

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

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The decline in average family size and its implications for the average benefits of within-household sharing

By Carsten Schröder ^a, Katrin Rehdanz ^b, Daiju Narita ^c, and Toshihiro Okubo ^d

a German Institute of Economic Research (DIW Berlin), Socio-Economic Panel Study (SOEP), Mohrenstr. 58, Berlin, Germany; and Free University Berlin, Germany; e-mail: cschroeder@diw.de

b Kiel Institute for World Economy and University of Kiel

c JICA Research Institute and Kiel Institute for World Economy

d Keio University

Abstract

Economic policies rely on demographic projections. Yet in making these projections, researchers often ignore the aspect of household formation—despite sustained trends in many industrialized countries towards smaller household units with fewer members. Over the long term, this trend is likely to reduce the benefits of sharing goods/services within households (household economies of scale) at the micro level, thereby increasing household-sector demand at the macro level. We propose a framework to (a) quantify the level of household economies of scale for different household types; and (b) assess how the decline in average household size impacts aggregate household-sector demand. We apply the framework to energy consumption in Japan. The application indicates that household economies of scale in energy use are substantial and that the 5% decline in average household size in Japan between 2005 and 2010 led to an economy-wide loss in household economies of scale amounting to almost 4%.

JEL: D11, D12, J10, Q42.

1 Introduction

Demographic change affects economies in a multitude of ways. Aspects such as population size, age structure, and household formation can impact economic growth, the financial viability of social security systems, labour and capital markets, cross-border capital flows, sharing of GDP between working-age and retiree populations, income and wealth distribution, and households' consumption patterns.¹

Policy makers rely on demographic projections when designing economic policies. The projections they use are based on changes in population size and, to a lesser extent, age structure. Yet their projections frequently ignore changes in household formation, i.e., in the average number of household members. This is surprising given the sustained trend towards smaller-sized household units in many industrialized countries. Figure 1 displays this long-term secular trend for two sample countries, the United States (US) and Japan. Within less than a century (1920-2010), average household size in both countries decreased by about 2 members per family (from 4.4 to 2.6 members for the US and from 4.8 to 2.4 members for Japan).²

Figure 1 about here

Ignoring the trend towards smaller-sized household units may invalidate projections of household-sector demand for goods and services such as housing, transportation, durable goods, and energy. This is because multi-member households benefit from household economies of scale by sharing goods and services,³ thereby reducing their *per capita* demand for living space and energy. In the presence of household economies of scale, the inter-temporal decline in average household size means a loss in average household economies of scale and, consequently, an increase in household-sector demand.

In this article, we suggest a two-step procedure to assess the impact of changes in household size on household-sector demand. In the first step, we use micro data on household demand and composition to estimate household economies of scale. In a second step, we combine our estimates with census data on population shares by household size. This allows us to quantify how the decline in average household size reduces household economies of scale across the entire economy and increases household demand.

Conceptually, our procedure builds on Ironmonger *et al.* (1995) and O'Neill and Chen (2002), but differs in two important respects. First, we provide formal statistical tests of household economies of scale. Second, our study builds on panel data to identify household economies of scale, whereas Ironmonger *et al.* (1995) and O'Neill and Chen (2002) rely on a single cross-section of household micro data. Accordingly, the aforementioned authors cannot control for fixed effects, and they are only able to infer household economies of scale based on differences in household composition across household units.

¹ See, e.g., Prskawetz *et al.* (2007) on economic growth impacts in EU countries, Gruber and Wise (1998), on the financial viability of social security systems, Poterba (2001) on labour and capital markets, Higgins (1998) on cross-border capital flows, Razin *et al.* (2002) and Disney (2007) on GDP sharing between working-age and retiree populations, and Pestieau (1989) on income and wealth distribution.

² Data sources: Statistics Bureau of Japan (<http://www.stat.go.jp/english/data/chouki/02.htm>, last accessed: 2015-03-13) and the US Census Bureau (<http://www.census.gov/population/socdemo/hh-fam/tabHH-6.pdf>, last accessed: 2015-03-13).

³ See, e.g., the pioneering work of Pollak and Wales (1981).

We apply the two-step procedure to household energy consumption in Japan. We find that the 5% decline in average household size during the period 2005-10 resulted in forgone household economies of scale equivalent to a 3.5% increase in household-sector energy demand. This relationship between average household size, household economies of scale, and household energy use has been largely overlooked in most previous projections of energy demand. Governments of industrialized countries including the US, Canada, Japan, Norway and countries in the EU tend to focus instead on GDP and population growth to forecast future household energy demand.⁴

The remainder of the article proceeds as follows. Section 2 reviews the literature on residential energy demand. Section 3 introduces the concepts and procedures used in the identification of household economies of scale in energy use. Section 4 describes the data, their preparation, and the sample composition. Section 5 applies the proposed two-step procedure to household energy demand in Japan. Section 6 concludes.

2 Residential energy demand: A brief review of the literature

Despite the obvious link between average household size, household economies of scale, and household energy demand, a review of the literature reveals that household size has been considered in a very limited number of analyses to date. Interestingly, other demographic factors such as population size, age structure, and lifestyles are recognized as important determinants of energy demand and have been addressed in a number of studies.⁵

Relevant studies fall into three categories: (1) energy demand forecasts; (2) analyses of the relationship between demographic change and greenhouse gas (mainly CO₂) emissions, and (3) econometric investigations of the determinants of residential energy use (see OECD (2013) for an overview of the literature).

The first category of studies generally models and forecasts energy demand⁶ using macro-economic data (see Suganthi and Samuel (2012) for a recent overview of the respective literature). The Residential Demand Module of the US National Energy Modeling System (NEMS), for example, includes projections of energy consumption. The Energy Consumption Component of the NEMS uses population size as an input to the model (EIA, 2013).⁷ Shimoda *et al.* (2010) study population-wide averages of energy use for selected household types over time, and use these estimates for their projections.

⁴ See, e.g., <http://www.eia.gov/forecasts/aeo/> (US); <http://www.neb-one.gc.ca/clf-nsi/mrgynfmr/nrgyrprt/nrgyfr/2013/nrgfr2013-eng.html> (Canada); <http://www.enecho.meti.go.jp/en/reports/> (Japan); <http://www.ife.no/no/publications/2013/ensys/future-energy-demand-a-norwegian-overview> (Norway); http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf (EU) (last accessed: 2015-03-31).

⁵ O'Neill *et al.* (2012) review studies that consider population size, age structure, and urbanization; for a recent analysis of the impact of population aging on energy use see, e.g., Garau *et al.* (2013). Estiri (2014) shows that household characteristics have direct (energy-related behaviour) and indirect effects on energy consumption (choice of housing characteristics).

⁶ Modelling approaches include, e.g., input-output models, ARIMA models, bottom-up models such as MARKAL and soft computing techniques such as fuzzy logic and neural networks.

⁷ NEMS has a Macroeconomic Activity Module that distinguishes between three dwelling types in their projections for new and existing housing (single family, multiple families, mobile homes). Projections are based on the propensity of specific age-gender groups to form independent households (EIA, 2014).

