

# **Essays on Energy Economics**

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## **Empirical Analyses Based on German Household Data**

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## List of Abbreviations

2M – twice median

ACER – Agency for the Cooperation of Energy Regulators

AIC – Akaike Information Criterion

AIDS – Almost Ideal Demand System

APC – Age Period Cohort

APCD – De-trended Age Period Cohort

APC-IE – Age Period Cohort Intrinsic Estimator

BIC – Bayesian Information Criterion

CFT – Car Fuels Tax

CO<sub>2</sub> – Carbon Dioxide

CV – Compensating Variation

DAIDS – Demographically-scaled Almost Ideal Demand System

DQUAIDS – Demographically-scaled Quadratic Almost Ideal Demand System

EEA – European Environment Agency

EEG – Renewable Energy Act

EKC – Environmental Kuznets Curve

ETR – Environmental Tax Reform

E.U. – European Union

EUR – euro

EV – Equivalent Variation

FIT – Feed-In-Tariffs

FGT – Foster, Greer, and Thorbecke

G.B. – Great Britain

HC – Head Count

IEA – International Energy Agency

IES – Income and Expenditure Survey

kWh – kilowatt hour

l – liter

LIHC – Low Income High Costs

MIS – Minimum Income Standard

NO<sub>x</sub> – Nitrogen Oxides

OECD – Organization for Economic Co-operation and Development

PIGLOG – Price-Independent Generalized Logarithmic

POTP – Post-Tax Total Prices

QUAIDS – Quadratic Almost Ideal Demand System

RES – Renewable Energy Sources

S – Scenario

S0 – Status quo/Initial scenario

SPI – Stone Price Indices

SH – Schleswig-Holstein

SO<sub>2</sub> – Sulfur Dioxide

t – ton

TPR – Ten Percent Rule

U.K. – United Kingdom

U.S. – United States

VAT – Value Added Tax



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## Motivation and contribution to literature

Recent literature in the field of energy economics has returned to investigating the household or the individual by implementing household's decision models. Household's decision models are useful for studying the effectiveness of energy and environmental policies. In particular, energy demand systems include behavioral responses of households and allow for welfare and environmental analyses of energy policy reforms. Such frameworks can help to find the groups which are overconsuming energy relative to the population as a whole so that they can be targeted with various policy measures in order to change their consumer behavior.

Demand systems have been widely applied in the context of residential energy demand in several countries and to explore different energy policy changes. Several studies have explored the effects of gasoline or electricity taxes using demand models. Namely, Dumagan and Mount (1992) were among the first to apply such framework and to show that carbon tax has regressive effect in the US i.e. the tax burden as share of income is larger proportion for the poor than for the rich households. Some years later, West and Williams III (2004) find gasoline tax to be regressive in the U.S., and Brännlund and Nordström (2004) also find carbon tax (on gasoline and electricity) to be regressive in Sweden. Tiezzi (2005) finds that carbon tax burden is progressively distributed across Italian households, but she uses total expenditures instead of income as the ordering criterion. Beznoska (2014) considers an eco-tax on gasoline and diesel, and finds that the regressively of the gasoline tax to be lower than the regressively of taxes on electricity in Germany. Gahvari and Tsang (2011) study the effects of electricity taxes in the U.S. and prove that an energy tax on electricity is detrimental for consumer welfare, despite its environmental benefits. While many papers have considered the distribution or welfare impacts, only few papers have dealt with the environmental effects of energy taxes (for example: Brännlund and Nordström (2007)), even fewer that deal with the effects of energy taxes on poverty, and almost none which have considered all of those effects in a consistent framework. The paper of Klauss (2016) is unique in the sense that it estimates how an energy price change influences poverty. The author finds that gas price increase leads to higher poverty levels among Armenian households but he does not consider the separate effects of energy taxes on poverty nor does he consider behavioral responses. Other studies have applied demand system to estimate price and income elasticities without conducting tax simulations (see for instance Filipinni (1995), Kohn and Missong (2003), and Kratena and Wüger (2009) among others). None of these

studies have addressed the trade-offs between emissions and inequality, and emissions and consumer welfare. Nor have they studied energy poverty or the effects of energy taxes or surcharges on income poverty and energy poverty.

The year of birth can influence life opportunities and also consumer or environmental habits of the individual. However, the role of birth cohorts in explaining energy consumption and energy related residential emissions has not been widely researched. The few studies which have addressed this question include Chancel (2014), Segall (2013), Sánchez-Peña (2013), and Aguiar and Hurst (2013). Chancel (2014) finds that the French households with leaders born between 1930 and 1955 are the highest CO<sub>2</sub> emitters. The results of Sánchez-Peña (2013) confirm that the cohorts born 1923–1968 consume more energy (and emit more CO<sub>2</sub>) than the average household in Mexico. Both Aguiar and Hurst (2013) and Segall (2013) find significant cohort effects in explaining utilities consumption or energy budget allocation in the U.S. However, all of those studies have only considered the cohort effects of the household's leader and none has examined the birth cohort effects of other household's members.

The dissertation contributes to the existing literature in several ways. To begin with, Germany is at the center of the analyses of this dissertation. Germany is particularly interesting case to analyse since it is one of the EU countries which prioritize both distributive justice and environmental protection in their policy agenda. In this country, energy taxes and surcharges are imposed with the goal to restrict energy consumption and to finance green energy, and energy prices are among the highest in the EU. Secondly, this dissertation uses very recent and very detailed data on energy expenditures of German households. The dataset preparation was complex task since demand systems impose strict requirements for the data: waves must be comparable, consistent, of high quality, and randomly drawn. The final dataset is very extensive and covers around 170,000 (220,000) German households in 4 (5) cross sections between 1993 and 2008 (2013). Most importantly, I provide a consistent framework in which consumer welfare, income distribution, environmental, and poverty effects of different energy policy reforms can be measured. The demand system itself is quadratic, demographically scaled, corrects for potential endogeneity, and encompasses improved price variation. The tax simulations allow for studying the effects of changes in car fuels and (or) electricity price on the dimensions mentioned above. In addition, energy related emissions are calculated and the following emissions' determinants are considered: income, area of residence, age, and birth cohort. A significant gap in the literature is filled by considering the birth cohort effects of other household's members in addition to the households' leader.

As mentioned, German households are faced with relatively high energy prices, which are mainly caused by increasing taxes and surcharges. The Ecological Tax Reform-ETR in Germany (1998–2003) led to increases in the existing taxes on fossil fuels and an introduction of tax on electricity. Moreover, in 2007 the value-added tax rate was increased from 16 to 19 percent. By 2008, energy and other taxes constituted 59 percent of the price of car fuels (gasoline and diesel). Furthermore, the electricity price has been also growing due to increases in the yearly adjusted surcharge for renewable energy (Renewable Energy Act surcharge or EEG-Umlage<sup>1</sup>), which has grown from 0.2 euro cents per kWh in 2000 to 6.35 euro cents per kWh of electricity in 2016. In 2013 energy and other taxes and surcharges were amounting to 45 percent of the electricity price in Germany and it was the second highest in Europe.

Three essays which deal with households' energy demand and CO<sub>2</sub> emissions are part of the dissertation. The first paper examines the environmental, distributive, and welfare effects of the car fuels tax. Higher car fuels taxes could potentially lead to lower car fuels' consumption and lower CO<sub>2</sub> emissions but can increase inequality in the post-tax income distribution and decrease consumer welfare. The second paper scrutinizes the effects of the EEG surcharge, which was introduced in Germany as means to finance renewable energy production, on energy poverty, income poverty, and CO<sub>2</sub> emissions. Abolishing of the EEG surcharge is expected to lower the tax burdens of the low income households and hence decrease both income poverty and energy poverty. Both chapters can provide policy makers with empirical evidence about how to weight environmental and inequality/poverty concerns, and point out potential targets groups (of households) that can lead to largest energy consumption savings or largest energy poverty decreases. The third paper investigates the determinant of energy related emissions' inequalities among three dimensions: income, area of residence, and birth cohort. Again, this kind of analyses will help to find the determinants of CO<sub>2</sub> emissions, and to identify the groups of the population that should be targeted in order to decrease the inequalities and emissions altogether.

The first paper is titled "On the Emissions–Inequality and Emissions–Welfare Trade-offs in Energy Taxation: Evidence on the German Car Fuels Tax" and examines how changes in the car fuels tax affect households in Germany. The price elasticity of demand for car fuels is critical for the size of the environmental effect and the shape of the Engel curve is crucial for the welfare and distributive effects. Moreover, analyzing the determinants of demand for energy goods is important especially since residential energy consumption has recently increased in Europe despite higher energy taxes (The World Bank, 2013). For that purpose, a

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<sup>1</sup> I refer to it as the EEG surcharge throughout the dissertation.

Demographically-scaled Quadratic Almost Ideal Demand System (DQUAIDS) is estimated using German household level data for the years 1993–2008 (Ray (1983), Banks et al. (1997), and Blacklow et al. (2010)). The parameter estimates are consistent, statistically significant, and allow for calculation of income and price elasticities: car fuels are necessity good and demand is price inelastic ( $-0.203$ ). The several tax simulations reveal the existence of the emissions inequality and emissions welfare trade-offs in energy taxation: if the car fuels tax increases, the CO<sub>2</sub> emissions decrease but the income inequality and the welfare loss both increase.

Even though many papers have investigated the impact of energy taxes on the income distribution or on the energy related emissions, this study builds on those results in a number of dimensions. First of all, the study provides a consistent framework (which updates previous ones because it includes corrections for endogeneity and increased price variation) in which welfare, environmental, and inequality effects of an energy tax change can be measured. Secondly, the paper graphically scrutinizes the trade-offs between emissions, inequality, and welfare which most papers have overlooked. By addressing those trade-offs, we ensure that no groups in the German population will be harmed more than others due to a policy reform.

My contributions to this co-authored paper are described as follows. I have assembled and prepared all the relevant data: household income and expenditure micro data (Income and Expenditure Survey); time series of commodity prices; information on changes in energy and environmental policies. Moreover, I coded the STATA program files necessary for the econometric analyses (estimation of demographically scaled quadratic demand systems). Furthermore, I compiled the programs for executing the tax simulations (using the demand system estimates) in order to evaluate the effect of different levels of the car fuels tax on the three dimensions investigated in the study: (1) energy consumption; (2) CO<sub>2</sub> emissions levels; (3) distributional effects-consumer welfare and income inequality.

The second paper, entitled “How Electricity Prices Alter Poverty and CO<sub>2</sub> Emissions – The Case of Germany” deals with the effects of changes in the Renewable Energy Act Surcharge (EEG-Umlage) on energy poverty and residential electricity related emissions. By examining energy poverty, how it evolved over time, how it is related with income poverty, which are its determinants, and how energy taxes influence it, I have tackled a crucial topic in the face of growing energy costs and income poverty. Energy poverty (the lack of adequate energy services) represents a growing concern in developed countries with colder climates since can lead to health problems and rationing of other household budgets. Energy poverty is found to have increased in Germany between 1993 and 2013, and is higher among single



parents, unemployed, and households living in rural areas. Income poverty is found to be significant factor behind of the probability of being energy poor. Electricity demand is found to be price inelastic and a decrease in the electricity price (abolishing of the EEG surcharge and slight increase in the car fuels tax) is expected to be beneficial for households – by lowering energy poverty and electricity tax/surcharge burdens – while increasing emissions by a small amount and keeping government tax revenues almost constant.

This second paper addresses the gap in the literature by using a very recent data from 2013 for Germany. Moreover, it captures energy poverty in this country and analyses in detail the determinants of energy poverty. In addition, the effects of changes in the EEG surcharge on income and energy poverty, and also CO<sub>2</sub> emissions are investigated, which has not been done before. Furthermore, I identify a positive relationship between higher EEG surcharge and energy poverty indicating that an increase in the surcharge will always increase poverty and hurt the most vulnerable groups of households/individuals, such as low income households or single parents.

The third paper has the following title: “Inter- and Intra-generational Emissions Inequality in Germany: Empirical Analyses”. The main research question is to investigate the effect of income, area of residence, and birth cohort on residential energy related emissions. I identify: a) income related emissions inequalities, with low income households emitting much less CO<sub>2</sub> than high income households; b) area of residence emissions inequalities, with rural households having much higher emissions than urban households; and c) birth cohort emissions inequalities, with cohorts 1933–1963 being the highest CO<sub>2</sub> emitters. A De-trended Age Period Cohort (APCD) model allows for separation of the effects of birth cohort from the effects of age, income, and other explanatory variables, while it solves the identification problems inherent to Age Period Cohort (APC) models. The results from the APCD confirm that having either a household’s leader or household’s member from the cohorts 1943–1968 increases energy related emissions by more than the cohorts born before 1943 or after 1968.

The last paper has several contributions to the existing literature on residential energy related emissions. To start with, it calculates electricity, gas, and car fuels related emissions of German households using expenditure data, prices, and emissions factors. Second of all, the paper investigates the descriptive evidence of birth cohort related inequalities by carefully analyzing the demographic and economic characteristics of households according to the birth cohort of the household’s leader. Crucially, the APCD model examines the effects of birth cohorts of other household’s members on CO<sub>2</sub> emissions, which none of the previous studies have considered.



# Chapter 1

## On the Emissions–Inequality and Emissions–Welfare Trade-offs in Energy Taxation: Evidence on the German Car Fuels Tax ♦

### 1.1 Introduction

Faced with climate change and threats to environmental sustainability, many countries, particularly those in Europe, are redesigning and enhancing their environmental policies to reduce anthropogenic carbon dioxide emissions (World Nuclear Association, 2011). The introduction and increase of energy taxes has the aim to limit energy consumption, and special focus has been put on the households sector. Despite these changes, fossil fuels consumption, an important determining factor of CO<sub>2</sub> emissions, has increased in recent years (The World Bank, 2015). This apparently paradoxical situation calls for thorough investigation of the determinants of demand for car fuels and other energy goods by the households.

Our study deals with the environmental, distributive, and welfare effects of the car fuels tax in Germany, a country that places high priority on both environmental protection (International Energy Agency, 2007) and distributive justice. The car fuels tax is charged as a fixed monetary amount per liter and serves as an instrument to reduce households' vehicle emissions, the largest source of CO<sub>2</sub> emissions after the industrial sector (International Energy Agency, 2007). Crucial for the size of the environmental effect is the price elasticity of demand for car fuels: The more elastic the demand, the larger the environmental effect in terms of CO<sub>2</sub> emissions reductions. Crucial for the distributive and welfare effects is the shape of the Engel curve: If the expenditure (share) for fuels decreases in income, then households with a greater ability to pay will pay lower taxes relative to income and also incur a smaller relative reduction in welfare.

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♦ This chapter is based on joint work with Prof. Dr. Carsten Schröder from DIW Berlin, see Nikodinoska and Schröder (2016) <https://doi.org/10.1016/j.reseneeco.2016.03.001>.

The potential emissions–inequality and emissions–welfare trade-offs in energy tax policy have become an important issue in political and academic debate.<sup>2</sup> As pointed out by Baumol and Oates (1988), by ignoring these trade-offs, “we may either unintentionally harm certain groups in society or, alternatively, undermine the program politically” (p. 235). Most studies investigate the trade-offs in a traditional tax incidence framework, i.e., by quantifying average tax burdens at different points of the income distributions. Only a few studies, among them Jorgenson et al. (1992), Oladosu and Rose (2007), Araar et al. (2011), and Grösche and Schröder (2014a),<sup>3</sup> provide a detailed examination of the redistributive or welfare effects.

We suggest and implement a two-step procedure for a systematic assessment of the potential emissions–inequality and emissions–welfare trade-offs using the German car fuels tax as an example. First, we estimate a demographic specification of the Quadratic Almost Ideal Demand System, which describes how household demands respond to price and income changes. The estimated price elasticities reveal how household demands respond to variations of the car fuels tax. Second, based on the demand system estimates we quantify the following three outcomes of interest for various tax levels: (a) emissions; (b) inequality, by means of a comprehensive set of inequality indices; and (c) household welfare, by means of equivalent/compensating variations and tax burdens over the quantiles of the income distribution. In sum, the proposed two-step procedure gives answers to the following type of question: “Suppose the car fuels tax increases by five percent: How does the tax increase change emissions, inequality, and households’ economic welfare?” The answers are visualized by means of trade-off curves that depict how the three outcomes vary with the tax rate.

Each separate ingredient of the proposed procedure is well-known. However, the combination of the tools provides a comprehensive picture of the intensity of emissions–inequality and emissions–welfare trade-offs that most previous literature has been lacking and that can be applied fruitfully in many other settings. The procedure can also be embedded in a broader framework that combines the household-micro level perspective with multisector general equilibrium techniques as presented in Araar et al. (2011).

To our knowledge, we are the first to implement such a detailed trade-off analyses. This study focuses on Germany, a country where environmental sustainability is highly prioritized on the policy agenda. Our estimates indicate the presence of an emissions–inequality trade-

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<sup>2</sup> See Pearson and Smith (1991), Wier et al. (2005), Scott and Eakins (2004), Oladosu and Rose (2007), Callan et al. (2008), Fullerton (2009), Grainger and Kolstad (2009), Jacobsen et al. (2003), or Grösche and Schröder (2014a).

<sup>3</sup> Other studies for Germany include Bach et al. (2002) and Sterner (2012), but they provide less detailed analyses.

off: As an example, increasing the original tax rate by 50 percent (from 0.606 euros/liter to 0.909 euros/liter) reduces CO<sub>2</sub> emissions by about 8.2 percent, and increases the Gini index from the distribution of equivalent disposable income by about 0.2 percent. This is because the associated tax burden relative to disposable income decreases in household needs-adjusted (equivalent) income.<sup>4</sup>

At first glance, the redistributive effect and the intensity of the emissions–inequality trade-off may appear small. The key reason for the small magnitude of the effect is the small share of car-fuel expenditures in household budgets, about 3.75 percent. Our basic interest, however, is in the sign of the redistributive effect, which turns out to be regressive: Several of the environmental taxes in Germany (electricity taxes or taxes on heating fuels) work in a comparable manner to the car fuels tax and thus add to the regressive effect.<sup>5</sup> According to a simulation analyses for various OECD countries, Flues and Thomas (2015) conclude that also taxes on heating fuels and, particularly, electricity are “clearly regressive” (p. 40). These environmental taxes thus add to the regressive effect of fuels taxes measured in the present study. Our analyses also reveals an emissions–welfare trade-off. A 50 percent tax increase amounts to an annual welfare loss in terms of equivalent variation by 283 euros on average, and by 148 euros for the first decile, a sizeable amount for low-income households.

The paper is structured as follows. Section 1.2 provides a literature review. Section 1.3 describes the data and Section 1.4 the quantitative methods. Section 1.5 provides the demand system estimates and Section 1.6 the results from the policy analyses. Section 1.7 provides sensitivity analyses, and Section 1.8 presents the concluding remarks.

## 1.2 Literature review

Several studies have investigated environmental taxes and their impact on households’ energy consumption, welfare or emissions levels. From a technical perspective, the studies can be classified according to three criteria: (a) static one-period vs. dynamic multi-period framework; (b) partial analyses of a single sector vs. total analyses with inter-sector linkages; (c) abstraction from or explicit modeling of behavioral responses.

Because the international literature is so extensive, we confine our review to selected works with a framework similar to ours: a one-period partial analyses of the household sector

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<sup>4</sup> Equivalent income is derived by dividing household income by the modified OECD equivalence scale (see Section 1.4.3 for details).

<sup>5</sup> For an assessment of the feed-in tariff induced redistributive effects in Germany’s electricity sector, see Grösche and Schröder (2014a).

with consideration of behavioral responses. One such study is Brännlund and Nordström (2004) using Swedish data. They use the Quadratic Almost Ideal Demand System (QUAIDS) and tax simulations to analyse the consumer responses and welfare effects of a CO<sub>2</sub> tax. The authors find that doubling of the CO<sub>2</sub> tax lowers petrol demand by ten percent.<sup>6</sup> Further, using the compensating variation as assessment criterion, the authors show that low-income households carry a larger share of the tax burden relative to their income (0.55 percent) in comparison to high-income households (0.33 percent), meaning that the tax is regressive.

Studies for the US include Dumagan and Mount (1992) and West and Williams III (2004). Using a generalized logit demand system, Dumagan and Mount (1992) investigate the welfare effect of carbon tax in the US and find evidence of a regressive effect. West and Williams III (2004) use a general demand system to quantify welfare changes and redistributive effects (but not the environmental effect) of the US gasoline tax. They find a regressive effect of the carbon tax (except in the case when the revenue is used to fund lump-sum transfers).

Tiezzi (2005) estimates an AIDS for Italy in order to explore the distributional and welfare effects of a carbon tax. She finds that the welfare loss from an introduction of the carbon tax is non-negligible: 2.32 billion euros over four years. Contrary to many other studies, she finds that the tax burden is progressively distributed across Italian households, but she uses total monthly expenditures as opposed to income as the ordering criterion.

Kohn and Missong (2003) and Beznoska (2014) have estimated demand systems for West Germany and Germany, respectively. Kohn and Missong (2003) estimate both linear and quadratic expenditure systems (both exclude demographic scaling) composed of several nondurables categories. Their estimates for the income elasticities reveal that food and shelter (which includes energy) are necessity goods while mobility (which includes car fuels) is a luxury good. Price elasticities reveal that food, shelter, and mobility are relatively price inelastic. Their study does not investigate the effects on any potential tax policy changes. Beznoska (2014) estimates a demand system of energy, mobility, and leisure using a non-scaled AIDS. His results demonstrate substitutional character between mobility (consisting of diesel, gasoline, and public transport) and heating and between mobility and leisure. The author conducts welfare and distributional analyses of an eco-tax on gasoline and diesel and finds that the regressivity of the gasoline tax appears to be lower than the regressivity of other indirect taxes, including energy goods like electricity. His results show that static tax cut

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<sup>6</sup> In a later study, Brännlund et al. (2007) find that in order to keep CO<sub>2</sub> emissions at their initial levels (to neutralize the rebound effect), CO<sub>2</sub> tax should be raised by 130 percent.

of 15 cents per liter shows a progressive effect up to the third decile of income (seventh decile of expenditures), which is followed by a regressive effect.

This study contributes to the existing literature in several ways. Most importantly, we suggest a coherent framework to study how a car fuels tax affects a set of outcomes: (a) environmental effects – evaluated by CO<sub>2</sub> emissions; (b) redistributive effects – by a comprehensive set of inequality indices; (c) welfare implications – by means of the compensating and equivalent variation and also tax burdens over the deciles of the income distribution. In particular, this framework allows a systematic assessment of the potential trade-offs between emission reductions and inequality increases, and between emissions reductions and welfare. Further, our analyses relies on thorough demand estimations: We have estimated a demographic specification of the quadratic demand system, which takes into account differences in households' size and behavioral responses and corrects for the potential endogeneity of total expenditures. Finally, we are the first to present such a detailed analyses for Germany, a country which is in the focus of large number of studies in the area of environmental economics.

### **1.3 Data and data preparation**

We use two data sources provided by the German Federal Statistical Office. The first is the German Income and Expenditure Survey (IES), i.e., representative micro-level household income and expenditure data. The second source is consumer price data for various expenditure categories.

#### **1.3.1 German Income and Expenditure Survey**

The German IES is a cross-sectional household micro database, collected once every five years. Each wave includes a quota sample of about 60,000 German households, for which frequency weights are provided to ensure representativeness (for further information on the data, see Bönke et al., 2013, and references therein). The variable spectrum of the data is broad, including socio-economic and demographic characteristics, income and other revenues, paid taxes and contributions, inventories, wealth (accumulation), et cetera. Most importantly for our purposes, IES is the single German database providing in-depth information on all kinds of household expenditures – from food and electrical appliances to cars and car fuels.

From the most recent IES waves 1993 to 2008, we have generated a pooled database with time-consistent information. Details on the pooling strategy can be found in Bönke et al. (2013). Most importantly, we have converted all expenditures to yearly amounts in euros and implemented a symmetric trimming of disposable incomes (lowest and highest percentile of the distribution). Furthermore, households with extreme ratios of total expenditures relative to disposable income are not included in the sample.<sup>7</sup>

The final working sample includes 169,486 households in four cross-sections. The following IES variables are used in the empirical analyses: total expenditures; expenditures for food, electricity, other fuels, and car fuels;<sup>8</sup> disposable income; number and age of household members; population size of the place of residence; and frequency weights.

The core variable for the analyses that follows is expenditure on car fuels. It can be derived from the original IES waves by combining a set of variables, identified by a uniform short notation “ef” (German abbreviation for an identifier) and a serial number. For 1993, expenditure on car fuels is the sum of ef761, ef762, and ef763. For 1998–2008, it is ef810, ef299, and ef300 respectively.<sup>9</sup> Unfortunately, separate data on gasoline and diesel fuel is available only for 1993, making it impossible to separate the two fuels in the empirical analyses. For this reason we cannot control for substitutability between gasoline and diesel, which is taxed-favored by many governments in Europe (exceptions are Switzerland and the United Kingdom). Hence, we also cannot distinguish emissions of carbon and harmful air pollutants from using gasoline and diesel,<sup>10</sup> although emission costs are known to be higher for diesel (see Harding, 2014). For the inequality analyses the inability to distinguish gasoline and diesel means that we cannot separate the distributional effects of taxes on gasoline and diesel.<sup>11</sup> Table 1.6 in the Appendix provides details on the construction of all the expenditure variables used in our empirical analyses. Summary statistics of these variables as well as others are provided in Tables 1.7–1.10 in the Appendix.

Figure 1.1 represents the development of the expenditure shares between 1993 and 2008. The expenditure share of a good is its related expenditure divided by total household expenditures. Each panel in Figure 1.1 shows the tenth, fiftieth (median), and ninetieth percentile of the expenditure share for each good. The expenditure share of car fuels increased

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<sup>7</sup> Households belonging to the lowest and highest percentiles of the distribution of total expenditures relative to disposable income were excluded from the sample.

<sup>8</sup> The choice of the expenditure categories follows Brännlund et al. (2007).

<sup>9</sup> For further details about the original IES variables, please refer to Table 1.6 in the Appendix.

<sup>10</sup> In this study, the emissions per liter of car fuels are also derived by weighting the carbon emissions content of gasoline and diesel.

<sup>11</sup> According to Flues and Thomas (2015, p. 25) taxing diesel higher usually hits high-income households harder than low-income households.



steadily over the period under consideration. The increasing expenditure share of car fuels reflects the increasing fuel prices during the period and less changes in demand.<sup>12</sup> The price increases are due to both increasing energy taxes on car fuels (see Section 1.4.2 for details) and prices of crude oil. The question of whether increases in oil prices are immediately and fully passed-through to retail fuel prices in Germany has been widely researched. E.g., the German Federal Statistical Office in their 2015 report on “Prices- Data on Energy Price Trends” conclude that the development of both gasoline and diesel price strongly depends on the dynamics of crude oil price on the world markets. The second driver in Germany is energy taxes (see Table 1.1 in Section 1.4.2 for further details).

Figure 1.2 shows the relationship between the expenditure shares and disposable income. The expenditure share of car fuels displays a nonlinear relationship with income: For the households in the first income decile it is 0.023; it increases to around 0.045 for the sixth and seventh deciles; and then decreases slightly to 0.041 for the tenth decile. The expenditure share of other fuels is also decreasing with disposable income. The share of food in total expenditures is highest (0.171) for the households belonging to the lowest disposable income deciles and decreases with income; for the richest households it is 0.125. While for the poorest households, electricity makes up 3.5 percent of their total expenditures, for the richest households it is only 2.2 percent. In contrast to all the other expenditure shares, the share of other goods is increasing with disposable income, indicating that as households become richer, they can afford more leisure, travel, culture, education, et cetera.

