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Abstract

We apply a quadratic expenditure system to estimate price and expenditure elasticities of residential energy demand (electricity and heating) in Germany. Using official expenditure data from 1993 to 2008, we estimate an expenditure elasticity for electricity of 0.3988 and of 0.4055 for space heating. The own price elasticity for electricity is -0.4310 and -0.5008 in the case of space heating. Disaggregation of households by expenditure and demographic composition reveals that the behavioural response to energy price changes is weaker (stronger) for low-income (top-income) households. There are considerable economies of scale in residential energy use but scale effects are not well approximated by the new OEDC equivalence scale. Real increases in energy prices show a regressive pattern of incidence, implying that the welfare consequences of direct energy taxation are larger for low income households. The application of zero-elasticities in assessments of welfare consequences of energy taxation strongly underestimates potential welfare effects. The increase in inequality is 22% smaller when compared to the application of rich and disaggregated behavioural response patterns as estimated in this paper.

Keywords: Energy consumption; price elasticities; expenditure elasticities
JEL-Classification: D12; Q41; Q54

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1 Introduction

The response of consumers to changes in prices is instrumental for any ex ante assessment of taxation. In particular in the case of energy taxation or the taxation of the carbon content of fossil fuels, such assessments are of importance for at least two reasons: First, it allows for an appraisal of the quantitative response of consumer demand. Second, it allows for an estimation of the incidence of carbon or energy taxation. Both aspects are relevant for the design of energy and climate policy.

This paper contributes to the literature by providing detailed empirical information on energy demand of households in Germany. We use official German income and expenditure data (Einkommens- und Verbrauchsstichprobe, EVS) to estimate a quadratic expenditure system (QES) and derive expenditure elasticities and price elasticities for a number of goods, including electricity, space heating, transportation, food, clothing, housing, health, mobility and education. The results are disaggregated in order to provide evidence on the demand of different household types (singles, couples, with and without children). The demographic translation is used to assess demand at the household level and it allows a cross-evaluation of the new OECD equivalence scale, which is used to compare income or expenditure across households of different size. In addition, the elasticities are estimated at different loci of the expenditure distribution (i.e. the quartile means of the total expenditure distribution) in order to provide richer information of the impact of total expenditure on energy consumption and substitution patterns. These results are eventually used to assess the incidence and welfare consequences of energy taxation in a counterfactual scenario.

Our work is related to different strands of literature. It augments a number of studies on household energy consumption behaviour. In this canon of articles, evidence on energy consumption for many countries can be found, but to the best of our knowledge, there is no up to date contribution with respect to German households (Espey and Espey, 2004; Krishnamurthy and Kriström, 2015; Meier et al., 2013a; Narayan et al., 2007; Nikodinoska and Schröder, 2016). In particular, there is no contribution which provides detailed results on the consumption of electricity, heating, and transportation by means of providing income and price elasticities. While Kohn and Missong (2003) use similar data and methods as we do, they do not consider energy demand. Nikodinoska and Schröder (2016) provide elasticities for energy goods, however they do not differentiate by household type.

Ultimately, consumption - or more precisely substitution - of goods constitutes the incidence of a tax. Especially in the case of energy taxation, there is evidence that direct taxation causes a regressive effect.[1] This effect originates from the nature of energy goods, which are necessary goods with an income elasticity of energy demand lower than unity (Meier et al., 2013a). In particular in the case of a more ambitious climate policy, which may cause an increase in energy prices, distributive effects of the policy are an important element of policy planning. While Baumol and Oates (1988) express the view that distributive effects of environmental policies are '*of interest in and of itself in a world in which inequality and poverty have assumed high priority among social issues*' (Chapter 15, p. 235), the problem can be framed in a broader discussion on the distribution of tax burdens as found in public finance (Musgrave, 2002). Whatever specific view on the distribution of burdens one may take, if energy taxation contributes to the overall tax burden to a non-negligible extent, the assessment of tax incidence is required to inform policy makers about expected outcomes of reforms. Such assessments can be facilitated by means of microsimulation, which requires detailed information as provided in this article (Flues and Thomas, 2015).

Related to aspects of the distribution of burdens, fuel poverty or energy poverty, has received increased interest in the literature in recent years. A number of different definitions exist (Hills, 2012; Moore, 2012; Healy, 2004) which have quite distinctive policy implications (Heindl and Schuessler, 2015; Heindl, 2015). Without taking a stance on the various definitions and setting aside possible methodological problems, most definitions pivot around household income and expenditure on energy services, and thus have the notion of a bivariate poverty measure. The results of this study help to foster understanding of the driving forces behind affordability of energy services, contingent on detailed household characteristics. They therefore contribute to the literature on fuel or energy poverty, in particular by providing information on the expected change in expenditure on energy services by households as a response to changes in energy prices. Since some definitions rely on equivalised energy costs, e.g. the fuel poverty definition by Hills (2012), the results of this paper also help to improve measurement techniques by providing empirical evidence on how energy (electricity and space heating) is used on a per capita basis, given that there are economies of scale in energy use by households.

Our results show that there are considerable differences in price and income elasticities of energy consumption across income levels and household types. Energy services clearly have the notion of a necessary good. Energy demand of low-income households shows a weak reaction to changes in energy prices. Energy demand of households belonging to the upper 25 percent of incomes is about factor three times

[1] See Heindl and Löschel (2014) for a review of literature.

more price-elastic when compared to households belonging to the lowest 25 percent of incomes. The observed consumption and substitution patterns have several important implications. First, an increase in energy prices will cause a moderate reduction in consumption of low-income households, while households belonging to the upper brackets of the income distribution show a more pronounced response. Second, for a given change in energy prices, there are significant differences in the impact on household welfare as a result of the price change. Welfare losses (expressed as compensating variation) tend to be large for low-income households and/or small households (e.g. single households). Thus, a given change in energy prices will impose unequal burdens on the considered types of households, which is at odds with many principles of just taxation (Musgrave, 2002). Finally, the observed consumption patterns will have a bearing on affordability of energy services, as low-income households face larger burdens compared to wealthier households. Wether expressed in terms of the expenditure share spent on energy services or in terms of welfare, price increases for energy services do not have a uniform impact on households. From this perspective, the discussion on energy poverty may be reconciled with the neoclassical view on the household production function. In situations in which the expenditure share spent on necessary goods becomes large, it is possible that deprivation in other domains of consumption occurs. This, prima facie, justifies a priority view on low-income households in the design of energy and climate policies (Parfit, 1997).

The remainder of this paper is organised as follows. Section 2 presents a description of the quadratic expenditure system. Section 3 provides a detailed data description and a description of the estimation procedure. Section 4 comprises the discussion of the empirical results. Section 5 concludes.

2 Methodology

2.1 Demand Systems

The use of demand systems has a long history. The development has moved from rather inflexible systems like the *Linear Expenditure System (LES)*, first estimated by Stone (1954), to more flexible systems. The *Almost Ideal Demand System (AIDS)*, proposed by Deaton and Muellbauer (1980a), has achieved a high degree of popularity for the flexibility of its underlying cost function. The *Quadratic Expenditure System (QES)* (Pollak and Wales (1978)) and the *Quadratic Almost Ideal Demand System (QUAIDS)* (Banks et al. (1997)) are examples of demand systems that exhibit a high degree of flexibility in the total expenditure dimension. The most

modern system that emerged from this long-lasting development is the *Exact Affine Stone Index Implicit Marshallian Demand System (EASI)*, proposed by Lewbel and Pendakur (2009). It combines a high degree of flexibility in both aforementioned categories.
The use of demand systems plays an important role in the estimation of consumer demands. Their wide acceptance stems from the possibility to impose desirable properties on the system of fitted demand equations and to create a theoretically plausible model. A theoretically plausible model satisfies four conditions, known as *Integrability conditions* (Barnett and Serletis (2009)). Its demand curves exhibit:

- *Positivity* - Demands are nonnegative
- *Summability* - The product of prices and demanded quantities sums up to the total expenditure: $\boldsymbol{P}^T \cdot \boldsymbol{q}(\boldsymbol{P}, \mu) = \mu$
- *Homogeneity of degree zero* in $(\boldsymbol{P}, \mu)$ - If prices and total expenditure are multiplied by a common factor, demand is not affected: $\boldsymbol{q}(\boldsymbol{P}, \mu) = \boldsymbol{q}(t\boldsymbol{P}, t\mu)$
- The *Slutsky substitution matrix* is symmetric and negative semidefinite

Hurwicz and Uzawa (1971) show that a demand system can be generated by utility maximization if, and only if, these properties hold.

2.2 The Quadratic Expenditure System

While all typical demand systems impose at least some of the above mentioned properties, different demand systems differ in the exact forms of their demand and utility functions. These differences lead to different properties of the systems. The most suitable demand system has to be chosen on the basis of the given problem and data set. In our study, we chose to work with the *QES*. The system exploits the full potential of Engel curve flexibility and can be estimated with a relatively small number of free parameters. We thus find that – in the context of the data set at hand – the *QES* is the best compromise between flexibility, especially in the total expenditure dimension, and feasibility in the face of few cross sections and a wide range of commodity groups.
A mathematically rigorous description of the *QES* is provided by Howe et al. (1979). Here we will confine ourselves to a brief outline of the major features of the system

described by Howe et al. (1979). Each theoretically plausible quadratic expenditure system is generated by the following indirect utility function:

$$\Psi(\boldsymbol{P},\mu) = -\frac{g(\boldsymbol{P})}{\mu - f(\boldsymbol{P})} - \frac{\alpha(\boldsymbol{P})}{g(\boldsymbol{P})}, \tag{1}$$

where $\boldsymbol{P}^T = (p_1, ..., p_n)$ is the vector of prices for n commodity groups and μ denotes total expenditure. The realisation of the variable vector $(\boldsymbol{P},\mu)$ can differ for each entity which is described by the demand system. For Ψ to be homogeneous of degree zero in $(\boldsymbol{P},\mu)$, the functions $f(\boldsymbol{P})$, $g(\boldsymbol{P})$ and $\alpha(\boldsymbol{P})$ must be homogeneous of degree one in $\boldsymbol{P}$. Applying Roy's identity yields the following Marshallian demand equation for the demand q_i of the ith good:

$$q_i(\boldsymbol{P},\mu) = \frac{1}{g^2}(\alpha_{p_i} - \frac{g_{p_i}}{g}\alpha)(\mu - f)^2 + \frac{g_{p_i}}{g}(\mu - f) + f_{p_i}. \tag{2}$$

Hereby the subscript p_i denotes partial derivatives with respect to p_i. As specification of the functions f, g and α, we use a system also presented by Howe et al. (1979):

$$g(\boldsymbol{P}) = \prod_i p_i^{a_i}, \tag{3}$$

$$f(\boldsymbol{P}) = \sum_i p_i \tilde{b}_i, \tag{4}$$

$$\alpha(\boldsymbol{P}) = \sum_i p_i c_i, \tag{5}$$

$$\sum_i a_i = 1. \tag{6}$$

This system includes the final model parameters $a_i, \tilde{b}_i, c_i$ for $i \in \{1, ..., n\}$. Restriction 6 ensures summability of the resulting demand system. The resulting system is characterised by the indirect utility function (7) and expenditure functions (8) (adopted from Kohn and Missong (2003)):

$$\Psi(\boldsymbol{P},\mu) = -\frac{\prod_i p_i^{a_i}}{\mu - \sum_i p_i \tilde{b}_i} - \frac{\sum_i p_i c_i}{\prod_i p_i^{a_i}}, \tag{7}$$

$$\begin{aligned} p_i q_i(\boldsymbol{P},\mu) = {} & p_i \tilde{b}_i + a_i(\mu - \sum_k p_k \tilde{b}_k) + \\ & (c_i p_i - \sum_k p_k c_k) \prod_k p_k^{-2a_k} (\mu - \sum_k p_k \tilde{b}_k)^2, \qquad \sum_k a_k = 1. \end{aligned} \tag{8}$$

Note here, that the i index in sums and products 3-6 is changed to k for notational clarity. This specification reduces to a linear demand system in case of $c_i = 0 \; \forall i$. The system of Marshallian demands $\boldsymbol{q}^T = (q_1, ..., q_n)$ satisfies by construction the summability constraint, is homogeneous of degree zero in $(\boldsymbol{P}, \mu)$ and has a symmetric Slutsky matrix. Testing for theoretical plausibility of the estimated demand system therefore consists in testing for positivity and negative semidefiniteness of the Slutsky matrix. The specification shown here is to be preferred over others due to its low number of free parameters. It has $3n - 1$ free parameters, i.e. for each of the n equations exists a parameter set $\left\{a_i, \tilde{b}_i, c_i\right\}$. However, due to the summability constraint realised by $\sum_i a_i = 1$ one a_i is determined by the others.