Studies in the second category relate to analyses of the so-called IPAT equation, the relationship between environmental impact (I) of human activities, population size (P), affluence (A), and technology (T). In the climate change literature, this is also known as the Kaya identity.⁸ While earlier projections of future emissions only took population size into account, more recent studies also include demographic factors such as aging, urbanization, and changes in household size. However, most of these studies are cross-country analyses on the macro level (see O'Neill *et al.* (2012) for an overview), and thus cannot control for changes in household composition at the micro level. One exception is O'Neill and Chen (2002). They analyze past residential and transportation energy use in the US for future projections. Their results indicate that ignoring changes in household size would have led to an underestimation of US energy demand between 1960 and 1993 by about 14%.

The third category comprises econometric investigations of the determinants of residential energy use. Most of the studies consider demographic characteristics as a control variable, but do not further investigate household economies of scale and the connection to the macro-level aggregate household-sector energy demand (see, e.g., Rehdanz, 2007, Meier and Rehdanz, 2010, or more recently Brounen *et al.*, 2012). Some studies, including Ironmonger *et al.* (1995), Vringer and Blok (1995), and Brounen *et al.* (2012) provide estimates of household economies of scale from cross-sectional household surveys, but again do not address the macro-level implications.

3 Household economies of scale: Definition and identification

Multi-member households can share goods and services (e.g., vehicles, appliances, housing) and thus benefit from household economies of scale.

In the literature, household economies of scale in consumption are frequently assessed using what is known as a general equivalence scale, S . A general equivalence scale indicates the change in overall household consumption as additional members are added to the household, holding constant the level of household material well-being. A one-member household, the so-called reference household, r , serves as the benchmark. If the general equivalence scale of a household is smaller than the number of household members, household economies of scale are achieved. The most common of these is the OECD equivalence scale (OECD, 2011). It assigns a weight of 1.0 to 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, Exp , 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 (excluding energy-related expenditures) and household composition, d , i.e., $energy = energy(Exp, d)$. Household composition, for example, can be stated as the total number of household members, n , or as the number of adults and children, n_A and n_C . A multi-member household, j , benefits from household economies of scale in the use of energy if the energy equivalence scale of the same household is smaller than the number of its members, i.e.,

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

where n^r denotes a one-member household, our so-called reference household type.

⁸ The Kaya identity explains annual carbon emissions as the product of population size, *per capita* income, energy intensity and carbon intensity.

Typically, equivalence scales are quantified using estimates of household cost functions from demand systems. Household cost functions give the minimum expenditures required for a household with a particular demographic composition to attain a particular utility level at constant prices (see, e.g., Blundell and Lewbel, 1991, or Pashardes, 1995). Demand systems reveal the shape of indifference curves but not the associated utility levels. For this reason, the indifference curves that guarantee an identical living standard for different household types remain unknown. To resolve this under-identification problem (Pollak and Wales, 1979), the majority of the literature assumes cost functions across family types to be proportional with respect to income. This is the so-called “independence of base” (IB) (Lewbel, 1989) or “equivalence scale exactness” (ESE) assumption (Blackorby and Donaldson, 1993). The OECD equivalence scale is of the IB/ESE-type.

Of course, many other general equivalence scales have been suggested in the literature.⁹ 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 economies of scale is sensitive to the general equivalence scale that is used. However, it should be noted that our use of the OECD scale to identify household economies of scale in energy use does not conflict with 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.

4 Database and data preparation

We use the Keio Household Panel Survey (KHPS), which is representative of the Japanese population, conducted by Keio University. The first wave of the KHPS was conducted in 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.¹⁰

The KHPS provides a variety of household- and personal-level information: household composition, income, expenses, assets, employment, school attendance, and lifestyle. Crucially for our analysis, it also provides household composition, total household expenditures, and aggregate expenditures on electricity, gas, water, and sewage.¹¹ Although the aggregate expenditures also include money spent on water and sewage, we will refer to these as energy-related expenditures.^{12,13} Figure A1 in the Appendix provides wave specific histograms of energy expenditures. The histograms indicate that the distributions are close to the normal. Particularly left-censoring (at zero) does not seem to be an issue.¹⁴

⁹ Lewbel and Pendakur (2007) and Schröder (2009) provide a review of the literature on equivalence scales.

¹⁰ 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).

¹¹ The data reflect monthly expenditures for one month, which in all cases is January.

¹² For the years 2004 and 2005, expenditures on gas and electricity are reported as separate categories. Accordingly, it is possible to compute the expenditure share related to water and sewage in energy-related expenditures. Over the two years it is about 20%.

¹³ Previous studies on (pro-)environmental behaviour indicate that under-reporting of environmentally-damaging behaviour, response anomalies, and weak indicators (e.g., usage of plastic vs. cloth bags) may bias estimates of the environmental impact of household consumption/behaviour (Gatersleben *et al.*, 2002, e.g., provide a literature review). However, energy expenditure, in our view, is a powerful indicator of the environmental impact of household consumption/behaviour as it seems unlikely that respondents associate low (high) reported expenditures with environmentally friendly (damaging) behaviour. This conjecture is substantiated by the empirical fact that average monthly energy expenditures reported in KHPS are very close to official numbers. For example, according to Statistics Bureau, Ministry of Internal Affairs and Communication average monthly expenditures of private households (with two or more members) amount to about JPY 26,000.

In preparing our working sample, we excluded some KHPS households with incomplete information relevant to our analysis. Further, to prevent that outliers bias our estimates, we discarded the 1% of the households with the lowest and highest total and also energy-related expenditures.

Altogether, our unbalanced working sample comprises 21,469 observations from 5,152 household units. Table 1a 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 ($A2C2^+$); 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% (1,817) come under the heading childless households (with one, two, or three or 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 reliable estimates.

Our empirical analysis uses household fixed effects. The key coefficients (measuring household economies of scale in energy use and differences in energy expenditures) are identified from households that gain and lose members. One prerequisite is that enough households gain or lose members over time. For our working sample, Table 1b gives the transition probabilities of switching from one household type to another. Those household units are included for which we have at least two observations between 2004 and 2010. For example, take the entry 5.98 in row $A1C0$, column $A2C0$. It indicates that, over the observation period, a one-adult household without children has a 5.98% probability of becoming a two-adult household without children. As can be seen from the numbers on the diagonal, the majority of the households do not change type. At the same time, about ten to 32% of the households switch from one type to another, suggesting that there is sufficient variation in household composition at the level of each household unit to identify how changes in household size change energy-related expenditures.

Tables 1a and 1b about here

KHPS is based on stratified two-step random sampling. The stratification variables (region/city size) are not available in the data. However, the data provider gave us access to the households' city codes, the lowest level of stratification. In the econometric analyses below, these codes have been used to obtain standard errors robust to unknown heteroskedasticity.

5 Application of the framework

5.1 Energy expenditures by household type

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. Each graph provides the predicted *per capita* energy-related expenditures and its 95% confidence interval from a linear regression with equivalent total expenditures and squared equivalent total expenditures as explanatory variables.¹⁵ Expenditures are given in 1,000 Japanese Yen (JPY) per month at 2010 prices.¹⁶

For the same year and household types, the KHPS average is about JPY 27,000 (<http://www.e-stat.go.jp/SG1/estat/List.do?lid=000001063051>, last accessed: 2015-3-03-13).