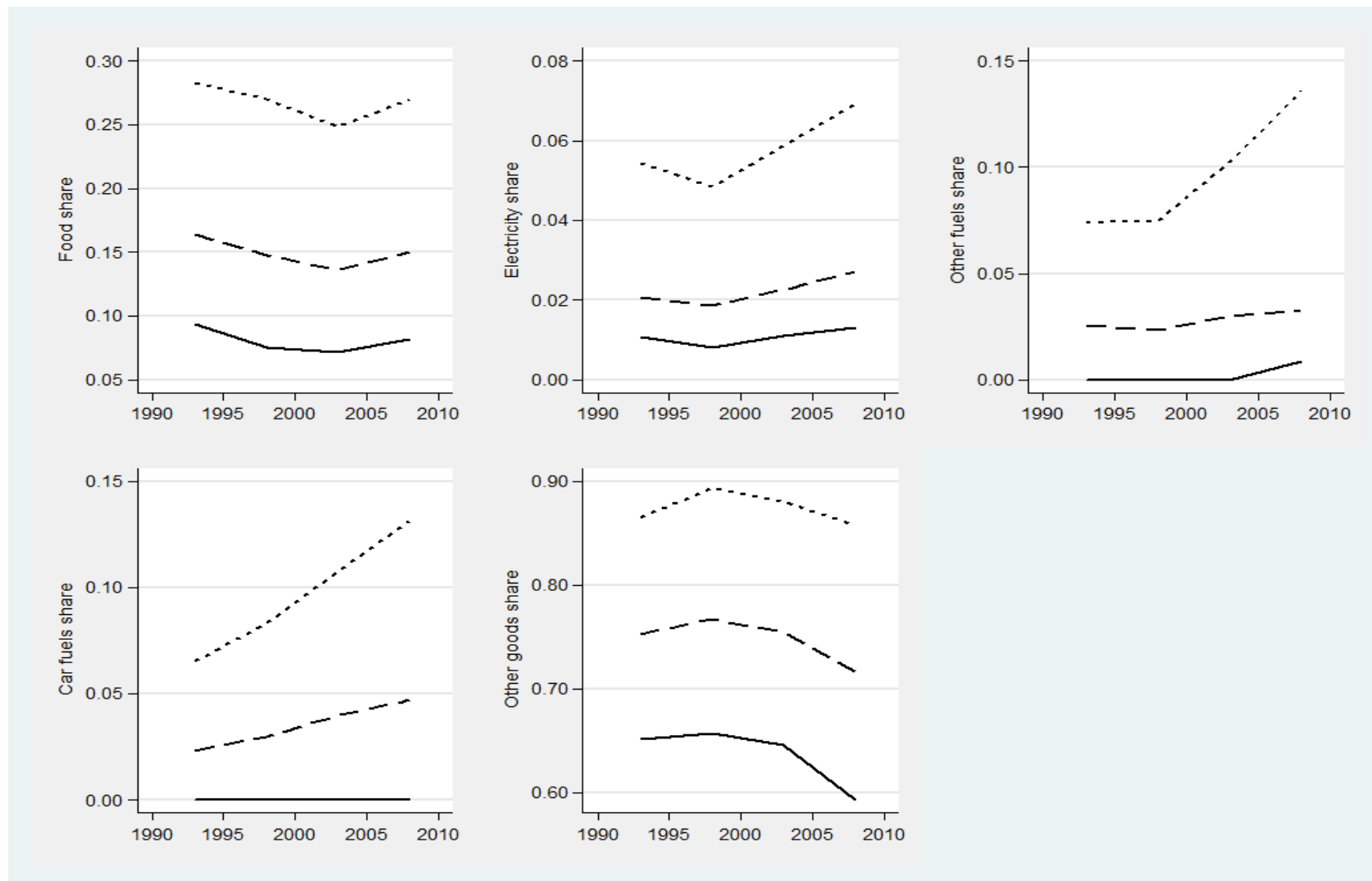
Figure 1.5 in the Appendix provides the kernel density functions for the expenditure shares by household type for 2008. For other fuels and car fuels, a substantial fraction of households do not seem to consume the goods as they have no related expenditures. The densities also indicate some marked differences across household types: In particular, the expenditure shares for food and car fuels increase with household size, whereas the opposite holds for other goods. Densities for food and electricity indicate that both goods have characteristics of basic goods: Basically all households report positive expenditure shares.<sup>13</sup>

### 1.3.2 Consumer prices

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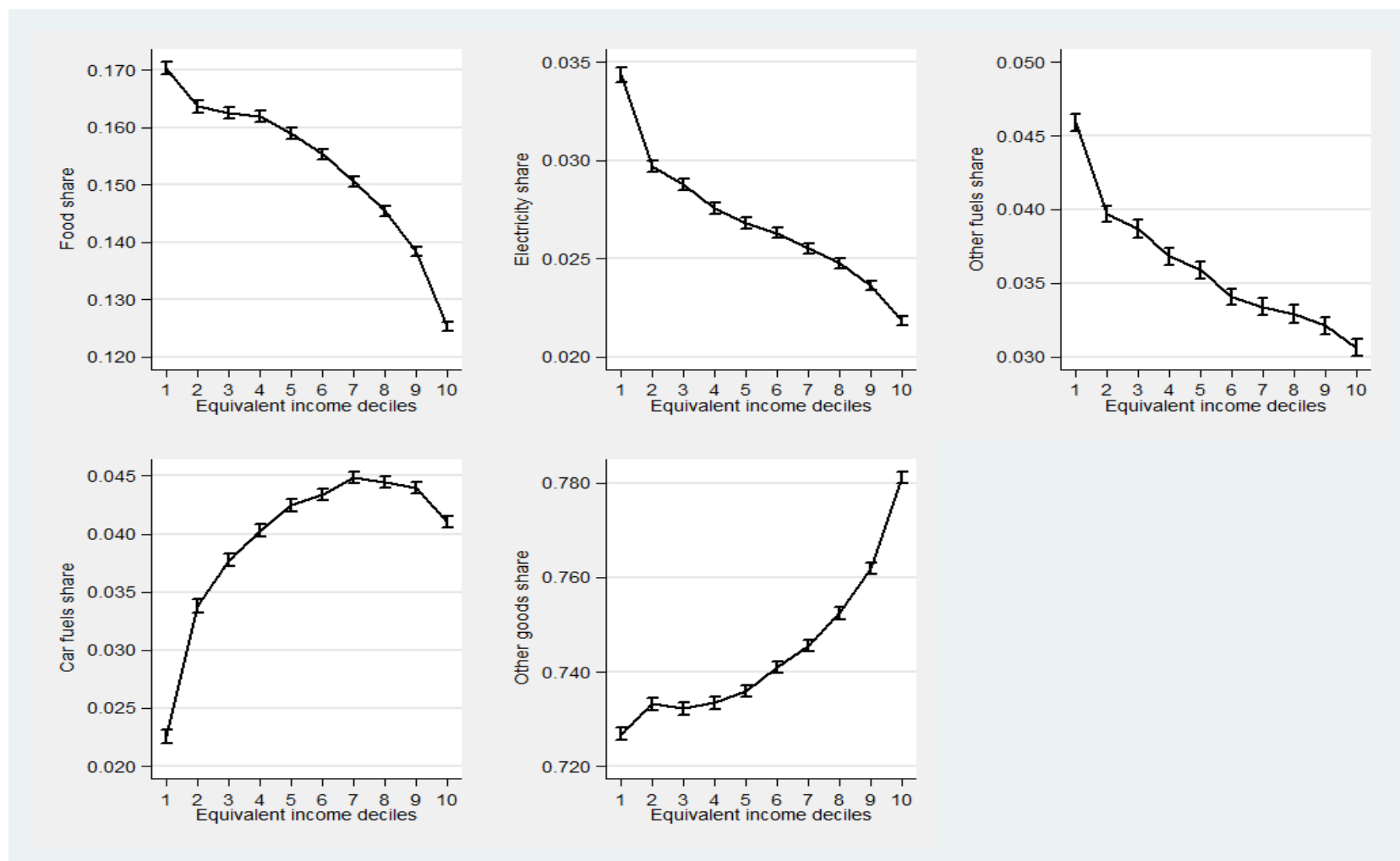
<sup>12</sup> Between 1993 and 1998, demand increased by around 13.5 percent for the average German household, decreased by about 7 percent up to 2003,0 and by another 12.4 percent up to 2008.

<sup>13</sup> The small fraction of households with expenditure shares of zero for electricity can be explained by particular social security instruments that step in once households cannot afford to pay their electricity bills.



**Figure 1.1** Development of expenditure shares over time

*Note.* Median values (dashed line) of expenditure shares and tenth (solid line) and ninetieth (dotted line) percentile are given. Database is IES, 1993–2008.



**Figure 1. 2 Expenditure shares and income**

Note. Average values of variables and lower and upper bound of 95 percent confidence intervals are presented. Database is IES 2008.

Because the German Federal Statistical Office is responsible for collecting the IES data and computing consumer prices for various goods, we find the same categorization of consumption aggregates in both data sources. From the consumer prices and household expenditure data, we derive Stone Price Indices (SPI) for three aggregated expenditure categories: food, other fuels, and other goods. As car fuels and electricity are not composed of any subcategories, we take the price indices as provided by the statistical office. The SPIs reflect differences in consumption patterns across household units. To derive the SPIs, we follow the approach outlined in Hoderlein and Mihaleva (2008). Let  $a = 1, \dots, A$  denote the different expenditure categories. An expenditure category can encompass several subcategories of expenditures,  $a_1, \dots, a_s$ . The corresponding prices are  $p_{a_1}, \dots, p_{a_s}$ . The expenditure share of an expenditure category  $a$  for household  $h$  in period  $t$ ,  $w_{a,h,t}$ , is defined as,  $w_{a,h,t} = x_{a,h,t} / \sum_a x_{a,h,t}$ , with  $x_{a,h,t}$  denoting nominal expenditures. The SPI for category  $a$  is:

$$P_{a,h,t} = \frac{1}{k} \prod_{a_s} \left( \frac{p_{a_s}}{w_{a_s,h,t}} \right)^{w_{a_s,h,t}} \quad (1.1)$$

with  $k = \prod_{a_s} (\bar{w}_{a_s,t})^{-\bar{w}_{a_s,t}}$ , and with  $\bar{w}_{a_s,t}$  denoting the expenditure share of the reference household in period  $t$ . A household with average budget shares is taken as the reference household. Finally, the prices for each category are divided by the lowest price in the base period (1993).

Summary statistics of prices are provided in Tables 1.7–1.10 in the Appendix. The price of car fuels increased over time during the period under observation; the mean price index was 1.552 in 2008, which represents 83 percent increase from the price in 1993. Thus, the increase in car fuel expenditures over the period can be attributed largely to price increases but also to changes in the quantity of fuels consumed.

## 1.4 Estimation strategy and policy evaluation criteria

### 1.4.1 Demographically-Scaled Quadratic Almost Ideal Demand System

There exists a wide range of demand systems. Our analyses builds on a Quadratic Almost Ideal Demand System (DQUAIDS). It allows for the modelling of household demographics within the QAIDS framework, and incorporates the well-known AIDS as a

nested model.<sup>14</sup> Demand systems are an exceptionally useful tool for (ex-ante) evaluation of policy reforms as they describe consumer choices in a consistent framework that secures basic economic assumptions. That is, estimates are consistent with the household budget constraints, satisfy the axioms of order, and aggregate over consumers (see Banks et al., 1997). Most importantly, the demand system estimation takes into account behavioral responses of the households, and should, in practice, match the patterns of observed consumer behavior and at the same time be consistent with consumer theory (see Banks et al., 1997).

The motivation for applying the DQUAIDS is threefold. First, compared to the linear, the quadratic specification allows for more flexibility and budget shares which are non-linear in log of total expenditures. The QUAIDS model was proven to be more flexible and superior to the AIDS in several empirical cases.<sup>15</sup> Secondly, the QUAIDS is shown to provide more precise valuations of welfare changes in comparison to the AIDS.<sup>16</sup> Third, the quadratic expenditure term allow for goods to be necessities at specific expenditure levels and luxuries at others. Finally, like the AIDS, the demographic version of QUAIDS allows the incorporation of demographic variables.<sup>17</sup>

A detailed description of the DQUAIDS used in the present study can be found in Banks et al. (1997), Ray (1983), Blacklow et al. (2010), and Poi (2012). Here we focus on the central equations. In order to ease notation, household and time period subscripts are suppressed. The estimable demand system takes the following form:

$$\begin{aligned}
 w_i = & \alpha_i + \sum_{j=1}^n \gamma_{ij} \ln(p_j) + \left( \beta_i + \sum_{s=1}^t \theta_{is} z_s \right) \\
 & * \left( \ln(m) - \ln(a(p)) - \ln \left( 1 + \sum_{s=1}^t \rho_s z_s \right) \right) + \left( \frac{\lambda_i}{(b(p)c(p, z))} \right) \\
 & * \left\{ \left( \ln(m) - \ln(a(p)) - \ln \left( 1 + \sum_{s=1}^t \rho_s z_s \right) \right) \right\}^2 + u_i
 \end{aligned} \tag{1.2}$$

with  $w_i$  denoting the expenditure share of commodity  $i = 1, \dots, n$  in total expenditures  $m$ . The variable  $p_j$  denotes the price of good  $j$ , and  $a(p)$  the subsistence level. The variable  $z_s$

<sup>14</sup> See Deaton and Muellbauer (1980).

<sup>15</sup> See Banks et al. (1997) for the UK, Kohn and Missong (2003) for Germany, and Betti (2000) for Italy.

<sup>16</sup> Gahvari and Tsang (2011) find AIDS to overestimate welfare losses ( $EV$ ), and the bias increases with income.

<sup>17</sup> Blow (2003) argues that household's composition affects expenditures allocation due to different needs of members and economies of scale.

describes the demographic characteristic,  $s$ ,<sup>18</sup> with  $s = 1, \dots, t$ . The bliss level is  $b(p)$ , and  $c(p, z)$  is a Cobb-Douglas price aggregator.<sup>19</sup>

Accordingly, the parameters to be estimated are  $\alpha_i, \beta_i, \gamma_{ij}, \rho_i, \theta_i, \lambda_i$ , with  $\alpha_0$  set at the lowest level of natural logarithm of total expenditures in the base year (1993). Several restrictions are imposed on the parameters in order to ensure adding up of the budget constraint, homogeneity of degree zero, and Slutsky symmetry, summarized in equation (1.3):

$$\sum_i \alpha_i = 1; \quad \sum_i \beta_i = 0; \quad \sum_i \lambda_i = 0; \quad \sum_k \gamma_{kj} = 0; \quad \sum_i \theta_{i1} = \sum_i \theta_{i2} = 0. \quad (1.3)$$

The DQUAIDS can be tested against nested models including the QUAIDS and the AIDS. All results are provided in Section 1.5.

### 1.4.2 The car fuels tax

In Germany, two taxes are levied on top of the producer price of car fuels: the car fuels tax and the value-added tax. The car fuels tax is a quantity tax charged per liter and it differs between gasoline and diesel fuel. The tax base of the value-added tax is the fuel price per liter including the car fuels taxes. Hence, for our period of investigation, 2008, the end consumer price of car fuels takes the form:<sup>20</sup>

$$p_f = (p_{im,f} + CM_f + T_f) * (1 + VAT) \quad (1.4)$$

where  $p_f$  denotes the consumer price for fuel of type  $f$ , gasoline or diesel. The import price is  $p_{im,f}$  (in 2008: 0.525 euros/liter gasoline and 0.650 euros/liter diesel);  $CM_f$  denotes the contribution margins (this part covers the expenses of mineral-oil companies and their profits plus costs of the emergency storage fund);  $T_f$  is the car fuels tax, and VAT the value-added tax.<sup>21</sup> Because we cannot distinguish between diesel and gasoline after 1993 in our household

<sup>18</sup> The number of adults and number of children in the household are included as demographics. When the difference between rural and urban households is considered, a variable for city size is also included.

<sup>19</sup> Details on subsistence and bliss levels, cost and indirect utility functions are provided in Section 1.9.2.1 in the Appendix. Section 1.9.2.2 in the Appendix outlines the method for correcting for potential endogeneity.

<sup>20</sup> See Federal Ministry of Finance, 2014.

<sup>21</sup> Value-added tax is imposed on the basis of the Value Added Tax Act of 15 July 2006. See Federal Ministry of Justice and Consumer Protection, 2014d.

micro data, we have constructed a weighted average for the end user price on car fuels using the consumption shares of gasoline and diesel in total car fuel consumption in 2008 as weights (0.73 and 0.27, respectively<sup>22</sup>). A weighted average was constructed in the same way for the car fuels tax.

Table 1.1 provides a summary of pre-tax prices,<sup>23</sup> car fuels taxes,<sup>24</sup> and final consumer prices of car fuels in Germany during the investigation period 1993–2008. During the period, the car fuels tax was increased several times. For example, the tax on gasoline (diesel) increased from 0.4193 (0.2812) to 0.5011 (0.3170) euros per liter between 1993 and 1994. Since 2003 it has averaged 0.6545 (0.4704) euros per liter. Also in 2007 the value-added tax was increased from 16 to 19 percent, leading to a further increase in the consumer price of car fuels. The tax and import-price increases are the key drivers of the rise in car fuel expenditures shares documented in Figure 1.1 in Section 1.3.1.

**Table 1.1 Pre-tax and final consumer prices of car fuels**

Period	Diesel (EUR/liter)			Gasoline (EUR/liter)		
	Pre-tax price	Car fuels tax	Total price	Pre-tax price	Car fuels tax	Total price
01.01.93–31.12.93	0.195	0.281	0.548	0.199	0.419	0.712
01.01.94–31.12.94	0.191	0.317	0.584	0.192	0.419	0.797
01.01.95–31.12.95	0.181	0.317	0.573	0.188	0.501	0.793
01.01.96–31.12.96	0.224	0.317	0.622	0.218	0.501	0.827
01.01.97–31.12.97	0.234	0.317	0.634	0.242	0.501	0.854
01.01.98–31.12.98	0.186	0.317	0.582	0.202	0.501	0.814
01.01.99–31.12.99	0.210	0.348	0.638	0.229	0.532	0.874
01.01.00–31.12.00	0.312	0.378	0.801	0.312	0.562	1.015
01.01.01–31.12.01	0.300	0.409	0.822	0.289	0.593	1.024
01.01.02–31.12.02	0.284	0.440	0.840	0.279	0.624	1.048
01.01.03–31.12.03	0.294	0.470	0.886	0.287	0.655	1.093
01.01.04–31.12.04	0.338	0.470	0.937	0.324	0.655	1.136
01.01.05–31.12.05	0.448	0.470	1.065	0.399	0.655	1.223
01.01.06–31.12.06	0.492	0.470	1.116	0.456	0.655	1.289
01.01.07–31.12.07	0.512	0.470	1.169	0.472	0.655	1.341
01.01.08–31.12.08	0.650	0.470	1.333	0.525	0.655	1.403

*Note.* Source: International Energy Agency (2008). All numbers are in nominal terms.

### 1.4.3 Policy evaluation criteria

<sup>22</sup> See Statista, 2014.

<sup>23</sup> The question of the extent to which changes in oil prices are passed through to retail fuel prices in Germany has been widely researched. For example, the German Federal Statistical Office (2015) concludes that the development of both gasoline and diesel prices depends heavily on the dynamics of crude oil prices on world markets.

<sup>24</sup> The car fuels tax replaced the mineral oil tax in 2006. It is imposed on the basis of the Energy Tax Act of 15 July 2006. See Energy Tax Act, Federal Ministry of Justice and Consumer Protection, 2014a.

Our central aim is the quantification of the potential trade-offs between emissions and inequality as well as emissions and households' material welfare. To achieve this goal, we take the DQUAIDS estimates and derive household expenditures and demands in year 2008 for various levels of the tax on car fuels (including its actual value in 2008 as a benchmark). Then we derive the outcomes of interest: aggregate car-related CO<sub>2</sub> emissions, inequality in the post-tax income distribution, and household material welfare.

Our assessment of the responsiveness of aggregate car-related CO<sub>2</sub> emissions of the household sector to car fuel taxes follows Brännlund et al. (2007). The percentage change in CO<sub>2</sub> emissions ( $\Delta E$ ) for a particular change in the car fuels tax is:

$$\Delta E = \frac{(\theta q^1 - \theta q^0)}{\theta q^0} \quad (1.5)$$

with  $\theta$  denoting the carbon factor of car fuels in tons per liter, and  $q^0$  ( $q^1$ ) denoting average fuel demand in the status quo (after the tax variation).

Our assessment of the distributional effects relies on two standard inequality measures: the Gini and the Theil index. Let  $\bar{y}$  denote the mean equivalent income of the population and  $F(y)$  the proportion of the population with income less than or equal to  $y$ , or:

$$\Phi(y) = \frac{1}{y} \int_0^y z dF(z). \quad (1.6)$$

The term  $\Phi(y)$  gives the proportion of total income received by individuals with income less than  $y$  and  $z$  is the integration variable, income. Then the Gini index ( $G$ ) is defined as:

$$G = 1 - 2 \int_0^1 \Phi dF. \quad (1.7)$$

It is thus defined as twice the area between the line of perfect equality (everyone has the same income) and the Lorenz curve ( $F, \Phi$ ), the graphical representation of population proportion  $F$  versus the income proportion  $\Phi$ .<sup>25</sup> A Gini index of 0 means perfect equality and index of 1 means perfect inequality. The Gini index puts a great deal of weight to the middle

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<sup>25</sup> See The World Bank, 2014.



of the income distribution. As an alternative measure, we consider the Theil entropy index,  $T$ , defined as:

$$T = \frac{1}{n} \sum_{i=1}^n \frac{y_i}{\bar{y}} \log \left( \frac{y_i}{\bar{y}} \right). \quad (1.8)$$

If the Gini or the Theil index increases (decreases) with the tax rate, the tax is regressive (progressive), increasing (decreasing) inequality. Both indices are derived from the distribution of equivalent disposable income after car fuels taxes. Equivalent disposable income is the household's disposable income adjusted by the household's equivalence scale. Equivalence scales adjust for differences in needs of households of different composition (number of adults and children). Here we use the OECD modified equivalence scale ( $ES$ ),

$$ES = 1 + 0.5 * (n_{adults} - 1) + 0.3 * n_{children}, \quad (1.9)$$

with  $n_{adults}$  ( $n_{children}$ ) denoting the number of adults (children) in the household.

Our assessment of the welfare changes relies on three indicators. The first indicator is the change in tax burden ( $\Delta t$ ) due to a change in the tax rate,

$$\Delta t = ET^1 q^1 - ET^0 q^0, \quad (1.10)$$

with  $ET^0$  and  $ET^1$  denoting the tax burden in the status quo and in another tax regime. Further we make use of two standard measures from welfare analyses: equivalent and compensating variations. The equivalent variation ( $EV$ ), the amount of money that a household is willing to give up in order to avert the price change, is:

$$EV = e(p^1, V^1) - e(p^0, V^1), \quad (1.11)$$

with  $e(p^1, V^1)$  denoting the expenditure function at new prices and utility levels and  $e(p^0, V^1)$  representing the expenditure at old prices and utility after the tax change. Positive value for the equivalent variation indicates a welfare loss due to a tax change while the negative value indicates a welfare gain. The compensating variation ( $CV$ ) measures how much

money each household should be given in order to maintain their old utility levels after the price change:

$$CV = e(p^1, V^0) - e(p^0, V^0). \quad (1.12)$$

To gain a more detailed picture of the welfare changes, we further derive the welfare indicators for different quantiles of the distribution of equivalent disposable income. The emissions–inequality and emissions–welfare trade-offs are visualized graphically by the combinations of the three outcomes for different levels of the car fuels tax. For example, the emissions–inequality trade-off is visualized by all potential combinations of CO<sub>2</sub> emissions and the Gini index.

## 1.5 Demand System Estimates

In the DQUAIDS estimation, we have considered five commodities: car fuels, food,<sup>26</sup> electricity, other fuels, and an aggregate of other goods. A demographically scaled version is estimated using the numbers of adults and children as explanatory variables.<sup>27</sup> The estimated coefficients do not have direct economic interpretations and hence we have shifted them to Table 1.12 in the Appendix. The table also provides the results from the non-scaled AIDS/QUAIDS and the analogous DAIDS specification. The results confirm the DQUAIDS as the appropriate specification.

Table 1.2 summarizes all mean income and uncompensated price elasticities together with the lower and upper bounds of 95 percent confidence intervals.<sup>28</sup> Following Banks et al. (1997), a weighted average elasticity is constructed with the household’s share of total sample expenditure for the relevant good as weight. The income elasticities show that car fuels, food, electricity, and other fuels are normal and necessity goods: That is, a one percent income increase raises the demand for car fuels by 0.832 percent. The aggregate of other goods is normal but a luxury good (income elasticity above one).

The price elasticities for car fuels indicate that the demand is highly price-inelastic. According to our estimates, a one percent price increase lowers the demand by only 0.084 percent. Gicheva et al. (2007, 2010) find a similar result for households in California. There

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<sup>26</sup> Food includes food away from home and non-alcoholic beverages.

<sup>27</sup> Children are household members below age 15.

<sup>28</sup> Section 1.9.2 in the Appendix explains the calculation of own-price, cross-price, and income elasticities.

are at least two explanations for the inelastic demand. First, many households rely on automobiles on a daily basis (i.e., commuters) and they have trouble reducing their consumption of car fuels – at least in the short run – particularly because purchasing a new car is a costly investment. Second, many people perceive cars as status symbols or prefer driving to public transportation – even in the presence of a good public transport system. Indeed, we find low price elasticities for residents of both rural and urban areas,<sup>29</sup> with the latter having presumably better public transport systems and shorter commuting distances. Cross-price elasticities reveal that car fuels are a complementary good to food and other goods.<sup>30</sup> Car fuels are found to be substitutes for electricity and other fuels, but all of these cross-price elasticities are rather low.

Interestingly, we find a rather high price elasticity for food (– 0.972). However, this is the uncompensated elasticity, and compensated elasticities are usually lower in absolute terms. Other studies find estimates of similar sizes.<sup>31</sup> Another interesting result pertains to food and electricity, which appear to be substitute goods. One explanation is that the IES food aggregate includes food at home and food at restaurants. It might be that as restaurant food becomes increasingly expensive people start to cook more at home, hence using more electricity. Indeed, Gicheva et al. (2007, 2010) find that as gasoline prices increase, people in California shift from eating out to buying groceries and cooking at home. This result is not at odds with our finding of complementarity between food and car fuels, as our food aggregate also covers food away from home.<sup>32</sup>

**Table 1. 2 Income and price elasticities (uncompensated)**

Income elasticities	Price elasticities				
	Food	Electricity	Other fuels	Car fuels	Other goods

<sup>29</sup> See Table 1.14 in the Appendix.

<sup>30</sup> Gicheva et al. (2007) also find that as gasoline prices rise, households in California reduce their food expenditures.

<sup>31</sup> Banks et al. (1997) obtain an elasticity of –0.959 and Bränlund et al. (2004) of –0.840. Andreyeva et al. (2010) review 160 studies on the price elasticity of food demand and concluded that the elasticity ranged from 0.27 to 0.81 (absolute values). They argue that “food away from home, soft drinks, juice, and meats being most responsive” (p. 216), components that are also included in the food aggregate in the German Income and Expenditure Survey underlying our estimations.

<sup>32</sup> Our elasticities estimates are comparable to the estimates from previous studies for other countries as well to estimates for Germany of Kohn and Missong (2003) and Beznoska (2014). Kohn and Missong (2003) estimate a non-demographic QUAIDS for broad number of goods categories in Germany for the years 1988–1993, while Beznoska (2014) estimates a non-demographic AIDS for Germany for energy, mobility and leisure for the years 1998–2008. Both of those studies include the category mobility, which includes car fuels as well as expenditures on public transport. See Table 1.15 in the Appendix for comparison of our results with those studies as well as others.

**Table 1. 2 (continued)**

	Income elasticities	Price elasticities				
		Food	Electricity	Other fuels	Car fuels	Other goods
Food	0.415 [0.376; 0.445]	−0.972 [−0.975; −0.969]	0.030 [0.027; 0.032]	−0.041 [−0.042; −0.040]	−0.041 [−0.042; −0.040]	0.608 [0.600; 0.616]
Electricity	0.507 [0.505; 0.509]	0.140 [0.139; 0.141]	−0.811 [−0.813; −0.810]	0.216 [0.214; 0.216]	0.083 [0.082; 0.084]	−0.135 [−0.136; −0.134]
Other fuels	0.724 [0.723; 0.725]	−0.171 [−0.173; −0.168]	0.153 [0.151; 0.155]	−0.559 [−0.560; −0.558]	0.152 [0.150; 0.154]	−0.299 [−0.301; −0.298]
Car fuels	0.832 [0.831; 0.833]	−0.180 [−0.182; −0.178]	0.046 [0.044; 0.048]	0.134 [0.133; 0.135]	−0.084 [−0.085; −0.083]	−0.747 [−0.745; −0.749]
Other goods	1.136 [1.133; 1.139]	0.007 [0.006; 0.005]	−0.021 [−0.022; −0.020]	−0.028 [−0.029; −0.027]	−0.050 [−0.052; −0.048]	−1.044 [−1.045; −1.043]

*Note.* Average values of the coefficient estimates and lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 1993–2008.

## 1.6 Policy analyses

To assess the effects of the car fuels tax on emissions, inequality, and household welfare, we proceed as follows. We start with a summary of indicators for the three outcome domains in the status quo – 2008, the last year observed in the data. That is, we provide the level of emissions together with the set of inequality and welfare indices explained in Section 1.4.3. We proceed with a simulation of a 1 percent variation of the tax on car fuels to derive the marginal effects on the indicators from all outcome domains. We conduct the same exercise but for four “sizeable” tax reforms, i.e., an increase and decrease of 25 and 50 percent in the car fuels tax. This exercise adds to the marginal analyses as our simulations rely on a quadratic demand system, meaning that the results from the marginal tax variation cannot be extrapolated in a linear manner. Finally, we provide the emissions–inequality and emissions–welfare trade-offs by means of the graphical devices detailed in Section 1.4.3. For example, one graph shows the emissions–inequality trade-off by providing, for a wide range of tax rates, potential combinations of CO<sub>2</sub> emissions and the Gini index, while another shows the emissions–welfare trade-off by presenting potential combinations of emissions and equivalent variation (Figure 1.4).

We first characterize the status quo, that is, the situation in 2008. In that year, the car fuels tax amounted to 0.606 euros per liter of car fuel. Table 1.3 presents the corresponding

key figures on emissions, tax burdens, and inequality indices for the post-tax distributions. All the numbers relate to the average German household for a period of one year. The average household produces car fuels-related emissions of 2.065 tons of CO<sub>2</sub> and pays 622 euros for car fuels tax. The level of inequality in the post-tax equivalent income distribution, as captured by the Gini index (Theil index), is 0.266 (0.112). We take the 2008 situation as a benchmark and now simulate a marginal 1 percent tax variation in the car fuels tax. If the tax is reduced by one percent, emissions increase by 0.003 tons (0.15 percent) while the tax burden decreases by 6.4 euros (1.03 percent). Because the additional tax burden is small compared to household incomes, the Gini index and Theil index remain basically unchanged. If the tax is increased by one percent, emissions decrease by 0.003 tons (0.15 percent) and the tax burden increases by 3.9 euros (0.627 percent).

**Table 1.3 Status quo**

	Tax rate (in EUR/liter)	Emissions (in tons)	Tax burden (in EUR)	Gini index	Theil index
Status quo	0.606	2.065 [2.055; 2.075]	621.675 [617.639; 623.712]	0.266 [0.265; 0.267]	0.114 [0.112; 0.116]
1 percent tax decrease	0.600	2.068 [2.058; 2.079]	615.309 [612.299; 618.318]	0.266 [0.265; 0.267]	0.114 [0.112; 0.116]
1 percent tax increase	0.612	2.062 [2.051; 2.072]	625.631 [622.569; 628.693]	0.266 [0.265; 0.267]	0.114 [0.112; 0.116]

*Note.* Average values of the variables and 95 percent lower and upper confidence intervals are provided. Database is IES, 2008.

Departing from the status quo, we assess four alternative scenarios: tax reductions and increases of 25 and 50 percent. The results of the four tax scenarios are summarized in Table 1.4. For the 50 (25) percent reduction of the tax, the tax burden is 46 (22) percent lower than in the status quo and the welfare gain amounts to 307 (150) euros for the average German household as measured by the *EV*.<sup>33</sup> The average emissions increase to 2.22 (2.15) tons per household or by 7.99 (4.11) percent in comparison to the status quo. The Gini and the Theil indices indicate a moderate reduction of inequality (by about 0.001 (0.0007) points). The small change in the inequality can be attributed to the fact that the poorer households spend a much smaller proportion of their total expenditures on car fuels (2.95 percent in the status quo) in comparison to the richer households (4.98 percent in the status quo). Car fuels expenditures relative to income in the status quo is 2.75 percent for low-income (equivalent

<sup>33</sup> All the welfare results derived from the EV are reconfirmed by the CV. The respective results are provided in the Appendix (see Table 1.16 and Figure 1.6).

income below 12,221 euros), 3.70 percent for middle-income (equivalent income between 23,528 and 26,412 euros), and 2.39 percent for high-income households (equivalent income above 42,419 euros). Further, the mean tax burden paid for car fuels in the status quo represents 1.96 percent of the disposable income of the average household. For the 50 (25) percent tax increases, the tax burden increases by 37 (19) percent and the households suffer a welfare loss of 284 (146) euros. The inequality in the post-tax distribution is 0.005 (0.0001) percentage points higher, while emissions drop by 8.2 (4.3) percent relative to the status quo.<sup>34</sup>

**Table 1. 4 Tax simulations with 50 and 25 percent tax decrease, and 25 and 50 percent tax increase**

	Tax rate (in EUR/liter)	Emissions (in tons)	Tax burden (in EUR)	EV (in EUR)	Gini index	Theil index
50 percent tax reduction	0.303	2.223	334.027	−306.556	0.2649	0.1123
		[2.213; 2.234]	[332.412; 335.643]	[−307.892; −305.220]	[0.2648; 0.2650]	[0.1122; 0.1124]
25 percent tax reduction	0.455	2.150	484.536	−149.958	0.2653	0.1137
		[2.140; 2.161]	[482.180; 486.892]	[−150.620; −149.300]	[0.2652; 0.2654]	[0.1136; 0.1138]
25 percent tax increase	0.758	1.979	743.138	145.898	0.2661	0.1144
		[1.969; 1.988]	[739.478; 746.798]	[145.244; 146.552]	[0.2660; 0.2662]	[0.1143; 0.1145]
50 percent tax increase	0.909	1.895	854.230	284.318	0.2665	0.1147
		[1.886; 1.905]	[849.995; 858.464]	[283.033; 285.603]	[0.2664; 0.2666]	[0.1146; 0.1148]

*Note.* Average values of the variables and lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 2008.