2.3 Demographic Translating

Demographic variables are incorporated via the method of *demographic translating*, described by Pollak and Wales (1978). This approach seems most convenient for our expenditure system, since it is realised by a simple linear extension of the $\tilde{b}_i$ parameters. It is therefore easier to compute than an additional nonlinear demographic element as obtained for example through *demographic scaling* (Pollak and Wales (1981)).

Demographic translating is based on the assumption that demographics influence the indirect utility function mostly via some total expenditure offset:

$$\overline{\Psi}(\boldsymbol{P}, \mu) = \Psi(\boldsymbol{P}, \mu - \sum_{i=1}^{n} p_i \cdot d_i(\boldsymbol{\delta})), \tag{9}$$

where $\overline{\Psi}$ denotes the indirect utility function of the translated system and $d_i(\boldsymbol{\delta}) = \sum_j \beta_{ij} \cdot \delta_j$ sums up the direct influence of the N demographic variables δ_j for $j \in \{1, ..., N\}$ on the ith equation.

This results in the modified Marshallian demand equation:

$$\overline{q_i} = d_i + q_i(\boldsymbol{P}, \mu - \sum_{k=1}^{n} p_k \cdot d_k). \tag{10}$$

Since the d_i act in the same way on the demand equations as the $\tilde{b}_i$ parameters, we present them in the following as the combined sum $b_i = \tilde{b}_i + d_i$.

2.4 Stone-Lewbel Cross Section Prices

We further introduce household specific *Stone-Lewbel cross section prices* as proposed by Lewbel (1989). These reflect the fact that the composition of consumed commodity groups differs between households and therefore the perceived prices for these commodity groups differ between households as well. The increased price variation can additionally improve the fitting routine thanks to the higher variation in the price variables.

Lewbel presents a theory of household specific price indices under the assumption of *weakly separable* demands.[2] We adopt Lewbel's approach, who constructs price indices for the case of Cobb-Douglas within group utility functions:

$$u_i(\boldsymbol{q_i}, \boldsymbol{s}) = g_i \cdot \prod_h q_{ih}^{w_{ih}(\boldsymbol{s})}, \quad \sum_h w_{ih}(\boldsymbol{s}) = 1. \tag{11}$$

Thereby $\boldsymbol{s}$ denotes a vector of demographic characteristics, g_i is a scaling factor, and q_{ih} and w_{ih} denote consumed quantity and group budget share of good h in commodity group i. In the case of within group utility functions as in equation 11 one obtains the household specific price index $p_i(\boldsymbol{s})$:

$$p_i(\boldsymbol{s}) = \frac{1}{g_i} \cdot \prod_h (\frac{\hat{p}_{ih}}{w_{ih}})^{w_{ih}}, \tag{12}$$

whereby $\hat{p}_{ih}$ denotes prices for good h of commodity group i and the scaling factor g_i represents the reference household with its group budget shares $\overline{w_{ih}}$:

$$g_i = \prod_h (\overline{w_{ih}})^{-\overline{w_{ih}}}. \tag{13}$$

We adopt the approach by Hoderlein and Mihaleva (2008) and use as reference household a fictive household with average within group budget shares in each good category of each commodity group.

[2]Our model exhibits a rather high level of commodity disaggregation, since only fairly similar goods are allocated to the same commodity group. Hence the condition of weak separability (for an introductory discussion compare Deaton and Muellbauer (1980b), chapter 5) is likely to be met at least approximately.

2.5 Elasticities

Price and expenditure elasticities can be derived from the well-defined expenditure system. In the *QES* expenditure elasticities $\frac{\delta q_i(\boldsymbol{P},\mu)}{\delta\mu}\frac{\mu}{q_i(\boldsymbol{P},\mu)}$ are given by:

$$\eta^i_\mu = \frac{\mu}{q_i}\{\frac{a_i}{p_i} + 2(c_i - \frac{a_i}{p_i}\sum_{k=1}^n p_k c_k)\prod_{k=1}^n p_k^{-2a_k}(\mu - \sum_{k=1}^n p_k b_k)\} \tag{14}$$

and own-price elasticities $\frac{\delta q_i(\boldsymbol{P},\mu)}{\delta p_i}\frac{p_i}{q_i(\boldsymbol{P},\mu)}$ are given by:

$$\begin{aligned}\eta^i_{p_i} = &-\frac{1}{p_i q_i}\{a_i(\mu - \sum_{k=1}^n p_k b_k) + p_i a_i b_i - (a_i\sum_{k=1}^n p_k c_k - p_i a_i c_i)\prod_{k=1}^n p_k^{-2a_k}(\mu - \sum_{k=1}^n p_k b_k)^2 \\ &- 2(a_i\sum_{k=1}^n p_k c_k - p_i c_i)\prod_{k=1}^n p_k^{-2a_k}(\mu - \sum_{k=1}^n p_k b_k)(a_i(\mu - \sum_{k=1}^n p_k b_k) + p_i b_i)\}.\end{aligned} \tag{15}$$

Finally, cross-price elasticities $\frac{\delta q_i(\boldsymbol{P},\mu)}{\delta p_j}\frac{p_j}{q_i(\boldsymbol{P},\mu)}$ are given by:

$$\begin{aligned}\eta^i_{p_j} = -\frac{p_j}{q_i}\{\frac{a_i b_j}{p_i} + (\mu - \sum_{k=1}^n p_k b_k)^2\prod_{k=1}^n p_k^{-2a_k}\{\frac{a_i c_j}{p_i} \\ + 2(c_i - \frac{a_i}{p_i}\sum_{k=1}^n p_k c_k)(\frac{a_j}{p_j} + \frac{b_j}{\mu - \sum_{k=1}^n p_k b_k})\}\}.\end{aligned} \tag{16}$$

3 Data and Estimation Method

3.1 Expenditure Data

Income and expenditure data in the following analysis is drawn from the German Income and Expenditure Survey (IES). This survey is published every five years by the German Federal Office of Statistics. It comprises detailed expenditure data from about 60,000 German households, which are selected by quota sampling. Participation in the survey is voluntary (Statistisches Bundesamt (2012)). We use data from the IES of the years 1993, 1998, 2003 and 2008. To adjust data sets to each other, we convert all expenditures to quarterly values (relevant for IES1993) and to euros (relevant for IES1993, IES1998) using the constant conversion rate of 1 euro = 1.95583 DM. For a more detailed description of the data preparation process, see Appendix B.

3.2 Commodity Groups

We start the analysis with a demand system comprising ten commodity groups. Thereby, seven commodity groups are chosen as in Kohn and Missong (2003) and the energy dimension is added via three additional energy categories. The final aggregation allows for comparability with the results by Kohn and Missong (2003) and gives the opportunity to identify the interactions between energy consumption and other consumption on a differentiated level. Table 1 gives an overview of the commodity groups.

[Table 1 about here.]

Durable goods represent a large part of the commodity groups mobility, education and others. The choice on the inclusion of durable goods in demand systems is based on a trade-off. On the one hand, durable goods are long-time investments due to their high transaction costs. Hence, their actual consumption does not necessarily reflect an optimal consumption choice.[3] Additionally, the resulting infrequent purchases in this category are hardly accurately captured by a time-limited survey. On the other hand, neglecting categories of durable goods leads to the exclusion of a potentially important portion of consumption. This holds also true in the context of energy demand analysis, since households' energy consumption is closely related to the possession of electrical appliances and motorised vehicles.

Thus, we feel that the information gain of including durable goods surmounts its drawbacks. Like Kohn and Missong (2003), we therefore include durable goods in the analysis. We distinguish durable goods by the three categories mobility, education and others. In doing so, we get a mixture of durables in each of these categories, so that reported expenditure is more likely to reflect average expenditure on durables.

3.3 Demographic Groups

The demand system can be refined by introducing demographic variables, which allow to differentiate the behaviour of different groups in society. We therefore introduce demographic variables which describe the household composition. We follow the differentiation of household types found in Kohn and Missong (2003) and group households according to the number of children and adults living in the household. The resulting household types are single adults without children (S0) or with one child (S1) and couple households without children (C0), with one child (C1) or with two (C2) or three children (C3). Other household types were excluded from

[3]See Deaton (1981) for an introductory discussion.

the analysis due to their infrequent appearance in the data set. In the definition of household types, children are up to 17 years old.
Table 2 shows the 6 household types used in the analysis and their shares in the data set. The share of couple households without children is largest, followed by singles without children, couples with two children, couples with one child, couples with three children and singles with one child.

[Table 2 about here.]

3.4 Price Data

Besides expenditure data, price indices are needed for the estimation of expenditure curves. We use differentiated price data from the German consumer price index (CPI) of the years 1993, 1998, 2003 and 2008. For the years 1998, 2003 and 2008 we make use of the monthly CPI. We average the monthly CPI over three-month periods to obtain quarterly price data. For 1993 the IES provides expenditure data on a yearly basis. Correspondingly, we use the twelve-month averaged CPI. The CPI is based on price data collected by the German Federal Office of Statistics and provides price indices which correspond to the sub-commodity groups of the IES.

