002)	0.005*	(0.002)
DP_{2004}	reference		reference		reference	
DP_{2005}	-0.107	(0.093)	-0.108	(0.093)	-0.113	(0.097)
$exp \times DN^2$			0.001	(0.003)	0.001	(0.003)
$exp \times DN^3$			-0.000	(0.002)	-0.000	(0.002)
$exp \times DN^4$			0.001	(0.002)	0.001	(0.002)
$exp \times DN^5$			-0.002	(0.002)	-0.002	(0.002)
$exp \times DN^6$			-0.001	(0.002)	-0.001	(0.002)
$exp \times DN^7$			-0.001	(0.004)	-0.001	(0.004)
$exp \times DN^8$			0.001	(0.012)	0.002	(0.013)
$Semi\ detached$					0.205	(0.373)
$Condo\ steel$					-0.106	(0.182)
$Wooden\ app.$					0.005	(0.280)
$House\ other$					1.457	(0.847)
$Age\ building$					-0.009	(0.005)
$constant$	4.244***	(0.233)	4.309***	(0.445)	4.594***	(0.523)
N	5,657		5,657		5,483	
ρ	0.640		0.640		0.634	
R^2_{within}	0.00849		0.00992		0.0105	
$R^2_{between}$	0.0944		0.0937		0.0932	
$R^2_{overall}$	0.0856		0.0851		0.0861	
χ^2	327.1		344.0		369.7	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero. *Database*. KHPS 2004-2005.

Table 12. Gas-related expenditures by adults and children: estimates from random effects

Specification	(1)		(2)		(3)	
DA^2	0.890***	(0.239)	1.752**	(0.579)	1.617**	(2.61)
DA^3	0.509*	(0.204)	0.424	(0.462)	0.462	(0.99)
DA^4	0.561*	(0.240)	1.276*	(0.513)	1.367**	(2.65)
DC^1	0.431*	(0.215)	0.237	(0.507)	0.083	(0.16)
DC^2	0.302	(0.244)	1.293*	(0.601)	1.143	(1.88)
DC^3	0.018	(0.353)	-0.086	(0.835)	0.044	(0.05)
exp	0.006***	(0.001)	0.011***	(0.003)	0.011***	(3.92)
DP_{2004}	reference		reference		reference	
DP_{2005}	-0.108	(0.093)	-0.108	(0.093)	-0.112	(-1.16)
$exp \times DA^2$			-0.004	(0.003)	-0.004	(-1.27)
$exp \times DA^3$			0.000	(0.002)	0.000	(0.08)
$exp \times DA^4$			-0.002	(0.002)	-0.002	(-1.50)
$exp \times DC^1$			0.001	(0.002)	0.001	(0.38)
$exp \times DC^2$			-0.003	(0.002)	-0.003	(-1.49)
$exp \times DC^3$			0.001	(0.003)	0.000	(0.04)
$Semi\ detached$					0.272	(0.73)
$Condo\ steel$					-0.086	(-0.45)
$Wooden\ app.$					-0.098	(-0.34)
$House\ other$					1.510	(1.82)
$Age\ building$					-0.013*	(-2.34)
$constant$	4.867***	(0.234)	3.824***	(0.519)	4.220***	(7.11)
N	5,657		5,657		5,483	
ρ	0.642		0.644		0.637	
R^2_{within}	0.00638		0.0108		0.0109	
$R^2_{between}$	0.0882		0.0871		0.0875	
$R^2_{overall}$	0.0791		0.0787		0.0803	
χ^2	238.9		257.9		271.5	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero.
Database. KHPS 2004-2005.