To better understand how changes in the car fuels tax rate impact “rich” and “poor” households, Figure 1.3 provides, for each of the four different scenarios, the decile-specific<sup>35</sup> averages of the following outcomes: changes in CO<sub>2</sub> emissions, changes in tax burdens, and equivalent variations. Hence, there is a set of three graphs per scenario, one graph per outcome. In each graph, the abscissa indicates the deciles. The left (right) ordinate depicts the average (percentage) change of the outcome within a decile. Solid (dashed) lines indicate the total (percentage) changes.

We first comment on the two scenarios of tax reductions. The first row of graphs provides the decile-specific changes in emissions. If the tax is decreased by 50 (25) percent,

<sup>34</sup> Austin and Dinan (2005) find the gasoline tax to be an efficient policy instrument for achieving great immediate gasoline and emissions savings by encouraging people to drive less and eventually to buy more fuel-efficient cars.

<sup>35</sup> The deciles are identified based on equivalent disposable income in the status quo.

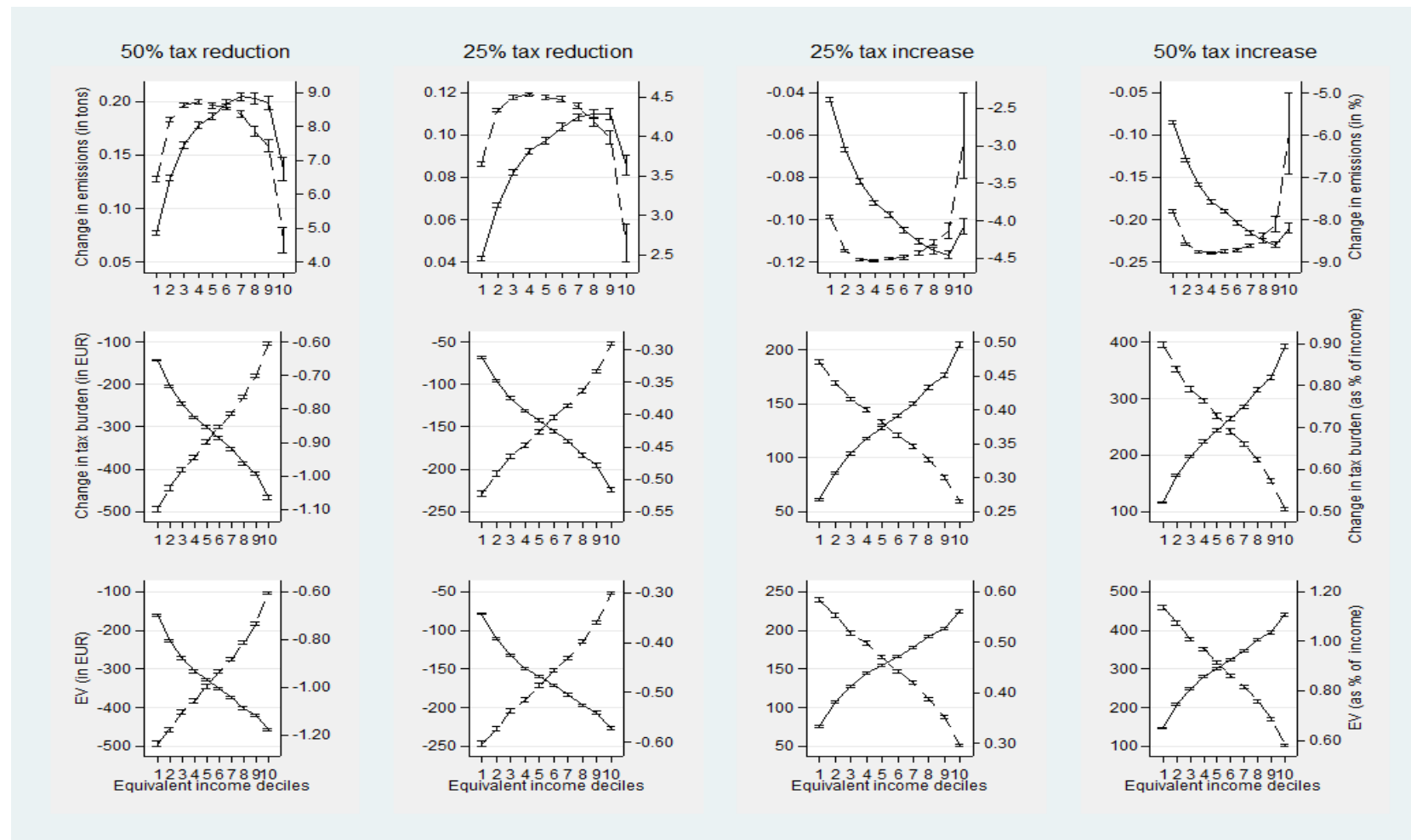
emissions increase for all the deciles and exhibit an inverse u-shaped relationship. The percentage increase in CO<sub>2</sub> emissions is about 6.3 (3.7) percent for the lowest deciles, grows to 8.6 (4.5) percent for the households in the fourth decile, and declines thereafter. Thus, CO<sub>2</sub> emissions reductions are largest for the middle part of the equivalent income distribution under both scenarios. The second row gives the decile-specific average changes in tax burden. A tax reduction of 50 percent implies an average nominal tax relief of 143 euros for the bottom and of 466 euros for the top decile. While the tax relief, in absolute terms, increases over the deciles, the opposite holds for the relative relief as percentage of income: it is highest for the lowest decile – 1.1 (0.5) percent – and lowest for the richest households – 0.6 (0.3) percent. The third row gives the welfare changes, expressed by the equivalent variation (*EV*). The *EV*, as proportion of income, is highest for the poorest households, 1.2 (0.6) percent, and decreases with income, indicating that the monetary welfare gain is highest for the bottom of the equivalent income distribution.

We now comment on the two scenarios of tax increases. If the tax is increased by 50 (25) percent, the emissions decrease over the deciles, with the decline exhibiting an inverse-u shape. For the lowest decile, emissions decline by about 7.8 (3.9) percent for the poorest, by about 8.5 (3.5) percent for the third to fifth decile, and by around 6.0 (2.9) percent for the richest households. In absolute (relative) terms, the change in the average tax burden is increasing (decreasing) over the deciles. The pattern is very similar for the average decile-specific *EV*. The monetary loss, in terms of equivalent variation, for the poorest households amounts to 150 (76) euros and for the richest to around 440 (225) euros.<sup>36</sup>

In a final step, we derive the functional relationships between emissions, inequality, and welfare by systematically varying the tax rate: the emissions–inequality and emissions–welfare trade-offs. The results are summarized in Figure 1.4, which provides six graphs in total. The three graphs in the upper row and the first graph in the lower row give the relationships between nominal car fuel tax rates (in EUR/liter) and the following four outcomes at the household-sector level: CO<sub>2</sub> emissions, car fuels tax burden, welfare (equivalent variation), and inequality (Gini index). The last two graphs in the lower row give the corresponding emissions–inequality and emissions–welfare trade-offs.

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<sup>36</sup> The tax simulations of Brännlund and Nordström (2004) involve a doubling of the CO<sub>2</sub> tax and reduction of the general VAT in Sweden, which meant higher prices of petrol and oil and lower price of electricity. They find on 10.8 percent reduction in the consumption of petrol and CV of around 105 euros (0.47 percent of income). If car fuels tax is doubled in Germany and revenue is not recycled, our results demonstrate that consumption decreases by around 15.6 percent and the CV is found to be 555 euros (1.8 percent of income).



**Figure 1. 3 Four tax scenarios: effects of tax change on emissions, tax burdens, and EV across the equivalent income deciles**

*Note.* Average values of variables and lower and upper bound of 95 percent confidence intervals are presented. In the first row of the graph, solids line stands for emissions changes in tons and the size can be read from the left y axis while the dashed line stands for percentage change and the size can be read from the right y axis. Similarly in the second (third) row solid line represents the change in tax burden (EV) in euros and the dashed line represents the change in tax burden (EV) as percentage of income. Database is IES 2008.



While the relationship between CO<sub>2</sub> emissions and tax rate is negative and almost linear, the relationship between the tax rate and the other three outcomes (tax burden, welfare, and inequality) is positive, suggesting the presence of systematic emissions – inequality and emissions – welfare trade-offs. As an example, in the status quo, the total car fuels-related emissions of German households are 77.6 megatons (Mt), and the inequality in the post-tax income distribution is 0.266 percent (Gini index).<sup>37</sup> Increasing (lowering) the tax by 50 percent lowers (increases) emissions by 8.25 percent (7.63 percent) but increases (decreases) the Gini index by 0.27 percent (0.34 percent). The figure also indicates the trade-off between emissions and households welfare. Increasing (lowering) the tax by 50 percent decreases (increases) monetary welfare by a total of 11.51 (10.7) billion euros as measured by the sum of the equivalent variation over all households, but nevertheless lowers (increases) emissions by 8.25 percent (7.63 percent). Policy makers are yet to decide how to weigh environmental goals against equality and welfare concerns to determine an optimal tax level.

At first glance, the small changes in the Gini coefficient might suggest that one need not worry about the redistribute effects of the car fuels tax. However, one should keep in mind that the moderate changes in inequality are due to the small expenditure share of car fuels in households' overall budgets. Accordingly, the nominal tax burden is relatively small, and so is the change in the inequality measures. Our basic interest should thus be in the sign of the effect, which turned out to be regressive. The sign matters because the car fuel tax is not the only environmental tax in Germany that taxes households' demands as a basis. Another such tax is the electricity tax, which has also been shown to be regressive (Grösche and Schröder, 2014a). Flues and Thomas (2015) show that also taxes on heating fuels are “clearly regressive” (p. 40). Both thus add to the regressive effect of fuels taxes measured here. Finally, the associated welfare losses are sizeable, especially for poor households.

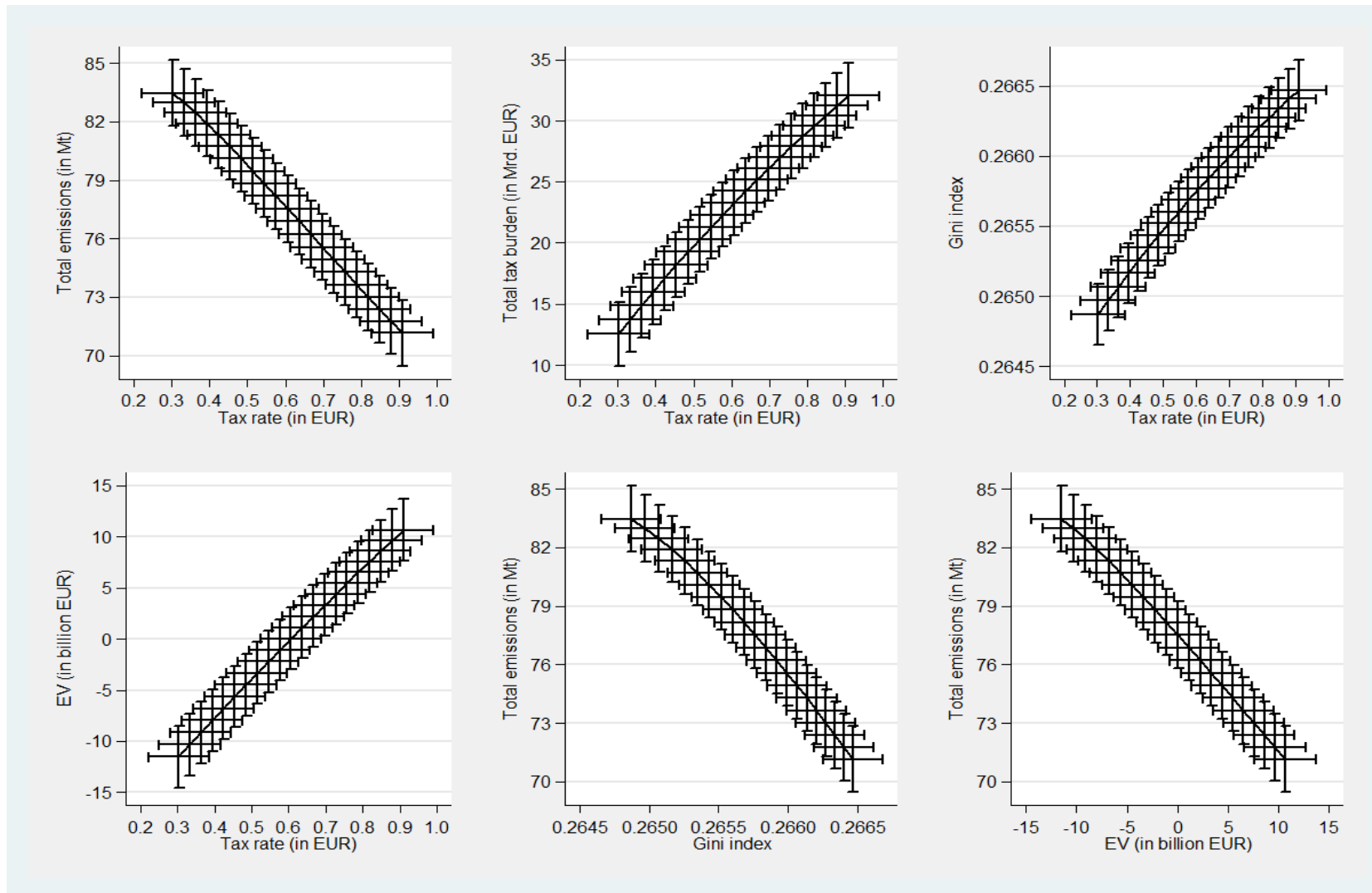
## 1.7 Sensitivity analyses

In Sections 1.4.1 and 1.9.3 we have shown the advantages of the DQAIDS model specification over nested models like QAIDS<sup>38</sup> or (D)AIDS. Also, we already addressed the potential differences in demand patterns between residents of rural and urban areas. As another robustness check, we have re-estimated the original DQAIDS specification separately by quartiles of the equivalent disposable income distribution. Table 1.5 shows the elasticities

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<sup>37</sup> The relationship between the Theil index (*CV*) and the tax rate and the Theil index (*CV*) and emissions is depicted in Figure 1.7 in the Appendix, and the patterns are the same as with the Gini index and *EV*.

<sup>38</sup> See Tables 1.12 and 1.13.



**Figure 1.4** The relationship between tax rate, emissions, tax burden, Gini index, and EV

*Note.* Average values of total emissions (and Gini index) and lower and upper bound of 95 percent confidence intervals are presented. Database is IES 2008.

for each quartile of the equivalent income distribution. Overall, the estimated income elasticities do not differ substantially across quartiles. Critical for our policy analyses is the price elasticity of demand for car fuels. The results are that households at the top of the distribution respond to an increase in the price of car fuels with a stronger reduction in fuel demand than households at the bottom of the distribution. Using the quartile-specific elasticities would therefore imply an intensification of the estimated emissions–inequality trade-off.

**Table 1. 5 Elasticities by equivalent income classes**

Equivalent income quartiles	0–25 percent	25–50 percent	50–75 percent	75–100 percent
<b>Income elasticities</b>				
Food	1.034 [1.033; 1.035]	1.116 [1.113; 1.119]	1.128 [1.127; 1.129]	0.667 [0.665; 0.669]
Electricity	0.771 [0.769; 0.773]	0.862 [0.861; 0.863]	0.861 [0.860; 0.862]	0.392 [0.390; 0.394]
Other fuels	0.657 [0.655; 0.659]	0.677 [0.675; 0.679]	0.656 [0.654; 0.658]	0.521 [0.520; 0.522]
Car fuels	1.336 [1.334; 1.338]	1.022 [1.021; 1.023]	0.937 [0.935; 0.939]	0.355 [0.354; 0.356]
Other goods	1.007 [1.005; 1.009]	0.992 [0.990; 0.994]	0.996 [0.993; 0.999]	1.121 [1.120; 1.122]
<b>Price elasticities</b>				
Food	-1.175 [-1.176; -1.174]	-1.205 [-1.207; -1.203]	-1.206 [-1.208; -1.204]	-1.036 [-1.038; -1.034]
Electricity	-0.822 [-0.824; -0.820]	-0.749 [-0.751; -0.747]	-0.885 [-0.886; -0.884]	-0.523 [-0.525; -0.521]
Other fuels	-0.659 [-0.661; -0.657]	-0.790 [-0.792; -0.788]	-0.776 [-0.778; -0.774]	-0.621 [-0.623; -0.619]
Car fuels	-0.064 [-0.065; -0.063]	-0.240 [-0.242; -0.238]	-0.244 [-0.246; -0.242]	-0.404 [-0.406; -0.402]
Other goods	-0.914 [-0.916; -0.912]	-0.904 [-0.905; -0.903]	-0.900 [-0.901; -0.899]	-1.028 [-2.030; -1.026]

*Note.* Average values of the variables and lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 1993–2008.

## 1.8 Interim Conclusion

In many countries, policies have been implemented that tackle the issues of climate change and environmental pollution. Environmental and energy taxes are important

components of these policies. These taxes are intended to promote environmentally friendly activities by means of economic incentives. The German car fuels tax is a prototypical example: for every purchased liter of gasoline, 0.525 euros (which represents 38 percent of the price) are levied on the consumers, increasing the relative consumer price of gasoline. The quantitative effect on the demand for car fuels and thus the potential emissions reduction hinges on the price elasticity of this demand.

Environmental taxes not only alter demands, they also affect households' budgets (income after taxes), implying distributional and welfare effects. As the tax base is consumption of particular commodities rather than economic capability, regressive effects cannot be excluded. If the effect is regressive, environmental taxes might counteract efforts at reducing inequality and poverty.

Here we have suggested and implemented a framework to systematically investigate the potential trade-offs between emission, distribution, and welfare targets that builds on a demographically-scaled Quadratic Almost Ideal Demand System. Our estimates indicate the presence of an emissions–inequality and an emissions–welfare trade-off: Increasing the 2008 car fuels tax by 5 percent implies an emissions reduction of 0.9 percent, an increase in inequality of 0.04 percent (according to the Gini coefficient), and a considerable welfare reduction (according to the equivalent variation) for low-income households of 17 euros (0.12 percent of income).

A partial equilibrium framework such as ours has been adopted in many studies worldwide (e.g., West and Williams III, 2004, and Bento et al., 2009). Such a framework ignores possible general equilibrium effects. While such effects are possibly small for small-scale policy changes, they might invalidate the conclusions from partial equilibrium analyses for major policy reforms (see Goulder and Williams III, 2003, Böhringer and Rutherford, 1997, Fullerton and Heutel, 2010, Bhattacharyya, 1996, or Araar et al., 2011). Future work could incorporate our household-sector analyses into a computable general equilibrium framework to study the role of general equilibrium effects for tax variations of different magnitudes.

## 1.9 Appendix

### 1.9.1 Data tables

**Table 1. 6 Identifiers of the underlying original IES variables**

Original IES variables in each category	Content				
	1993	1998	2003	2008	
Food and beverages expenditures (no alcohol, no tobacco)	ef109	ef125	ef51	ef61	Food, beverages and tobacco
	ef644	ef740			Other beverages, tobacco
Electricity expenditures	ef705	ef770 ef771 ef772	ef258	ef251	Electricity (including solar from 2003 on)
Other fuels expenditures	ef707	ef773; ef774; ef775 ef776;	ef259	ef252	Gas
	ef709	ef777; ef778	ef260	ef253	Liquid fuels
	ef711; ef713; ef715	ef779; ef780; ef781	ef261	ef254	Solid fuels: including hard coal, coke, wood, lignite, etc.
	ef718	ef782; ef783; ef784	ef262	ef255	District heating, hot water
Car fuels expenditures	ef761				Gasoline
	ef762	ef810	ef299	ef300	Diesel
	ef763				Consumables for motor vehicles and bicycles

*Note.* Database is IES 1993–2008.

**Table 1. 7 Descriptive statistics for 1993**

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>y</i>	38378	33630.450	17749.480	7016.458	105893.200
<i>e<sub>total</sub></i>	38378	26732.410	13139.430	3488.475	138006.000
<i>e<sub>food</sub></i>	38378	4338.383	2399.318	2556.453	47433.570
<i>e<sub>electricity</sub></i>	38378	601.557	4356.844	0.000	8141.812
<i>e<sub>other fuels</sub></i>	38378	701.997	5169.145	0.000	13367.220
<i>e<sub>car fuels</sub></i>	38378	698.220	5816.776	0.000	6959.194
<i>e<sub>other goods</sub></i>	38378	20392.250	11219.500	1221.674	126590.700
<i>s<sub>food</sub></i>	38378	0.172	0.066	0.000	0.616
<i>s<sub>electricity</sub></i>	38378	0.026	0.018	0.000	0.286
<i>s<sub>other fuels</sub></i>	38378	0.033	0.026	0.000	0.349
<i>s<sub>car fuels</sub></i>	38378	0.025	0.023	0.000	0.230
<i>s<sub>other goods</sub></i>	38378	0.744	0.076	0.317	0.978
<i>ln(p<sub>food</sub>)</i>	38378	1.285	0.115	0.993	1.681
<i>ln(p<sub>electricity</sub>)</i>	38378	1.201	0.000	1.201	1.201
<i>ln(p<sub>other fuels</sub>)</i>	38378	0.945	0.129	0.384	1.222
<i>ln(p<sub>car fuels</sub>)</i>	38378	0.848	0.000	0.848	0.848
<i>ln(p<sub>other goods</sub>)</i>	38378	1.212	0.087	0.049	1.640
<i>n<sub>adults</sub></i>	38378	2.036	0.831	1.000	8.000
<i>n<sub>children</sub></i>	38378	0.595	0.960	0.000	6.000
<i>rural</i>	38378	0.637	0.481	0	1

Note. Database is IES 1993.

**Table 1. 8 Descriptive statistics for 1998**

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>y</i>	47747	38462.200	20493.800	7454.636	124794.100
<i>e<sub>total</sub></i>	47747	29171.110	17187.370	3675.714	215394.200
<i>e<sub>food</sub></i>	47747	4087.903	2.067.809	4090.335	23813.930
<i>e<sub>electricity</sub></i>	47747	570.083	4.102.481	0.000	7415.777
<i>e<sub>other fuels</sub></i>	47747	691.718	7.366.757	0.000	16563.810
<i>e<sub>car fuels</sub></i>	47747	940.144	7.681.655	0.000	10872.110
<i>e<sub>other goods</sub></i>	47747	22881.260	15783.510	2164.336	207614.400
<i>S<sub>food</sub></i>	47747	0.155	0.069	0.000	0.525
<i>S<sub>electricity</sub></i>	47747	0.024	0.017	0.000	0.283
<i>S<sub>other fuels</sub></i>	47747	0.030	0.029	0.000	0.383
<i>S<sub>car fuels</sub></i>	47747	0.031	0.029	0.000	0.353
<i>S<sub>other goods</sub></i>	47747	0.760	0.085	0.347	0.983
<i>ln(p<sub>food</sub>)</i>	47747	1.347	0.004	1.062	1.755
<i>ln(p<sub>electricity</sub>)</i>	47747	1.193	0.000	1.193	1.193
<i>ln(p<sub>other fuels</sub>)</i>	47747	0.951	0.122	0.527	1.304
<i>ln(p<sub>car fuels</sub>)</i>	47747	0.960	0.000	0.960	0.960
<i>ln(p<sub>other goods</sub>)</i>	47747	1.343	0.098	0.153	1.713
<i>n<sub>adults</sub></i>	47747	2.021	0.815	1.000	8.000
<i>n<sub>children</sub></i>	47747	0.568	0.912	0.000	6.000
<i>rural</i>	47748	0.646	0.478	0	1

Note. Database is IES 1998.

**Table 1. 9 Descriptive statistics for 2003**

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>y</i>	41046	41307.400	22416.890	7612.000	131484.000
<i>e<sub>total</sub></i>	41046	27869.260	16098.570	3206.515	232843.300
<i>e<sub>food</sub></i>	41046	3650.286	1909.102	32.000	21440.000
<i>e<sub>electricity</sub></i>	41046	662.423	4840.913	0.000	10064.000
<i>e<sub>other fuels</sub></i>	41046	930.854	1082.000	0.000	23628.000
<i>e<sub>car fuels</sub></i>	41046	1201.276	9895.956	0.000	11424.000
<i>e<sub>other goods</sub></i>	41046	21424.420	14489.550	2470.718	225339.300
<i>S<sub>food</sub></i>	41046	0.144	0.061	0.001	0.571
<i>S<sub>electricity</sub></i>	41046	0.028	0.019	0.000	0.350
<i>S<sub>other fuels</sub></i>	41046	0.038	0.038	0.000	0.518
<i>S<sub>car fuels</sub></i>	41046	0.041	0.037	0.000	0.360
<i>S<sub>other goods</sub></i>	41046	0.749	0.083	0.319	0.982
<i>ln(p<sub>food</sub>)</i>	41046	1.386	0.122	1.081	1.756
<i>ln(p<sub>electricity</sub>)</i>	41046	1.312	0.000	1.313	1.312
<i>ln(p<sub>other fuels</sub>)</i>	41046	1.238	0.065	0.931	1.378
<i>ln(p<sub>car fuels</sub>)</i>	41046	1.276	0.000	1.276	1.276
<i>ln(p<sub>other goods</sub>)</i>	41046	1.373	0.074	0.084	1.708
<i>n<sub>adults</sub></i>	41046	1.997	0.824	1.000	8.000
<i>n<sub>children</sub></i>	41046	0.440	0.826	0.000	6.000
<i>rural</i>	41046	0.706	0.456	0	1

Note. Database is IES 2003.



**Table 1. 10 Descriptive statistics for 2008**

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>y</i>	42315	40989.970	22710.660	7504.000	129240.000
<i>e<sub>total</sub></i>	42315	26306.320	14525.560	3111.000	213739.000
<i>e<sub>food</sub></i>	42315	3847.322	2037.563	28.000	21924.000
<i>e<sub>electricity</sub></i>	42315	755.444	5664.706	0.000	11620.000
<i>e<sub>other fuels</sub></i>	42315	1203.773	1716.214	255.000	29391.000
<i>e<sub>car fuels</sub></i>	42315	1398.887	1223.770	0.000	13376.000
<i>e<sub>other goods</sub></i>	42315	19100.890	12446.150	1812.000	201304.000
<i>S<sub>food</sub></i>	42315	0.158	0.066	0.001	0.595
<i>S<sub>electricity</sub></i>	42315	0.034	0.023	0.000	0.372
<i>S<sub>other fuels</sub></i>	42315	0.049	0.052	0.001	0.634
<i>S<sub>car fuels</sub></i>	42315	0.049	0.045	0.000	0.531
<i>S<sub>other goods</sub></i>	42315	0.710	0.094	0.100	0.975
<i>ln(p<sub>food</sub>)</i>	42315	1.512	0.172	1.195	1.868
<i>ln(p<sub>electricity</sub>)</i>	42315	1.566	0.000	1.566	1.566
<i>ln(p<sub>other fuels</sub>)</i>	42315	1.662	0.044	1.134	1.907
<i>ln(p<sub>car fuels</sub>)</i>	42315	1.552	0.000	1.553	1.553
<i>ln(p<sub>other goods</sub>)</i>	42315	1.389	0.063	0.181	1.751
<i>n<sub>adults</sub></i>	42315	1.933	0.807	1.000	8.000
<i>n<sub>children</sub></i>	42315	0.358	0.749	0.000	6.000
<i>rural</i>	42316	0.689	0.463	0	1

Note. Database is IES 2008.

## 1.9.2 Estimation details

### 1.9.2.1 Technical details concerning the methodology

The first step for obtaining the demand equations is the specification of a function, which is general enough to be a second-order approximation of the utility or cost function. Banks et al. (1997) rely on the Price-Independent Generalized Logarithmic (PIGLOG) preferences, with demands having expenditure shares linear in logarithm of total expenditures. These demands arise from indirect utility functions ( $V$ ), which are linear in logarithm of total expenditures, but also include an extra term,  $\lambda(p)$ , which allows for non-linearity:

$$\ln(V) = \left[ \left( \frac{\ln(m) - \ln(a(p))}{b(p)} \right)^{(-1)} + \lambda(p) \right]^{(-1)}. \quad (1.13)$$

In equation (1.13),  $\ln(a(p))$  represents the cost of subsistence, which takes a translog form:

$$\ln(a(p)) = \alpha_0 + \sum_{i=1}^n \alpha_i \ln(p_i) + 0.5 \sum_{i=1}^n \sum_{j=1}^n \gamma_{ij} \ln(p_i) \ln(p_j). \quad (1.14)$$

Moreover,  $b(p)$  represents the cost of bliss, and is a simple Cobb-Douglass price aggregator:

$$b(p) = \prod_{i=1}^n p_i^{\beta_i}. \quad (1.15)$$

$c(p, z)$  is also a price aggregator, dependent on the demographics:

$$c(p, z) = \prod_{j=1}^k p_j^{\sum_{s=1}^t \theta_{js} z_s} \quad (1.16)$$

And  $\lambda$  represents the nonlinear specification of the Engel curves; it is a differentiable, homogeneous function of degree zero in prices:

$$\lambda(p) = \sum_{i=1}^n \lambda_i \ln p_i. \quad (1.17)$$

Cost function, which defines the minimum expenditure necessary to attain specific utility level given the prices, can also be used to represent the PIGLOG preferences. Such a cost function takes the following form:

$$\ln(C(V, p)) = \ln(a(p)) + b(p) \left( \ln V - \frac{1}{\lambda(p)} \right). \quad (1.18)$$

By price differentiation of equation (1.18), the demand functions can be derived:

$$\frac{\partial \ln(C)}{\partial \ln(p_i)} = \frac{p_i q_i}{C} = w_i. \quad (1.19)$$

### 1.9.2.2 Correcting for endogeneity

Exogeneity is necessary in the estimation of demand systems in order to have consistent and unbiased estimates. As LaFrance (1991) claims, it is almost impossible for expenditures to be exogenous in a set of demand functions and he presents evidence that the endogeneity significantly impacts the demand parameter estimates. According to Dhar et al. (2003), any inference based on endogenous estimates would be invalid.

The exogeneity assumption is likely to be violated as the budget shares of the commodities are likely to be jointly determined with total expenditures, which makes total expenditures endogenous in the budget equations. Let us rewrite equation (1) as  $w_{ij} = g_j(\ln(m)) + \varepsilon_{ij}$ . Then endogeneity implies that  $E(\varepsilon_j | \ln(m)) \neq 0$ . We follow the augmented regression technique of Blundell et al. (1998) to correct for the potential endogeneity. Let us suppose there exists a variable  $y$  such that  $\ln(m) = \pi * y + \vartheta$  with  $E(\vartheta | y) = 0$ . Then assume the following model holds true:

$$w_j = g_j(\ln(m)) + \vartheta * \rho_j + \varepsilon_j \text{ with } E(\varepsilon_j | \ln(m)) = 0, \quad (1.20)$$

which implies that  $w_j - E(w_j | \ln(m)) = (\vartheta - E(\vartheta | \ln(m)))\rho_j + \varepsilon_j$ . The estimator of  $g_j(\ln(m))$  is given by:

$$\widehat{g}_{jh}(\ln(m)) = \widehat{t}_{jh}^w(\ln(m)) + \widehat{t}_{jh}^y(\ln(m))\widehat{\rho}_j \quad (1.21)$$

And in place of the unobservable error component, the first stage residuals are used:

$$\widehat{\vartheta} = m - y\widehat{\pi}, \quad (1.22)$$

where  $\widehat{\pi}$  is the least squares estimator of  $\pi$ . All the variables included in the augmented equation are statistically significant (see Table 1.11).