3.5 Estimation Method

3.5.1 Stochastic Specification

A typical form of heteroscedasticity arising in the context of demand system estimation is a positive correlation of the demand curve error variances and total expenditure. If households have a higher total expenditure, their attainable spendings in each category cover a larger range. Thus, the observed variation of spending in each category is likely to increase with total expenditure. A common approach to correct for this form of heteroscedasticity is to estimate expenditure systems with share equations, hence with expenditure equations divided by total expenditure. However, as Park (1966) already points out, dividing by total expenditure is a rather restrictive approach since it assumes that the error variance increases proportionately to the squared expenditure. Park therefore proposes a more general approach by assuming that the error variance $\sigma^2_{u_i}$ increases proportionately to power γ_i of total expenditure:

$$\sigma^2_{u_i} \propto \mu^{\gamma_i} \cdot exp(\nu_i) \tag{17}$$

with ν_i being a *'well-behaved error term'* (Park (1966)). It is possible to estimate γ_i in a two-step procedure. First, an estimate of the standard error σ_{u_i} is obtained. For this purpose expenditure in each category is regressed on total expenditure, total expenditure squared, and the regression residuals are calculated:

$$\hat{\sigma}_{u_i} = y_i - \hat{\Theta}_{0i} - \hat{\Theta}_{1i}\mu - \hat{\Theta}_{2i}\mu^2. \tag{18}$$

$\hat{\Theta}_{0i}, \hat{\Theta}_{1i}, \hat{\Theta}_{2i}$ denote the estimation coefficients. The squared residual $\hat{\sigma}^2_{u_i}$ can then be inserted into the logarithmic version of equation 17, so that one obtains the linear regression equation:

$$ln(\hat{\sigma}^2_{u_i}) = const + \gamma_i \cdot ln(\mu) + e_i \tag{19}$$

with e_i being again a well-behaved additive error term.
With equation 19 a linear regression can be run and the obtained coefficients $\hat{\gamma}_i$ can be used to divide the expenditure equations by generalised total expenditure $\mu^{\frac{\hat{\gamma}_i}{2}}$ to obtain generalised expenditure shares with homoscedastic error terms.
Adopting this approach, we obtain the final regression equations based on equations 8 and 10, extended by an additive error term ε_i and divided by generalised total expenditure:

$$w_i = \frac{q_i p_i}{\mu^{\frac{\hat{\gamma}_i}{2}}} = \{\theta_{1i} + \theta_{2i}\mu + \theta_{3i}\mu^2 + \varepsilon_i\}/\mu^{\frac{\hat{\gamma}_i}{2}}. \tag{20}$$

Thereby the θ_{mi} for $m \in \{1,2,3\}$ are provided by Kohn and Missong (2003) as follows:

$$\theta_{1i} = p_i b_i - a_i \sum_k p_k b_k + \theta_{3i}(\sum_k p_k b_k)^2, \tag{21}$$

$$\theta_{2i} = a_i - 2\theta_{3i} \sum_k p_k b_k, \tag{22}$$

$$\theta_{3i} = (p_i c_i - a_i \sum_k p_k c_k) \prod_k p_k^{-2a_k}. \tag{23}$$

3.5.2 Estimation Procedure

The summability constraint $\sum_i q_i p_i = \mu$ imposed by the *QES* results in a zero sum of regression residuals $\sum_i \hat{\varepsilon}_i = 0$ for each household. This however means that each household's residual variance covariance matrix $\hat{\tilde{\boldsymbol{\varepsilon}}}\hat{\tilde{\boldsymbol{\varepsilon}}}^T$ with $\hat{\tilde{\boldsymbol{\varepsilon}}}^T = (\hat{\varepsilon}_1/\mu^{\frac{\hat{\gamma}_1}{2}}, ..., \hat{\varepsilon}_n/\mu^{\frac{\hat{\gamma}_n}{2}})$ becomes singular. Inversion of the matrix needed for parameter estimation is no longer possible. To make the estimation feasible, we drop the "others" category and reconstruct its parameters from the estimated system.[4]

We thus specify the system as a nonlinear seemingly unrelated regression model and we use an iterated feasible generalised least squares estimator. Accordingly the errors $\tilde{\varepsilon}_i = \varepsilon_i / \mu^{\frac{\hat{\gamma}_i}{2}}$ for $i \in \{1, ..., n\}$ are assumed to be correlated for different expenditure curves of the same household, but not for different households (Zivot and Wang (2007), section 10.4).

To find starting values for the iterative estimation process, we follow a step-wise procedure. In a first attempt, we estimate a *LES*, with parameter starting values set to zero. We then estimate an aggregated *QES*, using the coefficient estimates from the *LES*, where available. All other parameter estimates are again set to zero. We continue in the same manner with the demographically translated system.

The final estimates of the demographically translated *QES* are tested for heteroscedasticity in the total expenditure dimension by regressing the estimation residuals on total expenditure and total expenditure squared. For residuals of all equations, coefficients on total expenditure are significant at the 1% level. We therefore report heteroscedasticity robust standard errors.

4 Results

Table 10 presents the estimated basis coefficients of the demographically translated demand system. All c_i coefficients are significant at the 1% percent level and so is the Wald test of their joint significance. We therefore conclude that the quadratic model is superior to a *LES* for the demand system at hand. The Akaike information criterion and Bayesian information criterion yield superior values for the demographically translated model (AIC: -2642460, BIC: -2641702) as compared to an aggregated model (AIC: -2602648, BIC: -2602370). Hence, the differentiation by household types adds valuable information to the demand system.

Furthermore, the estimated demand system is theoretically plausible at the means of the household type specific 2008 total expenditure quartiles for which we present elasticities in Section 4.1 below. That is, demands are positive and the Slutsky ma-

[4] In a preliminary analysis possible instrumentations of the system were tested. We failed to identify valid instruments, despite the testing of a variety of instruments and different forms of introducing them to the system. The Sargan-Hansen test rejected the independence of error terms from the instruments at the 1% level. We then compared demand elasticities of an aggregated total expenditure system estimated with (1) a generalised methods of moments regression using disposable income as an instrument and (2) a non-instrumented nonlinear seemingly unrelated regression. The situations described by the different results resemble each other. The invariance to the instrumentation with a typical income variable convinced us to continue the estimation procedure without instrumentation.

trix is negative semidefinite. The negative semidefiniteness of the Slutsky matrix is tested by calculating its eigenvalues. Table 11 shows the eigenvalues of the system Slutsky matrix at the means of the household type specific total expenditure quartiles. One of the eigenvalues is by construction zero within the range of computer precision. This is due to the singularity of the Slutsky matrix which follows from the imposed summability constraint of the demand equations (Mas-Colell et al., 1995, p. 35). All other eigenvalues are negative, confirming the negative semidefiniteness of the Slutsky matrix at the analysed points.

4.1 Elasticities

4.1.1 Expenditure and Income Elasticities

Table 3 shows the weighted means of household type specific predicted elasticities, evaluated at the means of the total expenditure and price distributions of the year 2008. Predicted elasticities characterise electricity, heating, transport, food and housing as necessity goods with expenditure elasticities $\mu < 1$. The corresponding price elasticities p_i are inelastic. The remaining commodity groups are characterised as luxury goods.[5]

We take a closer look at the price and expenditure elasticities for electricity, heating, transport, and food in Tables 4 and 5 by using the demographic translation and by differentiating the quartiles of the expenditure distribution (see Tables 12 and 13 for the remaining goods). The disaggregated figures show that expenditure elasticities increase monotonically with increasing total expenditure, implying a decreasing necessity character of the respective goods for households with higher total expenditure. The only exemptions are the heating expenditures of families with two or more children (C2, C3) which decrease slightly for the top expenditure profiles (μ_{50-100}). Energy goods might also have a luxury component with regard to high income households. With increasing expenditure more (luxury) goods become attainable which rely on energy inputs. The cross-price elasticities in Table 3 provide evidence in support of this hypothesis: Heating is a complementary good to housing, which exhibits expenditure elasticities that increase in total expenditure and transport is a complementary good to the luxury good education.

[5] A detailed account of elasticities by expenditure profile and household type is comprised in Tables 12 and 13. Interestingly, education is characterised as a necessity for family households with two or three children, i.e. in the lower half of the expenditure distribution. Mobility also shows an expenditure elasticity below unity for family households with three or more children in the upper quarter of the expenditure distribution. All remaining consumption categories show an expenditure elasticity above unity.

Park et al. (1996) note that the use of real income elasticities instead of expenditure elasticities can result in a different trend over the total expenditure range. This is due to the fact that most demand systems do not capture all expenditures, so that the variation of the neglected expenditure can affect income elasticity trends. We therefore apply the method used by Park et al. (1996) as a robustness check and derive estimates of real income elasticities for comparison. Total expenditure is regressed on disposable income, disposable income squared and indicator variables for each household type. An estimated analytical relationship between disposable income (ι) and total expenditure (μ) is obtained which allows for the calculation of income elasticities of total expenditure η^{μ}_{ι}. Real income elasticities for the different commodity groups are then obtained by multiplying their expenditure elasticities with the income elasticity of total expenditure: $\eta^{i}_{\iota} = \eta^{i}_{\mu} \cdot \eta^{\mu}_{\iota}$. Table 14 shows the income elasticities for energy commodities and food. Income elasticities do not differ substantially from expenditure elasticities. Income elasticities are slightly lower, since total expenditure on consumption goods does not increase proportionately with disposable income. We see a trend inversion for income elasticities of food for the highest expenditure quartile of couple households (C0-C3). Similar to expenditure elasticities of heating, income elasticities of heating exhibit a trend inversion for the highest expenditure quartiles of couple households.

The variation of expenditure elasticities between different household types is especially interesting for the first expenditure quartile since these households are the most vulnerable ones. Electricity and heating have a stronger necessity character for single households (S0) and lone parents (S1) when compared to couples. This finding is in line with the concept of scale economics in energy use, which is well documented in the literature (Brounen et al., 2012).

[Table 3 about here.]

[Table 4 about here.]

4.1.2 Price Elasticities

The modulus of price elasticities (in the following simply termed price elasticities) for energy goods and food, shown in table 5, increases monotonically with increasing total expenditure. While all energy commodity groups remain in the inelastic range over the whole total expenditure distribution (with the exception of food for couples without children), price elasticities are relatively low in the lower quartile of the expenditure distribution and particularly low for single households (S0) and lone parents (S1) with respect to electricity.

Concerning the differences between household types, there seems to be a significant increase in price elasticities from single to couple households. The number of children, on the other hand, plays a minor role in determining elasticities. Looking at single households, the price elasticities for all households, except those belonging to the lowest expenditure quartile, is higher for singles without children (S0) than for lone parents (S1). The differences are, however, small and sometimes not significant at the 5% level.

[Table 5 about here.]

Our results yield the same classification of necessities and luxury goods as found in Kohn and Missong (2003), but price elasticities show a different pattern. Unlike Kohn and Missong (2003), we observe price elasticities below and above unity. This can be explained by different time horizons underlying the studies. While Kohn and Missong (2003) use data from 1988 to 1993, we use data from 1993 to 2008, and by that cover a longer period in time and take a long-run perspective. The price elasticities obtained in the present study do not reflect instant demand changes due to increased prices under constraint budget. They also entail demand changes which are due to long-term effects, such as changes in lifestyle or the social environment and acquisitions or replacement of durable goods over time as alternative reaction to changes in prices. The latter aspect could include the increase in energy efficiency over time.

Nikodinoska and Schröder (2016) classify electricity, car fuels and other fuels as necessity goods, their estimates – especially for expenditure on energy – are somewhat higher than the one obtained in this study. The predominant form of elasticity curves derived by Nikodinoska and Schröder (2016) over total expenditure is inverted U-shape, whereas we observe a monotonic increase of elasticities. It is, however, not clear to which extent both demand systems comprise the same goods and there are methodological differences. Therefore, the comparability of the results is limited. Our results are in line with those by Beznoska (2014), i.e. with respect to a higher price responsiveness in the case of heating fuels when compared to electricity.

[Table 6 about here.]

4.2 Subsistence Expenditure

The *QES* includes b_i parameters, which can be interpreted as absolute subsistence quantities with corresponding expenditure $b_i p_i$ (compare Kohn and Missong (2003) or Lewbel (1997, p.188)). The interpretation as subsistence parameters is illustrated by the expenditure functions (Equation 8), which describe expenditure as the fixed term $b_i p_i$ and additional terms depending on the supernumerary expenditure $\mu - \sum_i p_i b_i$.

There are however differing views on the interpretation of the b_i parameters as subsistence expenditure. Pollak and Wales (1978) argue that the b_i parameters are generally allowed to be negative, which contradicts the interpretation as subsistence quantities. In the demand system at hand, there are in fact negative b_i parameters for the commodity groups health, mobility and other goods. All of these goods are luxury goods, especially for households of the lowest expenditure quartiles. It is therefore possible, that any purchasing decision for these goods happens within the range of apportionment of supernumerary expenditure, implying that actual subsistence levels for these goods are zero. Given the methodological issues attached to negative b_i parameters, we refrain from evaluating overall subsistence expenditure, and focus on subsistence expenditure on heating and electricity. Table 7 shows the respective monthly subsistence expenditures in euro at the price level of 2014.