¹⁴ Furthermore, regression estimates from the linear regressions (see below) and Tobit estimates (results not shown) hardly differ.

¹⁵ The regression includes year dummies to control for period effects. The estimates are for the year 2010.

¹⁶ One US dollar is worth 97.43 Japanese Yen based on the average exchange rate for June 2013.

Figure 2 about here

Fixing a particular level of equivalent total expenditure and then comparing the corresponding *per capita* energy-related expenditures across household types give us an initial idea of the role of household economies of scale 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 20,597 JPY. With the same equivalent income, a childless two-adult household (A2C0) spends only about 14,580 JPY *per capita* on energy, a childless three-adult household (A3⁺C0) 11,279 JPY (-23%).

Fixing the number of household members and equivalent income sheds light on the different roles of adults and children in 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 11,279 JPY *per capita* and only 9,857 JPY for a two-adult household with one child (A2C1; -13%). It is 9,788 JPY for a three-adult household with one child (A3⁺C1; -13%) and only 8,784 for a two-adult household with two children (or more) (A2C2⁺; -22%).

5.2 Estimation of household economies of scale (step 1)

5.2.1 Specification of regressions

Our econometric estimation of household economies of scale builds on fixed-effects estimations. 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” (Greene, 2003, p. 285). If the error terms are correlated, then the random-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.¹⁷ All test statistics favour the use of the fixed-effects model. We have also tested whether time fixed effects are needed in the fixed-effects model. Joint tests of 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

$$energy_{i,t} = \sum_{n=1}^N \alpha^n DN_{i,t}^n + \beta Exp_{i,t} + \overline{\kappa age}_{i,t} + \sum_{t=1}^6 \pi_t DP_t + \phi X_{i,t} + u_i + \varepsilon_{i,t}. \quad (2)$$

¹⁷ The Hausman test is implemented by STATA's `xtoverid` package using the artificial regression approach described by Arellano (1993) and Wooldridge (2002, pp. 290-91). The test extends to clustered data, and guarantees nonnegative test statistics.

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 $n = 3$ ($n = 1$), then $DN_{i,t}^1 = DN_{i,t}^2 = DN_{i,t}^3 = 1$ ($DN_{i,t}^1 = 1$) and all the other dummies are zero. The respective regression coefficients α^n indicate how basic energy-related expenditures change with each additional household member, while adding up the coefficients for a particular household size indicates basic needs at the household level. The coefficient β captures how energy-related expenditures change with total household expenditures, $Exp_{i,t}$.¹⁸ The third variable is the average age of all household members, $\overline{age}_{i,t}$; κ captures changes in energy-related expenditures over a household's lifecycle. The term DP_t denotes the period dummy for period t . Because the observation period comprises seven years, we have included six period dummies. The corresponding coefficients π_t capture period effects. The vector $\mathbf{X}_{i,t}$ represents other independent variables observed at household level, for example, 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.

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

$$energy_{i,t} = \sum_{n_A=1}^{N_A} \alpha^{n_A} DA_{i,t}^{n_A} + \sum_{n_C=1}^{N_C} \gamma^{n_C} DC_{i,t}^{n_C} + \beta Exp_{i,t} + \kappa \overline{age}_{i,t} + \sum_{t=1}^6 \pi_t DP_t + \phi \mathbf{X}_{i,t} + u_i + \varepsilon_{i,t}. \quad (3)$$

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 α^{n_A} and γ^{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

$$energy_{i,t} = \sum_{type} \alpha^{type} DT_{i,t}^{type} + \beta Exp_{i,t} + \kappa \overline{age}_{i,t} + \sum_{t=1}^6 \pi_t DP_t + \phi \mathbf{X}_{i,t} + u_i + \varepsilon_{i,t}. \quad (4)$$

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 α^{type} distinguish energy-related expenditures across types.

To check for robustness, we fitted functional forms (2), (3), and (4) using two different sets of variables contained in the vector $\mathbf{X}_{i,t}$. In the baseline specification (S1), $\mathbf{X}_{i,t}$ is empty. In the second specification (S2), the vector $\mathbf{X}_{i,t}$ 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.

¹⁸ We have excluded energy-related expenditures from total expenditures because total expenditure is a function of energy-related expenditures.

Controlling for period effects and the variables contained in $\mathbf{X}_{i,t}$, we can take the estimated coefficients pertaining to household demographics to estimate the energy equivalence scales of different household types. More specifically, the energy equivalence scale of a household type j is the ratio of energy-related expenditures of household type j and energy-related expenditures in the one-member reference household, r , evaluated at the same level of equivalent expenditures (defined by the OECD equivalence scale), as defined in Equation (1). Household economies of scale are achieved if $S^{energy,j} < n^j$.

5.2.2 Results

Results from fixed-effects regressions are summarized in Tables 2, 4, and 6. Standard errors reported allow for intragroup correlation (i.e., intra-strata correlation). 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 F statistic 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 α^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 non-energy related total expenditures increase by 100 JPY, only 0.7 JPY are related to energy.¹⁹ Compared to the one-member household, further members joining the household unit make for higher energy-related expenditures.²⁰ 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 (4.925) (third member is 3.014) is only about one-third (one-fifth) of the first (constant is 13.209). These figures indicate substantial household economies of scale that are also increasing with 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).

Table 2 about here

¹⁹ 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.

²⁰ In their descriptive analysis for Japan, Fong *et al.* (2007) find supporting evidence for the positive relationship between energy consumption and household size.

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 coefficient related to the dummy for the one-member household, α^1 , differs statistically from the coefficient that relates to the two-member household, α^2 , whether α^2 differs statistically from α^3 , and so forth. The test statistics are summarized in Table 3. They indicate a significant drop in energy-related consumption (rising household economies of scale) for each additional household member up to a household size of three. For households larger than six members, the α coefficients are not different from zero. In addition, we have compared the probability distribution of observed and estimated energy expenditures by plotting their quantiles against each other (Figure A2 in Appendix). In general, we slightly overestimate (underestimate) low (high) levels of energy expenditures. However, the differences are, in our view, quantitatively small.

Table 3 about here

Table 4 shows the results from equation (3) (functional form distinguishing between adults and children). The regression results convey three general messages. First, the presence of 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.

Tables 4 and 5 about here

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 energy expenditures. 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 at the 5% level.

Tables 6 and 7 about here

Based on the regression estimates from equation (4) we proceed with the quantification of household economies of scale for energy based on the energy equivalence scale defined in equation (1).

Figure 3 summarizes our results in eight separate graphs, one graph per household type excluding the one-member reference type.²¹ A graph provides energy equivalence scales evaluated at different levels of equivalent expenditures. In sum, household economies of scale play a significant role in households' energy consumption. As an example, a childless two-adult household requires about 1.4 times the energy-related expenditures of a one-member household. Adding further members leads to a further increase of household economies of scale: the energy equivalence scale of a childless three-adult household is only about 1.7. Another apparent pattern is that adding children to a household unit increases the energy equivalence scale by a smaller amount compared to adding an adult household member. These patterns hold for all levels of equivalent expenditure as household economies of scale in energy consumption exhibit little variation in equivalent expenditures.