Table 13. Gas-related expenditures by household type: estimates from random effects

Specification	(1)		(2)		(3)	
DT^2 (A1C1$^+$)	1.448*	(0.580)	0.463	(1.106)	0.362	(0.31)
DT^3(A2C0)	1.379***	(0.258)	1.320*	(0.560)	1.301*	(2.19)
DT^4(A2C1)	1.989***	(0.289)	2.186**	(0.686)	1.936**	(2.70)
DT^5(A2C2$^+$)	2.640***	(0.285)	2.502***	(0.640)	2.062**	(3.08)
DT^6(A3$^+$C0)	2.505***	(0.263)	2.327***	(0.533)	2.319***	(4.02)
DT^7(A3$^+$C1)	2.859***	(0.361)	2.251*	(0.898)	2.113*	(2.26)
DT^8(A3$^+$C2$^+$)	2.766***	(0.362)	3.405***	(0.860)	3.444***	(3.80)
exp	0.006***	(0.001)	0.005*	(0.002)	0.005*	(2.13)
DP_{2005}	-0.112	(0.093)	-0.109	(0.093)	-0.115	(-1.19)
$exp \times DT^2$			0.004	(0.005)	0.004	(0.84)
$exp \times DT^3$			0.000	(0.003)	0.001	(0.27)
$exp \times DT^4$			-0.001	(0.003)	0.000	(0.01)
$exp \times DT^5$			0.001	(0.003)	0.002	(0.65)
$exp \times DT^6$			0.001	(0.002)	0.001	(0.48)
$exp \times DT^7$			0.002	(0.003)	0.002	(0.73)
$exp \times DT^8$			-0.002	(0.003)	-0.002	(-0.50)
$Semi\ detached$					0.242	(0.65)
$Condo\ steel$					-0.015	(-0.08)
$Wooden\ app.$					0.075	(0.26)
$House\ other$					1.496	(1.77)
$Age\ building$					-0.011*	(-2.10)
$constant$	4.235***	(0.234)	4.317***	(0.446)	4.602***	(8.77)
N	5657		5657		5483	
ρ	0.641		0.641		0.635	
R^2_{within}	0.00816		0.00963		0.0106	
$R^2_{between}$	0.0913		0.0904		0.0905	
$R^2_{overall}$	0.0825		0.0825		0.0846	
χ^2	308.7		329.0		353.7	

Note. Own calculations. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ρ is the intra-class correlation. χ^2 is the test whether all the coefficients in the model are different from zero.
Database. KHPS 2004-2005.

Table 14. Wald tests on equality of household-size coefficients (electricity and gas)

	$\hat{\alpha}^{N1} = \hat{\alpha}^{N2}$		$\hat{\alpha}^{N2} = \hat{\alpha}^{N3}$		$\hat{\alpha}^{N3} = \hat{\alpha}^{N4}$		$\hat{\alpha}^{N4} = \hat{\alpha}^{N5}$		$\hat{\alpha}^{N5} = \hat{\alpha}^{N6}$	
	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2
Electr.	0.220	1.504	0.000	23.581	0.483	0.493	0.131	2.286	0.894	0.018
Gas	0.000	43.351	0.078	3.097	0.467	0.529	0.016	5.788	0.561	0.337

Note. Own calculations. Tests rely on coefficients from specification (1) in Tables 8 (electricity) and 11 (gas).
Database. KHPS 2004-2010.

Table 15. Wald tests on equality of coefficients for adults and children (electricity and gas)

	$\hat{\alpha}^{A1} = \hat{\alpha}^{A2}$		$\hat{\alpha}^{A2} = \hat{\alpha}^{A3}$		$\hat{\alpha}^{C1} = \hat{\alpha}^{C2}$		$\hat{\alpha}^{C2} = \hat{\alpha}^{C3}$	
	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2
Electr.	0.000	50.079	0.093	2.814	0.082	3.033	0.221	1.500
Gas	0.000	87.205	0.281	1.164	0.750	0.102	0.555	0.348

Note. Own calculations. Tests rely on coefficients from specification (1) in Tables 9 (electricity) and 12 (gas).
Database. KHPS 2004-2010.