### 1.9.2.3 Calculation of income and price elasticities of demand

We differentiate equation (1.2) from Section 1.4.1 with respect to  $\ln(m)$  to obtain the income elasticity, and with respect to  $\ln(p_j)$ , to derive the price elasticity.

$$\varepsilon_i = \frac{\mu_i}{w_i} + 1 \quad (1.23)$$

where

$$\begin{aligned} \mu_i &\equiv \frac{\partial w_i}{\partial \ln(m)} = \beta_i \\ &+ \sum_{s=1}^t \theta_{is} z_s \\ &+ \left\{ \frac{2\lambda_i}{b(p)c(p, z)} \right\} \left\{ \ln m - \ln(a(p)) - \ln \left( 1 + \sum_{s=1}^t \rho_s z_s \right) \right\} \end{aligned} \quad (1.24)$$

Equation (1.23) represents the income elasticity of demand. Income elasticity lower than one indicates necessities, while elasticity greater than one indicates luxury goods.

Positive income elasticity is associated with normal goods whereas negative income elasticity is associated with Giffen goods.

The uncompensated price elasticity is calculated in the following manner:

$$\varepsilon_{ij}^u = \frac{\mu_{ij}}{w_i} - \delta_{ij} \quad (1.25)$$

where

$$\begin{aligned} \mu_{ij} \equiv \frac{\partial w_i}{\partial \ln(p_j)} &= \gamma_{ij} - \mu_i(\alpha_j + \sum_{k=1}^n \gamma_{jk} \ln(p_k)) \\ &- \left\{ \frac{(\lambda_i(\beta_j + \sum_{s=1}^t \theta_{is} z_s))}{b(p)c(p, z)} \right\} \{(\ln(m) - \ln(a)) \\ &- \ln\left(1 + \sum_{s=1}^t \rho_s z_s\right)\}^2 \end{aligned} \quad (1.26)$$

and  $\delta_{ij}$  is the Kroneker delta,  $\delta_{ij} = 1$  for  $i = j$  and 0 otherwise.

The compensated price elasticity is derived from the following equation:

$$\varepsilon_{ij}^c = \varepsilon_{ij}^u + \varepsilon_i w_j \quad (1.27)$$

Own-price elasticity should be negative;  $\varepsilon_{ij}^c$  lower than one is a sign of inelastic demand;  $\varepsilon_{ij}^c$  higher than one is a sign of price-elastic demand. Substitute goods are associated with positive cross-price elasticity whereas complementary goods are associated with negative cross-price elasticity. For instance, if a price of a certain good goes up, the demand for the complementary good will go down.

### 1.9.3 Estimation Tables and Figures

**Table 1. 11** The augmented equation for  $\ln(m)$

Variable	Coefficient
<i>year</i>	0.175***
$\ln(y)$	1.131***
$\ln((y)^2)$	-0.024***
$\ln(p_{food})$	-0.024***
$\ln(p_{electricity})$	0.102***
$\ln(p_{other\ fuels})$	-0.075***
$\ln(p_{car\ fuels})$	-0.675***
$\ln(p_{other\ goods})$	-0.836***
$n_{adults}$	0.083***
$n_{children}$	0.044***
<i>constant</i>	2.216***

*Note.* Authors' calculations; Database is IES 1993–2008. \*\*\* Significant at 1 percent.

**Table 1. 12 Coefficient estimates of the demand systems**

Coefficient	AIDS	QUAIDS	DAIDS	DQUAIDS
$\alpha_1$	0.173***	0.169***	0.147***	0.147***
$\alpha_2$	0.034***	0.033***	0.026***	0.026***
$\alpha_3$	0.048***	0.047***	0.038***	0.039***
$\alpha_4$	0.044***	0.039***	0.045***	0.047***
$\beta_1$	-0.027***	-0.002***	-0.068***	-0.069***
$\beta_2$	-0.009***	-0.008***	-0.012***	-0.013***
$\beta_3$	-0.014***	-0.009***	-0.013***	-0.011***
$\beta_4$	0.004***	0.026***	-0.001***	0.006***
$\gamma_{11}$	-0.027***	-0.014***	-0.004***	-0.007***
$\gamma_{12}$	0.000	0.001*	0.003***	0.002***
$\gamma_{13}$	-0.001***	-0.004***	-0.007***	-0.007***
$\gamma_{14}$	-0.015***	-0.006***	-0.011***	-0.008***
$\gamma_{22}$	0.008***	0.007***	0.005***	0.004***
$\gamma_{23}$	0.005***	0.004***	0.005***	0.005***
$\gamma_{24}$	-0.001***	0.001***	0.002***	0.002***
$\gamma_{33}$	0.008***	0.011***	0.014***	0.015***
$\gamma_{34}$	0.009***	0.007***	0.005***	0.005***
$\gamma_{44}$	0.030***	0.035***	0.032***	0.035***
$\rho_1$			0.964***	-0.002***
$\rho_2$			0.410***	0.001***
$\theta_{11}$			-0.003***	0.001***
$\theta_{21}$			0.001*	-0.009***
$\theta_{31}$			0.002***	0.010***
$\theta_{41}$			-0.006***	-0.006***
$\theta_{21}$			-0.006***	0.001***
$\theta_{22}$			0.001	-0.005**
$\theta_{32}$			0.002***	0.010***
$\theta_{42}$			-0.004***	0.942***
$\lambda_1$		-0.017***		0.004***
$\lambda_2$		-0.001***		0.001***
$\lambda_3$		-0.003***		-0.003***
$\lambda_4$		-0.014***		-0.011***
$\nu_1$	-0.012***	-0.011***	0.010***	0.008***
$\nu_2$	-0.003***	-0.004***	-0.003***	-0.003***
$\nu_3$	0.006***	0.005***	0.002***	0.003***
$\nu_4$	-0.014***	-0.015***	-0.005***	-0.008***

*Note.* Authors' calculations; Database is IES 1993–2008. \* Significant at 10 percent, \*\* Significant at 5 percent, \*\*\* Significant at 1 percent.

**Table 1. 13 Comparison of Base and Demographic QUAIDS elasticities**

	Income elasticities		Price elasticities	
	Base	Demographic	Base	Demographic
Food	0.991 [0.990; 0.992]	0.415 [0.376; 0.445]	-1.083 [-1.085; -1.081]	-0.972 [-0.975; -0.969]
Electricity	0.703 [0.701; 0.705]	0.507 [0.505; 0.509]	-0.714 [-0.715; -0.713]	-0.811 [-0.813; -0.810]
Other fuels	0.749 [0.748; 0.750]	0.724 [0.723; 0.725]	-0.686 [-0.690; -0.680]	-0.559 [-0.560; -0.558]
Car fuels	1.520 [1.518; 1.522]	0.832 [0.831; 0.833]	-0.305 [-0.307; -0.303]	-0.084 [-0.085; -0.083]
Other goods	0.991 [0.990; 0.992]	1.136 [1.133; 1.139]	-0.930 [-0.935; -0.925]	-1.044 [-1.045; -1.043]

*Note.* Average values of the variables and lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 1993–2008.

**Table 1. 14 Comparison of rural and urban households' elasticities**

	Income elasticities		Price elasticities	
	Rural	Urban	Rural	Urban
Food	0.611 [0.601; 0.621]	0.519 [0.515; 0.523]	-1.004 [-1.010; -0.980]	-0.995 [-0.998; -0.992]
Electricity	0.445 [0.436; 0.454]	0.486 [0.482; 0.490]	-0.788 [-0.792; -0.784]	-0.766 [-0.768; -0.764]
Other fuels	0.793 [0.783; 0.803]	0.701 [0.699; 0.703]	-0.582 [-0.587; -0.573]	-0.556 [-0.558; -0.554]
Car fuels	0.549 [0.542; 0.556]	0.868 [0.866; 0.870]	-0.146 [-0.150; -0.142]	-0.068 [-0.070; -0.066]
Other goods	1.138 [1.135; 1.141]	1.131 [1.130; 1.132]	-1.047 [-1.050; -1.044]	-1.043 [-1.045; -1.041]

*Note.* Average values of the variables and lower and upper bound of 95 percent confidence intervals are provided. Rural dummy is included as a demographic variable in the demand system estimation. Rural households are those living in areas with fewer than 20,000 inhabitants. Database is IES, 1993–2008.



**Table 1. 15 Comparison with previous literature estimates**

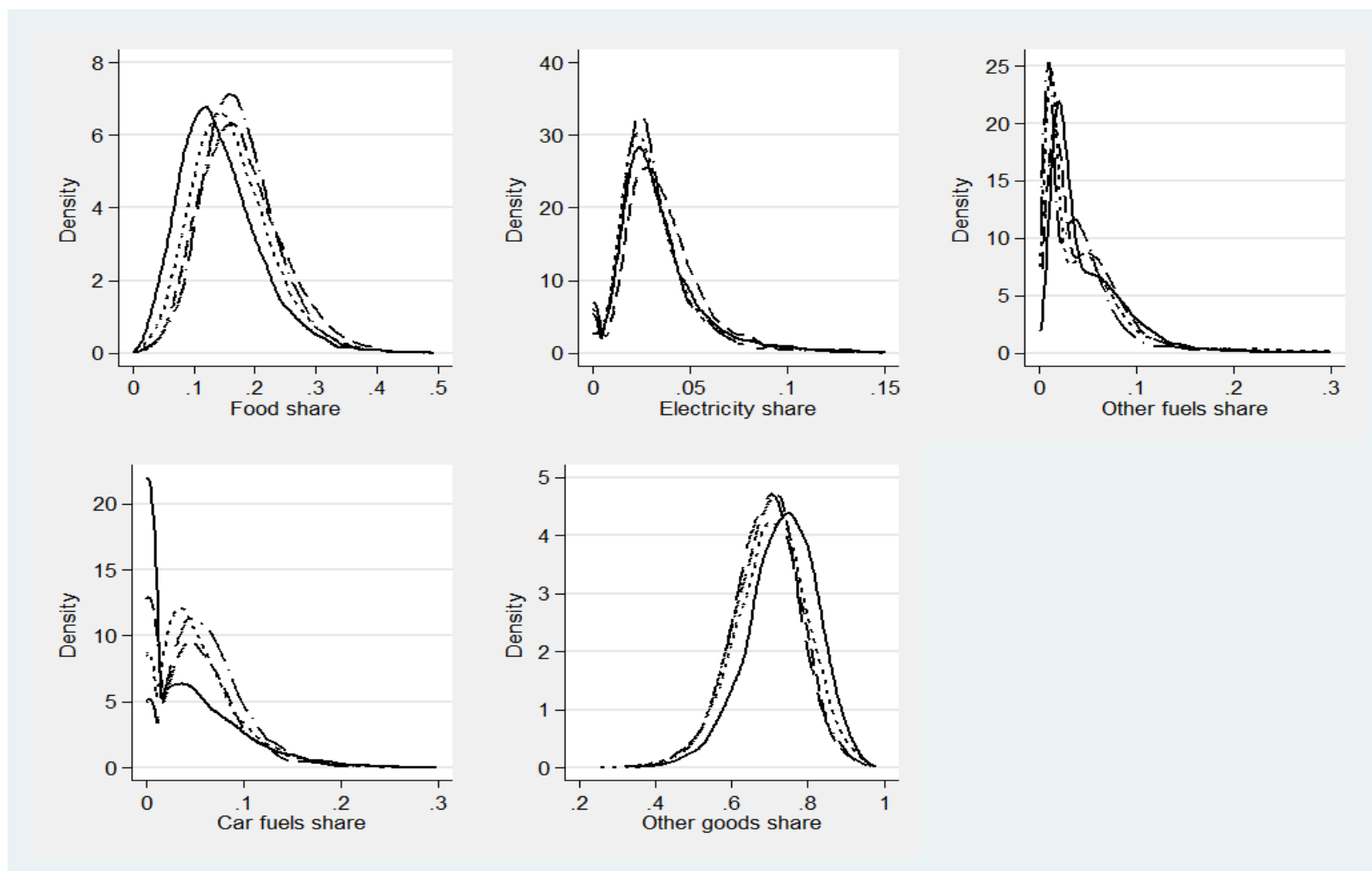
Studies	DQUAIDS 5 Germany	Bränlund et al. (2004)	Banks et al. (1997)	Kohn and Missong (2003)	Labandeira et al. (2006)	Beznoska (2014)
Income elasticities						
Food	0.415	0.770	0.568	0.684	0.600	-
Electricity	0.507	0.830	-	-	0.811	0.840
Other fuels	0.724	1.290	-	-	0.621	1.230
Car fuels	0.832	1.060	0.475	1.236	1.790	0.810
Other goods	1.136	1.490	1.261	1.532	-	1.010
Price elasticities						
Food	-0.972	-0.840	-0.959	-0.326	-0.422	-
Electricity	-0.811	-0.710	-	-	-0.797	-0.680
Other fuels	-0.559	-0.610	-	-	-0.207	-0.910
Car fuels	-0.084	-0.920	-0.804	-0.385	-0.110	-0.500
Other goods	-1.044	-0.860	-0.683	-0.465	-	-1.080

*Note.* Elasticities estimates are taken from the relevant studies.

**Table 1. 16 Compensating variation with 50 and 25 percent tax decrease, and 25 and 50 percent tax increase**

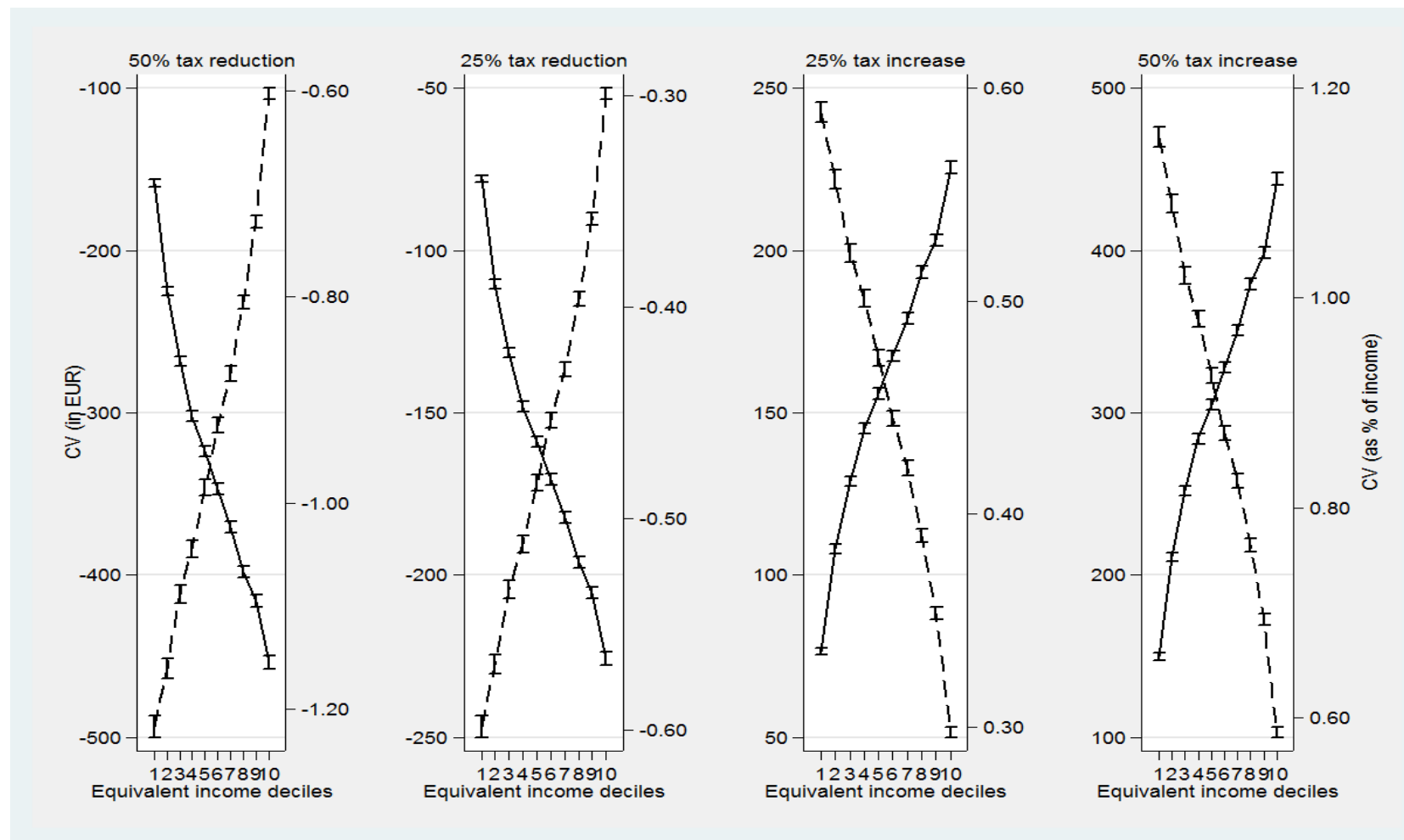
	Tax rate (in EUR/l)	CV (in EUR)
50 percent tax reduction	0.303	-303.014 [-304.347; -301.680]
25 percent tax reduction	0.455	-149.102 [-149.761; -148.443]
25 percent tax increase	0.758	146.727 [146.072; 147.382]
50 percent tax increase	0.909	287.494 [286.204; 288.784]

*Note.* Average values of the variables and lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 2008.



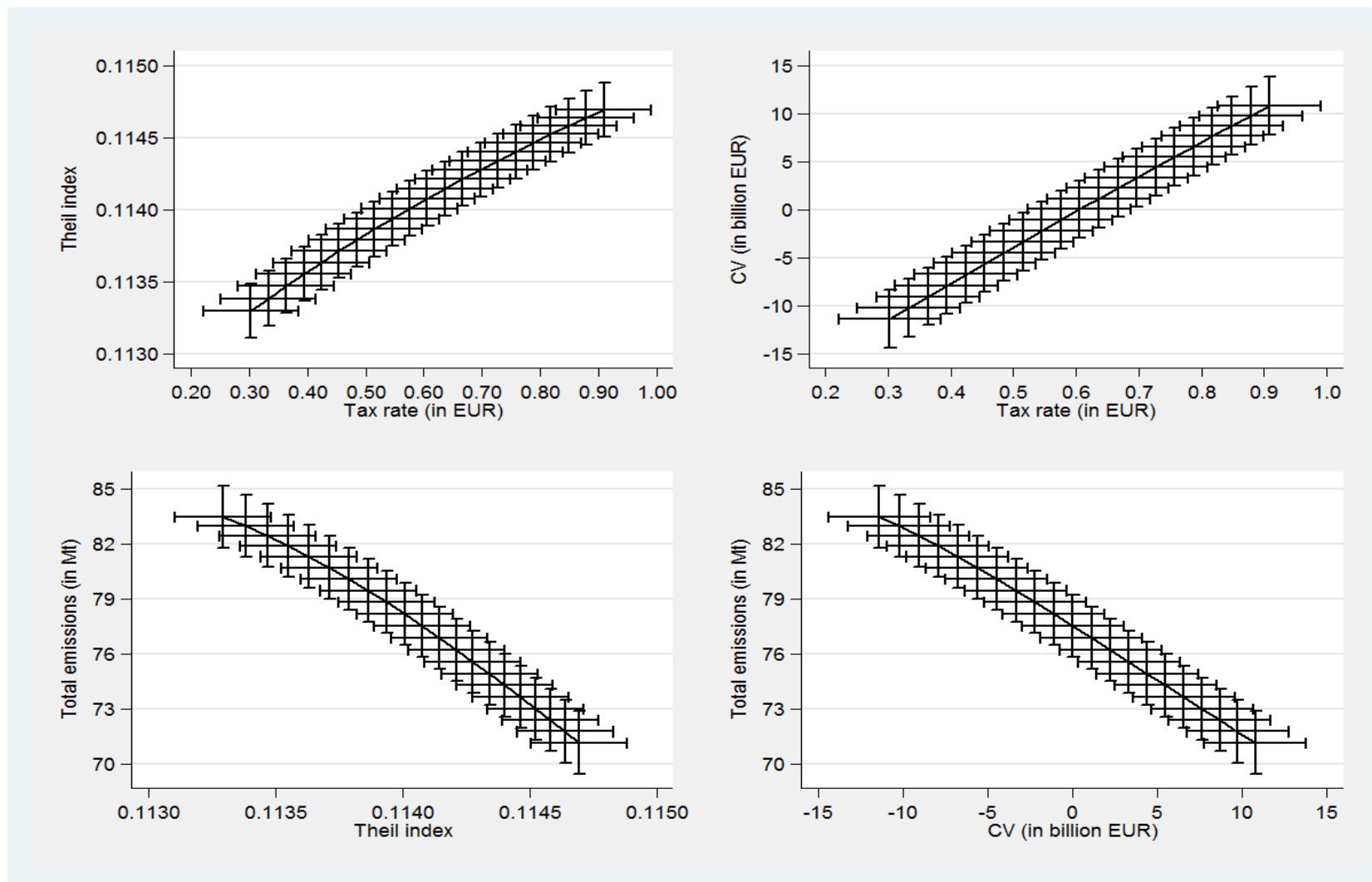
**Figure 1.5** Density functions for the expenditure shares

*Note.* Database is IES, 2008. Solid line: household type 1 – single adults; dashed line: household type 2 – single parents; dotted line: household type 3 – two adults with no children; dashed and dotted line: household type 4 – two or more adults with children.



**Figure 1. 6 Four scenarios: effects on compensating variation**

*Note.* Average values of CV and lower and upper bound of 95 percent confidence intervals are provided. Solids line stands for CV in euros and the size can be read from the left y axis while the dashed line stands for CV as percentage of income, and the size can be read from the right y axis. Database is IES 2008.



**Figure 1. 7 The relationship between tax rate, emissions, Theil index, and CV**

*Note.* Average values of the inequality index and total emissions; as well as lower and upper bound of 95 percent confidence intervals are provided. Database is IES, 2008.



## **Chapter 2**

# **How Electricity Prices Alter Poverty and CO<sub>2</sub> Emissions – The Case of Germany**

### **2.1 Introduction**

Energy poverty, defined as lack of (adequate) energy services, is present and growing concern both in developing and developed countries in cold climate regions. In Darby (2013), the definition of energy poverty is the inability to heat the home up to a socially and materially necessitated level. Energy poverty can have severe consequences, ranging from rationing of energy consumption and cold homes (affecting human health and quality of life) to potential energy debts and reduction of other budgets like food (Dubois, 2012). In particular, Murray (2012) finds evidence of the heat or eat behavior among poor U.S. households.

Growing energy prices and low incomes are usually found to be associated with energy poverty. Those factors have been present even in developed countries such as the U.K. and Germany. The results of Palmer et al. (2008) confirm that high fuel prices and income poverty, as well as poor energy efficiency of dwellings are major factors behind energy poverty in England. In Germany, the electricity prices have been constantly growing in recent years and are among the highest in Europe nowadays. The International Energy Agency (IEA, 2013) warns that between 2007 and 2011 the constant and the nominal electricity prices in Germany increased by 40 and 60 percent respectively. Neuhoff et al. (2013) find that poor German households suffer the most from the increase in the electricity price, which is caused by increases in the Renewable Energy Act Surcharge (EEG-Umlage), which is part of the electricity bill.<sup>39</sup> Taxes and surcharges constituted 45 percent of the final consumer price for electricity in 2013 (IEA, 2013). Schumacher et al. (2015) discern that an increasing number of

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<sup>39</sup> For details on the composition of households' electricity price in Germany, refer to Section 2.4.

German households cannot afford to pay their energy bills due to increasing prices of necessities like electricity<sup>40</sup> and housing, and stagnating incomes. In addition, the risk of income poverty in Germany has increased by 12.1 percent: from 14 percent in 2006 to 15.7 percent in 2015 (Statista (2016)). Up-to-date, most of the studies for Germany measure poverty based on disposable equivalent income, i.e. income after income taxes plus transfers, adjusted for household size. Grabka et al. (2015) find that the risk of poverty among the German population grew considerably between 2000 and 2009 but stagnated between 2010 and 2012. The results of Grabka et al. (2012) show that young adults among the age groups and single adults and single parents among the household types are at highest poverty risk. However, none of those studies have considered the potential effect of energy taxes or energy expenditures on poverty in Germany.

Energy and (or) environmental taxes and surcharges have been introduced in many European countries, with the aim to reduce energy consumption and to finance a greener energy production. In Germany, one of the pioneer countries when it comes to renewable energy, the Renewable Energy Act Surcharge (EEG Umlage)<sup>41</sup> is implemented since 2000 as means to finance the production of electricity from Renewable Energy Sources (RES). The EEG surcharge is calculated as the difference between the Feed-in-Tariffs (FITs) paid by utilities for renewable energy and the revenues from sales of that energy. This surcharge is also the main driver of the electricity price increase in Germany (the EEG surcharge has increased by 80 percent increase since 2001 while the before tax electricity price only by 2 percent). Neuhoff et al. (2013) find that because of the raising surcharge, electricity share in spending will increase to 2.5 percent in 2013, 0.5 percent of which is the surcharge.

This paper contributes to the existing literature in several ways. First of all, income poverty is measured by taking energy taxes and surcharges into consideration. Secondly, the development of energy poverty among German households is analysed. In addition, the impact of income poverty on energy poverty is studied with a probit model. Third of all, the impact of energy taxes on income poverty and energy poverty is further scrutinized with the help of tax simulations, which rely on estimates from an energy demand system. Furthermore, the paper uses a very recent data set and focuses on measuring energy poverty in Germany unlike the previous studies which just compared a set of indicators, without providing a concrete conclusion. Last but not least, the relationship between poverty and energy taxes is

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<sup>40</sup> The study states that in 2011 alone, 322,000 cases of disconnection from the electricity grid have been reported and this number might be even higher in reality.

<sup>41</sup> The Renewable Energy Act (EEG) was introduced to ensure sustainable energy supply for the future and development of technologies for the generation of electricity from renewable energy sources (RES). For more details see Federal Ministry of Justice and Consumer Protection, 2016.

graphically analysed by considering the trade-offs between poverty and energy surcharges or taxes.

The descriptive evidence reveals that income poverty, measured at the individual level, has increased by around 31.6 percent between 1993 and 2013. That is, if the headcount ratio is calculated using disposable equivalent income and 60 percent of the median disposable equivalent income is used as the poverty line. Once the headcount ratio is calculated on disposable equivalent income after electricity taxes and car fuels taxes, income poverty is higher for all years.<sup>42</sup> On top of less income available to meet the needs for necessities, the price of electricity for households increased from 0.143 euros/kWh in 1993 to 0.268 euros/kWh in 2013 (87 percent price growth over 20 years period). So the increasing prices of electricity, other energy goods, and housing, made it gradually more difficult for low-income households to afford their energy bills, which in turn led to growing energy poverty among German households. Energy poverty, using the ten percent rule (TPR) of energy expenditures share in income, has more than tripled in the period 1993–2013. Energy poverty is particularly pronounced among single parent households, households with unemployed or self-employed leaders, and households in rural areas. Probability of becoming energy poor is confirmed to be higher for the aforementioned categories of households as well as for households which are income poor. The elasticities obtained from the energy demand system indicate that electricity is a necessity good in Germany, with moderately low price elasticity (−0.235) that is especially low among high income households (−0.174).

The paper investigates four alternative policy scenarios: doubling of the EEG surcharge, abolishing of the EEG surcharge, doubling or abolishing of the car fuels tax (CFT) accompanied by equivalent change in EEG. Doubling of the surcharge increases the electricity tax burden for all income deciles but the increase is highest percentage of income for the poorest households. Both income and energy poverty would increase by 1.4 and 13.3 percent respectively while CO<sub>2</sub> emissions coming from electricity decrease by around 9 percent. Doubling of both the CFT and the EEG surcharge, leads to 5.1 percent increase in income poverty and 55.1 percent increase in energy poverty. Under such reform, CO<sub>2</sub> emissions would be 9.1 percent lower than in the status quo. If on the contrary the EEG is abolished, electricity related emissions would increase by around 6 percent. Energy poverty will decrease by 10.4 percent and income poverty will be 1.8 percent lower. The poorest households would benefit from elimination of the electricity tax also by having lower energy

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<sup>42</sup> The poverty lines are defined to be 60 percent of the median disposable equivalent income and 60 percent of the median disposable equivalent income after energy taxes respectively.



tax burdens. When the CFT is also abolished, income poverty and energy poverty decrease by 7.2 and 48.7 percent respectively and electricity related emissions increase by 12.3 percent.

The rest of the study is structured as follows: Section 2.2 provides an overview of the existing literature while Section 2.3 describes the data. Section 2.4 outlines the estimation methods and Section 2.5 provides an overview of the empirical evidence. The scenarios' design and results are outlined in Section 2.6 and Section 2.7 concludes the paper.

## 2.2 Literature review

There is a substantial set of international literature on energy poverty, the impacts of energy taxes (or surcharges) on the income distribution or on the environmental deterioration. Table 2.8 in the Appendix provides an overview of all the relevant household level studies, which deal with energy demand, distributive effects, energy poverty, or emissions analyses.

It is often argued that poor households spend a larger share of their income on energy taxes than rich households implying that energy taxes have regressive effects. According to this argument, higher energy taxes would affect the lower income households particularly hard (Flues and Thomas (2015)). One stream of the literature relies on the development of electricity tax burden across income deciles to investigate its impact on the income distribution, while ignoring the behavioral responses of the households. For instance, Jacobsen et al. (2003) find that taxing electricity as a necessity good harms the lowest income groups more than the richer ones in Denmark. Flues and Thomas (2015) also provide evidence that electricity taxes are regressive in Germany. Withana et al. 2013 finds that in terms of distributional impacts, the electricity tax in Germany (as part of the Environmental Tax Reform-ETR) has demonstrated elements of regressivity.<sup>43</sup>

Other studies<sup>44</sup> investigate the impact of electricity taxes or surcharges by employing demand systems with the aim to include behavioral reactions while providing partial equilibrium analyses (restricted to the household sector only). Two such papers have considered the effects of electricity tax changes. Combining energy demand system and tax simulations, Brännlund and Nordström (2004) find evidence that a CO<sub>2</sub> tax on electricity is regressive in Sweden. Gahvari and Tsang (2011) prove that an energy tax (on electricity) is

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<sup>43</sup> ETR schemes in Denmark, Finland, Ireland and British Columbia were also found to be regressive.

<sup>44</sup> Studies that deal with demand systems (including behavioral responses) and impact of energy taxes on the income distribution include West and Williams III (2004), Beznoska (2014), Tiezzi (2005), Dumagan and Mount (1992), et cetera. Filipinni (1995) and Kohn and Missong (2003) estimate energy demand systems but refrain from distributional or poverty analyses.

detrimental for consumer welfare in the U.S., in spite of its environmental benefits. Neither of those studies have conducted detailed poverty analyses.

Even though many studies<sup>45</sup> have investigated the impact of energy taxes (including but not limited to electricity tax) on the income distribution, the effects of taxes or surcharges on poverty has barely received any attention in the existing literature. The only study I came across is the one of Klauss (2016), which by means of partial equilibrium model estimates how an energy price change influences poverty. Using Armenian data, the author finds that 40 percent increase in the gas price leads to 2.8 percent higher poverty among households and 8 percent of households shifting away from gas. Still, he does not consider the separate effects of energy taxes on poverty nor does he consider the behavioral responses of households. Meyer and Sullivan (2009) have analysed the impact of income taxes on poverty in the U.S. Their results confirm that poverty has declined due to changes in the income tax policy, particularly for families with children.