²¹ All the energy equivalence scales are evaluated at the average household age separated by household type and level of expenditure.

Figure 3 about here

5.3 Linking the micro with the macro level (step 2)

We proceed with the second step of our analysis, the quantification of impact of the decline of average household size (see Figure 4) on the household sector's energy consumption, holding all other determinants constant.

Figure 4 about here

To do so, we take the regression estimates from the household size regression for energy (Table 2, spec. 2), and predict energy-related expenditures for the KHPS households in 2010. Next, 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 4. We start with 2005 (and not 2004) since our database on population statistics is on a five-year level. Our assessment is *ceteris paribus* in the following sense: (1) distributions of all the explanatory variables are as in 2010; (2) relationships between the explanatory variables and energy-related expenditures are constant over time; (3) total population size is held constant over time.

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%. 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 4). These demographic changes, in isolation, imply a loss of household economies of scale amounting to a 3.5% 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 by the total population size, P , is a reasonable approximation of 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, $D = P \times \sum_{n=1}^{10^+} p_n \times \overline{Exp}_n$, with estimates of \overline{Exp}_n for period 2010 summarized in Table 8.

Table 8 about here

6 Concluding Remarks

Population size is a crucial demographic variable in predictions of future pathways of economies. Usually ignored in these predictions is the composition of the population by household types, with types being defined by the number/age of household members. The present work has proposed a two-step procedure to first quantify the level of household economies of scale and second to assess how the trend toward household types with fewer members affects aggregate household-sector demand. We apply the framework to energy consumption in Japan. Using micro data on household demands and composition, our application indicates that household economies of scale in energy use are substantial. Combining our estimates with census data on population shares by household size, it indicates that ignoring changes in the population shares by household types may lead to sizeable biases in economic projections. For household energy consumption in Japan, the 5% decline in average household size between 2005 and 2010 implies an economy-wide loss in household economies of scale of almost 4%. This is the direct effect of 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 be echoed in aggregate energy demand. This issue is not addressed here but left for future research.

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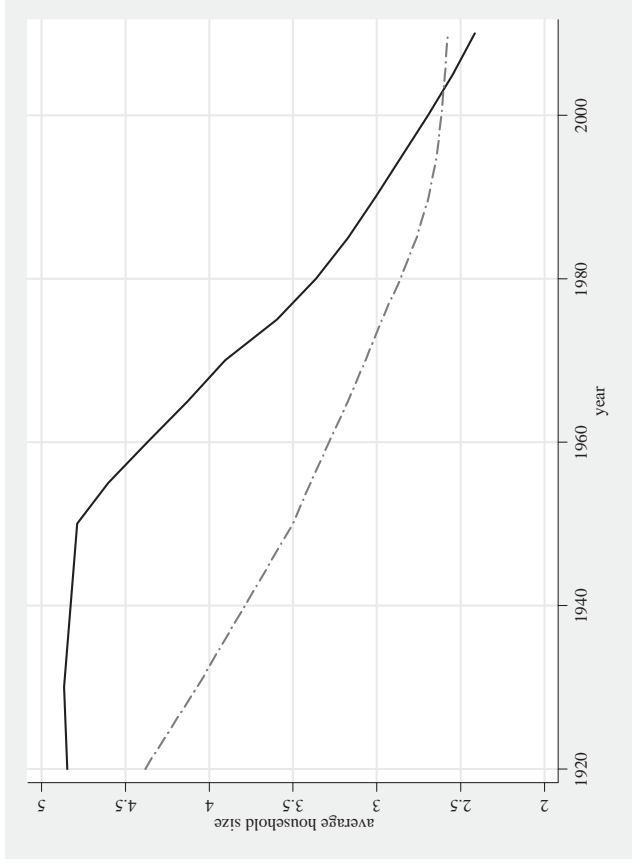
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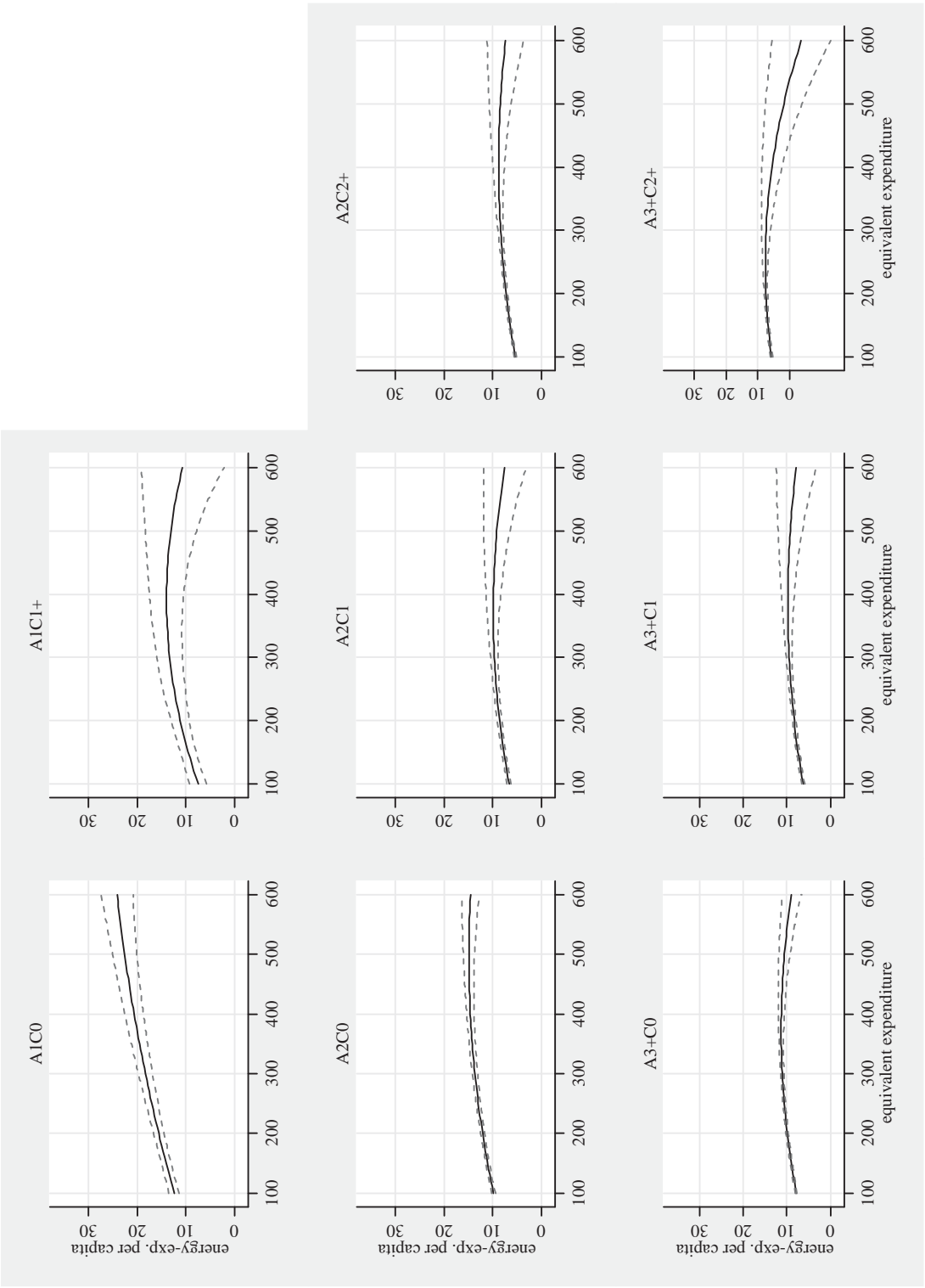
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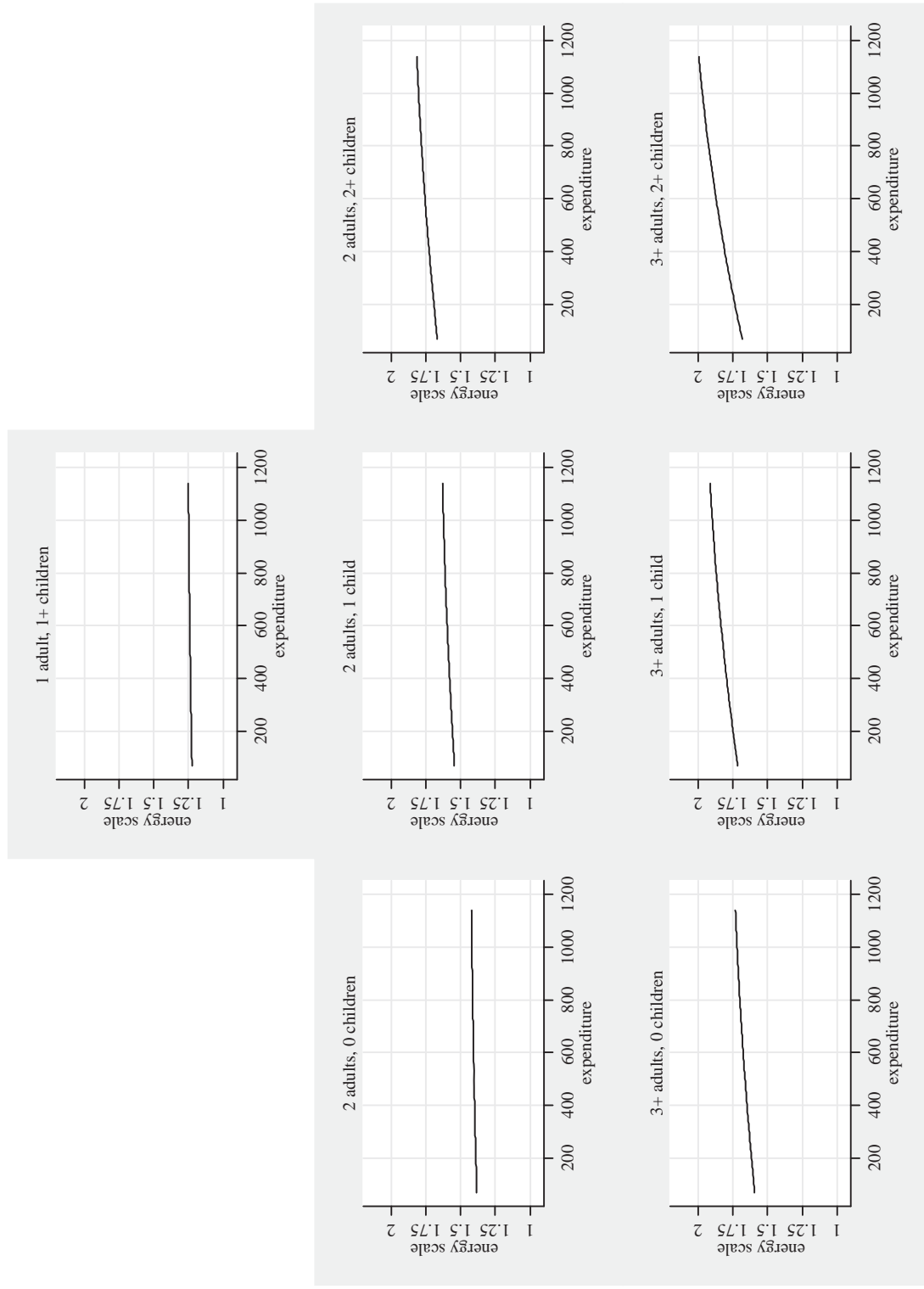
Note. Data from the Statistics Bureau of Japan (census data) and the US Census Bureau. Solid line: Japan. Dashed-dotted line: US.