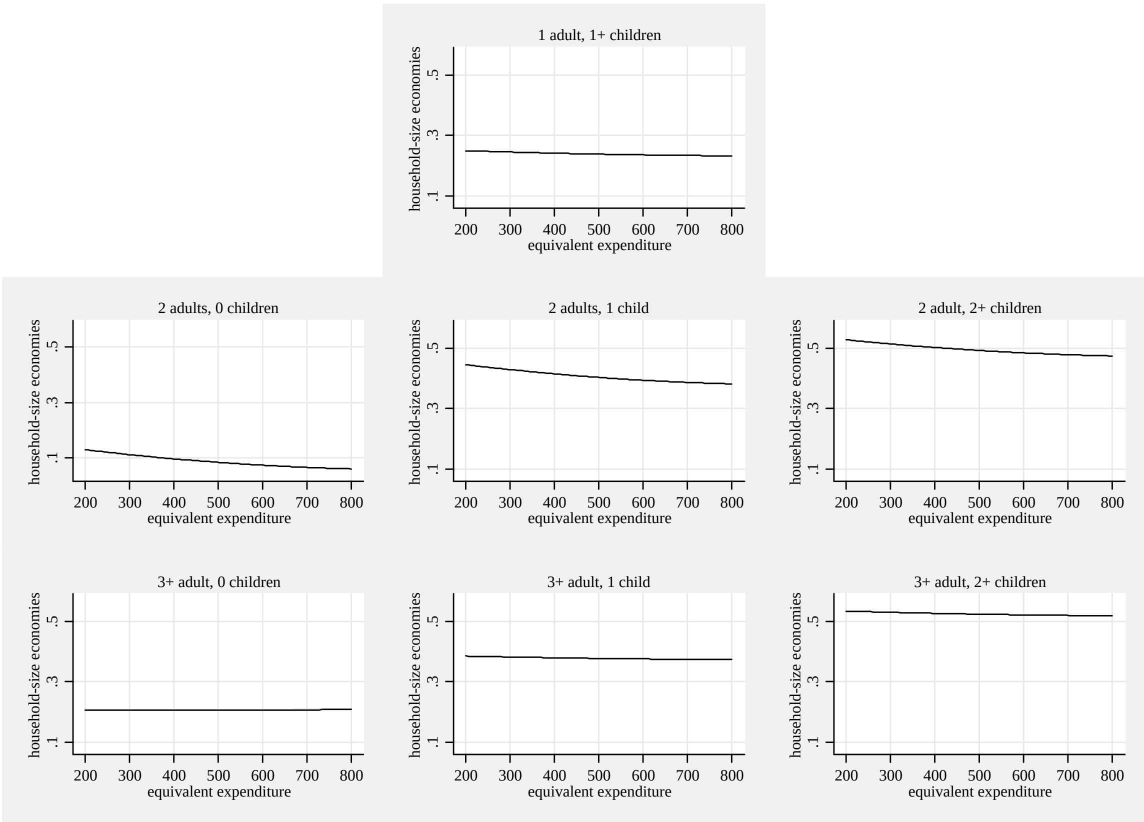
Table 16. Wald tests on equality of coefficients for household types (electricity and gas)

	$\hat{\alpha}^{A1C1^+} = \hat{\alpha}^{A2C1} - \hat{\alpha}^{A2C0}$		$\hat{\alpha}^{A1C1^+} = \hat{\alpha}^{A3C1} - \hat{\alpha}^{A3C0}$		$\hat{\alpha}^{A2C1} - \hat{\alpha}^{A2C0} = \hat{\alpha}^{A3C1} - \hat{\alpha}^{A3C0}$		$\hat{\alpha}^{A2C2^+} - \hat{\alpha}^{A2C1} = \hat{\alpha}^{A3C2^+} - \hat{\alpha}^{A2C1}$	
	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2	$Prob > \chi^2$	χ^2
Electr.	0.000	17.947	0.003	8.584	0.071	3.259	0.851	0.035
Gas	0.178	1.811	0.102	2.671	0.536	0.384	0.118	2.442

Note. Own calculations. Tests rely on coefficients from specification (1) in Tables 10 (electricity) and 13 (gas).
Database. KHPS 2004-2010.