The table also shows actual electricity expenditure of low income households in Germany which receive basic social security allowances (SGB II). These figures are drawn from Aigeltinger et al. (2015).[6] The last column shows modified electricity expenditure. It denotes electricity expenditure as predicted by the QES at total expenditure levels corresponding to the German social security allowances.[7] The amount of German social security allowances roughly corresponds to the risk of income poverty line in Germany (60% of median equivalised income, see also BMAS (2013)). Thus, the allowances define an overall expenditure level at which expenditures in the energy categories correspond to a more generous definition of subsistence levels.

Table 7 shows that subsistence expenditure is contingent on household type (i.e. the number of persons in the household), and that heating subsistence expenditures are in general higher when compared to electricity, as expected. The ratio between necessary heating and electricity expenditures decreases with an increasing number of household members. This implies that scale effect in energy use are stronger with

[6] There are no corresponding figures for heating expenditures available since heating expenses are directly reimbursed by the welfare agency as part of housing costs.

[7] To overcome conceptual difference of subsistence expenditure estimates and basic social security allowances, we estimate electricity expenditures at total expenditure levels corresponding to the German overall benefit payments. The necessary analytical relationship between total expenditure and expenditure comprising only the goods which are covered by benefit payments is derived through an auxiliary linear regression. Resulting electricity expenditures are shown in the last column of Table 7. Where the benefit payments cover a range, we provide estimated electricity expenditures at the mean of the upper and lower bounds of total benefit payments.

regard to space heating when compared to electricity consumption. When we compare the subsistence expenditure on electricity with actual electricity expenditure of low-income households receiving basic social security payments, we find that actual expenditure is very close to the subsistence level. We find that modified electricity expenditure, as predicted by the *QES*, is slightly higher than what households receiving basic social security payments actually spend.

Overall, the concept of subsistence expenditure, and the corresponding figures as shown in Table 7 are relevant with respect to the discussion on fuel poverty or energy poverty. The prevailing methodological approach is to evaluate the risk of fuel poverty based on energy expenditures and income of households (Hills, 2012; Moore, 2012). Such approaches appear arbitrary since they lack theoretical foundation and partly violate widely accepted demands of poverty measurement (Healy, 2004; Heindl and Schuessler, 2015; Heindl, 2015). Subsistence expenditure can be interpreted as an absolute fuel poverty line, i.e. an amount of money spent on energy, which must at least be available to households in order to afford a minimum standard of energy services. Arguably, there are conceptual difficulties attached to this concept, but subsistence expenditure might at least provide a rough indication of necessary minimum energy expenditure that – on average – corresponds to a level of energy consumption free from severe restrictions.

[Table 7 about here.]

4.3 Equivalence Scales

It is interesting per se how 'shareable' energy goods are, in particular because economies of scale in residential energy use might exist, implying that larger households can use energy goods more effectively compared to smaller ones. But economies of scale in energy use also play an important role in the discussion on fuel poverty. In the presence of economies of scale, smaller households might face a higher risk of being deprived compared to larger households, other things equal. To account for scale effects in residential energy use, Hills (2012) suggests using equivalised figures of household energy expenditure and income in assessments of affordability of energy services and fuel poverty. By doing so, Hills refers to the new OECD equivalence scale. This scale assigns a weight of 0.5 to any additional adult person in the household and a weight of 0.3 to any child ($\leq$15 years) in the household (Anyaegbu, 2010). In the QES, Kohn and Missong (2003) present a way to determine equivalence scales. Again using the b_i parameters, equivalence scales are estimated by dividing subsistence levels $\sum_i p_i b_i$ for each household type by the subsistence level of the reference household type S0 (single household).

The results, comprised in Table 8, show that the OECD scale matches the estimated empirical equivalence scale for electricity very well. However, heating expenditures show very strong scale effects, implying that the OECD scale overestimates actual expenditure of larger households in this case. With respect to expenditure on energy services in total (electricity and heating), the OECD scale approximates expenditure of lone parent households (S1) and couple households (C0) well, but overestimates expenditure of couple households with children (C1-C3). This implies that the OECD scale should not be applied to generate figures of energy expenditure 'per head' as suggested by Hills (2012) because such an approach would yield inaccurate figures.

[Table 8 about here.]

4.4 Effects of Price Changes

The *QES* allows for a counterfactual assessment of the incidence of changing energy prices at the household level. The standard tool for such an assessment is the compensating variation. For given household preferences - as derived from the estimated demand system - we exogenously change the prices of energy goods and obtain a new consumption schedule for each household. The compensating variation is the amount of money that would be required to obtain the original utility level given the new price vector.[8] This amount of money is eventually divided by the expenditure budget of the respective household, so that it represents a *relative* burden.

To assess the effects of price increases on welfare between 2000 and 2015, we create a base scenario for the year 2000 and analyse behavioural responses to changes in the prices of the base scenario. In the base scenario, we use the total expenditure and household type distribution of 2008. The prices for all commodity groups apart from electricity and heating are also taken from 2008. We use mean prices of the individualised prices described in Section 2.4. For the energy commodities electricity and heating fuels, real prices for 2000 in terms of the 2008 price level are used.[9]

[8] Please note, that this is not an inter-personal (or inter-household) comparison of utility, because utility levels before and after a change in prices are compared within and not across households.

[9] Price developments are calculated using the German CPI for electricity and heating fuels deflated by the overall German CPI. The price for heating fuels is a combined price of gas, oil, coal and district heating prices. The combination follows the weighting schemes of the German Federal Statistical Office used for the calculation of the CPI in the respective year. For 2000 prices the weighting scheme of 2000 is used, for 2008 prices the 2005 weighting scheme is used and for 2015 prices the 2010 weighting scheme is applied.

This scenario is contrasted by the 2015 scenario. In the 2015 scenario, the total expenditure and household type distribution as well as prices for non-energy goods are kept constant (viz. at the level of the base scenario). The prices for electricity and heating are set at their real 2015 price level in terms of the 2008 price level. The resulting price increases amount to 61.5% of 2000 prices for electricity and to 35.5% of 2000 prices for heating fuels.
By comparing the two described settings, we can assess the consequences of energy price increases for a society composed as in 2008 and with a wealth level as in 2008. While the analysis is based on the status of society in 2008, its main findings shall have a more universal character, since the composition of the German society in terms of wealth distribution has not changed crucially since 2008. Deflated overall consumption expenditure of private households increased by about 4% between 2008 and 2014 according to a report by the German Federal Statistical Office (Statistisches Bundesamt (2016), p.9). Inequality has remained on a constant level since 2005 according to Goebel et al. (2015).

[Figure 1 about here.]

Figure 1 shows the predicted compensating variation of energy price increases between 2000 and 2015 divided by total expenditure for each household type. For energy price increases between 2000 and 2015, relative compensating variation covers a range of about 1.75% for the richest couple households to 3.75% for the poorest singles without children. It has a mean value of 2.5%. The result clearly shows that there are significant differences of relative burdens born across the quartiles of the expenditure distribution. Thus, energy price increases (electricity and heating fuels) tend to be regressive. The variation of relative burdens across household types is less pronounced. While burdens are somewhat smaller for families with children when compared to single households or single parents, the expenditure budget appears to be the most important determinant.
Previous research has shown, that the expenditure share for necessities, and in particular for energy services, differs strongly across the income distribution, whereby low-income households spend larger portions of income on energy series when compared to wealthier households (Meier et al., 2013b; Heindl, 2015). This pattern contributes to regressive effects of energy price increases, but the impact of differentiated price elasticities has not been discussed so far. The assumption of zero price elasticities made in previous studies (Grösche and Schröder, 2014; Neuhoff et al., 2013) distorts actual income distributions after imposition of the burdens from price increases in two respects: If the modulus of energy price elasticities is

larger than zero, households will reduce their energy consumption in response to price increases. Thus, the burden from price increases decreases. If price elasticties are the same for all households, the inequality in remaining income/total expenditure after subtraction of the burden is smaller than in case of zero expenditure elasticities. On the other hand, energy price elasticities in the system estimated in this work are not constant over households. Richer households reduce their consumption relatively more than poorer households and thus evade the burdens of price increases more effectively. This effect increases inequality compared to the case of constant elasticities.
To investigate the effect of behavioural responses to price increases, we estimate the change in the Gini coefficient[10] of the equivalent total expenditure distribution due to residential energy price increases as between 2000 and 2015. The change in the expenditure distribution is induced by the subtraction of the burden $\sum_{i=1}^{2}(p_{i,2015} - p_{i,2000}) \cdot q_{i,2015}$ which arises from price increases of electricity (p_1) and heating fuels (p_2).
After subtraction of the burden arising from residential energy price, the Gini coefficient of equivalent total expenditure increases between 2000 and 2015 amounts to 2.143 (+1.3%). Thus, uncompensated energy price increases lead to increasing inequality in the *QES*. This is in line with the findings by Grösche and Schröder (2014) which are based on a different methodology. However, the increase is 22% higher than the change in Gini coefficient resulting from a scenario with zero price elasticities. The assumption of zero elasticities therefore clearly understates the true effects of residential energy price increases as between 2000 and 2015.

4.5 Robustness of Results

To assess the robustness of the estimated system, we compare the obtained elasticities with results from other meaningful system specifications. We test for robustness in face of variations in two dimensions: the number of commodity groups and the time-dependence of preferences. As a first alternative system specification we estimate a demand system comprising five commodity groups: electricity, heating, transport, food and other goods. The other goods category comprises commodity groups 5 to 10 of the ten-good-system presented above (reference system). In the second alternative specification we extend the translation of the b_i parameters by

[10]The Gini coefficient is an inequality measure based on the difference between the actual Lorenz curve and the Lorenz curve of perfect equality. The Lorenz curve depicts normalised cumulated income/wealth/etc. as a function of the share of population, orderer from poor to rich. For a detailed description of the Gini coefficient and other inequality measures see Grösche and Schröder (2014).

adding year indicator variables for the years 1993 to 2003. We, therewith, overcome the assumption of constant preferences implicit in the reference system.
Table 9 gives an overview of predicted elasticities for 2008. In the upper part it shows household means of elasticities evaluated at the mean total expenditure and price level in 2008 for all commodity groups. In the lower part it shows household means of elasticities evaluated at the means of the 2008 total expenditure quartiles and respective price means for electricity and heating fuels. The upper part shows that the classification into necessity and luxury goods as well as into price elastic and inelastic goods is robust over all demand system specifications. Mean elasticities for comparable commodity groups, however, differ significantly in most cases. The mean absolute relative difference of the comparable expenditure elasticities $1/n \sum_i |(\eta^i_\mu - \eta^{i'}_\mu)/\eta^{i'}_\mu|$ between the five goods and the reference system amounts to 0.2 whereas it amounts only to 0.05 in the comparison of the ten goods system with year indicator variables to the reference system. For price elasticities, the respective differences are 0.13 and 0.07. It thus seems that estimated elasticities are rather robust in face of time dependence of the subsistence parameters. They are, however, less robust to the number of commodity groups described by the demand system. The lower part of the table focuses on residential energy goods. It provides a similar picture as the upper part. The estimated trends of elasticities over the total expenditure distribution are robust. In all three systems expenditure elasticities and absolute price elasticities increase with increasing total expenditure for both commodity groups. However, the range of elasticities covered differs between systems.

[Table 9 about here.]