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



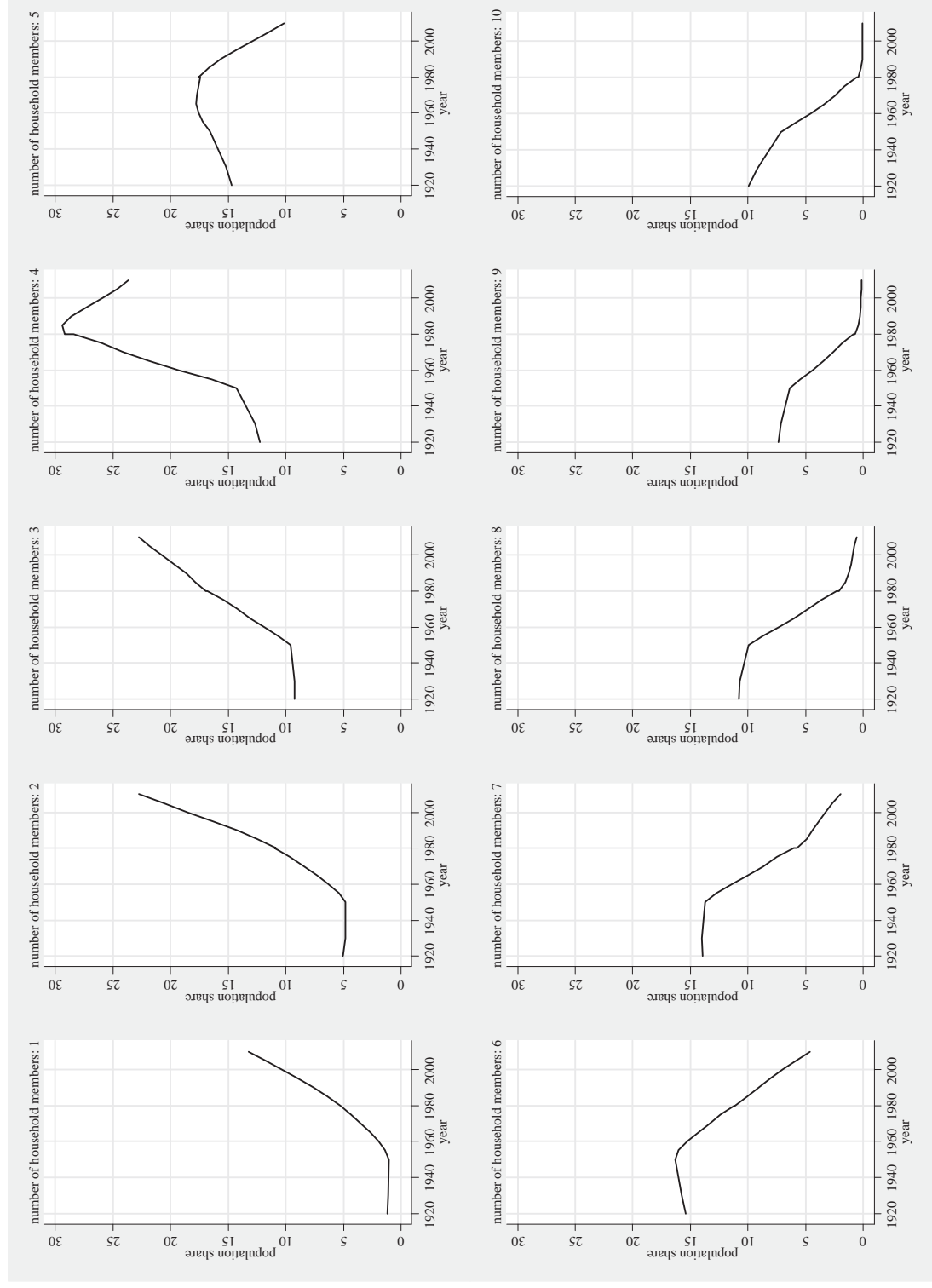
Note. “A” denotes adult; “C” denotes child. Adjacent number is the respective number of adults / children. Own computations. Database is KHPS 2010. Dashed lines indicate 95 percent confidence intervals.