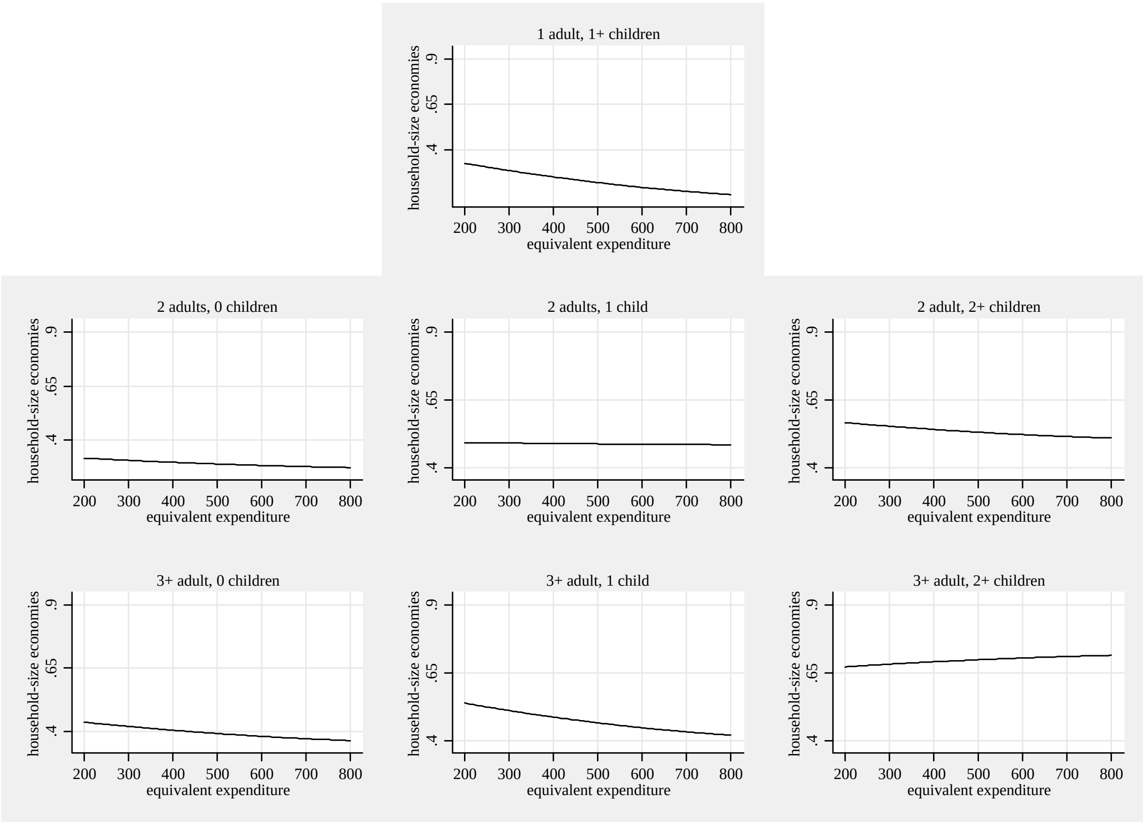
Comparing the results for electricity and gas, the regressions convey three messages. First, relative to one-adult households, enlarging household size leads to a stronger increase of expenditures on electricity than on gas. Second, electricity responds more elastically than gas to changes in total expenditures, but both react inelastically. Third, interactions between demographic dummies and expenditures are insignificant both for electricity and gas, suggesting that adding further members creates additional fixed costs and has no expenditure-dependent component. Finally, regarding the impacts of additional conditioning variables, the endowment with electrical appliances is of course positively related to electricity expenditures. Because endowment is positively related to household size, including the endowments in the regression lowers the impact of the demographic variables. Age and type of building have no effect on expenditures for gas.