5 Discussion and Conclusion

We investigate price and expenditure elasticities of residential energy demand (electricity and space heating) in Germany by applying a quadratic expenditure system (QES) and using official expenditure data from 1993 to 2008. Households are disaggregated along two dimensions: (i) total expenditure and (ii) household size. This approach allows a detailed description of consumption behaviour, which is instrumental for understanding the consequences of changes in energy prices on welfare, e.g. as a result from direct energy taxation.
The estimated expenditure elasticity for electricity amounts to 0.3988 and to 0.4055 for space heating . The own price elasticity for electricity is -0.4310 and -0.5008 for space heating. Disaggregation across the dimensions of total expenditure and household size yields more detailed results: Expenditure and price elasticities show

considerable variation if differentiated with respect to the quartiles of the expenditure distribution.
The expenditure elasticity for electricity of a single household in the lowest quartile of the expenditure distribution is 0.260, compared to 0.485 in the highest quartile. Similarly, the expenditure elasticity of a single household for space heating amounts to 0.279 in the lowest quartile, compared to 0.452 in the top quartile. Price elasticities also differ considerably for the different brackets of the expenditure distribution: The price elasticity of electricity demand is -0.179 for a single household situated in the lowest quartile of the expenditure distribution, compared to -0.566 if situated in the top quartile. The price elasticity for space heating in the lowest quartile equals -0.205 compared to -0.616 in the top quartile.
The results suggest that the reaction to changes in prices for energy goods is strongly dependent on total household expenditure. This view is supported by the analysis of an isolated increase in energy prices, where expenditure and prices for other goods are kept constant. The relative compensating variation clearly shows a regressive pattern of price increases for energy services. Relative burdens at the household level are strongly dependent on total expenditure.
The disaggregated view on household size further shows that there are considerable economies of scale in residential energy use. Lager households tend to use energy services more effectively compared to smaller ones. A household, consisting of two adult persons for instance, faces costs for energy services of about 1.48-times the amount a single household spends on energy services. A household, consisting of one adult person and one child, spends about 1.26-times the amount a single person spends on energy services. The results indicate, that the 'new OECD equivalence scale' can be used to approximate scale effects in residential electricity use but not scale effects with respect to space heating. Consequently, the OECD equivalence scale is a poor approximation of scale effects which are present in total household expenditure on energy services (electricity and space heating).
The results have important implications for energy and climate policy. A real increase in energy prices has regressive effects at the household level. This implies that direct energy taxation or carbon finance mechanisms based on a surcharge per unit of energy consumption will increase economic inequality. Larger relative burdens which fall on households with low income or low expenditure budget will further increase the likelihood of energy related deprivation or deprivation which occurs in other domains of consumption as a consequence of increased energy prices. Of course price increases also contribute to a reduction of energy consumption and therefore to energy conservation. But these effects are contingent on the position of house-

holds in the expenditure distribution. The estimated price elasticities imply that low income household will tend to decrease energy consumption to a lower extent compared to households with a higher income.
Our results clearly show that assessments of the welfare consequences of real energy price increases hinge on the modelling assumptions. Most importantly, adequate modelling of the behavioural response of households is instrumental. The increase in inequality as a consequence of an increase in real energy prices as between 2000 and 2015 is about 22% larger if detailed price and expenditure elasticities are used when compared to a situation in which elasticities are set to zero. The application of differentiated price and income elasticities of energy demand across the dimensions of expenditure, income, or household size will further help to improve the accuracy of behavioural models of energy demand. This is because the average behavioural response, viz. using uniform price and expenditure elasticities for all households, overestimates behavioural responses at the lower end of the expenditure distribution and underestimates the response at the upper end.

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A Tables

[Table 10 about here.]

[Table 11 about here.]

[Table 12 about here.]

[Table 13 about here.]

[Table 14 about here.]

B Data preparation

Table 15 shows the allocation of expenditure variables to the different commodity groups for each cross-section.

[Table 15 about here.]

After the allocation of expenditures to the commodity groups, the data is corrected for outliers and misreporting. We first deal with zero expenditure data in any category. Zero expenditure data amounts to about 21% of all data points. However, 80% of it is due to zero expenditure in the heating category alone, where infrequency of purchase prevents an accurate consumption recording. To correct for this inaccuracy without having to drop data, we impute heating expenditure values for zero heating expenditure households. We, therefore, use a linear regression based on data from households reporting a positive expenditure on heating fuels. As independent variables we use among others heating fuel prices, total expenditure and powers of disposable income, household type and year bivariate variables and expenditure in related categories.

The second category with a notable amount of reported zero expenditures is the transport category. We again impute expenditure values for these households in a similar procedure as for heating expenditure.[11] The occurrences of the remaining reported zero expenditures show a random pattern. We drop them under the assumption of misreporting given the broad definition of the expenditure categories. About 5% of the data is dropped due to zero expenditures.

We also drop outliers characterised by an extreme ratio between expenditure and disposable income or by an extreme expenditure share in at least one commodity group. That is, observations are dropped if they either fall in any commodity group in the highest or lowest percent of the distribution of the expenditure to disposable income ratio (adopted from Nikodinoska and Schröder (2016)) or if they deviate by more than three standard deviations from the year-specific mean expenditure share in any commodity group.[12] In total about 15% of the zero expenditure adjusted data is dropped during the process.

Further descriptive statistics for the IES are published by the German Federal Office of Statistics. An overview of incomes and expenditures in the 2008 cross section is presented by the German Federal Office of Statistics (Statistisches Bundesamt, 2010).

[11]The analysis of the consumption behaviour and the wealth status of these households suggests that the large majority is not in possession of a motorised vehicle. Thus the regression used for imputation is based exclusively on households which report positive expenditure on public transport but not on car fuels.

[12]In the case of the mobility category we drop data points only if the expenditure shares deviate by more than 5 standard deviations from the mean expenditure share. This is to account for the fact that in this category expenditure on expensive durable goods and expenditure on consumption goods are superimposed. This yields a strongly positively skewed expenditure share distribution.

Table 1: **Definition of commodity groups**

No.	Code	Comprised goods
1	ELECTRICITY	electricity
2	HEATING	gas, oil, solid fuels, district heating
3	TRANSPORT	car fuel, public transport
4	FOOD	food, food away from home, (alcoholic) beverages, tobacco
5	CLOTHES	clothes, shoes, shoe repair
6	HOUSING	rent, rent equivalent for homeowners, maintenance and repair
7	HEALTH	health care, personal hygiene, care of the elderly/disabled
8	MOBILITY	private transport (except for car fuel), communication
9	EDUCATION	education, entertainment, child daycare
10	OTHERS	furniture, household appliances, jewellery, vacation trips, financial services, other services

Table 2: **Definition of household types and composition of data set**

Code	S0	S1	C0	C1	C2	C3
Type	*Single without children*	*Single with one child*	*Couple without children*	*Couple with one child*	*Couple with two children*	*Couple with three children*
Share	25.8%	2.8%	39.3%	11.6%	15.8%	4.7%

Age of children: from 0 up to and including 17 years.

Table 3: **Mean expenditure, own-price and cross-price elasticities for all commodity groups:** Weighted average of household type specific predicted elasticities at the means of the 2008 total expenditure and prices distributions. Standard errors in parentheses are derived with the delta method.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
μ	**0.398 8**	**0.405 5**	**0.636 9**	**0.658 3**	**1.196 2**	**0.696 2**	**1.367 8**	**1.412 0**	**1.204 7**	**1.748 3**
	(0.003 6)	(0.006 4)	(0.004 9)	(0.002 7)	(0.004 1)	(0.003 3)	(0.006 0)	(0.006 3)	(0.003 8)	(0.005 0)
p_1	**−0.431 0**	−0.004 8	−0.009 5	−0.008 7	−0.016 6	−0.011 2	−0.017 6	−0.017 4	−0.017 7	−0.026 0
	(0.005 9)	(0.000 2)	(0.000 1)	(0.000 1)	(0.000 2)	(0.000 1)	(0.000 3)	(0.000 3)	(0.000 2)	(0.000 3)
p_2	−0.008 0	**−0.500 8**	−0.015 4	−0.013 5	−0.025 6	−0.018 5	−0.024 9	−0.024 5	−0.028 1	−0.039 7
	(0.000 2)	(0.005 4)	(0.000 3)	(0.000 2)	(0.000 4)	(0.000 2)	(0.000 5)	(0.000 6)	(0.000 3)	(0.000 5)
p_3	−0.008 6	−0.007 3	**−0.572 6**	−0.014 6	−0.028 0	−0.020 7	−0.027 6	−0.026 6	−0.030 9	−0.044 7
	(0.000 2)	(0.000 4)	(0.005 9)	(0.000 3)	(0.000 5)	(0.000 2)	(0.000 7)	(0.000 7)	(0.000 4)	(0.000 7)
p_4	−0.021 4	−0.014 8	−0.050 2	**−0.725 9**	−0.075 0	−0.065 1	−0.063 4	−0.057 0	−0.089 1	−0.127 1
	(0.000 9)	(0.001 7)	(0.001 2)	(0.004 9)	(0.001 6)	(0.000 8)	(0.002 3)	(0.002 3)	(0.001 4)	(0.002 3)
p_5	0.007 0	0.011 7	0.002 2	0.010 6	**−1.209 9**	−0.002 9	(0.037 2	0.042 7	0.010 1	0.020 2
	(0.000 4)	(0.000 7)	(0.000 5)	(0.000 5)	(0.005 1)	(0.000 4)	(0.001 0)	(0.000 9)	(0.000 6)	(0.000 8)
p_6	−0.038 8	−0.033 4	−0.074 7	−0.065 5	−0.122 4	**−0.625 7**	−0.119 4	−0.116 6	−0.134 3	−0.190 4
	(0.000 8)	(0.001 7)	(0.001 3)	(0.000 9)	(0.001 7)	(0.004 7)	(0.002 5)	(0.002 7)	(0.001 5)	(0.002 3)
p_7	0.015 5	0.022 1	0.013 0	0.024 3	0.043 5	0.007 7	**−1.549 3**	0.081 6	0.033 2	0.059 8
	(0.000 5)	(0.000 8)	(0.000 6)	(0.000 6)	(0.000 8)	(0.000 5)	(0.007 8)	(0.001 3)	(0.000 8)	(0.001 2)
p_8	0.028 8	0.039 8	0.026 3	0.045 4	0.081 2	0.017 6	0.133 3	**−1.587 5**	0.064 1	0.109 9
	(0.000 9)	(0.001 4)	(0.001 1)	(0.001 0)	(0.001 3)	(0.000 8)	(0.002 1)	(0.005 5)	(0.001 2)	(0.001 8)
p_9	0.007 1	0.013 9	−0.001 7	0.010 3	0.017 0	−0.009 4	0.043 0	0.051 0	**−1.122 9**	0.015 5
	(0.000 6)	(0.001 1)	(0.000 8)	(0.000 7)	(0.001 0)	(0.000 6)	(0.001 5)	(0.001 5)	(0.005 4)	(0.001 4)
p_{10}	0.048 5	0.066 6	0.045 4	0.076 6	0.137 7	0.031 8	0.226 4	0.245 2	0.109 6	**−1.520 9**
	(0.001 4)	(0.002 2)	(0.001 7)	(0.001 6)	(0.001 9)	(0.001 3)	(0.003 3)	(0.002 8)	(0.001 9)	(0.005 1)

1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD, 5: CLOTHES, 6: HOUSING, 7: HEALTH, 8: MOBILITY, 9: EDUCATION, 10: OTHERS

Table 4: **Expenditure elasticities for energy goods and food for different household types at different total expenditure levels:** Predicted values at the means of the 2008 household type specific total expenditure quartiles and at respective price means. Standard errors in parentheses are derived with the delta method.