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



Note. “A” denotes adult; “C” denotes child. Adjacent number is the respective number of adults / children. Own computations. Database is KHPS 2004-2010.

Figure 3. Energy equivalence scale



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

Figure 4. Population shares by household type in Japan

Table 1a. Number of observations by wave and household type

| Wave | A1C0 | A1C1 ⁺ | A2C0 | A2C1 | A2C2 ⁺ | A3 ⁺ C0 | A3 ⁺ C1 | A3 ⁺ C1 ⁺ | All types |
|------|------|-------------------|-------|------|-------------------|--------------------|--------------------|---------------------------------|-----------|
| 2004 | 273 | 39 | 637 | 261 | 482 | 1062 | 238 | 245 | 3237 |
| 2005 | 212 | 39 | 552 | 228 | 447 | 930 | 208 | 205 | 2821 |
| 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 | 1670 | 279 | 4580 | 1555 | 3434 | 6896 | 1549 | 1506 | 21469 |
| % | 7.78 | 1.30 | 21.33 | 7.24 | 16.00 | 32.12 | 7.22 | 7.01 | 100 |

Note. Own calculations.

Database. KHPS 2004-2010.

Table 1b. Transition probabilities

| Household type | A1C0 | A1C1 ⁺ | A2C0 | A2C1 | A2C2 ⁺ | A3 ⁺ C0 | A3 ⁺ C1 | A3 ⁺ C1 ⁺ | Total |
|---------------------------------|-------|-------------------|-------|-------|-------------------|--------------------|--------------------|---------------------------------|-------|
| A1C0 | 89.13 | 0.17 | 5.98 | 0.93 | 0.51 | 3.03 | 0.17 | 0.08 | 100 |
| A1C1 ⁺ | 1.75 | 72.81 | 2.19 | 8.77 | 10.53 | 1.32 | 1.32 | 1.32 | 100 |
| A2C0 | 2.89 | 0.03 | 88.63 | 2.66 | 0.12 | 4.79 | 0.32 | 0.56 | 100 |
| A2C1 | 0.33 | 1.31 | 0.66 | 80.39 | 9.76 | 5.58 | 1.80 | 0.16 | 100 |
| A2C2 ⁺ | 0.40 | 1.09 | 0.07 | 0.40 | 88.94 | 0.04 | 4.87 | 4.18 | 100 |
| A3 ⁺ C0 | 1.14 | 0.00 | 7.76 | 0.14 | 0.00 | 89.50 | 1.08 | 0.39 | 100 |
| A3 ⁺ C1 | 1.10 | 0.08 | 1.44 | 5.18 | 0.25 | 21.16 | 67.54 | 3.23 | 100 |
| A3 ⁺ C1 ⁺ | 0.61 | 0.35 | 2.25 | 0.09 | 5.11 | 1.47 | 12.22 | 77.90 | 100 |

Note. Own calculations.

Database. KHPS 2004-2010.

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

| Specification | (1) | | (2) | |
|----------------------|-----------|---------|-----------|----------|
| DN^2 | 4.925*** | (0.530) | 5.590*** | (0.754) |
| DN^3 | 3.014*** | (0.330) | 2.604*** | (0.588) |
| DN^4 | 2.886*** | (0.307) | 2.665*** | (0.569) |
| DN^5 | 1.655*** | (0.449) | 2.181** | (0.827) |
| DN^6 | 2.084** | (0.635) | 1.712 | (1.340) |
| DN^7 | 1.108 | (0.969) | -0.680 | (1.846) |
| DN^8 | -0.657 | (1.493) | 0.933 | (3.152) |
| DN^9 | 2.760 | (4.518) | -10.237 | (8.855) |
| DN^{10+} | 6.691 | (7.763) | 25.418 | (16.754) |
| Exp | 0.007*** | (0.001) | 0.008** | (0.003) |
| \overline{age} | 0.046** | (0.017) | 0.045** | (0.017) |
| DP_{2004} | reference | | reference | |
| DP_{2005} | -0.045 | (0.232) | -0.047 | (0.232) |
| DP_{2006} | 1.260*** | (0.228) | 1.258*** | (0.228) |
| DP_{2007} | 0.300 | (0.227) | 0.295 | (0.229) |
| DP_{2008} | 1.445*** | (0.221) | 1.433*** | (0.220) |
| DP_{2009} | 2.435*** | (0.240) | 2.422*** | (0.241) |
| DP_{2010} | 1.190*** | (0.243) | 1.175*** | (0.242) |
| $Exp \times DN^2$ | | | -0.003 | (0.003) |
| $Exp \times DN^3$ | | | 0.002 | (0.002) |
| $Exp \times DN^4$ | | | 0.001 | (0.002) |
| $Exp \times DN^5$ | | | -0.002 | (0.002) |
| $Exp \times DN^6$ | | | 0.001 | (0.004) |
| $Exp \times DN^7$ | | | 0.006 | (0.005) |
| $Exp \times DN^8$ | | | -0.005 | (0.009) |
| $Exp \times DN^9$ | | | 0.046 | (0.032) |
| $Exp \times DN^{10}$ | | | -0.063 | (0.039) |
| $Cons$ | 13.209*** | (0.943) | 12.999*** | (1.086) |
| N | 21,469 | | 21,469 | |
| $F statistic$ | 41.879 | | 29.745 | |
| ρ | 0.631 | | 0.631 | |
| R^2_{within} | 0.056 | | 0.057 | |
| $R^2_{between}$ | 0.260 | | 0.260 | |
| $R^2_{overall}$ | 0.201 | | 0.201 | |