Fourth set of research deals with the determinants of energy poverty and the role of energy expenditures (including taxes and surcharges) in pushing individuals or households below the poverty line. Legendre and Ricci (2015) propose a fuel vulnerability definition: households are fuel vulnerable if they are pushed into income poverty because of their domestic (heating) energy expenses. The authors estimate a logit model on the probability of being fuel poor in France and find evidence that the probability is higher for retired people, single adult households, tenants, and households with low energy performance of their dwelling. Having higher education and using district heating systems are associated with lower chance of becoming fuel poor.

A fifth stream of literature investigates the overlap between income poverty and energy poverty, as well as the other determinants of energy poverty in partial equilibrium settings. Gonzales-Eguino (2015) claims that energy poverty is a reflection of both income inequality and income poverty. Households with low income have lower or inadequate energy consumption and are unable to invest in electric appliances and housing improvements, which is then manifested as energy poverty. Energy poverty could create a poverty trap and hence, the author recommends that energy poverty should be reduced by reducing absolute (income) poverty. Palmer et al. (2008) shown that in 2005, 75 percent of the fuel poor in England were also income poor. The authors find descriptive evidence that being a single adult (both working age and pensioners) or being a rural poor household is a big factor behind fuel

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<sup>45</sup> Other studies which deal with the distributive effects of energy taxes include: Araar et al. (2014), Oladisu and Rose (2007), Grösche and Schröder (2014), and many others.

poverty in England. A significant relationship between energy poverty and income poverty is also found in Papada and Kaliampakos (2016) for Greek households. Households under the income poverty threshold are much more likely to be energy poor (9 out of 10 households) than households above the threshold (4 out of 10 households). Heindl (2014) finds that half of the German households which are identified as fuel poor are pushed below the poverty line after expenditures on energy.

## 2.3 Data description

### 2.3.1 Income concepts for the poverty analyses

The Income and Expenditure Survey (IES) represents a comprehensive cross-sectional dataset, containing in-depth information on income, expenditures and characteristics of households in Germany. The households are asked to record their disposable income and wealth accumulation during the whole year. In addition, since 1998 they report expenditures on non-durables such as food during a four week period, while for some durable commodities or fuels they report their annual expenditures.

The focus is put on the most recent waves after the reunification of Germany, namely 1993, 1998, 2003, 2008, and 2013. The 2013 wave of the IES has become available only recently and this study is among the first ones to use it in such detailed poverty and energy demand analyses. As there are differences in the classification of the goods and also in the households characteristics between the five surveys, achieving comparability and including the 2013 data wave was a complex assignment. The data waves must be high quality, comparable, and random so that to ensure that the requirements for an estimation of the energy demand system are met. Expenditures categories were carefully aggregated by following the original survey definitions and the same procedure was applied for the demographic characteristics across all five waves. After the data cleaning, 219,826 households, across five time periods, are incorporated in the empirical analyses.<sup>46</sup> Several household types are formed according to the number and age of household members: household type 1 – single adults; household type 2 – single parents; household type 3 – two adults no children; household type 4 – two and more adults with children.

Before calculating the poverty indicators, the development of income, energy tax burdens, and energy expenditures should be considered (see Table 2.1). Energy expenditures

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<sup>46</sup> Please refer to Section 1.3.1 in Chapter 1 for the specificities of the IES data preparation.

are important for the calculation of the income poverty and energy poverty indicators. Disposable income has been steadily increasing (in nominal terms) between 1993 and 2008 but between 2008 and 2013 it stagnated. Disposable equivalent income (disposable income adjusted according to the modified OECD equivalence scale) has also been steadily increasing due to growing income but also to decreasing household size. While income grew by around 37 percent, electricity expenditures increased on average by 52 percent; car fuels expenditures more than doubled during the twenty years period. Total energy expenditures (including electricity, car fuels, gas and central heating) increased by 64 percent by 2013 relative to 1993. The tax burden for car fuels was around 330 euros in 1993 and reached 571 euros in 2013 and the electricity tax and surcharge burden was around 42 euros in 1993 but reached 274 euros in 2013, demonstrating that the average German household has been faced with constantly increasing burdens for energy goods.

**Table 2. 1 Development of variables relevant for measuring poverty**

	1993	1998	2003	2008	2013
Variable	Mean				
<i>ydisp</i>	28708.220	31426.280	33898.480	34692.720	36805.630
<i>ydisp<sub>eq</sub></i>	18210.710	20479.610	22324.790	23233.660	24929.150
<i>e<sub>electricity</sub></i>	554.758	521.153	601.535	694.849	840.644
<i>e<sub>car fuels</sub></i>	661.077	639.048	836.839	1089.509	920.666
<i>e<sub>energy</sub></i>	604.102	771.925	990.534	1174.111	1229.165
<i>t<sub>electricity</sub></i>	41.549	29.014	76.795	119.111	273.607
<i>t<sub>car fuels</sub></i>	329.308	456.179	698.937	611.335	570.766

*Note.* Dataset is IES 1993–2013. *ydisp* is disposable income, *e* and *t* stand for expenditures and tax burden. Weighted to assure representativeness of the German population.

### 2.3.2 Variables for the demand system

The following IES variables are needed for the demand system estimation: expenditures shares of food (food at home and food at restaurants) and nonalcoholic drinks; expenditures shares of electricity; expenditures shares of other fuels (gas, district heating, liquid and fossil fuels); expenditures shares of car fuels (gasoline and diesel); expenditures shares of residual expenditures (including education, leisure, furniture, hygiene products, communication, and housing); total expenditures (the sum of all expenditures); number and age of household members; place of residence; and frequency weights.<sup>47</sup> Then the IES data

<sup>47</sup> For descriptive statistics of the variables necessary for the demand system, refer to Table 2.9 in the Appendix. Table 2.10 includes the same variables across the different household types.

has to be combined with consumer prices, and in particular Stone Price Indices (SPIs) for the specific expenditures categories.<sup>48</sup>

## 2.4 Estimation techniques: A Demographically-Scaled Quadratic Almost Ideal Demand System (DQUIDS), price elasticities, and scenarios analyses

In order to assess the effects of a policy change, a reliable framework is provided by a demand system because it allows for consumer behavior responses while it satisfies some necessary economic assumptions. Out of the many different types of demand systems, a Demographically-Scaled Quadratic Almost Ideal Demand System (DQUAIDS)<sup>49</sup> is chosen for the analyses because of its desirable empirical properties outlined in Section 1.4.1 of Chapter 1.

As mentioned earlier, it is crucial to obtain price elasticities for the scenario analyses. The own and cross price elasticities are useful because they express the effect of price or tax change i.e. the percentage change in energy consumption that would result from one percent change in the price of specific good. Here, the elasticities from a DQUAIDS were obtained.<sup>50</sup> Namely, the uncompensated price elasticity is calculated in the following manner:

$$\varepsilon_{ij}^u = \frac{\mu_{ij}}{w_i} - \delta_{ij} \quad (2.1)$$

where,

$$\mu_{ij} \equiv \frac{\partial w_i}{\partial \ln(p_j)} = \gamma_{ij} - \mu_i(\alpha_j + \sum_{k=1}^n \gamma_{jk} \ln(p_k)) - \left\{ \frac{(\lambda_i(\beta_j + \sum_{s=1}^t \theta_{is} z_s))}{b(p)c(p,z)} \right\} \{(\ln(m) - \ln(a)) - \ln(1 + \sum_{s=1}^t \rho_s z_s)\}^2, \quad (2.2)$$

and  $w_i$  is the expenditure share of good  $i$  in total expenditures  $m$ ;  $p_j$  stands for the price of the good  $j$ ;  $a(p)$  is the subsistence level;  $z_s$  stands for the demographic variables;  $s = 1, \dots, t$  denotes the number of demographic variables;  $b(p)$  represents the bliss level;  $c(p, z)$  is a

<sup>48</sup> Table 2.9 in the Appendix provides summary statistics of the logarithm of prices for the years 1993–2013.

<sup>49</sup> For details on methodology, please refer to the Sections 1.4.1 and 1.9.2 of Chapter 1.

<sup>50</sup> The paper closely follows Banks et al. (1997), Ray (1983), Blacklow et al. (2010), and Poi (2012) estimation techniques while it corrects for potential endogeneity (see Section 1.9.2.2 of the Appendix in Chapter 1). In order to ease notation, household and time period subscripts are suppressed.

simple Cobb-Douglas price aggregator;<sup>51</sup>  $\alpha_i, \beta_i, \gamma_{ij}, \rho_i, \theta_i, \lambda_i$  are the parameters estimated from the demand system, and  $\delta_{ij}$  is the Kroneker delta,  $\delta_{ij} = 1$  for  $i = j$  and 0 otherwise.

Once the demand system estimates and the elasticities are obtained, scenarios involving different electricity price change reforms are considered. Before that the breakdown of the final electricity price for households is considered. The Agency for the Cooperation of Energy Regulators (ACER) defines post-tax total prices (POTP) as the sum of the commodity price, regulated transmission and distribution charges, and retail components (billing, metering, customer services, and a fair margin on such services) plus value-added tax, levies (local, national, and environmental), and any other surcharges.<sup>52</sup>

The following equation illustrates the breakdown of electricity price for German households in 2013:

$$p_e = (p_p + ED_e + EEG_e + CF_e) * (1 + VAT) \quad (2.3)$$

where  $p_p$  represents the producer price, it was 0.143 euros per kWh (which included the costs of energy procurement and sales, network charges, measurement and billing;  $ED_e$  denotes the electricity tax or duty,<sup>53</sup> which amounted to 0.0205 euros per kWh;  $EEG_e$  stands for the Renewable Energy Act Surcharge, which amounted to 0.0528 euros per kWh;  $CF_e$  denotes the concession fee, which was 0.0179 euros per kWh;  $VAT$  denotes the value added tax.<sup>54</sup> The final consumer price,  $p_e$ , was 0.268 euros per kWh in 2013, which is among the highest electricity prices in Europe.

To explore the effects of electricity price change through changes in the German EEG surcharge, the approach of Banks et al. (1997) is used. The amount of the EEG surcharge is changed upwards or downwards, and then the after-price change expenditure functions, indirect utility function, subsistence, and bliss levels are derived (all of these functions are available in the Appendix of Chapter 1: Section 1.9.2.1). The effects of the price change on income poverty, energy poverty, energy tax burdens, and CO<sub>2</sub> emissions are considered. In several scenarios, the price of car fuels is also changed together with the electricity price.

<sup>51</sup> For details concerning the subsistence and bliss levels, cost function, indirect utility function, please refer to Section 1.9.2.1 in the Appendix of Chapter 1.

<sup>52</sup> See International Energy Agency (2013).

<sup>53</sup> The electricity duty, as part of the Germany's Ecological Tax Reform, is imposed on the basis of the Electricity Duty Act of 24 March 1999 and the Electricity Duty Implementing Ordinance of 31 May 2000. See Federal Ministry of Justice and Consumer Protection, 2014b and 2014c.

<sup>54</sup> The Value Added Tax is imposed on the basis of the Value Added Tax Act of 15 July 2006. See Value Added Tax Act, Federal Ministry of Justice and Consumer Protection, 2014. See Federal Ministry of Justice and Consumer Protection, 2014d.

In order to measure income poverty, the paper implements the Foster, Greer, and Thorbecke (FGT) indicator. The general formula of the FGT indicator takes the following form:<sup>55</sup>

$$FGT_{\alpha} = \frac{1}{n} \sum_{i=1}^q \left( \frac{z - y_i}{z} \right)^{\alpha} \quad (2.4)$$

$n$  is the population size,  $q$  represents the number of poor (households with income below the poverty line  $z$ ),  $y_i$  is the household income and  $\alpha$  represents the sensitivity parameter. If  $\alpha$  is set at zero, one obtains measure of the headcount ratio (proportion of households which fall below the poverty line). If  $\alpha$  is set to one, the poverty gap is obtained and if it set at two, the squared poverty gap is computed. The poverty gap indicator shows how far below the poverty line households are affected and indicates whether the situation has improved i.e. if the poor move closer to the poverty line. The squared poverty gap indicator considers both the distance separating the poor from the poverty line and the inequality among the poor (higher burden is put on households far away from the poverty threshold). The depth and severity of poverty are hence measured with the poverty gap and squared poverty gap indicators. To see the effect of changes in the price of electricity on poverty, the change in the poverty measure on disposable equivalent income net of energy taxes is computed before and after the price change.

The paper goes one step further by incorporating energy taxes in the poverty analyses. Both  $z$  and  $y_i$  from equation (2.4) are assumed to be affected by energy taxes. The poverty line,  $z$ , is chosen to be 60 percent of the median disposable equivalent income<sup>56</sup> after energy taxes.  $y_i$  is also lower by the amount of energy taxes (including electricity and car fuels taxes). In the tax simulation scenarios, the poverty line remains unaffected by a change in a specific energy tax. The amount of disposable equivalent income changes with the tax change. The poverty levels before the tax change (status quo) are calculated in the following manner:

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<sup>55</sup> See Foster et al. (1984).

<sup>56</sup> Disposable equivalent income is disposable income divided by modified OECD equivalence scale  $(1 + 0.5 * (n_{adults} - 1) + 0.3 * n_{children})$ .

$$FGT_{\alpha}^0 = \frac{1}{n} \sum_{i=1}^q \left( \frac{(0.6 * r50(\frac{ydisp^0 - t_{energy}^0}{scale}) - (\frac{ydisp^0 - t_{energy}^0}{scale}))}{(0.6 * r50(\frac{ydisp^0 - t_{energy}^0}{scale}))} \right)^{\alpha}. \quad (2.5)$$

The poverty levels after the tax change are calculated in the following manner:

$$FGT_{\alpha}^1 = \frac{1}{n} \sum_{i=1}^q \left( \frac{(0.6 * r50(\frac{ydisp^0 - t_{energy}^0}{scale}) - (\frac{ydisp^0 - t_{energy}^1}{scale}))}{(0.6 * r50(\frac{ydisp^0 - t_{energy}^0}{scale}))} \right)^{\alpha}, \quad (2.6)$$

where  $r50$  indicates the median value,  $scale$  stands for the modified OECD equivalence scale, superscript zero means before the tax change (status quo) and superscript one indicates after the tax change.

Households that live with inadequate amount of energy services are defined as energy poor. Any energy poverty definition should take into account equalized incomes, housing cost, fuels costs, and minimum income standards (MIS). Following Heindl (2014) and sources therein, I use two alternative measures of energy poverty (the ten percent rule (TRP) and the twice median expenditure share (2M) rule) that have been proven to have the desirable properties. First, the total energy expenditure share in income is derived:

$$s_{energy} = \frac{e_{electricity} + e_{gas} + e_{car\ fuels}}{ydisp}. \quad (2.7)$$

The ten percent rule (TRP) classifies households that spend more than ten percent of their income on energy services as energy poor. The twice median (2M) rule classifies households as energy poor if their energy expenditures share in income exceed twice the median energy expenditures share of the population. Heindl and Schuster (2015) find that the TRP and the MIS fare well from a dynamic perspective, i.e. they properly measure changes in energy poverty over time. Moore (2012) on the other hand favors relative poverty measures (using multiples of the median energy expenditures) to absolute fuel poverty (using the ten percent of income cutoff).

Following Legendre and Ricci (2015), a probit model could be estimated to empirically test for the factors explaining energy or fuel poverty. The general probit model can be defined as:



$$\Pr(Y = 1|X_1, X_2, \dots, X_k) = \Phi(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k) \quad (2.8)$$

where  $\Pr(Y = 1)$  in this case stands for the probability of being energy poor to be equal to one,  $\Phi()$  is the standard normal cumulative distribution function (cdf) and  $X_i$  are the explanatory variables.<sup>57</sup> The marginal effects from the probit model are not constant (they depends on the position in the distribution) and cannot be directly interpreted.

The environmental criterion involves comparisons of the direct electricity related as well as the direct car fuels related CO<sub>2</sub> emissions for the status quo and the alternative scenarios. The change in tax burdens should measure the impact of the price change on the income distribution.<sup>58</sup> Finally, the relationship between income poverty, energy poverty, and energy taxes is then analysed by means of graphical representations.

## 2.5 Empirical evidence

### 2.5.1 Development of income and energy poverty

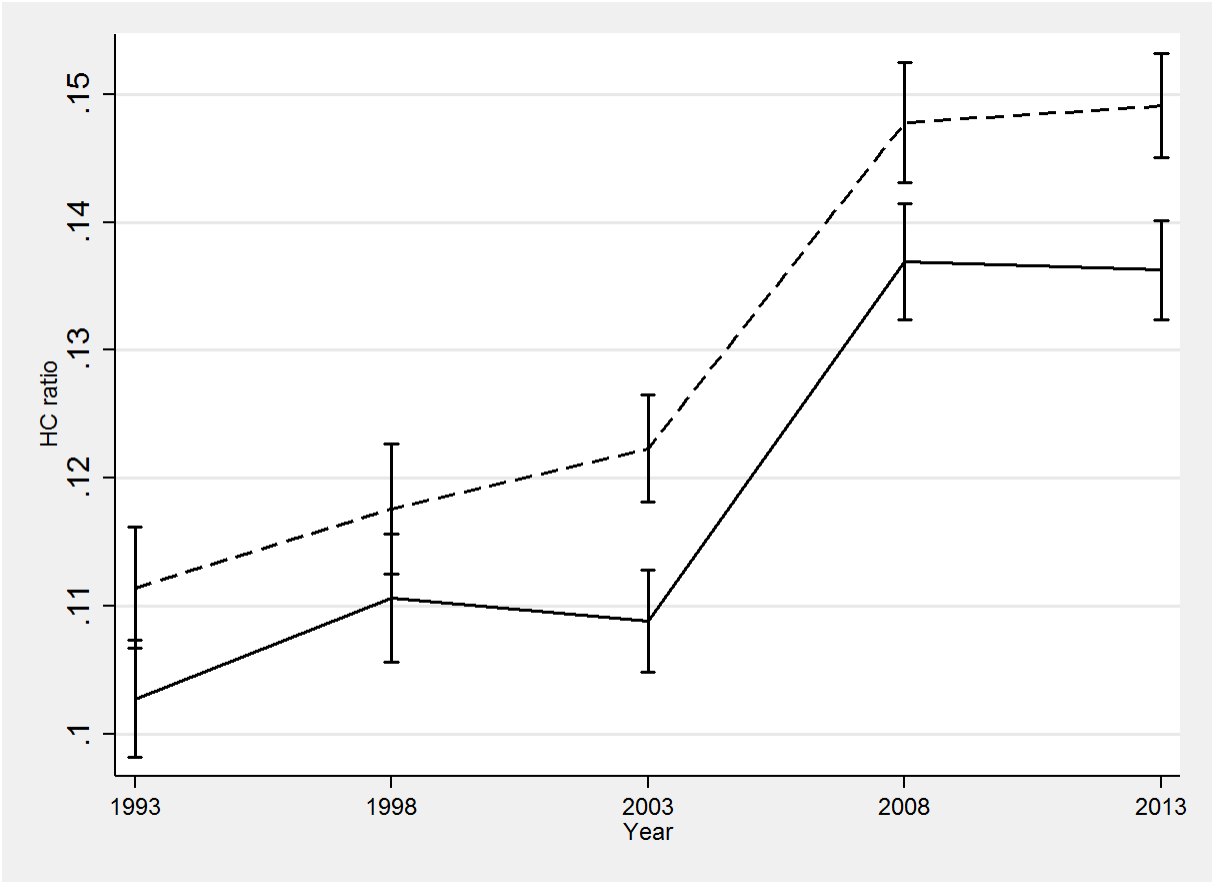
When measuring income poverty, Heindl (2014) recommends to use equivalent income as welfare measure, 60 percent of median income as poverty line and to estimate several poverty indicators. As a next step, poverty in Germany is calculated on disposable equivalent income and disposable equivalent income after energy taxes (electricity and car fuels taxes) using three poverty indices: the headcount ratio, poverty gap, and squared poverty gap. For comparison purposes, poverty is also calculated on equivalent expenditures and equivalent expenditures after energy taxes. Sixty percent of the median of the respective variable (equivalent disposable income or equivalent expenditures) is used as poverty line in both cases.

Figure 2.1 presents the patterns of income poverty over time and it shows an overall upward trend. The headcount ratio (alpha is set to zero in equation (2.4)) indicates that 10.35 percent of individuals were in income poverty in 1993 while the percentage increased to 13.62 in 2013 (solid line). But between 2008 and 2013 poverty did not increase but rather decreased by 0.5 percent. For comparison of those results with other studies on poverty in Germany see Table 2.11 in the Appendix. So, the calculations show that income poverty has grown by 31.59 percent during the past twenty years. The income poverty is higher in every

<sup>57</sup> See Wooldridge (2010), pages 387–388.

<sup>58</sup> See Section 1.4.3 in Chapter 1 for details on how CO<sub>2</sub> emissions and tax burdens are calculated.

following period if income after energy taxes<sup>59</sup> is considered and the gap between poverty measured on income and poverty measured on income after energy taxes widens over time. The headcount ratio calculated on disposable equivalent income after energy taxes is almost ten percent higher than the headcount ratio calculated on disposable equivalent income in 2013. But the overall increase in poverty between 1993 and 2013 is almost the same: 31.27 percent increase (from 11.11 percent in 1993 to 14.91 percent in 2013 (dashed line in Figure 2.1)). The data tables of Statista (2016) also show a slight upward trend for income poverty in Germany in the past ten years. For the U.S., Meyer and Sullivan (2009) find that relative income poverty rose in the early 1980s, but since 1990 the changes in relative poverty have been small.

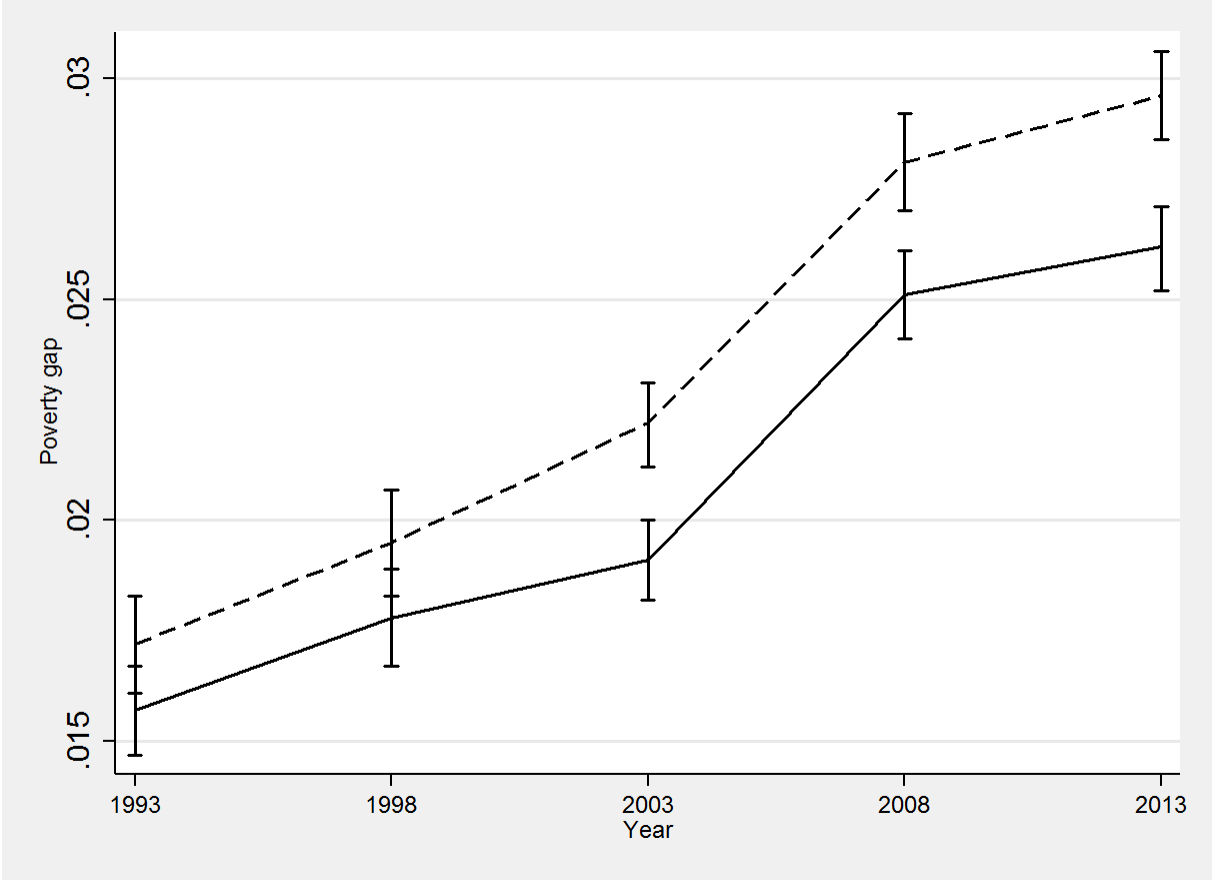


**Figure 2. 1 Headcount ratio over time**

*Note.* Own calculations. Dataset is IES 1993–2013. Solid line stands for poverty calculated on disposable equivalent income while dashed line stands for poverty calculated on disposable equivalent income minus energy taxes. Line segments indicate the 95 percent confidence intervals.

<sup>59</sup> The paper only considers electricity and car fuels taxes. Taxes on gas or district heating are not considered but it is expected that poverty will be even higher if these energy taxes are taken into consideration.

The poverty gap (alpha is set to one in equation (2.4)) and the squared poverty gap (alpha is set to two in equation (2.4)) demonstrate that income poverty in Germany has deepened after 1993. Figure 2.2 shows the upward trend in the poverty gap as indicator of income poverty. While the poverty gap of income after energy taxes is 0.0296 in 2013, it is almost half of that or 0.0172 in 1993. The poor individuals have moved further away from the poverty line in the period between 1993 and 2013. In both cases, poverty is significantly higher when energy taxes are taken into account.



**Figure 2. 2 Poverty gap over time**

*Note.* Own calculations. Dataset is IES 1993–2013. Solid line stands for poverty calculated on disposable equivalent income while dashed line stands for poverty calculated on equivalent income minus energy taxes. Line segments indicate the 95 percent confidence intervals.

Total household’s expenditures should be a proper measure of permanent income. Poverty measured on equivalent expenditures<sup>60</sup> is lower than poverty measured on equivalent income for all three poverty indices. The HC ratio shows percentage of people below the poverty line is 9.31 in 1993, drops to 7.03 percent by 2003 and increases afterwards. If one looks at the expenditures after energy taxes, 10.41 percent of the German population were

<sup>60</sup> Please refer to Figures 2.5 and 2.6 in the Appendix.

poor in 1993, 8.90 percent in 2003, and 9.80 percent in 2013 (HC ratio). The poverty gap indicates that individuals moved closer to the poverty line between 1993 and 2003 and moved further away from the poverty line after 2003.

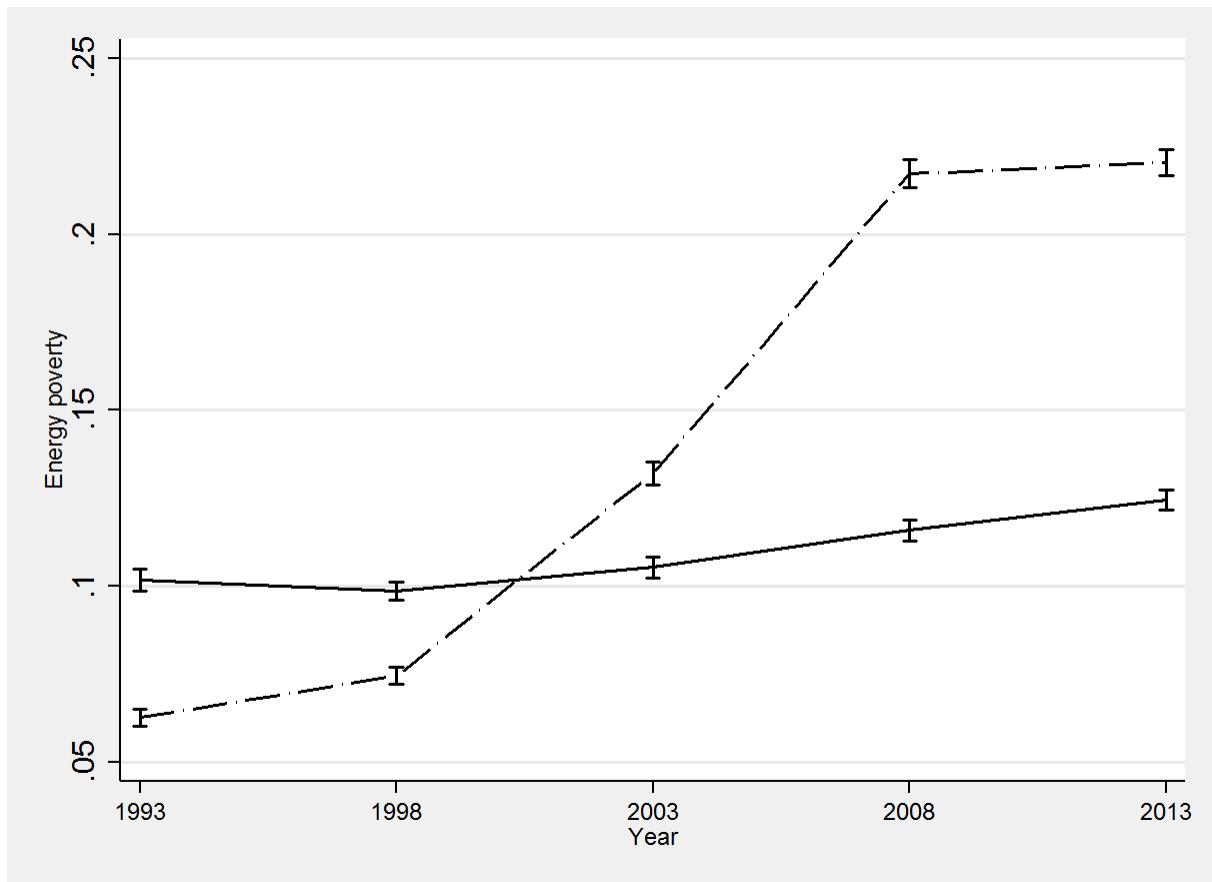
The results further show that energy poverty, as measured by the TPR, was relatively low before 2000: only 6.24 and 7.46 percent of Germans were energy poor in 1993 and 1998 (dashed line on the Figure 2.3). But after the environmental taxes on several energy goods were introduced in 1999, increasing in several steps, the German population became increasingly energy poor and less able to afford their energy bills. By 2003, energy poverty more than doubled in comparison to 1993. In 2013, 22.05 percent of German citizens were under the energy poverty threshold. Still, it is striking that energy poverty in Germany more than tripled during the 1993–2013 period. The increase does appear to be sizeable but if the development of the energy expenditure share in income over time is considered, it is to be expected. The median expenditure share has increased by around 44 percent between 1993 and 2013 and the variance of the expenditure share has also increased. Moreover, the whole distribution of the energy share gets flatter, shifts to the right (including the mode), and the tail gets fatter over time. All of those factors have made it easier for a household to exceed the TPR threshold.<sup>61</sup> Furthermore, as already mentioned all energy prices either doubled or more than doubled during the period and income did not increase enough to compensate for the price increases. There are also large differences in energy expenditures and poverty between the households living in east and west Germany, with households in the east having larger increases in expenditures and poverty relative to the west.