Household-size economies are shown in Figures 4 and 5 with a separate graph for each household type. For reasons of comparability with our estimates on energy, they are derived from specification (S2). Our estimates suggest that household-size economies for electricity are slightly lower than for energy as a whole. Household-size economies are particularly low for the two adult-only household types $A2C0$ and $A2C3^{+}$. As in the case of energy, additional family members increase the level of household-size economies. For households with at least two children, our findings indicate about the same level of household-size economies for electricity and energy. For gas we find the opposite result. We find markedly higher household-size economies than for electricity, at least for the two adult-only household types $A2C0$ and $A2C3^{+}$. As an example, for the $A2C0$ household type, household-size economies for electricity range between 5.9 and 13.11 percent. For gas the figures are 27.4 and 31.8 percent.



Note. Own computations. Database is KHPS.

Figure 4. Household-size economies for electricity



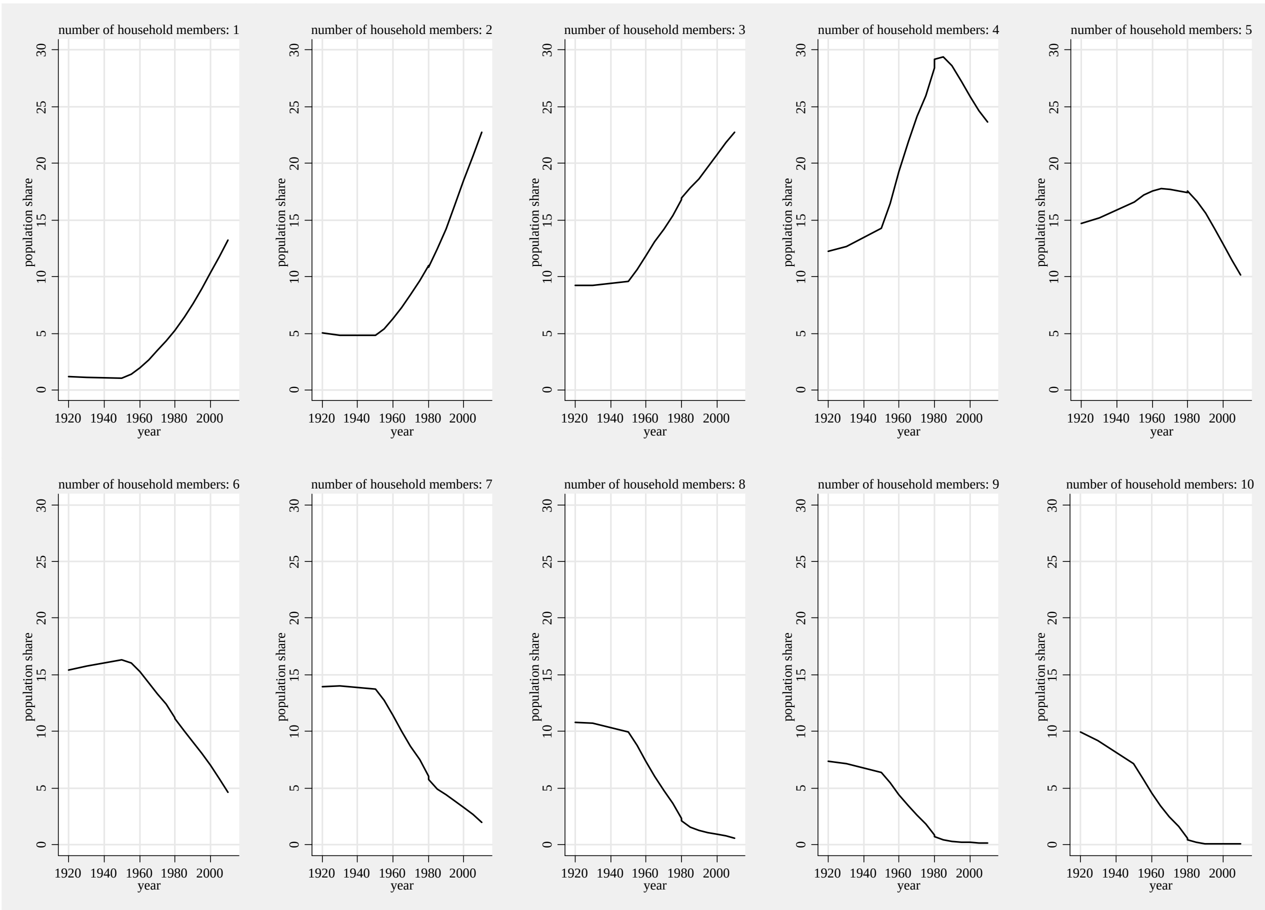
Note. Own computations. Database is KHPS.