Note. Own calculations. Standard errors (clustered) 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 3. Wald tests on equality of household-size coefficients for energy

| $\alpha^{N1} = \alpha^{N2}$ | | $\alpha^{N2} = \alpha^{N3}$ | | $\alpha^{N3} = \alpha^{N4}$ | | $\alpha^{N4} = \alpha^{N5}$ | | $\alpha^{N5} = \alpha^{N6}$ | | $\alpha^{N6} = \alpha^{N7}$ | |
|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|
| <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> |
| 0.000 | 42.006 | 0.005 | 7.810 | 0.784 | 0.075 | 0.033 | 4.553 | 0.617 | 0.251 | 0.437 | 0.606 |

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

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

| Specification | (1) | (2) |
|--------------------|----------------------|----------------------|
| DA^2 | 4.700*** (0.454) | 5.939*** (0.674) |
| DA^3 | 2.877*** (0.322) | 1.881** (0.571) |
| DA^4 | 2.758*** (0.337) | 2.647*** (0.641) |
| DC^1 | 1.848*** (0.411) | 2.525*** (0.714) |
| DC^2 | 2.102*** (0.383) | 0.842 (0.755) |
| DC^3 | 1.687** (0.597) | 2.438* (1.011) |
| Exp | 0.007*** (0.001) | 0.010*** (0.003) |
| \overline{age} | 0.030 (0.017) | 0.031 (0.017) |
| DP_{2004} | reference | reference |
| DP_{2005} | -0.047 (0.231) | -0.045 (0.231) |
| DP_{2006} | 1.239*** (0.227) | 1.237*** (0.227) |
| DP_{2007} | 0.269 (0.227) | 0.269 (0.228) |
| DP_{2008} | 1.401*** (0.219) | 1.409*** (0.219) |
| DP_{2009} | 2.395*** (0.239) | 2.386*** (0.239) |
| DP_{2010} | 1.128*** (0.244) | 1.125*** (0.245) |
| $Exp \times DA^2$ | | -0.005* (0.003) |
| $Exp \times DA^3$ | | 0.004* (0.002) |
| $Exp \times DA^4$ | | 0.000 (0.002) |
| $Exp \times DC^1$ | | -0.002 (0.002) |
| $Exp \times DC^2$ | | 0.005 (0.002) |
| $Exp \times DC^3$ | | -0.002 (0.003) |
| <i>Cons</i> | 14.808*** (0.943) | 14.167*** (1.080) |
| <i>N</i> | 21,469 | 21,469 |
| <i>F statistic</i> | 44.504 | 34.952 |
| ρ | 0.631 | 0.631 |
| R^2_{within} | 0.053 | 0.054 |
| $R^2_{between}$ | 0.270 | 0.268 |
| $R^2_{overall}$ | 0.206 | 0.205 |

Note. Own calculations. Standard errors (clustered) 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

| $\alpha^{A1} = \alpha^{A2}$ | | $\alpha^{A2} = \alpha^{A3}$ | | $\alpha^{C1} = \alpha^{C2}$ | | $\alpha^{C2} = \alpha^{C3}$ | |
|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|
| <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> | <i>Prob > F</i> | <i>F stat.</i> |
| 0 | 71.268 | 0.002 | 9.302 | 0.672 | 0.180 | 0.570 | 0.323 |

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

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

| Specification | (1) | | (2) | |
|-------------------|-----------|---------|-----------|---------|
| $DT^2(A1C1^+)$ | 6.353*** | (0.983) | 4.198** | (1.482) |
| $DT^3(A2C0)$ | 5.293*** | (0.539) | 5.832*** | (0.760) |
| $DT^4(A2C1)$ | 7.561*** | (0.725) | 9.004*** | (1.140) |
| $DT^5(A2C2^+)$ | 10.161*** | (0.752) | 10.969*** | (0.978) |
| $DT^6(A3^+C0)$ | 9.420*** | (0.586) | 9.108*** | (0.839) |
| $DT^7(A3^+C1)$ | 10.712*** | (0.683) | 11.226*** | (1.201) |
| $DT^8(A3^+C2^+)$ | 11.952*** | (0.824) | 10.582*** | (1.301) |
| Exp | 0.007*** | (0.001) | 0.008** | (0.003) |
| \overline{age} | 0.025 | (0.017) | 0.027 | (0.017) |
| DP_{2004} | reference | | reference | |
| DP_{2005} | -0.052 | (0.234) | -0.045 | (0.234) |
| DP_{2006} | 1.191*** | (0.229) | 1.186*** | (0.229) |
| DP_{2007} | 0.219 | (0.230) | 0.221 | (0.230) |
| DP_{2008} | 1.359*** | (0.222) | 1.364*** | (0.221) |
| DP_{2009} | 2.336*** | (0.241) | 2.324*** | (0.240) |
| DP_{2010} | 1.071*** | (0.246) | 1.067*** | (0.246) |
| $Exp \times DT^2$ | | | 0.009 | (0.006) |
| $Exp \times DT^3$ | | | -0.003 | (0.003) |
| $Exp \times DT^4$ | | | -0.006 | (0.004) |
| $Exp \times DT^5$ | | | -0.003 | (0.003) |
| $Exp \times DT^6$ | | | 0.001 | (0.003) |
| $Exp \times DT^7$ | | | -0.002 | (0.004) |
| $Exp \times DT^8$ | | | 0.004 | (0.004) |
| $Cons$ | 14.544*** | (0.983) | 14.382*** | (1.115) |
| N | 21,469 | | 21,469 | |
| $F statistic$ | 44.571 | | 32.837 | |
| ρ | 0.638 | | 0.638 | |
| R^2_{within} | 0.048 | | 0.049 | |
| $R^2_{between}$ | 0.244 | | 0.243 | |
| $R^2_{overall}$ | 0.185 | | 0.184 | |

Note. Own calculations. Standard errors (clustered) 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 of equality of coefficients for household types for energy

| α^{A1C1^+} | | α^{A1C1^+} | | $\alpha^{A2C1} - \alpha^{A2C0}$ | | $\alpha^{A2C2^+} - \alpha^{A2C1}$ | |
|-----------------------------------|---------|---------------------------------------|---------|---------------------------------------|---------|---|---------|
| $= \alpha^{A2C1} - \alpha^{A2C0}$ | | $= \alpha^{A3^+C1} - \alpha^{A3^+C0}$ | | $= \alpha^{A3^+C1} - \alpha^{A3^+C0}$ | | $= \alpha^{A3^+C2^+} - \alpha^{A3^+C1}$ | |
| Prob > F | F stat. | Prob > F | F stat. | Prob > F | F stat. | Prob > F | F stat. |
| 0.000 | 18.891 | 0.000 | 23.717 | 0.112 | 2.529 | 0.045 | 4.028 |

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

Table 8. Estimates of energy expenditures for representative households

| Number of household members | \overline{Exp}_n | | |
|-----------------------------------|--------------------|----------|----------------|
| | Lower bound | Estimate | Upper bound |
| 1 | 16.907 | 18.170 | 19.432 |
| 2 | 22.769 | 23.600 | 24.432 |
| 3 | 25.552 | 26.289 | 27.025 |
| 4 | 28.152 | 28.899 | 29.646 |
| 5 | 29.580 | 30.646 | 31.713 |
| 6 | 31.383 | 33.009 | 34.635 |
| 7 | 32.410 | 34.881 | 37.352 |
| 8 | 29.472 | 33.457 | 37.442 |
| 9 | 29.438 | 42.852 | 56.266 |
| 10+ | 21.151 | 44.454 | 67.756 |

Note. Estimates from fixed effects for year 2010 in 1,000 JPY. KHPS. Lower and upper bound give the 95% confidence interval. *Database.* KHPS 2010.