The second energy poverty indicator indicates whether energy expenditures are higher than twice the median expenditures – following the 2M rule. An interesting observation is that the 2M rule actually coincides with TPR for the years 1993 and 1998. The development of this energy poverty indicator demonstrates a more stable development between 1993 and 2013 but still an upward trend (solid line in Figure 2.3). In 1993, 10.17 percent of individuals were energy poor while 9.85 percent were poor in 1998. These numbers are slightly higher than the energy poverty measured using the TPR. According to the 2M after 1998 the energy poverty was increasing and reached 12.43 percent in 2013. So, following this measure shows that energy poverty increased by 22 percent in Germany during the past twenty years. The shift in the median energy expenditures share, as explained before, has made it more difficult

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<sup>61</sup> The kernel density functions of the energy expenditure share in income for each year of the IES data are provided in Figure 2.7 in The Appendix.

for households to exceed the 2M threshold and be qualified as energy poor according to this indicator.



**Figure 2. 3 Energy poverty over time**

*Note.* Own calculations. Dataset is IES 1993–2013. Dash and dotted line indicates energy poverty calculated using the ten percent rule (TPR) while solid line indicate energy poverty calculated using the twice median expenditures (2M) rule. Line segments indicate the 95 percent confidence intervals.

### 2.5.2 On the relationship between income poverty and energy poverty

In order for income poverty policies to have impact on energy poverty as well, there has to be an overlap between income poverty and energy poverty. The results in Table 2.2 indicate that around one quarter of the households that are energy poor are also income poor throughout the 1993–2013 period. The proportion of energy poor households, which are also income poor, reached 5.7 percent in 2013, almost four times larger than the proportion in 1993. This could indicate that income poverty is rather an important determinant of energy poverty. The share of energy poor households, which do not fall under income poverty, also increased by more than four times during this period. Similarly, the proportion of income poor households that are not energy poor has grown by around 55 percent.

Income poverty and energy poverty can be related to the type of employment status of the household's leader. German households with an unemployed leader are at highest risk of income poverty and households with a retired leader are at second highest risk, both of which show an upward trend since 1993 (refer to Table 2.12 in the Appendix). Urban households are more likely to become income poor than rural ones. The risk of energy poverty is again highest among the unemployed and second highest for the self-employed. A household with unemployed leader is twice as likely to be energy poor as a household with employed leader. The rural households are more prone to energy poverty in comparison to the urban households (in 2013 the percentage energy poor among rural was around twice the one of the urban). Palmer (2008) also found that energy poverty is higher among rural households in the U.K.

**Table 2. 2 The overlap between income poverty and energy poverty**

	Income poor	Income poor not energy poor	Both income and energy poor	Energy poor not income poor	Energy poor
(percent of all households)					
1993	7.504	6.282	1.390	4.408	5.680
1998	7.034	5.698	1.501	4.961	6.318
2003	9.108	6.638	2.829	9.842	12.148
2008	12.176	8.165	4.738	17.866	21.090
2013	14.485	9.848	5.673	18.173	22.011

*Note.* Own calculations. Dataset is IES 1993–2013. Weighted to assure representativeness of the German population.

Using the probit model from equation (2.8), I empirically investigate the effect of income poverty on the probability of becoming energy poor. Several variables are included as controls in the different probit specifications: binary indicator for income poverty, household size, working status, education, and binary indicator for rural area of residence.<sup>62</sup> Correlations of the variables included in the different probit model specifications are low to moderate in order to avoid multicollinearity. The estimates from the first probit specification (see Table 2.13 in the Appendix) do indeed prove that being income poor has positive and significant impact on energy poverty in Germany. An income poor household has a 29.1 percent chance to be energy poor.<sup>63</sup> Households which are not income poor are three times less likely to become energy poor (10.6 percent probability) in comparison to income poor households. Living in rural area leads to higher probability of being energy poor (12.5

<sup>62</sup> The choice of controls follows Palmer (2008), and Legendare and Ricci (2015).

<sup>63</sup> The marginal effect is calculated from the first specification without including any additional controls. The probability measured at the mean values of the variables in the third specification indicates 29.1 percent chance for poor household to become energy poor.

percent) than living in urban area (7.4 percent).<sup>64</sup> A household with unemployed leader has a 14.7 percent chance of becoming energy poor. Being self-employed increases the probability of energy poverty and being retired or living in bigger household reduces it. Those results are in line with the descriptive evidence of Table 2.12 in the Appendix. The fourth probit specification demonstrates that households with more income and more educated leaders tend to be less likely to be energy poor.

### 2.5.3 Differences in poverty levels across household types

Income poverty levels are different across the different household types in Germany. The most vulnerable category appears to be single parents and single adults are the second most vulnerable category. If disposable equivalent income is used to calculate the head count ratio, 29 percent of all single parent households are poor in 1993 and 34 percent in 2013. If disposable equivalent income after energy tax burdens is considered, 30 percent of all single parent households are poor in 1993 and 36 percent in 2013.

As before, energy poverty is measured using two different indicators. Table 2.3 indicates that single parent households have the highest energy poverty levels under the TPR but the 2M shows that households with two adults and children are most energy poor (this is also due to the fact that the second indicator does not take household size into account). During the period between 1993 and 2013, the TPR points out that energy poverty increased among all the household types, with the number of energy poor single parent households increasing by 188 percent. The second indicator of energy poverty shows that poverty among two adult households with children increased by around 73 percent.

**Table 2. 3 Income and energy poverty by household types**

	1993	1998	2003	2008	2013
<i>HC ratio (Disposable equivalent income)</i>					
<i>hh type 1</i>	16.071	17.751	19.946	24.330	26.343
<i>hh type 2</i>	27.712	31.894	28.831	32.149	28.343
<i>hh type 3</i>	7.394	7.403	8.017	9.669	9.556
<i>hh type 4</i>	8.496	8.987	6.496	8.964	7.790
<i>HC ratio (Disposable equivalent income minus energy tax burdens)</i>					
<i>hh type 1</i>	16.680	18.294	21.285	25.510	27.694
<i>hh type 2</i>	29.593	33.084	32.043	34.341	31.530
<i>hh type 3</i>	7.802	7.939	9.088	10.534	10.544
<i>hh type 4</i>	9.563	9.868	7.720	10.041	8.910

<sup>64</sup> All the other variables are considered to be at their mean values.

**Table 2. 4 (Continued)**

	1993	1998	2003	2008	2013
<i>Energy poverty (TPR)</i>					
<i>hh</i> type 1	7.762	8.366	13.887	20.609	20.394
<i>hh</i> type 2	9.057	9.125	16.636	27.016	26.534
<i>hh</i> type 3	4.759	4.883	10.105	18.917	20.181
<i>hh</i> type 4	4.126	5.109	10.140	18.259	18.135
<i>Energy poverty (2M)</i>					
<i>hh</i> type 1	0.961	0.953	0.760	1.110	1.452
<i>hh</i> type 2	4.848	3.797	4.187	3.959	5.484
<i>hh</i> type 3	6.044	5.894	6.483	8.300	11.037
<i>hh</i> type 4	15.879	15.257	17.125	20.776	26.967

*Note.* *hh*type 1 – single adult; *hh*type 2 – single parent; *hh*type 3 – two adults with no children; *hh*type 4 – two or more adults with children. Weighted to assure representativeness of the German population.

### 2.5.4 Price and expenditure elasticities of energy demand

The demand system estimates<sup>65</sup> allow for calculation of the price and expenditure elasticities of the energy goods. The elasticities obtained from the demand system are included in Table 2.4. Electricity is found to have rather low own price elasticity throughout Germany: for 1 percent increase in the price of electricity, demand would decrease by 0.235 percent, holding everything else constant. So, price change policies are not expected to be very efficient in reducing electricity consumption. The expenditure elasticity of electricity demand is 0.496, which shows that electricity is a necessity and normal good among German households: given 1 percent increase in expenditures will lead to 0.496 percent higher demand for electricity.<sup>66</sup> Car fuels are also a necessity good (elasticity is 0.994) and demand for fuels is price inelastic in Germany: for 1 percent price increase consumption would go down by 0.316 percent.

The elasticities in Table 2.4 also reveal that there are differences in price responses according to the level of income. Low income households have highest price elasticity of demand for electricity (–0.478) while high income households have lowest elasticity (–0.173) in absolute terms. Poor households in Germany are three times more responsive to electricity price changes in comparison to rich households. Murray (2012) finds higher elasticity for electricity among poor than among rich U.S. households. Car fuels demand is again most elastic for the poor income households and least elastic for high income households. Car fuels

<sup>65</sup> For details on the demand system coefficient estimates, please refer to Table 2.15 in the Appendix. Table 2.16 compares the elasticities obtained from demographic and base (QU) AIDS.

<sup>66</sup> Table 2.17 in the Appendix provides comparison of price and expenditure elasticities with similar papers from the existing literature.



are also found to be luxury good for the first six deciles of disposable equivalent income. Poor and rich German households also differ by the amount of their total expenditures devoted on energy goods. Low income households pay 4.024 percent of their total expenditures on electricity while for high income households the share is only 2.415 percent (almost 40 percent lower share than the poor). The reverse holds for car fuels: while the poor devote 2.968 percent of total expenditures to car fuels the rich devote 4.551 percent.

The price and income elasticities by household type are summarized in Table 2.14 in the Appendix. The table indicates that there are differences as well as similarities in demand responses of the various households' types. The price elasticities show that single parent households are most responsive to electricity price changes while single adults are least responsive. If the demand for car fuels is considered, single parents have highest price elasticity and couples without children have lowest price elasticity.

Low income households can ration their energy expenditures and also ration the food budget when faced with higher energy prices. The cross price elasticities reveal that food is complementary with electricity and other fuels among German households: as prices of energy goods would go up, food demand will tend to decrease, indicating a heat or eat behavior. Food demand will decrease by 0.097 if price of other fuels increases by 1 percent and will decrease by 0.003 percent if electricity price increases by 1 percent. Murray (2012) also finds that U.S. households consider food and energy to be complements, but the effects are larger. A one percent increase in natural gas price causes 0.47 percent reductions in the food at home expenditures and a one percent increase in electricity price causes reductions in the food at home by 0.14 percent.

## 2.6 Scenarios design and results

First of all, marginal (1 percent) changes in the EEG surcharge for 2013 are considered. Secondly, marginal changes of the car fuels tax<sup>67</sup> in addition to the EEG surcharge are studied. Then varying between 100 percent reduction and 100 percent increase in EEG only and both EEG and car fuels tax so overall four main scenarios are scrutinized. Moreover, the impact of such changes on income and energy poverty, and the environment is analysed in detail.

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<sup>67</sup> For details on the disaggregation and development of the car fuels tax and price, please refer to Section 1.4.2.

**Table 2. 5 Elasticities and expenditure shares according to disposable equivalent income deciles**

Disposable equivalent income deciles	Price elasticities					Expenditure elasticities					Expenditure shares (percent of total expenditures)				
	Food	Electricity	Other fuels	Car fuels	Other goods	Food	Electricity	Other fuels	Car fuels	Other goods	Food	Electricity	Other fuels	Car fuels	Other goods
1	-1.006	-0.478	-0.718	-0.327	-1.130	0.560	0.581	0.776	1.550	1.140	21.381	4.024	4.691	2.968	66.936
2	-1.006	-0.430	-0.704	-0.402	-1.133	0.525	0.576	0.783	1.301	1.145	20.189	3.449	4.169	3.938	68.255
3	-1.008	-0.395	-0.695	-0.421	-1.134	0.498	0.571	0.782	1.189	1.147	18.927	3.232	3.912	4.313	69.616
4	-1.009	-0.373	-0.688	-0.429	-1.134	0.477	0.570	0.783	1.119	1.148	17.935	3.095	3.779	4.529	70.662
5	-1.010	-0.352	-0.683	-0.431	-1.135	0.456	0.568	0.784	1.060	1.149	17.102	3.027	3.705	4.694	71.472
6	-1.011	-0.332	-0.677	-0.431	-1.134	0.440	0.564	0.778	1.022	1.148	16.336	2.964	3.660	4.823	72.217
7	-1.012	-0.317	-0.672	-0.427	-1.134	0.422	0.563	0.776	0.979	1.148	15.616	2.839	3.611	4.906	73.028
8	-1.014	-0.291	-0.665	-0.407	-1.133	0.392	0.558	0.770	0.914	1.148	21.381	2.761	3.561	4.929	73.946
9	-1.017	-0.263	-0.658	-0.379	-1.132	0.344	0.551	0.759	0.842	1.146	20.189	2.642	3.501	4.843	75.142
10	-1.028	-0.174	-0.617	-0.123	-1.128	0.239	0.526	0.705	0.371	1.142	18.927	2.415	3.342	4.551	77.671
Germany	-1.003	-0.235	-0.657	-0.316	-1.136	0.488	0.496	0.770	0.994	1.149	17.044	3.231	4.030	4.183	71.513
SE	0.001	0.008	0.001	0.005	0.000	0.005	0.003	0.001	0.008	0.000	0.075	0.023	0.043	0.039	0.095

*Note.* Own calculations. Dataset is IES 1993–2013.

### 2.6.1 Scenarios with marginal changes in EEG surcharge

Table 2.5 summarizes the results from the four marginal tax scenarios (S1–S4) and identifies the baseline scenario or the status quo (S0). The situation in 2013 is taken as the status quo: the electricity tax amounts to 0.0201 euros/kWh, the EEG surcharge amounts to 0.0528 euros/kWh, and the energy tax on car fuels amounts to 0.606 euros/liter. The average German household pays 186 euros for the EEG surcharge, 72 euros for electricity tax, and 575 euros for car fuels taxes (CFT) annually. The energy tax burdens for electricity and CFT represent 0.870 percent and 1.674 percent of income respectively. However, the tax payments in euros and as percentage of income differ largely between the poor and the rich families and also according to household type. In the status quo, the average household emits 1.649 tons of CO<sub>2</sub> related to electricity and 1.912 tons of CO<sub>2</sub> related to car fuels. Around 16 percent of the German households live in energy poverty and around 19 percent live in income poverty. All variables are predicted using the expenditures weights obtained from the demand system rather than using the actual expenditure shares.

Under the first scenario (S1), the EEG surcharge is one percent higher than under the baseline. Electricity related emissions would go down by 0.12 percent while income poverty as measured by the headcount ratio would increase by 0.04 percent and energy poverty would increase by 0.63 percent. Tax burden of electricity is around 0.12 percent lower than the status quo. If in addition to the EEG surcharge, the car fuels tax is increased by one percent (S3), income poverty is 0.05 percent higher than the baseline and energy poverty is 1.27 percent higher. S2 considers one percent decrease in the EEG surcharge and S4 considers one percent decrease in both the EEG surcharge and in the CFT. Under S2, electricity related emissions remain same as under the baseline (price change is too small), income poverty goes down by 0.05 percent, and energy poverty goes up by 0.63 percent. In the fourth scenario (S4), energy poverty is 1.27 percent lower and income poverty is 0.10 percent lower than under the baseline.

### 2.6.2 Other potential scenarios

Departing once again from the status quo, the changes in tax burdens, emissions, energy poverty, and income poverty are analysed for another four scenarios (S5–S8) across disposable equivalent income deciles and household types. Tables 2.6 and 2.7 include the

**Table 2. 6 Scenarios with marginal changes**

Variable	S0		S1: <i>EEG + 1%</i>		S2: <i>EEG – 1%</i>		S3: <i>EEG + 1%; CFT + 1%</i>		S4: <i>EEG – 1%; CFT – 1%</i>	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
Emissions electricity (t)	1.649	0.003	1.647	0.003	1.649	0.003	1.646	0.003	1.650	0.004
Emissions car fuels (t)	1.912	0.005	1.911	0.005	1.911	0.005	1.907	0.005	1.915	0.005
EEG surcharge (euros)	185.667	0.379	187.298	0.382	183.856	0.375	187.246	0.382	183.907	0.400
Tax burden electricity (euros)	72.087	0.147	72.000	0.147	72.105	0.147	71.980	0.147	72.124	0.156
Tax burden car fuels (euros)	574.607	1.362	574.150	1.361	574.290	1.361	578.802	1.372	569.618	1.347
Income poverty ( <i>HC ratio</i> )	18.785	0.002	18.792	0.000	18.775	0.000	18.796	0.000	18.767	0.000
Income poverty ( <i>Average normalized poverty gap</i> )	0.041	0.001	0.041	0.000	0.041	0.000	0.041	0.000	0.041	0.000
Income poverty ( <i>Average squared normalized poverty gap</i> )	0.013	0.000	0.013	0.000	0.013	0.000	0.013	0.000	0.013	0.000
Energy poverty ( <i>TPR</i> )	0.369	0.002	0.370	0.002	0.368	0.002	0.372	0.002	0.367	0.002

*Note.* EEG is the renewable energy surcharge and CFT is the car fuels tax. All poverty indices are calculated on disposable equivalent income after energy taxes.

results of S5: doubling of the EEG surcharge and S6: abolishing the EEG surcharge respectively. Tables 2.18 and 2.19 in the Appendix include the results from S7: doubling of both the EEG surcharge and the CFT and S8: abolishing both the EEG surcharge and the CFT.

Under S5, the electricity tax burden (the sum of EEG surcharge and electricity tax) increases for all income deciles but the increase is highest percentage for the low income households (0.69 percent of income). Withana et al. (2013) finds that the electricity tax is mainly born by low income households in Germany. The households in the first decile have also the largest percentage decrease in electricity related emissions (9.47 percent) while the households in the tenth decile will have smallest emissions reductions (4.32 percent) as they have the lowest price elasticity. The households in the top income deciles experience largest increase in energy poverty<sup>68</sup> of above 20 percent relative to the baseline. If the effects across the different household types are analysed, it appears that single parents have largest increase in electricity tax burden and largest emissions decrease if the EEG is doubled. Single adult households are least responsive to the change in the EEG surcharge so they would have smallest consumption and emissions reductions. Income poverty increases the most among two adults' households without children and energy poverty among two adults' households with children.

Abolishment of the EEG surcharge makes the electricity price 22 percent price lower, leads to 109 euros lower energy tax burden for the low income households and 250 euros lower burden for the high income households. The decrease in tax burden as percent of income is largest for low income German households and also among the single parents. The poorest households have largest emissions increase of 11.41 percent and the single parent's households also emit 8.90 percent more CO<sub>2</sub> emissions than under the baseline scenario.

In spite of largest tax burdens decreases among poor and single parents households, it is the households in the tenth decile that experience largest decrease in energy poverty of around 30 percent relative to S0. Among the different household types, the two adults' households with children will have largest income poverty decrease (3.25 percent) and largest energy poverty decrease (17.3 percent). Overall, income poverty is 2 percent lower and energy poverty almost 14 percent lower. Aasnesss et al. (2002) also find evidence that reduced electricity tax increase equality in the income distribution and improves consumer welfare.

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<sup>68</sup> By using the TPR.

**Table 2. 7 Scenario 5 (doubling of the EEG surcharge) results across income deciles and household types**

<i>Disposable equivalent income deciles</i>	Electricity tax burden				Electricity emissions				Income poverty (HC ratio)		Energy poverty (TPR)	
	euros		% of income		tons		% change		before	after	before	after
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Mean	Mean	Mean
1	88.054	32.951	0.688	0.117	-0.095	0.034	-9.473	1.006	1.000	1.000	33.356	36.664
2	114.153	43.711	0.579	0.093	-0.110	0.043	-8.660	1.181	0.659	0.685	26.973	29.620
3	132.124	49.812	0.524	0.089	-0.118	0.047	-8.085	1.373	0.000	0.000	21.655	24.306
4	147.610	57.179	0.482	0.086	-0.124	0.053	-7.713	1.565	0.000	0.000	17.757	20.538
5	162.140	63.028	0.451	0.081	-0.130	0.057	-7.394	1.650	0.000	0.000	13.270	15.625
6	170.999	66.950	0.422	0.082	-0.130	0.061	-7.051	1.885	0.000	0.000	8.986	10.627
7	181.561	70.580	0.391	0.075	-0.133	0.061	-6.846	1.844	0.000	0.000	6.805	8.161
8	193.635	78.055	0.368	0.082	-0.130	0.066	-6.399	2.208	0.000	0.000	3.794	4.635
9	206.947	82.302	0.334	0.076	-0.128	0.069	-5.970	2.466	0.000	0.000	2.305	2.921
10	226.009	93.571	0.286	0.084	-0.096	0.096	-4.322	4.433	0.000	0.000	1.353	1.623
<i>hhtype</i>												
1	95.392	28.289	0.494	0.151	-0.066	0.030	-7.052	3.017	0.329	0.332	17.158	19.165
2	144.640	46.685	0.539	0.137	-0.125	0.033	-8.170	1.630	0.398	0.402	23.482	26.297
3	172.756	54.869	0.461	0.152	-0.129	0.034	-7.495	2.217	0.138	0.140	15.272	17.281
4	234.379	75.164	0.448	0.136	-0.190	0.040	-7.803	1.575	0.116	0.119	12.052	13.988
<b>Overall change</b>	<b>154.009</b>	<b>75.477</b>	<b>0.476</b>	<b>0.150</b>	<b>-0.118</b>	<b>0.060</b>	<b>-7.451</b>	<b>2.459</b>	<b>1.629</b>	<b>0.000</b>	<b>13.333</b>	<b>0.000</b>

*Note.* Own calculations. Dataset is IES 2013. *hhtype* 1 – single adult; *hhtype* 2 – single parent; *hhtype* 3 – two adults with no children; *hhtype* 4 – two or more adults with children.

**Table 2. 8 Scenario 6 (abolishing the EEG surcharge) results across income deciles and household types**

	Electricity tax burden				Electricity emissions				Income poverty (HC ratio)		Energy poverty (TPR)	
	euros		% of income		tons		% change		before	after	before	after
<i>Disposable equivalent income deciles</i>	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Mean	Mean	Mean
1	-108.590	39.826	-0.849	0.132	0.114	0.042	11.406	1.931	1.000	1.000	33.356	29.925
2	-138.328	52.197	-0.701	0.097	0.125	0.053	9.842	2.266	0.659	0.629	26.973	23.975
3	-158.184	58.970	-0.625	0.092	0.127	0.060	8.737	2.635	0.000	0.000	21.655	18.806
4	-175.355	67.117	-0.570	0.085	0.129	0.068	8.021	3.003	0.000	0.000	17.757	14.526
5	-191.351	73.577	-0.530	0.081	0.130	0.073	7.408	3.167	0.000	0.000	13.270	11.710
6	-200.443	77.617	-0.492	0.081	0.125	0.082	6.748	3.617	0.000	0.000	8.986	7.078
7	-211.880	81.503	-0.455	0.074	0.124	0.081	6.354	3.539	0.000	0.000	6.805	5.538
8	-223.728	88.230	-0.423	0.079	0.112	0.096	5.495	4.240	0.000	0.000	3.794	2.944
9	-236.962	91.431	-0.381	0.072	0.100	0.106	4.670	4.735	0.000	0.000	2.305	1.641
10	-250.494	97.705	-0.316	0.081	0.033	0.176	1.516	8.354	0.000	0.000	1.353	1.084
<i>hhtype</i>												
1	-110.486	25.225	-0.584	0.189	0.058	0.065	6.761	5.745	0.329	0.325	17.158	15.064
2	-172.548	51.087	-0.649	0.169	0.133	0.051	8.899	3.131	0.398	0.388	23.482	20.841
3	-202.118	52.975	-0.547	0.185	0.123	0.083	7.600	4.262	0.138	0.135	15.272	13.248
4	-276.997	79.687	-0.533	0.163	0.192	0.072	8.183	3.028	0.116	0.113	12.052	9.964
<b>Overall change</b>	<b>-180.681</b>	<b>84.038</b>	<b>-0.566</b>	<b>0.184</b>	<b>0.114</b>	<b>0.089</b>	<b>7.518</b>	<b>4.698</b>	<b>-2.123</b>	<b>0.000</b>	<b>-13.291</b>	<b>0.000</b>

*Note.* Own calculations. Dataset is IES 2013. *hhtype* 1 – single adult; *hhtype* 2 – single parent; *hhtype* 3 – two adults with no children; *hhtype* 4 – two or more adults with children.

Doubling of the CFT, accompanied by doubling of the EEG surcharge (S7), increases both income poverty and energy poverty by 5.1 and 55.1 percent. Emissions among German households would decrease by 9.1 percent. When the CFT is abolished together with the EEG surcharge (S8), income poverty and energy poverty are 7.2 percent and 48.7 percent lower respectively, and emissions are 12.3 percent higher than under S0. Since the two goods are found to be complementary, having both goods cheaper also activates the income effect.

Alternatively, I have constructed a scenario in which total energy related emissions for the average German household would increase by only 0.03 tons while energy tax burden is around 65 euros lower than the status quo and the welfare loss is only 4.8 euros.<sup>69</sup> At the same time, income poverty is 0.79 percent lower and energy poverty is 5.3 percent lower. The above mentioned effects would follow from a scenario in which the EEG surcharge is abolished while the CFT is increased by 25 percent (S9). If the EEG surcharge is abolished and the CFT is increased by 50 percent (S10), emissions would go down by 0.7 tons, tax burden will be 46 euro higher, and welfare loss is 140 euros (0.34 percent of income). Income poverty and energy poverty would both increase under S10. On the other hand, S9 will be very beneficial for the German households while assuring minimal environmental damage and revenue loss for the government. Such policy would allow for large reduction in energy costs for the households and reductions in energy poverty and income poverty, and should definitely be considered by policy makers as a potential alternative for reducing electricity prices while assuring adequate revenues for financing the green energy.

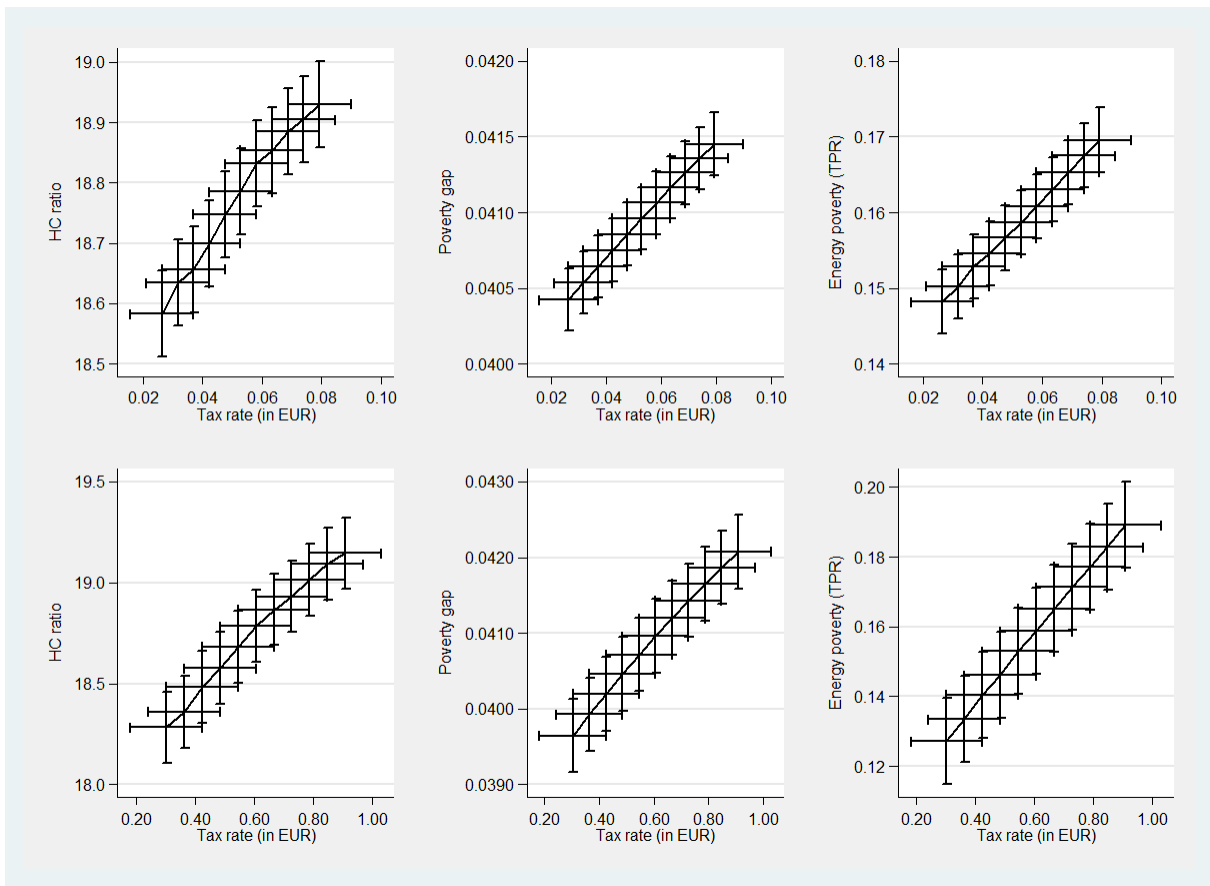
### 2.6.3 The relationship between poverty and energy taxes

Figure 2.4 includes a total of 6 graphs: the upper three graphs include the relationship between the EEG surcharge rate and the income poverty indicators (HC ratio and poverty gap) and between the EEG surcharge and the energy poverty indicator (TPR) and the lower three graphs include the relationship between the car fuels tax rate (CFT) and the income poverty indicators (HC ratio and poverty gap) and between the CFT and the energy poverty indicator (TPR). Both income poverty indicators show a positive relationship between poverty and the surcharge: income poverty increases with higher levels of EEG surcharge. Energy poverty is also growing in the EEG surcharge, with more pronounced effects than income poverty. As an example, by changing the EEG surcharge from 0.026 to 0.0317 euros per kWh, energy poverty would shift from 14.8 to 15.0 percent while income poverty would

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<sup>69</sup> See Table 2.20 in the Appendix.





**Figure 2. 4 The relationship between energy taxes and income poverty and energy poverty**

*Note.* Own calculations. Dataset is IES 2013. Line segments indicate the 95 percent confidence intervals.

shift from 18.58 to 18.63 percent. Increases in the CFT will potentially also lead to higher levels of income poverty and energy poverty among German households. For instance, increasing the CFT from 0.303 to 0.363 euros per liter, would change income poverty from 18.28 to 18.36 percent and energy poverty from 12.7 to 13.3 percent. The effect of changes in the CFT on both income poverty and energy poverty is more pronounced than the effect of the EEG surcharge changes. That might be a consequence of the price elasticities of demand as well as of proportion that each tax/surcharge represents in the respective energy price. In monetary terms, CFT is ten times higher than the EEG, and as percentage of prices they represent 0.390 and 0.197 percent of car fuels and electricity price respectively. Both car fuels and electricity are necessity goods among German households, and price elasticities are 0.316 and 0.235 respectively. The trade-offs between EEG surcharge, CFT, and poverty levels are hence confirmed by the graph and should be considered and addressed in policy design.

## 2.7 Interim conclusion

Reduction of both income poverty and energy poverty reduction are given high priority in the EU policy agenda. In Germany, income poverty has increased by around one third between 1993 and 2013. During the same time, the price of electricity for households increased by around 90 percent. Accordingly, the growing poverty together with the increasing electricity prices made it more difficult for households to afford their energy bills which in turn led to more than tripling of energy poverty among German households. I find empirical evidence that being income poor, unemployed, or living in rural residential area are all associated with higher probability of falling under energy poverty.