Figure 5. Household-size economies for gas

5 The Secular Trend toward Smaller-sized Household Units and Energy Demand

Our regression results enable us to determine how changes in the demographic characteristics of the population affect the residential sector's energy consumption. Our main aim is find an answer to the question of how the secular decline of average household size in Japan has affected energy consumption in the residential sector over time – holding all other determinants constant.

Between the first national census in Japan dating back to 1920 and the end of World War II, household size in Japan was fairly stable, with about 4.8 persons per unit. As can be seen from Figure 6, in 1920 more than 25 percent of the population was living in household units with eight or more members, whereas the population share living in households with three members or less was only about 15 percent. Since World War II, the picture has changed drastically. As in other industrialized countries, later population censuses indicate a systematic downward trend in average household size. It decreased form about 4.82 in 1945 to 4.53 in 1960, 3.22 in 1980, 3.0 in 1990, 2.55 in 2005, and 2.42 in 2010. Nowadays, households with eight or more members have basically disappeared, while the proportion of the population living in households with three members or less has increased to about 60 percent (see Figure 6). The decrease in average household size is the result of (a) low fertility (since the mid 1970s), (b) the relative increase in households with nuclear families over and against households with extended families (particularly before the 1970s), (c) increasing life expectancy (with more and more elderly people living in one- and two-member households), and (d) a rise in average age at first marriage (implying a larger number of one-member households) (e.g., Japan Ministry of Health, Labour and Welfare, 2011).



Note. Own computations. Data from the Statistics Bureau of Japan (census data)

Figure 6. Population shares by household type in Japan

Based on the census data and our regression estimates, we have computed how the changes in the relative proportions of people living in differently-sized households between 2005 and 2010 (the two most recent census years that fall within the KHPS observation period) affect energy demand in Japan's residential sector. To assess the isolated effect of these changes, our computations are based on the following assumptions: (1) The distributions of all the explanatory variables are as in year 2010. (2) The relationships between the explanatory variables and energy-related expenditures are constant over time. (3) Total population size is held constant over time.

More specifically, our computation proceeds in three steps. First we take the regression estimates from the household-size regression for energy (Table 2, spec. 2). Second, with the regression estimates we predict energy-related expenditures for the KHPS households in 2010. Third, we extrapolate the predictions on the basis of the census data on population shares by household size for 2005 and 2010 that underlie Figures 1 and 6.

During the period 2005-10, the average size of a household in Japan decreased from 2.55 to 2.42 members (see Figure 1). This is a relative decrease of 4.9 percent. In the same period, the census data indicate an increasing proportion of the population living in households with up to three children and a decreasing proportion living in households with four or more members (see Figure 6). These demographic changes, in isolation, imply a loss of household-size economies amounting to a 3.9 percent rise in energy demand for the residential sector.

The household-level predictions of energy demands in a particular year can be averaged over all household observations on a particular household size. This average, $\overline{exp}_n$, reflects demand in a representative household of a particular type. Weighting these averages with the shares of the population living in a household type of particular size n, p_n, adding up these numbers and multiplying the result with the total population size, P, is as a sensible approximation to assessing how changes in the relative proportions of the population living in households of a particular size change aggregate energy demand in the residential sector, $\widehat{\mathrm{D}} = P \times \sum_{n=1}^{10+}(p_n \times \overline{exp}_n)$, with estimates of $\overline{exp}_n$ for period 2010 summarized in Table 17.