Appendix to

The decline in average family size and its implications for the average benefits of within-household sharing

By Carsten Schröder ^a, Katrin Rehdzan ^b, Daiju Narita ^c, and Toshihiro Okubo ^d

^a German Institute of Economic Research (DIW Berlin), Socio-Economic Panel Study (SOEP), Mohrenstr. 58, Berlin, Germany; and Free University Berlin, Germany; e-mail: cschroeder@diw.de

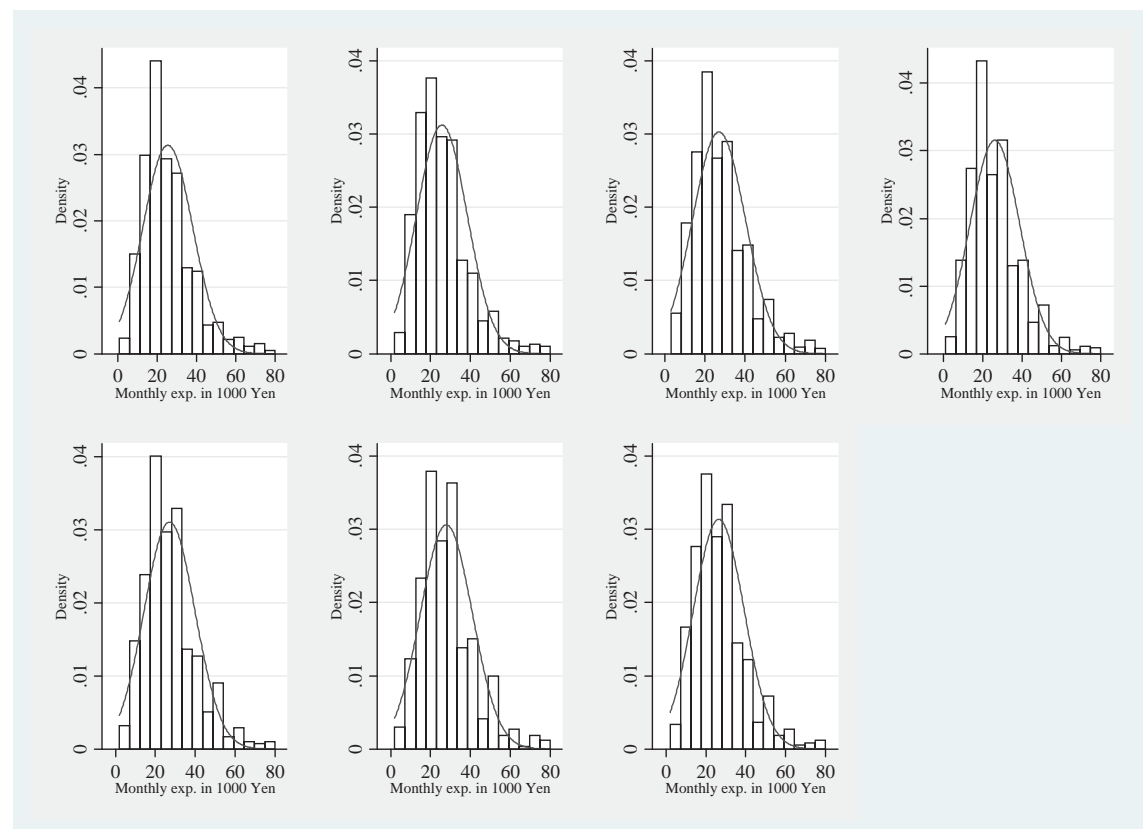
^b Kiel Institute for World Economy and University of Kiel

^c JICA Research Institute and Kiel Institute for World Economy

^d Keio University

Distribution of dependent variable

The dependent variable in the regression analysis is monthly expenditure (in 1,000 JPY). Its wave-specific histogram together with a normal density is provided in Figure A1. The histograms indicate that the distribution of the variable is close to the normal.

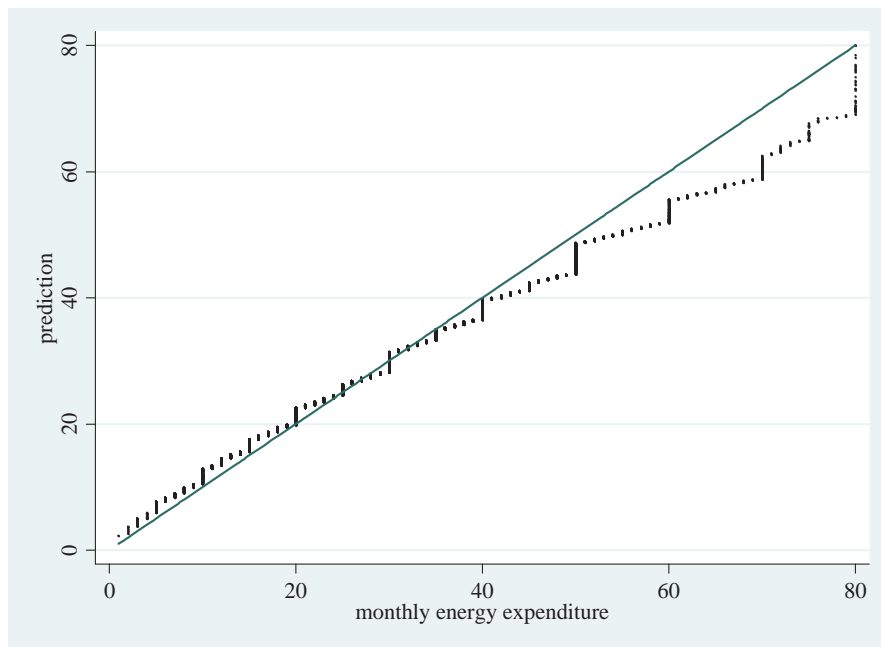


Note. From left to right and top to bottom: Wave-specific distributions for years 2004-10. Database. KHPS 2004-2010.

Figure A1. Wave-specific histograms of dependent variable

Goodness-of-fit assessment

Figure A2 compares the probability distributions of observed and estimated energy expenditures (equation 2, specification S2) by plotting their quantiles against each other (Q-Q plot).



Database. KHPS 2004-2010.

Figure A2. Q-Q plot for regression equation 2, specification S2.