Good		S0	S1	C0	C1	C2	C3
1	μ_{0-25}	0.260	0.253	0.281	0.291	0.298	0.281
		(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)
	μ_{25-50}	0.333	0.302	0.353	0.355	0.360	0.342
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
	μ_{50-75}	0.391	0.348	0.407	0.405	0.403	0.389
		(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
	μ_{75-100}	0.485	0.437	0.495	0.477	0.471	0.462
		(0.004)	(0.005)	(0.007)	(0.006)	(0.007)	(0.008)
2	μ_{0-25}	0.279	0.293	0.311	0.353	0.362	0.367
		(0.003)	(0.004)	(0.003)	(0.005)	(0.005)	(0.006)
	μ_{25-50}	0.343	0.338	0.364	0.401	0.408	0.405
		(0.003)	(0.005)	(0.005)	(0.006)	(0.007)	(0.009)
	μ_{50-75}	0.387	0.378	0.398	0.431	0.436	0.432
		(0.004)	(0.005)	(0.008)	(0.009)	(0.010)	(0.012)
	μ_{75-100}	0.452	0.445	0.419	0.447	0.434	0.407
		(0.007)	(0.008)	(0.017)	(0.017)	(0.019)	(0.024)
3	μ_{0-25}	0.447	0.485	0.482	0.425	0.484	0.515
		(0.005)	(0.009)	(0.005)	(0.005)	(0.005)	(0.008)
	μ_{25-50}	0.533	0.556	0.584	0.522	0.588	0.613
		(0.005)	(0.009)	(0.005)	(0.005)	(0.006)	(0.008)
	μ_{50-75}	0.601	0.618	0.668	0.592	0.652	0.687
		(0.005)	(0.009)	(0.006)	(0.006)	(0.007)	(0.009)
	μ_{75-100}	0.723	0.736	0.807	0.721	0.773	0.830
		(0.005)	(0.009)	(0.009)	(0.008)	(0.010)	(0.012)
4	μ_{0-25}	0.610	0.570	0.540	0.546	0.576	0.581
		(0.005)	(0.006)	(0.004)	(0.004)	(0.004)	(0.005)
	μ_{25-50}	0.667	0.625	0.595	0.605	0.634	0.649
		(0.004)	(0.006)	(0.003)	(0.003)	(0.003)	(0.004)
	μ_{50-75}	0.705	0.660	0.625	0.642	0.662	0.688
		(0.003)	(0.005)	(0.003)	(0.003)	(0.003)	(0.004)
	μ_{75-100}	0.749	0.736	0.656	0.677	0.693	0.720
		(0.003)	(0.004)	(0.006)	(0.005)	(0.005)	(0.005)

1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD

Table 5: **Price elasticities for different household types:** Predicted values at the means of the household type specific total expenditure quartiles and respective prices. Standard errors in parentheses are derived with the delta method.

Good		S0	S1	C0	C1	C2	C3
1	μ_{0-25}	−0.179	−0.174	−0.234	−0.227	−0.238	−0.215
		(0.004)	(0.007)	(0.004)	(0.005)	(0.005)	(0.006)
	μ_{25-50}	−0.282	−0.244	−0.353	−0.341	−0.351	−0.324
		(0.005)	(0.007)	(0.006)	(0.006)	(0.006)	(0.007)
	μ_{50-75}	−0.376	−0.319	−0.467	−0.440	−0.449	−0.430
		(0.006)	(0.008)	(0.007)	(0.007)	(0.007)	(0.008)
	μ_{75-100}	−0.566	−0.501	−0.724	−0.657	−0.665	−0.676
		(0.008)	(0.010)	(0.011)	(0.010)	(0.010)	(0.012)
2	μ_{0-25}	−0.205	−0.215	−0.281	−0.302	−0.320	−0.311
		(0.003)	(0.008)	(0.004)	(0.006)	(0.006)	(0.009)
	μ_{25-50}	−0.313	−0.294	−0.413	−0.439	−0.463	−0.451
		(0.004)	(0.009)	(0.005)	(0.007)	(0.007)	(0.010)
	μ_{50-75}	−0.411	−0.378	−0.542	−0.559	−0.587	−0.592
		(0.005)	(0.009)	(0.006)	(0.009)	(0.008)	(0.012)
	μ_{75-100}	−0.616	−0.584	−0.845	−0.829	−0.861	−0.921
		(0.008)	(0.012)	(0.013)	(0.014)	(0.014)	(0.020)
3	μ_{0-25}	−0.295	−0.316	−0.367	−0.308	−0.350	−0.352
		(0.005)	(0.012)	(0.006)	(0.006)	(0.006)	(0.010)
	μ_{25-50}	−0.416	−0.412	−0.506	−0.433	−0.485	−0.488
		(0.006)	(0.012)	(0.006)	(0.007)	(0.007)	(0.010)
	μ_{50-75}	−0.515	−0.502	−0.628	−0.533	−0.585	−0.605
		(0.006)	(0.012)	(0.007)	(0.007)	(0.008)	(0.011)
	μ_{75-100}	−0.700	−0.693	−0.862	−0.731	−0.786	−0.842
		(0.007)	(0.013)	(0.010)	(0.009)	(0.010)	(0.013)
4	μ_{0-25}	−0.471	−0.446	−0.495	−0.476	−0.497	−0.480
		(0.006)	(0.012)	(0.005)	(0.006)	(0.005)	(0.008)
	μ_{25-50}	−0.602	−0.543	−0.628	−0.609	−0.629	−0.615
		(0.006)	(0.011)	(0.005)	(0.006)	(0.006)	(0.008)
	μ_{50-75}	−0.707	−0.630	−0.746	−0.715	−0.731	−0.731
		(0.006)	(0.011)	(0.006)	(0.007)	(0.006)	(0.008)
	μ_{75-100}	−0.902	−0.831	−1.010	−0.934	−0.946	−0.975
		(0.007)	(0.011)	(0.009)	(0.009)	(0.009)	(0.011)

1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD

Table 6: **Comparison of predicted expenditure elasticities:** Comparison between own estimations (QES) and estimations by Nikodinoska and Schröder (2016) (QUAIDS). Mean of predicted expenditure elasticities from 1993 to 2008. 95% confidence intervals are shown in parentheses.

Good	eta^i_μ (QES)	eta^i_μ (QUAIDS)
Electricity	0.456	0.507
	[0.455; 0.457]	[0.505; 0.509]
Heating/	0.624	0.724
other fuels	[0.623; 0.626]	[0.723; 0.725]
TRANSPORT/	0.740	0.832
car fuels	[0.738; 0.741]	[0.831; 0.833]
Food	0.636	0.415
	[0.635; 0.637]	[0.376; 0.445]

Italic good description denotes deviating definitions by Nikodinoska and Schröder (2016).

Table 7: **Comparison of monthly subsistence expenditures for different household types:** Own estimations are evaluated at 2014 CPI prices. Age of children in QES up to 17 years, German unemployment benefit (ALGII) scales vary with age of children: lower limit: all children are up to 5 years old, upper limit: all children are between 14 and 17 years old. Modified electricity expenditure describes estimated electricity expenditure for households whose overall expenditure corresponds to the ALGII. Standard errors in parentheses are derived with the delta method.

HH-Type	Heating subsistence (QES)	Electricity subsistence (QES)	Electricity needs[1]	Electricity (QES, modified)
S0	69.16 (.51)	35.35 (0.24)	35.9	38.43 (0.19)
S1	84.87 (1.57)	47.32 (0.68)	42.7-52.8	51.98 (0.58)
C0	98.78 (.78)	55.42 (0.38)	52.8	60.87 (0.29)
C1	97.26 (1.27)	62.97 (0.57)	49.6-69.7	69.50 (0.47)
C2	108.44 (1.26)	72.54 (0.57)	56.4-86.6	80.89 (0.45)
C3	117.07 (2.31)	84.70 (0.93)	63.2-103.5	94.57 (0.79)

[1] According to estimates by Aigeltinger et al. (2015)

Table 8: **Comparison of equivalence scales for different household types:** *QES*-estimations are evaluated at 2014 prices. Age of children in *QES* up to 17 years, in OECD up to 15 years (Anyaegbu, 2010). Standard errors in parentheses are derived with the delta method.

HH	Energy ES (QES)	Electricity ES (QES)	Heating ES (QES)	OECD-modified scale
S0	1	1	1	1
S1	1.26	1.34	1.23	1.3
	(0.02)	(0.02)	(0.02)	
C0	1.48	1.57	1.43	1.5
	(0.01)	(0.02)	(0.02)	
C1	1.53	1.78	1.41	1.8
	(0.02)	(0.02)	(0.02)	
C2	1.73	2.05	1.57	2.1
	(0.02)	(0.02)	(0.02)	
C3	1.93	2.40	1.69	2.4
	(0.03)	(0.03)	(0.04)	

Table 9: **Elasticity robustness check:** Comparison of weighted averages of household type specific predicted elasticities; upper part shows elasticities evaluated at the 2008 price and expenditure means, lower part shows elasticities evaluated at the means of the 2008 total expenditure quartiles and respective price means. Predictions are obtained from the ten goods demographically translated QES with household types as demographic variables (10goods), a ten goods demographically translated QES with household types and years as demographic variables (Years) and a five goods demographically translated QES with household types as demographic variables (5goods). Standard errors in parentheses are derived with the delta method.

		η^i_μ			$\eta^i_{p_i}$		
Good		$10goods$	$Years$	$5goods$	$10goods$	$Years$	$5goods$
1		0.399	0.411	0.470	−0.431	−0.438	−0.467
		(0.004)	(0.004)	(0.004)	(0.006)	(0.006)	(0.005)
2		0.406	0.393	0.584	−0.501	−0.457	−0.579
		(0.006)	(0.006)	(0.004)	(0.005)	(0.006)	(0.004)
3		0.637	0.613	0.738	−0.573	−0.563	−0.709
		(0.005)	(0.005)	(0.004)	(0.006)	(0.005)	(0.005)
4		0.658	0.656	0.654	−0.726	−0.661	−0.685
		(0.003)	(0.003)	(0.002)	(0.005)	(0.005)	(0.003)
5		1.196	1.361		−1.210	−1.218	
		(0.004)	(0.005)		(0.005)	(0.008)	
6		0.696	0.664		−0.626	−0.573	
		(0.003)	(0.003)		(0.005)	(0.005)	
7		1.368	1.312		−1.549	−1.315	
		(0.006)	(0.006)		(0.008)	(0.010)	
8		1.412	1.522		−1.588	−1.472	
		(0.006)	(0.008)		(0.005)	(0.011)	
9		1.205	1.171		−1.123	−1.010	
		(0.004)	(0.004)		(0.005)	(0.007)	
10		1.748	1.816	1.173	−1.521	−1.416	−1.016
		(0.005)	(0.006)	(0.001)	(0.005)	(0.008)	(0.001)
1	μ_{0-25}	0.301	0.332	0.410	−0.235	−0.217	−0.359
		(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)
	μ_{25-50}	0.354	0.377	0.445	−0.337	−0.334	−0.419
		(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
	μ_{50-75}	0.389	0.401	0.456	−0.423	−0.432	−0.456
		(0.004)	(0.004)	(0.004)	(0.006)	(0.006)	(0.005)
	μ_{75-100}	0.465	0.441	0.469	−0.647	−0.683	−0.522
		(0.006)	(0.006)	(0.004)	(0.009)	(0.010)	(0.005)
2	μ_{0-25}	0.316	0.319	0.504	−0.264	−0.220	−0.444
		(0.003)	(0.003)	(0.005)	(0.004)	(0.004)	(0.005)
	μ_{25-50}	0.370	0.365	0.557	−0.389	−0.346	−0.525
		(0.004)	(0.004)	(0.005)	(0.004)	(0.005)	(0.004)
	μ_{50-75}	0.402	0.387	0.580	−0.504	−0.460	−0.579
		(0.007)	(0.006)	(0.005)	(0.006)	(0.006)	(0.004)
	μ_{75-100}	0.435	0.395	0.585	−0.790	−0.683	−0.647
		(0.015)	(0.016)	(0.006)	(0.011)	(0.010)	(0.005)

1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD, 5: CLOTHES, 6: HOUSING, 7: HEALTH, 8: MOBILITY, 9: EDUCATION, 10: OTHERS

Table 10: **Nonlinear seemingly unrelated regression coefficients:** Estimation is based on a *QES* with demographic translation; dependent variables: expenditure on different commodity groups divided by generalised total expenditure; translation coefficients are not shown.