Table 17. Estimates of energy expenditures for representative households

Number of household members	$\overline{exp}_n$ Lower bound	Estimate	Upper bound
1	16.445	17.706	18.967
2	22.417	23.094	23.772
3	25.671	26.262	26.853
4	28.685	29.286	29.887
5	30.085	31.079	32.073
6	31.678	33.295	34.911
7	33.019	35.629	38.238
8	29.078	33.431	37.782
9	31.925	44.924	57.923
10+	18.668	43.020	67.371

Note. Estimates from fixed effects for year 2010. KHPS. Lower and upper bound give the 95% confidence interval. *Database.*

6 Concluding Remarks

Managing future energy demand is on the political agenda of governments all round the world. With a share of 15-25 percent, the residential sector is a key driver of this demand. Steering demand in the residential sector could be expected not only to reduce a country's energy import dependency, but also to benefit the environment by lowering the impact of climate change and/or local air pollution. Accordingly, understanding the determinants of energy demand in the residential sector is of central import.

While numerous studies exist on the determinants of energy demand at the micro-level (the household), little is known on how changes in population demographics alter energy demand in the residential sector as a whole. Policy debates sometimes acknowledge that the increase in the total number of households over the last decades due to the decline in average household size is part of the explanation for increasing energy use and carbon dioxide emissions by the residential sector (e.g., Japan Ministry of Economy, Trade and Industry, 2012; Japan Ministry of the Environment, 2012). But so far, this observation has remained qualitative and has not been expressed in terms of quantitative estimates of an isolated effect.

The present article provides insights into the actual magnitude of the relationship between average household size and aggregate energy use in the residential sector. Household-level micro-data and census data for Japan serve as the basis for our empirical analysis. According to our estimates, the moderate 5 percent reduction of average household size in Japan from 2005 to 2010, ceteris paribus, increased energy demand in the residential sector by about four percent. In the context of Japanese energy and environmental policy, this is a significant matter, as increasing carbon dioxide emissions from the residential sector have been an important factor offsetting the declining trend in emissions from industry over the last two decades (e.g.; Japan Ministry of the Environment, 2012). In sum, our results indicate that demographic change should be considered a non-negligible determinant of residential energy demand. As such, it should be adequately modeled in any projections of economy-wide energy demand seeking to correctly anticipate future resource usage.

Acknowledgements

We would like to thank Swantje Sundt for outstanding research assistance in the process of our data preparation. The usual disclaimer applies.

References

Brounen, D., Kok, N., and J.M. Quigley (2012): Residential Energy Use and Conservation: Economics and Demographics, European Economic Review 56, 931-945.

Disney, R. (2007): Population Ageing and the Size of the Welfare State: Is there a Puzzle to Explain, European Journal of Political Economy 23(2), 542-553.

Greene, W.H. (2003) Econometric Analysis (5th ed.), Prentice Hall.

Gruber, J., and D. Wise (1998): Social Security and Retirement: An International Comparison, The American Economic Review 88(2), 158-163.

Higgins, M. (1998): Demography, National Savings, and International Capital Flows, International Economic Review 39(2), 343-369.

Ironmonger, D.S., Aitken, C.K., and B. Erbas (1995): Economies of Scale in Energy Use in Adult-only Households, Energy Economics 17 (4), 301-310.

Japan Ministry of Economy, Trade and Industry (2008): Choki enerugii jukyu mitoshi ("Long-term Energy Supply-Demand Outlook": in Japanese).

Japan Ministry of Economy, Trade and Industry (2012): Enerugii hakusho 2012 ("White Paper on Energy Use 2012": in Japanese).

Japan Ministry of the Environment (2012): Nihon no onshitsu kouka gas haishutsu ryo no santei kekka ("Results of the Calculation of the Greenhouse Gas Emissions of Japan": in Japanese), accessed on 29 January, 2013: http://www.env.go.jp/earth/ondanka/ghg/index.html.