The results from the energy demand system indicate that electricity is a necessity good, with relatively low elasticity of demand, demonstrating that price change policies will not be very efficient in reducing electricity consumption. The paper investigates the effect of change in the electricity price (though changing the EEG surcharge) on income poverty, energy poverty, and CO<sub>2</sub> emissions. Four rather extreme scenarios are scrutinized; doubling or eliminating of the EEG surcharge, doubling or eliminating of both the EEG surcharge and the car fuels tax (CFT).

Doubling of the EEG surcharge brings highest increase in the tax burden as percentage of income for the poorest households. Income poverty and energy poverty both increase while electricity related CO<sub>2</sub> emissions decrease. If in contrast, the EEG is abolished electricity related emissions would grow, which is not a desirable environmental result. However, energy poverty will decrease by around 13 percent and income poverty will decrease by around 2 percent. The low income and the single parent households would benefit from elimination of the EEG surcharge also by having lower energy tax burdens. Doubling of the CFT, accompanied by doubling of the EEG surcharge, leads to 5.1 percent increase in income poverty and 55.1 percent increase in energy poverty. Electricity related CO<sub>2</sub> emissions would decrease by 9.1 percent. When the CFT is abolished simultaneously with the EEG surcharge, income poverty and energy poverty are 7.2 percent and 48.7 percent lower respectively, and emissions are 12.3 percent higher.

Hence, I identify a positive relationship between poverty and energy surcharges or taxes is i.e. higher levels of EEG surcharge or CFT are associated with higher levels of income poverty and energy poverty in Germany. My results indicate a possibility of abolishing the EEG surcharge while increasing the CFT by one quarter. Overall energy tax

burden is slightly lower and energy related emissions increase by a very small amount while income poverty and energy poverty both decrease (Scenario 9). The higher CFT is expected to encourage switch towards more efficient vehicles or electric means of transportation. Such policy reform should definitely be scrutinized by energy policy makers as it is promising minimal revenue loss for the government and minimal environmental damage while reducing energy poverty and income poverty levels. Especially unemployed people, households in rural areas (as they already have higher poverty levels), single parent households (due to lower tax burdens), and larger families (due to lower poverty levels) are likely to benefit the most from lower electricity prices.

Alternatively, an energy solidarity payment could be introduced, as suggested by Grösche and Schröder (2014b). According to the authors, such payment will generate the same amount of revenues as the EEG surcharge but will assure more fair and proportional distribution of payments (as it will be calculated proportionally to income tax contributions and hence will be independent of consumption). Generating an adequate amount of revenues through solidarity payment will make room for abolishing either the EEG surcharge or the electricity tax. Renewable energy production could be sponsored through the solidarity payment and will lead to further shifting the electricity mix towards higher proportion of RES (and less carbon) so in the long run electricity emissions will go down, despite the lower electricity price. Income poverty and energy poverty will also decrease once the electricity price is reduced. Cheaper and cleaner electricity could also further motivate the use of electric cars, which would lead to even lower CO<sub>2</sub> emissions levels.

## 2.8 Appendix

### 2.8.1 Tables

**Table 2. 9 Relevant household level studies and their contribution to literature**

Study	Country, and time period	Energy goods	Behavioral responses	Scenarios with policy change	Income poverty /Energy poverty analyses	Emissions analyses	Distributional analyses
West and Williams III (2004)	U.S., 1996–1998	Gasoline	Yes	Yes	No/No	No	Yes
Tiezzi (2005)	Italy, 1985–1996	Domestic fuels, transport fuels, public transport	Yes	Yes	No/No	No	
Tiezzi and Verde (2016)	U.S., 2007–2009	Gasoline	Yes	Yes	No/No	No	No
Dumagan and Mount (1992)	U.S., 1960–1987	Electricity, natural gas, oil	Yes	No	No/No	No	Yes
Beznoska (2014)	Germany, 1998–2008	Heating, electricity, mobility	Yes	Yes	No/No	No	Yes
Filipinni (1995)	Switzerland, 1991	Electricity	Yes	No	No/No	No	No
Kohn and Missong (2003)	Germany, 1988–1993	Energy and shelter aggregate	Yes	No	No/No	No	No
Gahvari and Tsang (2011)	U.S., 1996–1999	Energy aggregate good	Yes	Yes	No/No	No	No
Brännlund and Nordström (2004)	Sweden, 1985–1992	Petrol, public transport, other transport, heating	Yes	Yes	No/No	No	Yes
Brännlund et al. (2007)	Sweden, 1980–1997	Electricity, district heating, oil, car, public and other transport	Yes	Yes	No/No	Yes	No
Berkhout et al. (2004)	Netherlands, 1992–1999	Electricity, gas	Yes	Yes	No/No	No	Yes
Miniaci et al. (2014)	Italy, 1998–2011	Electricity, gas	No	No	No/Yes	No	No
Withana et al. (2013)	Australia, British Columbia, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Sweden, and U.K.; (2010)	Natural gas, solid fuels, electricity, mineral oils	No	Yes	No/No	No	Yes
Flues and Thomas (2015)	21 OECD countries, 2008–2012	Transport fuels, heating fuels, electricity	No	No	No/No	No	Yes
Jacobsen et al. (2003)	Denmark, 1997	Heating, transport fuels, electricity	No	No	No/No	No	Yes
Klauss (2016)	Armenia, 2009–2011	Natural gas, biomass	No	Yes	Yes/No	No	No
Palmer et al. (2008)	U.K., 2005–2007	Heating fuels, electricity	No	No	Yes/Yes	No	No
Legendre and Ricci (2015)	France, 2006	Electricity, gas, heating	No	No	No/Yes	No	No

**Table 2. 8 (Continued)**

Study	Country, and time period	Energy goods	Behavioral responses	Scenarios with policy change	Income poverty /Energy poverty analyses	Emissions analyses	Distributional analyses
Papada and Kaliampakos (2016)	Greece, 2015	Electricity, space heating	No	No	No/Yes	No	No
Sterner (2012)	France, Germany, Italy, and Spain (2006), Serbia (2007), Sweden (2004–2006)	Transport fuels	No	No	No/No	No	Yes
Labandeira et al. (2006)	Spain, 1973–1995	Electricity, natural gas, LPG, car fuels, public transport	Yes	No	No/No	No	No
Labandeira et al. (2009)	Spain, 1973–1995	Electricity, natural gas, LPG, car fuels, public transport	Yes	Yes	No/No	No	Yes
Ekins et al. (2011)	Czech Republic, Germany, Spain, Sweden, U.K.; (2005)	Electricity, heating fuels, car fuels	No	Yes	No/No	No	Yes
Scarpellini et al. (2015)	Spain (reg. Aragon), 2011–2015	Electricity, heating	No	No	No/Yes	No	No
Faik (2012)	Germany, 2002–2010	-	No	No	Yes/No	No	Yes
Meyer and Sullivan (2009)	US, 1960–2005	-	No	No	Yes/No	No	No
Grabka et al. (2015)	Germany, 2000–2012	-	No	No	Yes/No	No	Yes
Grabka et al. (2012)	Germany, 2005–2010	-	No	No	Yes/No	No	Yes
Heindl (2014)	Germany, 2011	Electricity, heating	No	No	No/Yes	No	No
Moore (2012)	U.K., 2008	Heating fuels	No	No	No/Yes	No	No
Aasness et al. (2002)	Norway, 2000	Electricity	No	Yes	No/No	No	Yes
Alberini et al. (2011)	US, 1997–2007	Electricity, gas	Yes	No	No/No	No	No
Halvorsen and Nesbakken (2002)	Norway, 1993–1994	Electricity	No	Yes	No/No	No	Yes
Kratena and Wüger (2009)	Austria 1990–2006	Gasoline/diesel, heating, electricity	Yes	Yes	No/No	No	No
Kratena and Wüger (2010)	Austria, 1972–2005	Gasoline, heating, electricity	Yes	Yes	No/No	No	No
Ghalwash (2007)	Sweden, 1980–2002	Petrol, public and other transport, electricity, district heating, oil	Yes	No	No/No	No	No
Blacklow et al. (2010)	Australia, 1988–2004	Electricity and housing fuels	Yes	No	No/No	No	Yes
Betti (2000)	Italy, 1985–1994	Fuel and heating, transport	Yes	No	No/No	No	No
Romero-Jordán et al. (2016)	Spain, 2006–2012	Electricity	No	No	No/No	No	Yes
Neuhoff et al. (2013)	Germany, 1998–2008	Electricity	No	No	No/No	No	Yes
Murray (2012)	U.S., 1999–2009	Natural gas, electricity	Yes	No	Yes/Yes	No	No

**Table 2. 8 (Continued)**

Study	Country, and time period	Energy goods	Behavioral responses	Scenarios with policy change	Income poverty /Energy poverty analyses	Emissions analyses	Distributional analyses
Grösche and Schröder (2014a)	Germany, 2010	Electricity	No	Yes	No	No	Yes
Nikodinoska and Schröder (2016)	Germany, 1993–2008	Electricity, other fuels, car fuels	Yes	Yes	No	Yes	Yes
Schumacher et al. (2015)	Bulgaria , France, Germany, Greece, Ireland, Italy, Poland, Spain, U.K., E.U.; (2013)	Electricity, gas	No	No	No/Yes	No	No
Frondel et al. (2015)	Germany, 2006–2012	Electricity	No	Yes	No/No	No	Yes
Boonekamp (2007)	Netherlands, 1990–2000	Electricity	No	Yes	No/No	No	No
Nygård (2013)	Norway, 1978–2010	Electricity, fuels and district heating, coal, coke, peat and wood	Yes	Yes	No/No	No	No
Hills (2012)	England, 2009	Electricity, gas	No	No	No/Yes	No	No

*Note.* All necessary information is taken from the respective studies.

**Table 2. 10 Descriptive statistics of the variables included in the demand system**

	1993	1998	2003	2008	2013
Variable	Mean				
$\ln(e_{total})$	9.723	9.834	9.871	9.900	9.965
$s_{food}$	0.214	0.177	0.153	0.158	0.155
$s_{electricity}$	0.032	0.027	0.030	0.034	0.038
$s_{other\ fuels}$	0.040	0.034	0.041	0.049	0.037
$s_{car\ fuels}$	0.031	0.036	0.044	0.049	0.048
$s_{other\ goods}$	0.683	0.726	0.732	0.710	0.722
$\ln(p_{food})$	1.581	1.644	1.684	1.805	1.885
$\ln(p_{electricity})$	1.497	1.488	1.608	1.861	2.163
$\ln(p_{other\ fuels})$	1.245	1.247	1.533	1.957	2.026
$\ln(p_{car\ fuels})$	1.143	1.255	1.571	1.848	1.954
$\ln(p_{other\ goods})$	1.539	1.655	1.681	1.691	1.777
$n_{adults}$	1.887	1.834	1.804	1.758	1.727
$n_{children}$	0.424	0.359	0.334	0.298	0.281

Note. Dataset is IES 1993–2013.  $e$  stands for expenditures,  $s$  stands for expenditures share,  $p$  is price and  $n$  is number.

**Table 2. 11 Summary statistics by household type**

<i>hhtype</i>	1	2	3	4
Variable	Mean			
<i>ydisp</i>	20132.800	25713.360	37193.620	47140.910
<i>e<sub>total</sub></i>	14233.230	19321.400	24450.130	30586.120
<i>e<sub>food</sub></i>	1951.818	3294.660	3790.314	5237.592
<i>e<sub>electricity</sub></i>	433.663	640.870	695.769	852.427
<i>e<sub>other fuels</sub></i>	601.943	785.250	952.226	998.902
<i>e<sub>car fuels</sub></i>	503.110	777.413	1045.769	1507.134
<i>e<sub>other goods</sub></i>	10742.700	13823.210	17966.050	21990.070
<i>S<sub>food</sub></i>	0.152	0.184	0.174	0.188
<i>S<sub>electricity</sub></i>	0.034	0.036	0.032	0.030
<i>S<sub>other fuels</sub></i>	0.044	0.043	0.041	0.034
<i>S<sub>car fuels</sub></i>	0.034	0.039	0.044	0.051
<i>S<sub>other goods</sub></i>	0.736	0.698	0.710	0.696

*Note.* *hhtype* 1 – single adult; *hhtype* 2 – single parent; *hhtype* 3 – two adults with no children; *hhtype* 4 – two or more adults with children. Weighted to assure representativeness of the German population.



**Table 2. 12 Comparison with previous studies on income and energy poverty**

Income poverty - Head Count ratio (equivalent disposable income)							
Variable	This study (2016)	EU-SILC (2014)	Faik (2012)	Grabka et al. (2015)	Grabka et al. (2012)	4th Poverty report (2013)	Statista (2016)
Germany							
1993	10.4					11.5	
1998	11.1					10.8	10.4
2003	10.9		16.8	13.0	14.2	13.2	
2008	13.7	15.3	17.0	14.4	14.6	14.3	14.4
2013	13.6	16.2					15.5
Energy poverty (TPR/LIHC)							
	This study (2016)	Palmer et al. (2008)				Legendre and Ricci (2015)	Hills (2012)
	Germany	England	Scotland	Wales	Northern Ireland	France	England
1993	5.3						
1998	6.0						
2003	11.4	6.0 (2004)	23.0 (2005-6)	11.0 (2004)	23.0 (2004)	16.6 (2006)	
2008	19.7	7.0 (2005)					15.0 (2009)
2013	20.3						

*Note.* Faik (2012) uses 50 percent of mean single person household's net income as poverty line while all the other studies use 60 percent of median disposable equivalent income (according to OECD modified scale). HC ratio indicates the percent of poor within the whole population on. TRP stands for the ten percent rule, as described earlier and LIHC stands for Low Income High Costs, a measure used in Hills (2012).

**Table 2. 13 Income and energy poverty according to working status and area of residence**

	Self- employed	Employed	Unemployed	Retired	Rural	Urban
Income poverty (proportion poor)						
1993	0.056	0.032	0.361	0.095	0.065	0.085
1998	0.044	0.033	0.386	0.078	0.055	0.089
2003	0.060	0.035	0.454	0.091	0.074	0.105
2008	0.076	0.039	0.719	0.109	0.086	0.138
2013	0.125	0.045	0.734	0.148	0.102	0.165
Energy poverty (proportion poor)						
1993	0.041	0.043	0.148	0.055	0.057	0.048
1998	0.058	0.057	0.144	0.048	0.063	0.054
2003	0.119	0.107	0.233	0.097	0.125	0.088
2008	0.220	0.186	0.363	0.186	0.222	0.143
2013	0.279	0.185	0.353	0.209	0.233	0.136

Note. Own calculations. Dataset is IES 1993–2013.

**Table 2. 14 Results of the probit model: probability to be energy poor**

<i>Prob(energy poor)</i>	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>income poor</i>	0.679	0.010			0.612	0.011		
<i>ln(ydisp)</i>			-0.546	0.006			-0.644	0.008
<i>hhsiz</i>					-0.086	0.003	0.044	0.004
<i>rural</i>					0.327	0.008	0.375	0.008
<i>educ2</i>					-0.198	0.011	-0.080	0.011
<i>educ3</i>					-0.276	0.011	-0.144	0.011
<i>selfemployed</i>					0.103	0.017	0.121	0.017
<i>unemployed</i>					0.174	0.017	0.089	0.016
<i>retired</i>					-0.077	0.008	-0.119	0.009
<i>constant</i>	-1.218	0.004	4.504	0.064	-1.166	0.011	5.196	0.079
<i>Pseudo R<sup>2</sup></i>		0.026		0.048		0.047		0.068

Note. Own calculations. Dataset is IES 1993–2013.

**Table 2. 15 Elasticities for the different household types**

<i>hhtype</i>	1		2		3		4	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Price elasticities								
Food	-1.0156	0.0192	-1.0051	0.0065	-1.0133	0.1051	-1.0024	0.0412
Electricity	-0.3284	0.1853	-0.3971	0.1004	-0.3555	0.1364	-0.3743	0.0970
Other fuels	-0.6746	0.3353	-0.6931	0.0263	-0.6871	0.0424	-0.6828	0.0233
Car fuels	-0.3814	0.5549	-0.3925	0.1878	-0.3638	0.2212	-0.3880	0.2723
Other goods	-1.1212	0.0012	-1.1371	0.0083	-1.1310	0.0023	-1.1512	0.0112
Expenditure elasticities								
Food	0.4561	0.2002	0.4830	0.0909	0.4532	0.1102	0.4250	0.7033
Electricity	0.5104	0.0620	0.5770	0.0387	0.5710	0.0346	0.6287	0.0341
Other fuels	0.6962	0.3328	0.7985	0.0435	0.7690	0.0341	0.8785	0.0546
Car fuels	1.3018	0.8325	1.1830	0.4012	1.0320	0.3956	0.7944	0.4706
Other goods	1.1306	0.0013	1.1506	0.0106	1.1436	0.0016	1.1698	0.0141

*Note.* Own calculations. Dataset is IES 1993–2013.

**Table 2. 16 DQUAIDS and QUAIDS Coefficient Estimates**

	DQUAIDS		QUAIDS		DAIDS		AIDS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\alpha_1$	0.1456	0.0002	0.1809	0.0002	0.1452	0.0002	0.1788	0.0003
$\alpha_2$	0.0250	0.0001	0.0331	0.0001	0.0252	0.0001	0.0329	0.0001
$\alpha_3$	0.0383	0.0001	0.0446	0.0001	0.0381	0.0001	0.0443	0.0001
$\alpha_4$	0.0492	0.0001	0.0464	0.0001	0.0470	0.0001	0.0450	0.0001
$\alpha_5$	0.7419	0.0000	0.6951	0.0000	0.7445	0.0000	0.6991	0.0000
$\beta_1$	-0.0772	0.0006	-0.0162	0.0005	-0.0776	0.0006	-0.0303	0.0004
$\beta_2$	-0.0164	0.0002	-0.0094	0.0002	-0.0163	0.0002	-0.0102	0.0002
$\beta_3$	-0.0123	0.0004	-0.0092	0.0003	-0.0123	0.0004	-0.0105	0.0003
$\beta_4$	0.0090	0.0003	0.0218	0.0003	0.0084	0.0003	0.0093	0.0003
$\beta_5$	0.0969	0.0000	0.0130	0.0000	0.0979	0.0000	0.0418	0.0000
$\gamma_{11}$	-0.0129	0.0011	-0.0209	0.0012	-0.0099	0.0011	-0.0321	0.0011
$\gamma_{12}$	-0.0028	0.0004	-0.0043	0.0004	-0.0013	0.0003	-0.0042	0.0006
$\gamma_{13}$	-0.0190	0.0005	-0.0216	0.0005	-0.0168	0.0005	-0.0177	0.0005
$\gamma_{14}$	-0.0102	0.0006	-0.0133	0.0006	-0.0152	0.0006	-0.0216	0.0006
$\gamma_{22}$	0.0225	0.0005	0.0207	0.0005	0.0229	0.0005	0.0210	0.0003
$\gamma_{23}$	-0.0018	0.0003	-0.0029	0.0003	-0.0017	0.0003	-0.0027	0.0003
$\gamma_{24}$	-0.0029	0.0004	-0.0017	0.0004	-0.0033	0.0004	-0.0025	0.0004
$\gamma_{33}$	0.0126	0.0007	0.0106	0.0007	0.0120	0.0007	0.0086	0.0007
$\gamma_{34}$	0.0017	0.0006	0.0043	0.0006	0.0019	0.0006	0.0055	0.0006
$\gamma_{44}$	0.0300	0.0007	0.0264	0.0007	0.0297	0.0007	0.0247	0.0008
$\gamma_{43}$	0.0017	0.0000	0.0043	0.0000	0.0019	0.0000	0.0055	0.0000
$\gamma_{42}$	-0.0029	0.0000	-0.0017	0.0000	-0.0033	0.0000	-0.0025	0.0000
$\gamma_{41}$	-0.0102	0.0000	-0.0133	0.0000	-0.0152	0.0000	-0.0216	0.0000
$\gamma_{32}$	-0.0018	0.0000	-0.0029	0.0000	-0.0017	0.0000	-0.0027	0.0000
$\gamma_{31}$	-0.0190	0.0000	-0.0216	0.0000	-0.0168	0.0000	-0.0177	0.0000
$\gamma_{21}$	-0.0028	0.0000	-0.0043	0.0000	-0.0013	0.0000	-0.0042	0.0000
$\gamma_{15}$	0.0449	0.0000	0.0601	0.0000	0.0432	0.0000	0.0756	0.0000
$\gamma_{25}$	-0.0152	0.0000	-0.0118	0.0000	-0.0167	0.0000	-0.0115	0.0000
$\gamma_{35}$	0.0065	0.0000	0.0096	0.0000	0.0046	0.0000	0.0063	0.0000
$\gamma_{45}$	-0.0185	0.0000	-0.0157	0.0000	-0.0130	0.0000	-0.0062	0.0000
$\gamma_{54}$	-0.0185	0.0000	-0.0157	0.0000	-0.0130	0.0000	-0.0062	0.0000
$\gamma_{53}$	0.0065	0.0000	0.0096	0.0000	0.0046	0.0000	0.0063	0.0000
$\gamma_{52}$	-0.0152	0.0000	-0.0118	0.0000	-0.0167	0.0000	-0.0115	0.0000
$\gamma_{51}$	0.0449	0.0000	0.0601	0.0000	0.0432	0.0000	0.0756	0.0000
$\gamma_{55}$	-0.0178	0.0000	-0.0423	0.0000	-0.0181	0.0000	-0.0642	0.0000
$\lambda_1$	0.0046	0.0004	-0.0177	0.0003				
$\lambda_2$	0.0022	0.0001	-0.0010	0.0001				
$\lambda_3$	-0.0001	0.0002	-0.0015	0.0002				
$\lambda_4$	-0.0131	0.0002	-0.0156	0.0002				
$\lambda_5$	0.0064	0.0000	0.0358	0.0000				
$\theta_{11}$	-0.0020	0.0004			-0.0023	0.0003		
$\theta_{21}$	-0.0079	0.0001			-0.0080	0.0001		
$\theta_{31}$	0.0019	0.0002			0.0015	0.0002		

**Table 2. 15 (Continued)**

	DQUAIDS		QUAIDS		DAIDS		AIDS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$\theta_{41}$	0.0011	0.0002			0.0009	0.0002		
$\theta_{21}$	0.0026	0.0004			0.0027	0.0004		
$\theta_{22}$	0.0027	0.0001			0.0028	0.0001		
$\theta_{32}$	-0.0112	0.0002			-0.0087	0.0002		
$\theta_{42}$	-0.0064	0.0002			-0.0053	0.0002		
$\theta_{51}$	0.0087	0.0000			0.0068	0.0000		
$\theta_{52}$	0.0105	0.0000			0.0097	0.0000		
$\rho_1$	0.9308	0.0057			0.9490	0.0059		
$\rho_2$	0.3674	0.0044			0.3713	0.0045		
$\nu_1$	0.0121	0.0006	-0.0103	0.0006	0.0122	0.0006	-0.0127	0.0005
$\nu_2$	-0.0025	0.0002	-0.0033	0.0002	-0.0025	0.0002	-0.0034	0.0002
$\nu_3$	0.0044	0.0004	0.0061	0.0004	0.0044	0.0004	0.0061	0.0005
$\nu_4$	-0.0146	0.0004	-0.0179	0.0003	-0.0145	0.0004	-0.0199	0.0003
$\nu_5$	0.0006	0.0000	0.0254	0.0000	0.0004	0.0000	0.0299	0.0000

*Note.* Own calculations. Dataset is IES 1993–2013.

**Table 2. 17 Comparison of demographic and base (QU)AIDS elasticities**

	DQUAIDS		QUAIDS		DAIDS		AIDS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Price elasticities								
Food	-1.0026	0.0005	-1.1020	0.0000	-0.9858	0.0000	-1.1585	0.0003
Electricity	-0.2346	0.0079	-0.3164	0.0004	-0.2163	0.0043	-0.2975	0.0003
Other fuels	-0.6569	0.0005	-0.7126	0.0002	-0.6740	0.0003	-0.7599	0.0001
Car fuels	-0.3164	0.0048	-0.4973	0.0003	-0.3274	0.0005	-0.4508	0.0002
Other goods	-1.1357	0.0000	-1.0730	0.0000	-1.1381	0.0000	-1.1299	0.0000
Expenditure elasticities								
Food	0.4876	0.0051	0.9080	0.0000	0.4989	0.0007	0.8196	0.0003
Electricity	0.4955	0.0032	0.6935	0.0002	0.5116	0.0029	0.6626	0.0002
Other fuels	0.7701	0.0005	0.7616	0.0002	0.7696	0.0003	0.7190	0.0002
Car fuels	0.9942	0.0076	1.4295	0.0003	0.9327	0.0005	1.2095	0.0001
Other goods	1.1491	0.0000	1.0185	0.0000	1.1512	0.0000	1.0581	0.0000

*Note.* Own calculations. Dataset is IES 1993–2013.

**Table 2. 18 Comparison with electricity demand elasticities from existing literature**

Studies	This study (2016)	Ghalwash (2007)	Kratena and Wüger (2010)	Dumagan and Mount (1992)	Labandeira et al. (2006)	Kratena and Wüger (2009)	Blacklow et al. (2010)	Nygård (2013)
Price elasticity	-0.235	-0.140	-0.179	-0.067	-0.447	-0.124	-0.331	-0.140
Expenditure elasticity	0.496	0.460	4.466	0.723	0.739	0.334	0.132	0.59

*Note.* Elasticities estimates are taken from the relevant studies.

**Table 2. 19 Scenario 7 (doubling of the EEG surcharge and CFT) results across income deciles and household types**

	Electricity tax burden				Electricity emissions				Income poverty (HC ratio)		Energy poverty (TPR)		
	euros		% of income		tons		% change		before	after	before	after	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Mean	Mean	Mean	
<i>Disposable equivalent income deciles</i>													
1	84.636	31.368	0.662	0.110	-0.108	0.039	-10.707	0.819	1.000	1.000	33.356	48.356	
2	109.220	41.406	0.554	0.086	-0.129	0.049	-10.069	0.962	0.659	0.740	26.973	38.217	
3	126.026	47.043	0.500	0.082	-0.140	0.055	-9.620	1.121	0.000	0.000	21.655	33.559	
4	140.479	53.830	0.458	0.078	-0.151	0.062	-9.336	1.275	0.000	0.000	17.757	28.070	
5	154.018	59.223	0.428	0.074	-0.160	0.066	-9.093	1.344	0.000	0.000	13.270	22.244	
6	162.160	62.773	0.400	0.075	-0.163	0.070	-8.825	1.533	0.000	0.000	8.986	16.998	
7	171.957	66.081	0.371	0.068	-0.169	0.072	-8.671	1.499	0.000	0.000	6.805	12.583	
8	182.944	72.685	0.347	0.074	-0.170	0.076	-8.322	1.783	0.000	0.000	3.794	8.134	
9	195.106	76.349	0.315	0.068	-0.172	0.076	-7.988	1.983	0.000	0.000	2.305	4.654	
10	211.653	85.791	0.268	0.076	-0.150	0.089	-6.674	3.525	0.000	0.000	1.353	2.353	
<i>hhtype</i>													
1	90.558	25.431	0.471	0.146	-0.083	0.021	-8.737	2.405	0.329	0.341	17.158	0.261	
2	137.799	43.383	0.515	0.132	-0.151	0.037	-9.715	1.293	0.398	0.414	23.482	0.349	
3	163.884	49.824	0.439	0.146	-0.162	0.025	-9.180	1.746	0.138	0.147	15.272	0.235	
4	222.078	69.101	0.425	0.129	-0.235	0.048	-9.527	1.221	0.116	0.123	12.052	0.204	
<b>Overall</b>	<b>146.118</b>	<b>70.284</b>	<b>0.454</b>	<b>0.144</b>	<b>-0.147</b>	<b>0.068</b>	<b>-9.132</b>	<b>1.960</b>	<b>5.117</b>	<b>0.000</b>	<b>55.063</b>	<b>0.000</b>	

Note. Own calculations. Dataset is IES 2013. *hhtype* 1 – single adult; *hhtype* 2 – single parent; *hhtype* 3 – two adults with no children; *hhtype* 4 – two or more adults with children.

**Table 2. 20 Scenario 8 (abolishing the EEG surcharge and CFT) results across income deciles and household types**

	Electricity tax burden				Electricity emissions				Income poverty (HC ratio)		Energy poverty (TPR)	
	euros		% of income		tons		% change		before	after	before	after
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Mean	Mean	Mean
<i>Disposable equivalent income deciles</i>												
1	-106.967	39.119	-0.836	0.130	0.151	0.055	15.025	1.422	1.000	1.000	33.356	20.417
2	-136.019	51.184	-0.689	0.094	0.178	0.070	13.921	1.671	0.659	0.551	26.973	14.821
3	-155.352	57.767	-0.614	0.089	0.192	0.078	13.144	1.946	0.000	0.000	21.655	10.390
4	-172.064	65.677	-0.559	0.082	0.205	0.087	12.654	2.213	0.000	0.000	17.757	7.601
5	-187.620	71.948	-0.520	0.078	0.216	0.094	12.235	2.332	0.000	0.000	13.270	5.820
6	-196.396	75.848	-0.482	0.077	0.218	0.099	11.771	2.661	0.000	0.000	8.986	3.154
7	-207.497	79.609	-0.445	0.071	0.224	0.101	11.505	2.602	0.000	0.000	6.805	2.848
8	-218.876	86.027	-0.414	0.075	0.223	0.107	10.899	3.096	0.000	0.000	3.794	1.445
9	-231.610	89.020	-0.372	0.069	0.222	0.110	10.319	3.450	0.000	0.000	2.305	0.887
10	-244.081	94.766	-0.308	0.078	0.180	0.141	8.025	6.136	0.000	0.000	1.353	0.609
<i>hhtype</i>												
1	-108.237	24.032	-0.573	0.186	0.109	0.039	11.607	4.166	0.329	0.313	17.158	9.720
2	-169.383	49.691	-0.638	0.167	0.206	0.052	13.314	2.241	0.398	0.374	23.482	12.110
3	-198.051	50.862	-0.537	0.182	0.216	0.045	12.380	3.044	0.138	0.126	15.272	7.535
4	-271.444	77.183	-0.523	0.160	0.319	0.066	12.998	2.134	0.116	0.106	12.052	4.857
<b>Overall</b>	<b>-177.068</b>	<b>81.872</b>	<b>-0.555</b>	<b>0.181</b>	<b>0.197</b>	<b>0.096</b>	<b>12.299</b>	<b>3.404</b>	<b>-7.165</b>	<b>0.000</b>	<b>-48.734</b>	<b>0.000</b>

Note. Own calculations. Dataset is IES 2013. *hhtype* 1 – single adult; *hhtype* 2 – single parent; *hhtype* 3 – two adults with no children; *hhtype* 4 – two or more adults with children.