	Coefficient	**(Robust Std. Err.)**
b1	0.843	(0.006)
b2	1.796	(0.013)
b3	1.720	(0.019)
b4	3.858	(0.040)
b5	0.045	(0.017)
b6	7.179	(0.051)
b7	-0.278	(0.021)
b8	-0.890	(0.029)
b9	0.464	(0.028)
b10	-3.421	(0.070)
a1	0.0953	(0.0001)
a2	0.0202	(0.0002)
a3	0.0280	(0.0003)
a4	0.1259	(0.0011)
a5	0.0743	(0.0004)
a6	0.1180	(0.0012)
a7	0.0914	(0.0006)
a8	0.1528	(0.0012)
a9	0.1118	(0.0007)
c1	-4.95e-05	(0.17e-05)
c2	-13.92e-05	(0.54e-05)
c3	-11.39e-05	(0.50e-05)
c4	-63.79e-05	(1.98e-05)
c5	-35.70e-05	(0.73e-05)
c6	-26.18e-05	(1.37e-05)
c7	-54.81e-05	(1.10e-05)
c8	-95.43e-05	(1.84e-05)
c9	-42.73e-05	(1.01e-05)
c10	-151.85e-05	(3.98e-05)
n	108686	
AIC	-2642460	
BIC	-2641702	
Wald test $c_i = 0\ \forall i$:	$\chi^2(10) = 3814.62$, Prob $> \chi^2 = 0.00$	

Table 11: **Slutsky matrix:** Eigenvalues (eg) evaluated at the means of the 2008 total expenditure quartiles of the household type specific distributions and at respective price means.

Good		eg1	eg2	eg3	eg4	eg5	eg6	eg7	eg8	eg9	eg10
S0	μ_{0-25}	-0.000	-0.002	-0.005	-0.009	-0.014	-0.017	-0.021	-0.025	-0.029	-0.058
	μ_{25-50}	0.000	-0.004	-0.009	-0.015	-0.025	-0.031	-0.037	-0.042	-0.050	-0.104
	μ_{50-75}	0.000	-0.005	-0.014	-0.021	-0.038	-0.045	-0.053	-0.059	-0.069	-0.153
	μ_{75-100}	0.000	-0.010	-0.024	-0.036	-0.068	-0.084	-0.094	-0.099	-0.122	-0.286
S1	μ_{0-25}	0.000	-0.003	-0.007	-0.011	-0.017	-0.022	-0.026	-0.033	-0.039	-0.073
	μ_{25-50}	0.000	-0.004	-0.011	-0.016	-0.026	-0.030	-0.037	-0.048	-0.057	-0.111
	μ_{50-75}	-0.000	-0.006	-0.015	-0.022	-0.036	-0.043	-0.052	-0.066	-0.079	-0.161
	μ_{75-100}	-0.000	-0.011	-0.028	-0.039	-0.069	-0.083	-0.097	-0.118	-0.135	-0.305
C0	μ_{0-25}	0.000	-0.004	-0.012	-0.017	-0.030	-0.036	-0.044	-0.053	-0.061	-0.126
	μ_{25-50}	0.000	-0.008	-0.019	-0.028	-0.052	-0.061	-0.074	-0.084	-0.096	-0.213
	μ_{50-75}	0.000	-0.011	-0.028	-0.040	-0.077	-0.090	-0.106	-0.116	-0.135	-0.315
	μ_{75-100}	0.000	-0.020	-0.051	-0.073	-0.147	-0.177	-0.190	-0.204	-0.257	-0.605
C1	μ_{0-25}	0.000	-0.005	-0.012	-0.019	-0.031	-0.037	-0.045	-0.058	-0.068	-0.136
	μ_{25-50}	-0.000	-0.008	-0.020	-0.031	-0.053	-0.062	-0.073	-0.093	-0.109	-0.222
	μ_{50-75}	0.000	-0.011	-0.028	-0.042	-0.076	-0.088	-0.102	-0.125	-0.145	-0.308
	μ_{75-100}	-0.000	-0.020	-0.049	-0.073	-0.133	-0.155	-0.178	-0.209	-0.258	-0.569
C2	μ_{0-25}	0.000	-0.006	-0.015	-0.022	-0.035	-0.042	-0.053	-0.070	-0.087	-0.162
	μ_{25-50}	0.000	-0.010	-0.024	-0.036	-0.058	-0.068	-0.084	-0.110	-0.134	-0.268
	μ_{50-75}	-0.000	-0.013	-0.034	-0.048	-0.081	-0.096	-0.116	-0.149	-0.176	-0.372
	μ_{75-100}	0.000	-0.023	-0.056	-0.081	-0.145	-0.171	-0.202	-0.246	-0.294	-0.666
C3	μ_{0-25}	0.000	-0.006	-0.015	-0.023	-0.035	-0.043	-0.056	-0.074	-0.095	-0.169
	μ_{25-50}	-0.000	-0.010	-0.025	-0.037	-0.060	-0.070	-0.088	-0.113	-0.147	-0.278
	μ_{50-75}	0.000	-0.014	-0.036	-0.052	-0.087	-0.104	-0.130	-0.164	-0.203	-0.384
	μ_{75-100}	-0.000	-0.026	-0.063	-0.096	-0.167	-0.202	-0.241	-0.295	-0.345	-0.743

List of goods: 1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD, 5: CLOTHES, 6: HOUSING, 7: HEALTH, 8: MOBILITY, 9: EDUCATION, 10: OTHERS

Table 12: **Expenditure elasticities for different household types:** Table 4 continued.

Good		S0	S1	C0	C1	C2	C3
5	μ_{0-25}	1.610	1.188	1.442	1.196	1.121	1.121
		(0.015)	(0.018)	(0.010)	(0.010)	(0.008)	(0.012)
	μ_{25-50}	1.377	1.156	1.298	1.144	1.089	1.096
		(0.007)	(0.013)	(0.006)	(0.007)	(0.006)	(0.009)
	μ_{50-75}	1.276	1.116	1.229	1.122	1.068	1.075
		(0.005)	(0.010)	(0.005)	(0.006)	(0.005)	(0.007)
	μ_{75-100}	1.173	1.076	1.150	1.084	1.046	1.036
		(0.003)	(0.006)	(0.005)	(0.005)	(0.006)	(0.007)
6	μ_{0-25}	0.380	0.437	0.529	0.559	0.579	0.556
		(0.004)	(0.005)	(0.004)	(0.005)	(0.005)	(0.006)
	μ_{25-50}	0.489	0.516	0.653	0.677	0.694	0.670
		(0.003)	(0.005)	(0.004)	(0.005)	(0.004)	(0.006)
	μ_{50-75}	0.581	0.594	0.755	0.765	0.783	0.776
		(0.003)	(0.005)	(0.004)	(0.005)	(0.005)	(0.006)
	μ_{75-100}	0.730	0.756	0.923	0.920	0.934	0.952
		(0.003)	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)
7	μ_{0-25}	2.039	2.593	1.635	2.242	2.230	2.367
		(0.024)	(0.065)	(0.014)	(0.028)	(0.023)	(0.043)
	μ_{25-50}	1.534	1.920	1.327	1.633	1.642	1.714
		(0.010)	(0.029)	(0.007)	(0.012)	(0.011)	(0.019)
	μ_{25-50}	1.335	1.599	1.183	1.406	1.412	1.439
		(0.006)	(0.017)	(0.006)	(0.008)	(0.008)	(0.013)
	μ_{75-100}	1.144	1.266	1.016	1.156	1.164	1.154
		(0.004)	(0.008)	(0.008)	(0.008)	(0.009)	(0.011)
8	μ_{0-25}	2.551	2.419	2.164	1.989	1.978	1.988
		(0.030)	(0.068)	(0.020)	(0.026)	(0.022)	(0.036)
	μ_{25-50}	1.731	1.831	1.567	1.516	1.513	1.506
		(0.010)	(0.032)	(0.009)	(0.013)	(0.011)	(0.019)
	μ_{50-75}	1.449	1.549	1.311	1.303	1.303	1.273
		(0.006)	(0.019)	(0.007)	(0.009)	(0.009)	(0.014)
	μ_{75-100}	1.171	1.196	1.017	1.066	1.039	0.959
		(0.004)	(0.010)	(0.009)	(0.009)	(0.010)	(0.013)
9	μ_{0-25}	1.348	1.074	1.457	1.137	0.977	0.959
		(0.011)	(0.015)	(0.010)	(0.009)	(0.007)	(0.010)
	μ_{25-50}	1.255	1.044	1.342	1.123	0.992	0.977
		(0.006)	(0.011)	(0.006)	(0.006)	(0.005)	(0.008)
	μ_{50-75}	1.210	1.052	1.290	1.118	1.013	0.987
		(0.004)	(0.009)	(0.004)	(0.005)	(0.005)	(0.007)
	μ_{75-100}	1.175	1.049	1.243	1.099	1.028	1.036
		(0.003)	(0.006)	(0.004)	(0.005)	(0.006)	(0.007)
10	μ_{0-25}	5.019	5.166	2.607	2.916	2.820	3.055
		(0.076	0.178)	(0.018)	(0.031)	(0.025)	(0.046)
	μ_{25-50}	2.328	2.754	1.823	1.979	1.972	2.076
		(0.011)	(0.040)	(0.006)	(0.011)	(0.009)	(0.017)
	μ_{50-75}	1.804	2.068	1.563	1.684	1.701	1.738
		(0.005)	(0.018)	(0.005)	(0.007)	(0.007)	(0.011)
	μ_{75-100}	1.440	1.542	1.340	1.423	1.452	1.444
		(0.003)	(0.007)	(0.005)	(0.006)	(0.006)	(0.008)

5: CLOTHES, 6: HOUSING, 7: HEALTH, 8: MOBILITY, 9: EDUCATION, 10: OTHERS

Table 13: **Own-price elasticities for different household types:** Table 5 continued.