Japan Ministry of Health, Labour and Welfare (2011): Roudou keizai no bunseki ("White Paper on the Labour Economy": in Japanese) Chapter 2, Section 1.

Kimura, M. (2005): The Sample Characteristics of the 2004 Keio Household Panel Survey (2004nen Keio Gijuku Kakei Paneru Chosa no Hyohon Tokusei), chapter 1 in Y. Higuchi (ed.), Dynamism of Household Behavior in Japan [I] (Nihon no Kakei Kodo no Dainamizumu [I]), Keio University Press, Tokyo, 13-41 (in Japanese).

Leach, G. (1987): Household energy in South Asia, Biomass 12(3), 155–184.

Lewbel, A., and K. Pendakur (2007): New Palgrave (2nd Edition) Entry on Equivalence Scales.

McKenzie, C.R., Miyauchi, T., Naoi, M., and K. Kiso (2007): Individual Behaviour and the Attrition Problem in the Labour Market (Rodo Shijo ni okeru Kojin Kodo to Datsuraku Mondai), chapter 1 in Y. Higuchi and M. Seko (eds), Dynamism of Household Behavior in Japan[II] (Nihon no Kakei Kodo no Dainamizumu [III]), Keio University Press, Tokyo, 13-75 (in Japanese).

Meier, H. and K. Rehdanz (2010): Determinants of Residential Space Heating Expenditures in Great Britain, Energy Economics 32, 949-959.

Miyauchi, T., McKenzie, C.R., and M. Kimura (2006): An Analysis of Panel Data Continuation and Responses (Paneru Deta Keizoku to Kaito Bunseki), chapter 1 in Y. Higuchi (ed.), Dynamism of Household Behavior in Japan [II] (Nihon no Kakei Kodo no Dainamizumu [II]), Keio University Press, Tokyo, 9-52 (in Japanese).

Naoi, M. (2008): Residential Mobility and Panel Attrition: Using the Interview Process As Identifying Instruments, Keio Economic Studies 44(1), 37-47.

OECD (2011): Families and Children: What are Equivalence Scales?, http://www.oecd.org/dataoecd/61/52/35411111.pdf.

O'Neill, B.C., and B.S. Chen (2002): Demographic Determinants of Household Energy Use in the United States, Population and Development Review 28,53-88.

O'Neill, B.C., Liddle, B., Jiang, L., Smith, K.R. Pachauri, S., Dalton, M., and R. Fuchs (2012): Demographic Change and Carbon Dioxide Emissions, The Lancet 380 (9837), 157-164.

Pestieau, P. (1989): The Demographics of Inequality, Journal of Population Economics 2(1), 3-24.

Pollak, R.A., and T.J. Wales (1981): Demographic Variables in Demand Analysis, Econometrica 49(6), 1533-1551.

Poterba, J.M. (2001): Demographic Structure and Asset Returns, The Review of Economics and Statistics 83(4), 565-584.

Prskawetz, A., Fent, T., Barthel, W., Crespo-Cuaresma, J., Lindh, T., Malmberg, B., and M. Halvarsson (2007): The Relationship Between Demographic Change and Economic Growth in the EU, Research Report, 32, Institut für Demographie, Österreichische Akademie der Wissenschaften.

Razin, A., Sadka, E., Swagel, P. (2002): The Aging Population and the Size of the Welfare State, Journal of Political Economy 110, 900-918.

Rehdanz, K. (2007): Determinants of Residential Space Heating Expenditures in Germany, Energy Economics 29**,** 167-182.

Schröder, C. (2009): The Construction and Estimation of Equivalence Scales and Their Uses, in Slottje, D. (ed.): Quantifying Consumer Preferences, Contributions to Economic Analysis 288, Bingley (UK): Emerald.

Vringer, K., and K. Blok (1995): The Direct and Indirect Energy Requirement of Households in the Netherlands, Energy Policy 23(10), 893-910.