Good		S0	S1	C0	C1	C2	C3
5	μ_{0-25}	-1.045	-0.799	-1.132	-0.909	-0.881	-0.850
		(0.014)	(0.025)	(0.012)	(0.013)	(0.011)	(0.017)
	μ_{0-25}	-1.113	-0.912	-1.228	-1.063	-1.050	-1.028
		(0.009)	(0.020)	(0.008)	(0.010)	(0.009)	(0.014)
	μ_{0-25}	-1.170	-1.006	-1.315	-1.173	-1.174	-1.173
		(0.007)	(0.018)	(0.007)	(0.009)	(0.008)	(0.013)
	μ_{0-25}	-1.294	-1.194	-1.521	-1.396	-1.418	-1.475
		(0.007)	(0.014)	(0.008)	(0.010)	(0.009)	(0.014)
6	μ_{0-25}	-0.327	-0.355	-0.449	-0.446	-0.460	-0.431
		(0.004)	(0.009)	(0.005)	(0.007)	(0.006)	(0.008)
	μ_{25-50}	-0.439	-0.439	-0.580	-0.574	-0.585	-0.555
		(0.005)	(0.009)	(0.005)	(0.007)	(0.006)	(0.008)
	μ_{50-75}	-0.532	-0.519	-0.688	-0.671	-0.680	-0.665
		(0.005)	(0.009)	(0.005)	(0.007)	(0.006)	(0.008)
	μ_{75-100}	-0.691	-0.692	-0.878	-0.843	-0.851	-0.860
		(0.005)	(0.008)	(0.007)	(0.007)	(0.007)	(0.008)
7	μ_{0-25}	-1.355	-1.706	-1.404	-1.761	-1.817	-1.826
		(0.021)	(0.059)	(0.017)	(0.029)	(0.024)	(0.041)
	μ_{25-50}	-1.320	-1.561	-1.463	-1.693	-1.763	-1.788
		(0.012)	(0.039)	(0.011)	(0.018)	(0.016)	(0.028)
	μ_{50-75}	-1.349	-1.530	-1.551	-1.708	-1.807	-1.825
		(0.009)	(0.029)	(0.010)	(0.015)	(0.014)	(0.023)
	μ_{75-100}	-1.461	-1.575	-1.799	-1.888	-1.989	-2.068
		(0.009)	(0.020)	(0.013)	(0.016)	(0.016)	(0.022)
8	μ_{0-25}	-1.617	-1.558	-1.752	-1.534	-1.588	-1.528
		(0.018)	(0.032)	(0.016)	(0.017)	(0.013)	(0.020)
	μ_{25-50}	-1.435	-1.451	-1.658	-1.535	-1.615	-1.609
		(0.009)	(0.022)	(0.010)	(0.012)	(0.009)	(0.016)
	μ_{50-75}	-1.430	-1.432	-1.712	-1.619	-1.702	-1.707
		(0.007)	(0.017)	(0.008)	(0.011)	(0.009)	(0.015)
	μ_{75-100}	-1.523	-1.568	-1.942	-1.821	-1.950	-2.060
		(0.007)	(0.016)	(0.011)	(0.012)	(0.013)	(0.018)
9	μ_{0-25}	-0.869	-0.719	-1.079	-0.848	-0.774	-0.733
		(0.012)	(0.021)	(0.012)	(0.013)	(0.010)	(0.016)
	μ_{25-50}	-0.977	-0.817	-1.161	-0.997	-0.940	-0.906
		(0.008)	(0.019)	(0.008)	(0.010)	(0.009)	(0.014)
	μ_{50-75}	-1.049	-0.913	-1.233	-1.100	-1.062	-1.048
		(0.007)	(0.016)	(0.007)	(0.009)	(0.008)	(0.013)
	μ_{75-100}	-1.172	-1.096	-1.390	-1.304	-1.290	-1.320
		(0.006)	(0.013)	(0.008)	(0.010)	(0.009)	(0.013)
10	μ_{0-25}	-2.651	-2.726	-1.768	-1.847	-1.832	-1.879
		(0.045	0.116)	(0.018)	(0.028)	(0.023)	(0.042)
	μ_{25-50}	-1.647	-1.825	-1.536	-1.597	-1.609	-1.637
		(0.012)	(0.042)	(0.008)	(0.014)	(0.012)	(0.022)
	μ_{50-75}	-1.483	-1.591	-1.500	-1.555	-1.579	-1.625
		(0.008)	(0.025)	(0.007)	(0.011)	(0.009)	(0.018)
	μ_{75-100}	-1.424	-1.485	-1.562	-1.585	-1.624	-1.689
		(0.006)	(0.015)	(0.009)	(0.010)	(0.010)	(0.015)

5: CLOTHES, 6: HOUSING, 7: HEALTH, 8: MOBILITY, 9: EDUCATION, 10: OTHERS

Table 14: **Disposable income elasticities for energy goods and food:** Predicted values at the means of the 2008 household type specific total expenditure quartiles and at respective price means. Standard errors in parentheses are derived with the delta method.

Good		S0	S1	C0	C1	C2	C3
1	μ_{0-25}	0.253	0.244	0.268	0.274	0.277	0.259
		(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
	μ_{25-50}	0.320	0.289	0.327	0.326	0.324	0.305
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
	μ_{50-75}	0.371	0.328	0.368	0.362	0.353	0.334
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
	μ_{75-100}	0.446	0.398	0.415	0.398	0.379	0.353
		(0.004)	(0.005)	(0.007)	(0.006)	(0.007)	(0.009)
2	μ_{0-25}	0.272	0.282	0.296	0.333	0.336	0.339
		(0.003)	(0.004)	(0.003)	(0.005)	(0.005)	(0.006)
	μ_{25-50}	0.329	0.322	0.337	0.368	0.367	0.361
		(0.003)	(0.005)	(0.005)	(0.006)	(0.007)	(0.008)
	μ_{50-75}	0.367	0.357	0.359	0.386	0.381	0.371
		(0.004)	(0.005)	(0.007)	(0.008)	(0.009)	(0.011)
	μ_{75-100}	0.415	0.405	0.351	0.372	0.349	0.311
		(0.007)	(0.008	(0.015)	(0.015)	(0.016)	(0.019)
3	μ_{0-25}	0.435	0.468	0.458	0.400	0.450	0.475
		(0.006)	(0.009)	(0.005)	(0.005)	(0.005)	(0.007)
	μ_{25-50}	0.513	0.530	0.542	0.479	0.530	0.547
		(0.005)	(0.009)	(0.005)	(0.005)	(0.006)	(0.008)
	μ_{50-75}	0.570	0.583	0.604	0.529	0.570	0.590
		(0.005)	(0.009)	(0.006)	(0.006)	(0.007)	(0.009)
	μ_{75-100}	0.665	0.669	0.677	0.601	0.621	0.634
		(0.005)	(0.008)	(0.010)	(0.009)	(0.011)	(0.014)
4	μ_{0-25}	0.594	0.550	0.513	0.514	0.535	0.536
		(0.006)	(0.007)	(0.004)	(0.004)	(0.004)	(0.005)
	μ_{25-50}	0.641	0.597	0.552	0.555	0.571	0.579
		(0.005)	(0.006)	(0.003)	(0.004)	(0.004)	(0.004)
	μ_{50-75}	0.669	0.622	0.565	0.574	0.578	0.591
		(0.004)	(0.005)	(0.003)	(0.004)	(0.004)	(0.005)
	μ_{75-100}	0.688	0.669	0.550	0.564	0.557	0.550
		(0.004)	(0.004)	(0.007)	(0.007)	(0.008)	(0.011)

1: ELECTRICITY, 2: HEATING, 3: TRANSPORT, 4: FOOD

Table 15: **Allocation of variable identifiers:** 1993 data was transformed from monthly/yearly basis to a quarterly basis and 1993/1998 data was transformed from DM to euro basis.

	1993	1998	2003	2008
ELECTRICTY	ef705	ef770-ef772	ef258	ef251
HEATING	ef707, ef709, ef711, ef713, ef715, ef717-ef719	ef773-ef784	ef259-ef262	ef252-ef255
TRANSPORT	ef761-ef762, ef771-ef773	ef 810, ef814-ef818	ef299, ef305-ef308	ef300, ef306, ef308
FOOD	ef642-ef645	ef737-ef740, ef847-ef850	ef225-ef228, ef343, ef344	ef217-ef220, ef350, ef351
CLOTHES	ef664-ef699	ef741-ef750	ef230-ef242	ef222-ef234
HOUSING	ef702, ef704, ef738, ef739	ef751, ef763, ef766-ef769	ef245, ef247-ef249, ef252-ef255	ef237, ef239-242, ef245-ef248
HEALTH	ef740-ef754	ef798-ef804, ef853, ef854, ef857	ef280-ef291, ef346-ef350, ef354	ef279-ef286, ef288-ef292, ef353-ef358, ef364, ef365
MOBILITY	ef755-ef760, ef764, ef765, ef767, ef774, ef775	ef805-ef809, ef811, ef813, ef819-ef821	ef292-ef295, ef297, ef298, ef300, ef304, ef309-ef313	ef293-ef296, ef298, ef299, ef301, ef305, ef310-ef315
EDUCATION	ef777-ef808, ef811-ef814, ef824-ef827, ef 852, ef855	ef134, ef822-ef841, ef858	ef63, ef314-ef336, ef368	ef73, ef316-ef342, ef362, ef363, ef381
OTHERS	ef816-ef829, ef721-ef737, ef843-ef848	ef129, ef842, ef843, ef851, ef852, ef855, ef856,, ef859, ef860, ef866-ef870	ef58, ef337, ef338, ef345, ef351-ef353, ef355, ef357, ef363-ef367	ef68, ef343, ef344, ef352, ef359-ef361, ef366, ef369, ef375-ef380

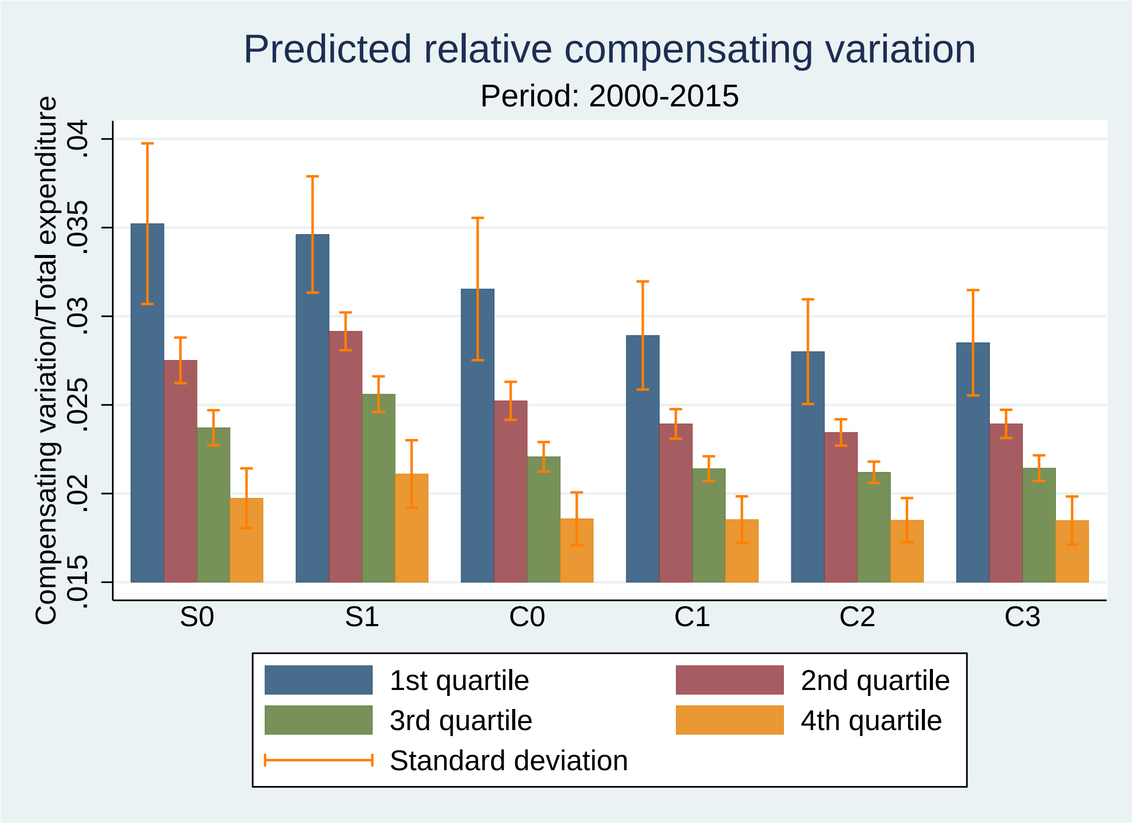

Figure 1: **Predicted compensating variation divided by total expenditure due to real price increases for electricity and heating fuels between 2000 and 2015**