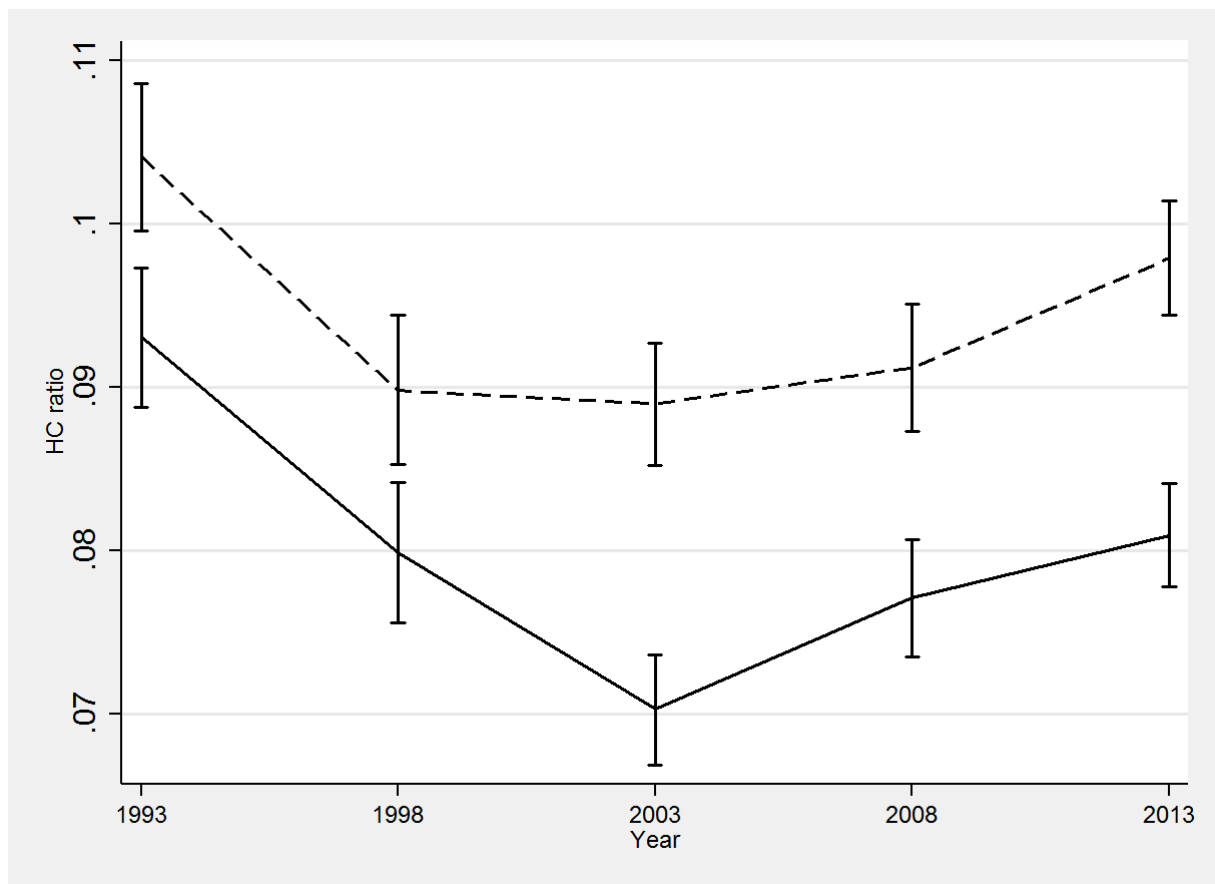


**Table 2. 21 Results of Scenario 9 and Scenario 10**

Change in variables	S9: <i>EEG</i> – 100%; <i>CFT</i> + 25%		S10: <i>EEG</i> – 100%; <i>CFT</i> + 50%	
	Mean	Std. Dev.	Mean	Std. Dev.
Emissions electricity (t)	0.102	0.095	0.089	0.098
Emissions electricity (%)	6.340	4.933	5.641	5.124
Emissions car fuels (t)	-0.071	0.058	-0.161	0.109
Emissions car fuels (%)	-3.368	0.000	-7.690	0.000
Tax burden electricity (euros)	-194.851	84.627	-195.420	84.964
Tax burden electricity (% of income)	-0.539	0.176	-0.540	0.176
Tax burden car fuels (euros)	130.353	63.594	241.355	119.380
Tax burden car fuels (% of income)	0.343	0.098	0.633	0.181
Income poverty ( <i>HC ratio</i> )	-0.793	0.000	0.144	0.000
Energy poverty ( <i>TPR</i> )	-5.300	0.000	3.165	0.000
Compensating variation (euros)	4.827	48.156	139.618	115.710
Compensating variation (% of income)	0.062	0.183	0.338	0.239

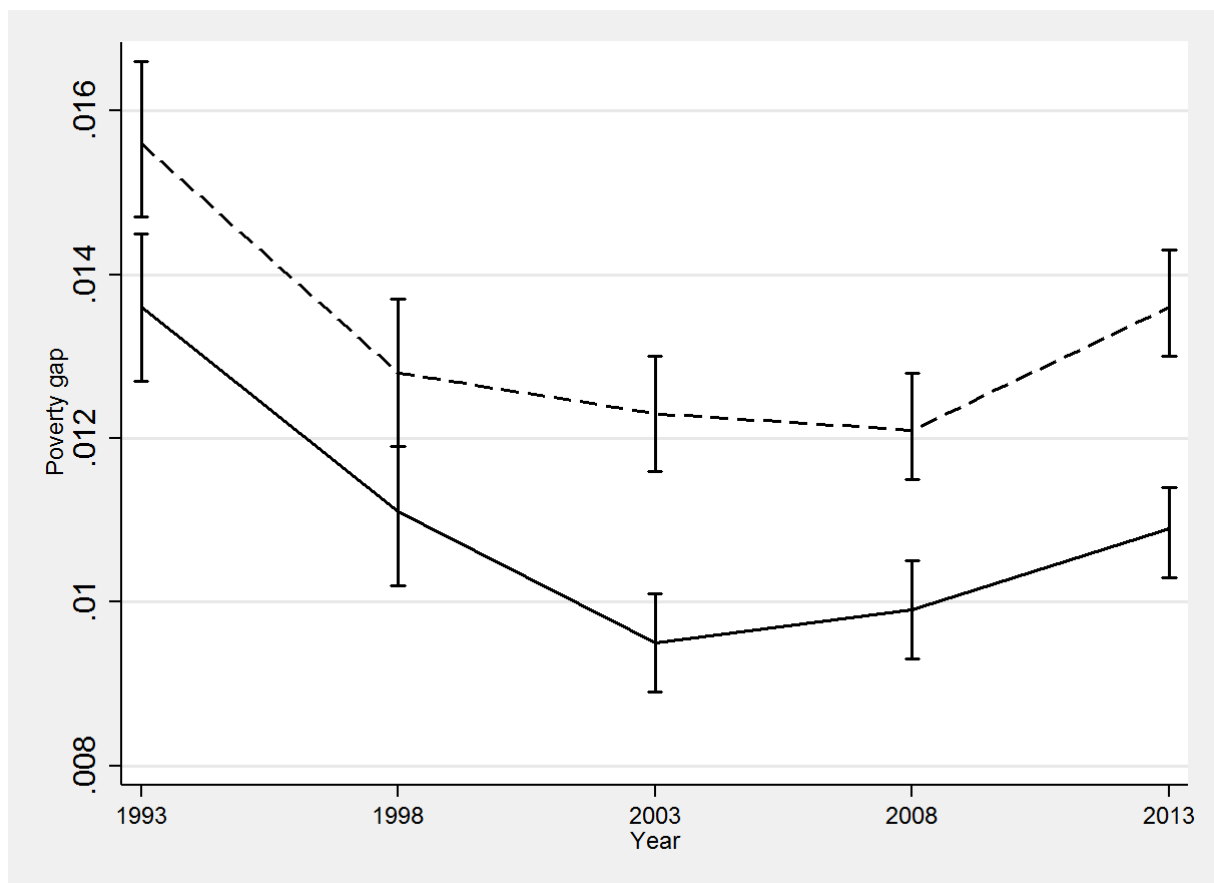
*Note.* Own calculations. Dataset is IES 2013.

## 2.8.2 Figures



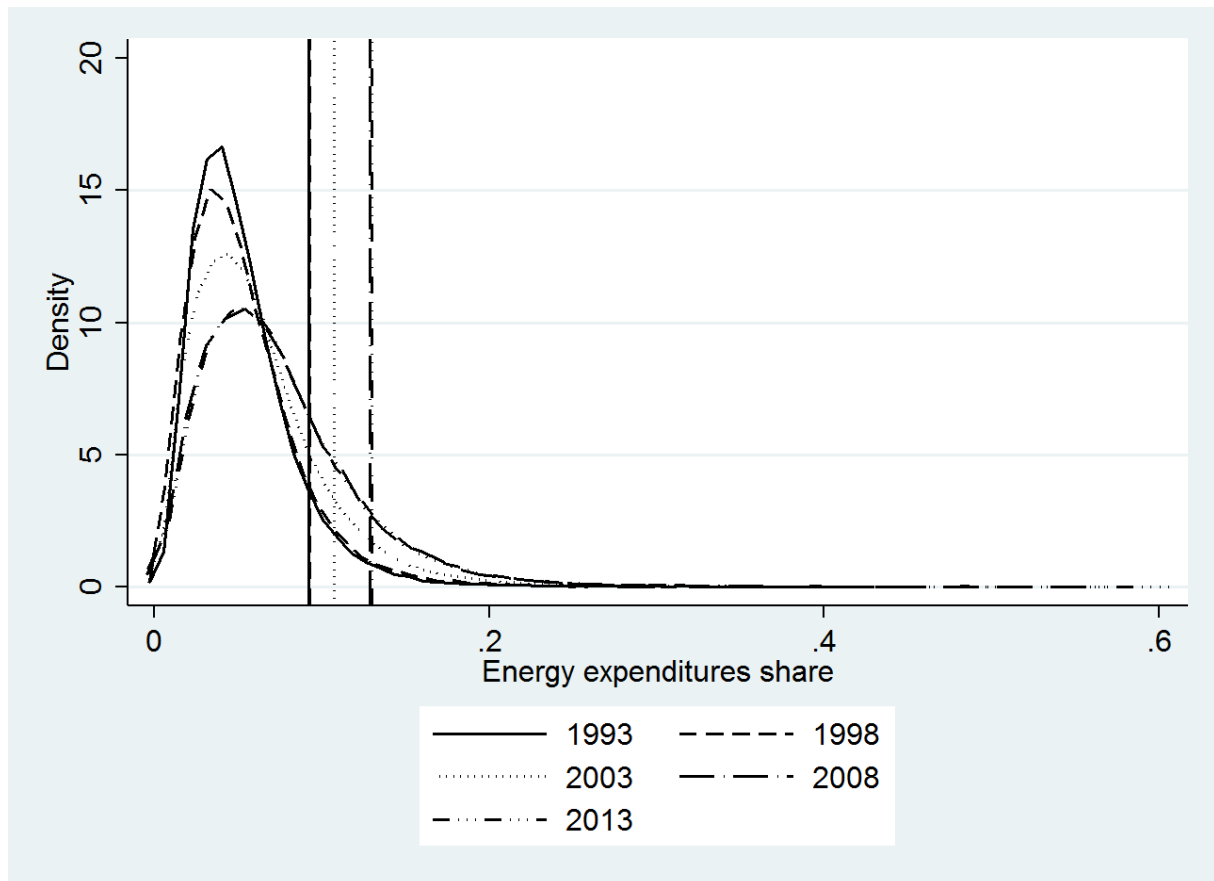
**Figure 2. 5 HC ratio on equivalent expenditures and equivalent expenditures after energy taxes**

*Note.* Own calculations. Dataset is IES 1993–2013. Solid line stands for poverty calculated on disposable equivalent expenditures while dashed line stands for poverty calculated on disposable equivalent expenditures minus energy taxes. Line segments indicate the 95 percent confidence intervals.



**Figure 2. 6 Poverty gap on equivalent expenditures and equivalent expenditures after energy taxes**

*Note.* Own calculations. Dataset is IES 1993–2013. Solid line stands for poverty calculated on disposable equivalent expenditures while dashed line stands for poverty calculated on disposable equivalent expenditures minus energy taxes. Line segments indicate the 95 percent confidence intervals.



**Figure 2. 7 Kernel density functions of energy expenditure share in income by years**

*Note.* Vertical lines stand for twice the median energy expenditure share (2M).



## **Chapter 3**

# **Inter- and Intra-generational Emissions Inequality in Germany: Empirical Analyses**

### **3.1 Introduction**

Several countries in Europe have experienced growing demand for residential energy and hence increasing anthropogenic carbon dioxide (CO<sub>2</sub>) emissions from the household sector (European Environment Agency, 2015). However, the increase in energy consumption and emissions has not been equally distributed among all households and it seems to be highly dependent on the level of income. Even in developed countries such as Germany, U.K., Sweden, France, U.S., and others there exists a wide gap in energy consumption and emissions (pollution) between rich (high income) and the poor (low income) households.<sup>70</sup> Chancel and Piketty (2015) find that global CO<sub>2</sub> emissions remain concentrated: the top 10 percent of emitters are responsible for 45 percent of the emissions and the bottom 50 percent are responsible for only 13 percent of global emissions. To address the challenge of increasing and unequally distributed emissions, the interactions between environmental degradation and economic inequalities in specific countries should be explored.

The differences in the levels of emissions/pollution among households are known as impact inequalities (Chancel (2014)). In this study, I distinguish between three types of impact inequalities: a) income – poor versus rich; b) place of residence – urban versus rural households; and c) year of birth – earlier (older) versus later cohorts (younger); the first two

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<sup>70</sup> Rehdanz (2007) finds that income is an important determinant of heating costs and heating expenditures increase with income in Germany. Jamasb and Meier (2010) find that total energy expenditures increase with income in the U.K. Rätty and Carlsson-Kanyama (2009) find that in Sweden and Germany CO<sub>2</sub> emissions intensity increases with income.

being intra-temporal and the latter being inter-temporal inequalities. Understanding the impact inequalities and their causes among households will provide a better understanding of inequalities in climate change and will contribute in creating public policies that aim at reduction of these inequalities possibly through changes in lifestyles. In addition, information about households' emissions distributions can prove useful in designing improved mitigation policies.

The results of this study should present evidence on the importance of birth cohorts in determining residential energy consumption and the related pollution in Germany. As the date of birth shapes lifestyle chances (access to education or employment, level of income, housing, et cetera.), it can also influence consumer behavior and the environmental footprint (see Chancel, 2014). If the cohort compositional differences are significant, this can provide an understanding about the creation and durability of energy and environmental practices among households. According to Mannheim (1952), cohort effects refer to how formative experiences are shaping individuals' behavior and values.

This study contributes to the existing literature in several ways. Initially, I quantify residential energy related CO<sub>2</sub> emissions in Germany by their source. Moreover, I investigate both intra-generational (by income and by place of residence) and inter-generational (by year of birth) emissions inequalities and their underlying causes. Furthermore, I scrutinize the differences between households according to the birth cohort of their household leader. Most importantly, I study the birth cohort effects of not only the household leader but also of the other household members on emissions (the presence of other birth cohorts in the household).

First of all, this study analyses the descriptive evidence on emissions inequalities, from a German micro data (Income and Expenditure Survey, 1993–2013), along the 3 dimensions mentioned above. I find that the richest German households emitted around 70 percent more CO<sub>2</sub> than the poorest households in 1993 and the gap has almost tripled by 2013.<sup>71</sup> The existence of emissions inequalities related to residence place is also confirmed: the rural households emitted around 11 percent more emissions than the urban households in 1993 and around 40 percent more in 2013. An inverted u-shaped relationship is found between total energy related emissions and the birth cohort of the household's leader. The emissions are highest for the households that have a leader born between 1933 and 1963, and these households are found to emit around 9 percent more CO<sub>2</sub> than the average German household

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<sup>71</sup> In 2013, the households in the tenth equivalent income decile emitted almost 200 percent more CO<sub>2</sub> than households in the first income decile. Chancel (2014) also finds that the rich households in France emit 3.2 times more CO<sub>2</sub> than the poor while in the U.S. the rich emit 3 times more CO<sub>2</sub> than the poor between 1980 and 2000, and the gaps have remained almost constant over time.

regardless of the age of the leader or the period in which the data was collected. The cohorts with leaders from the birth cohorts 1908–1928 and 1968–1993 have lower CO<sub>2</sub> emissions than the average level.

Next, this paper focuses on the effects of date of birth, age, and education of the household leader, income, and household size (or number of household members belonging to a specific birth cohort) on households' direct energy related CO<sub>2</sub> emissions in Germany. Special emphasis is put on the impact of year of birth of the household's leader and other household members (cohort effects). For that purpose, a de-trended Age Period Cohort (APCD) model is applied on German household data. The data set contains detailed information on energy expenditures, income, age, education, and many other characteristics of the households.

My estimates show that households with leaders born in 1933, 1938, 1943, 1948, 1953, 1958, 1963, 1968, and 1973 emit more CO<sub>2</sub> than the average German household and the cohort pure effects are statistically significant. The birth cohort effects of the household's leader are still present and significant once I control for all the relevant variables. The magnitude of the cohorts' effects is larger and they are positive for the cohorts born 1943–1973, indicating that these cohorts have a stronger tendency to emit more CO<sub>2</sub> than their predecessors or followers. Having an additional household member, who belongs to the cohorts 1923, 1928, 1933, 1938, 1943, 1948, 1953, 1958, 1963, and 1968 leads to higher emissions on average. The APCD model for total emissions as well as for the emissions coming from the separate energy sources also confirms the presence of income- and place of residence-related emissions inequalities.

The structure of the paper is the following: Section 3.2 provides a literature review; Section 3.3 describes the quantitative methods; Section 3.4 provides overview of the dataset and some descriptive evidence; Section 3.5 presents the empirical results; Section 3.6 outlines the results from the consistency check and Section 3.7 provides the concluding remarks.

## **3.2 Literature review**

Table 3.2 in the Appendix lists all the relevant studies which deal with the determinants energy related emissions or energy consumption and hence points out the gaps in the literature. The table includes both household level analyses as well as analyses of



aggregate data across countries.<sup>72</sup> Larger emphasis is put on the residential level studies, which focus on one or few (mostly developed) countries and are more relevant for the analyses here. Among the studies which investigate the determinants of energy related emissions, very few consider birth cohorts as important factors. Even fewer studies have addressed cohort effects in an age period cohort (APC) framework and none have addressed the effects of birth cohorts of other members of the household. This review first scrutinizes papers with determining factors of energy and emissions, then describes in detail the papers involving APC models in their household level analyses, and finally presents evidence from cross-countries analyses dealing with cohort effects.

A number of factors such as income and income inequality are found to be important determinants of energy consumption and intra-generational gaps in energy related emissions levels. Hargreaves et al. (2013) find that emissions of U.K. households are strongly correlated with income: the richest ten percent emit three times more than the poorest ten percent of households. The results of Weber and Matthews (2008) demonstrate that the total US household CO<sub>2</sub> footprint is best predicted by total household's income and expenditures. The authors also find that households differ considerably in their CO<sub>2</sub> responsibilities, with at least a factor of ten difference between low- and high-impact households. Fahmy et al. (2011) show that income inequalities are determining factors in explaining emissions and energy consumption of U.K. households. Rätty and Carlsson-Kanyama (2009) find that energy consumption of households increases almost linearly with income in Germany, Greece, Norway, and Sweden.

Brännlund and Ghalwash (2008) also provide evidence that residential CO<sub>2</sub> emissions in Sweden are increasing in income (at a decreasing rate) and are decreasing in income inequality. Moreover, Ghalwash (2007) finds evidence in support of the Environmental Kuznets Curve hypothesis (EKC – humped shaped relationship between emissions and per capita income<sup>73</sup>) in Sweden. According to his results, expenditure on environmental services increases with higher income. The results of Papathanasopoulou and Jackson (2009) confirm that fossil resources consumption inequality between rich and poor U.K. households grew by 24 percent while the inequality in the total expenditures rose by 13 percent between 1968 and 2000.

Area of residence, age, and household size are found to be the additional factors behind explaining emissions' levels. Hargreaves et al. (2013) find the following

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<sup>72</sup> For studies which conduct cross-countries analyses on the determinants of emissions, please refer to Lenzen et al. (2006), Grunewald et al. (2016), Ravallion et al. (2000), Heerink et al. (2001), Ajmi et al. (2015), et cetera.

<sup>73</sup> See Kuznets (1955).

characteristics of U.K. households to be associated with higher emissions: multi-adults households and couples, middle aged households (35–60 years), households containing multiple workers, households that use oil for heating, and properties in rural areas. Büchs and Schnepf (2013) show that elderly, low income, and jobless households in the U.K. are more likely to have high emissions from home energy than from other domains, which could indicate that they may be less affected by carbon taxes on transport or on total emissions. Energy consumed in housing increased with age in Norway, Sweden, Greece, and Germany (Räty and Carlsson-Kanyama (2009)).

Several studies have focused their analyses on German households. Weber and Perrels (2000) find that home energy emissions in West Germany are negatively related with income and positively related with age and household size. Transport related emissions are found to be positively related with income and negatively related with age and household size. The results of Rehdanz (2007) demonstrate that heating expenditures are lower among German households that own the dwelling where they live in comparison to households which rent their dwellings. Deutsch and Timpe (2013) provide evidence of clear age related effects (separate from overlaps with housing condition, household size, and economies of scale) in energy consumption in Germany. Similarly, Nikodinoska and Schröder (2016) find evidence of a trade-off between residential CO<sub>2</sub> emissions and income inequality in Germany. Räty and Carlsson-Kanyama (2009) find gender related consumption inequalities in Germany: men are higher energy consumers than women, and this is especially pronounced among older people (the generation born before 1945).

A number of articles in the field of economics have used Age Period Cohort (APC) models to explain inter-generational differences in residential energy consumption and emissions. For instance, Chancel (2014) applies a De-trended Age Period Cohort (APCD) model on direct CO<sub>2</sub> emissions of French and American households for the period 1980–2005. He finds no evidence of the effect of year of birth of the household leader on emissions in the USA, but in France strong birth cohort effects are present. The French households with leaders born between 1930 and 1955 are the highest CO<sub>2</sub> emitters compared to cohorts born before 1930 or after 1955 (even after introducing other control variables in the model). He concludes that the generational impact might be a consequence of progressive economic marginalization of younger generations as well as carbon intensive dwellings used by the older generations.

Moreover, using an APC model, Sánchez-Peña (2013) finds proof that cohort compositional differences are relevant in explaining residential energy consumption patterns

in Mexico. The results of the paper further show that for the cohorts that came to age during economic expansion there is a cohort pure effect i.e. they have higher consumption above and beyond their other characteristics. Pampel and Hunter (2012) use multi-level APC model to investigate the role of birth cohorts and socio economic status in explaining support for environmental spending in the U.S. They find that birth cohorts play an important role in explaining willingness to pay for environmental protection, with younger generations having higher willingness to pay (but they do not exhibit lower CO<sub>2</sub> emissions in comparison to other cohorts).

Furthermore, Segall (2013) integrates an APC model into Almost Ideal Demand System (AIDS) framework in order to test the existence of generational or cohort effect in the U.S. spending behavior. The model is then tested on consumer expenditure survey data and the results indicate that household budget allocations (including the budget for energy) show statistically significant cohort effects. Moreover, her results demonstrate that adding cohort effects improves demand models that only take age into account. Similarly, Aguiar and Hurst (2013) integrate cohort effects in demand system with the goal to deconstruct lifecycle expenditures of U.S. households. They find evidence of cohort and family compositional effects in explaining utilities consumption, which displays no decline after middle age but rather an increase.

Evidence from cross sectional analyses of OECD countries about cohorts effects in explaining emissions is mixed. Menz and Welsch (2012) have found that cohort composition has contributed to increasing carbon emissions. Their results clearly show robust cohort effects, with the people born after 1960 being found as relatively emissions intensive. The authors also found that higher per capita income raises carbon emissions, which is in contrast to the EKC. Menz and Küling (2011) do similar analyses of sulfur dioxide (SO<sub>2</sub>) emissions and find that people born before 1960 emit more SO<sub>2</sub> than their followers.

### **3.3 Methodology**

Age Period Cohort (APC) models have been extensively applied in social, behavioral, and human health sciences (see for instance Chauvel and Schröder (2014, and 2015), Yang et al. (2004, and 2008), Yang and Land (2006), Carstensen (2005), et cetera). Those studies have shown that generational factors can be important determinants of observed differences among households or individuals. According to Chauvel and Schröder (2015), an APC model can identify how an outcome (in this study CO<sub>2</sub> emissions) is explained by the position in the life

cycle (the effect of age), the time of measurement (the effect of the period), and year of birth (the effect of the cohort). The general APC model can be described as,

$$y^{apc} = f(a) + g(p) + h(c) \quad (3.1)$$

where  $y^{apc}$  can stand for the logged-CO<sub>2</sub> emissions (the variable of interest here),  $a$  is age,  $p$  refers to the period variable,  $c$  refers to the cohort variable, and  $f()$ ,  $g()$ , and  $h()$  are functions. The empirical identification of age, period and cohort effects is difficult due to the linear relationship between the explanatory variables, namely  $c = p - a$ . In order to assure identification, the model needs to be constrained. One such model is a de-trended Age Period Cohort (APCD) model (Chauvel, 2012). One of the main goals of the APCD model is the detection of “intrinsic” cohort effects, and according to Chancel (2014), the APCD cohort estimates are most reliable in comparison to other APC models. The main focus of the APCD model are the cohortal fluctuations, i.e. the non-linearities that cannot be represented by a combination of age and period variables. This model considers how the effects of age, period, and cohort fluctuate around a linear trend, which it absorbs. According to Chauvel (2012), and Chauvel and Schröder (2014, 2015), the APCD model can be defined as,

$$y^{apc} = \alpha_a + \pi_p + \gamma_c + \alpha_0 \text{rescale}(a) + \gamma_0 \text{rescale}(c) + \beta_0 + \sum_j \beta_j X_j + \varepsilon_i \quad (3.2)$$

where  $\alpha_a$  is the vector of age effect;  $\pi_p$  is the vector of period effect;  $\gamma_c$  is the vector of cohort effect (all those vectors reflect exclusively the nonlinear effects of age, period and cohort); the terms  $\alpha_0 \text{rescale}(a)$ , and  $\gamma_0 \text{rescale}(c)$  absorb the linear trends; *rescale* is a transformation that standardizes the coefficients  $\alpha_0$  and  $\gamma_0$  i.e. it transforms age ( $a$ ) from the initial code  $a_{min}$  to  $a_{max}$  to the interval  $-1$  to  $+1$ ; <sup>74</sup>  $\beta_0$  is the general intercept;  $X_j$  represent the additional control variables.

The constraints under (3.3) – (3.6) allow for unique estimates of the de-trended cohort effect and solve the identification problem:

$$p = a + c \quad (3.3)$$

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<sup>74</sup> For instance, if  $a$  is 45,  $a_{min}$  is 25 and  $a_{max}$  is 85, then  $\text{rescale}(a) = 2 * \frac{(a-a_{min})}{(a_{max}-a_{min})} - 1$  or  $-0.33$ . Cohort is similarly rescaled.

$$\sum_a \alpha_a = \sum_p \pi_p = \sum_c \gamma_c = 0 \quad (3.4)$$

$$\text{slope}_a(\alpha_a) = \text{slope}_p(\pi_p) = \text{slope}_c(\gamma_c) = 0 \quad (3.5)$$

$$\min(c) < c < \max(c). \quad (3.6)$$

Restrictions (3.4) and (3.5) indicate that each vector sums up to zero, and its slope is also zero (the orthogonality assumption, for details see Cartensen (2007), p. 3029 and Deaton (1997), p. 108). Restriction (3.6) indicates that the first and last cohorts, which appear just once in the model, are excluded.

Alternatively, the constrained generalized linear models (CGLIM) with equality constraints on age-period-cohort effects use a single equality constraint on the coefficients so that to solve the identification problem in APC models (see Chancel, 2014). This method includes an indicator variable for each unique value of age, period, and cohort as independent variable, uses a constraint to these indicator variables, and then completes the generalized linear model. According to the author, the CGLIM estimates are expected to have some bias since the cohort effects estimates assume that there is no time variation.

Yet another solution for the identification problem of age period cohort models has been suggested by Yang et al. (2004 and 2008); it is called the Age Period Cohort Intrinsic Estimator (APC-IE). As the authors infer, the numbers of age groups and time periods (the design matrix) may affect the estimates obtained from conventional CGLIM estimators. Hence, the APC-IE employs a special principal components regression that removes the influence of the null (column) space of the design matrix on the estimator. The APC-IE adds an indicator variable for each unique value of age, period, and cohort as independent variable, but omits one category for each of age, period, and cohort. Once the principal components regression has been estimated, the zero-sum constraints are used to obtain estimates for the deleted age, period, and cohort categories. In summary, the APC-IE tries to isolate a linear trend specific to cohorts. Chancel (2014) claims the results from the APC-IE should be interpreted with caution, but comparison of the APC-IE and APCD estimates should provide insight about the robustness of the cohort effect estimates.

### 3.4 Data and descriptive evidence

The main data source for this paper is the Income and Expenditure Survey (IES), an extensive micro data survey conducted by the German Federal Statistical Office. This survey represents a cross-sectional household data set, which is collected once in every five years since 1973.<sup>75</sup> The IES includes detailed information on various household's characteristics such as age, residential location, households size; as well as expenditures and incomes. The analyses here use the data from 1993 to 2013. In comparison to the dataset in Section 1.3.1 (Chapter 1), this paper includes the last available IES wave for 2013 and focuses only on the energy expenditures.

I use the following IES variables in the estimations: disposable income; education, and age of the household's leader; total expenditures; expenditures on electricity, gas, and car fuels; number and age of household members; dwelling size; type of heating system installed; number of electric appliances and cars; region (state); and frequency weights at the state level.<sup>76</sup> The final data comprises around 220,000 German households, across five cross-sections.

Since only household's expenditures information is available in the data, I have used the average commodity specific prices to calculate the consumed quantities of electricity and gas in kWh and car fuels (both diesel and gasoline) in liters. Then, the quantities are used so that to derive the household's direct energy related CO<sub>2</sub> emissions. The direct emissions from electricity ( $E_e$ ), gas ( $E_g$ ), and car fuels ( $E_{cf}$ ) are calculated as the product of the carbon factor of the respective energy good ( $\theta_i$ ) and the quantity of that energy good  $q_i$ :

$$E_i = \theta_i q_i \quad (3.7)$$

where  $i$  stands for  $e$ ,  $g$  or  $cf$ .<sup>77</sup> Total energy emissions ( $E_t$ ) are calculated as the sum of the three. The estimable APCD equation for emissions then takes the following form,

$$\ln(E_i)^{apc} = \alpha_{ai} + \pi_{pi} + \gamma_{ci} + \alpha_{0i} \text{rescale}(a) + \gamma_{0i} \text{rescale}(c) + \beta_{0i} + \beta_{1i} \text{hhsz} + \beta_{2i} \text{educ2} + \beta_{3i} \text{educ3} + \beta_{4i} \ln(ydisp) + \beta_{5i} \text{rural} + \varepsilon_i, \quad (3.8)$$

<sup>75</sup> For more detailed information on the dataset and pooling strategies, see Section 1.3.1 in Chapter 1 and Section 2.3.1 in Chapter 2.

<sup>76</sup> Frequency weights at the state level are used to ensure that the data is representative of the whole German population.

<sup>77</sup> For simplicity, household, age, period, and cohort sub-indices are omitted.

where *hsize* stands for household size (number of adults plus children), *educ2* is a binary variable indicating whether the household's leader<sup>78</sup> has completed high school or other specialized school, *educ3* similarly indicates if the household's leader has university or higher education, *ydisp* is the disposable income of the household, and *rural* is a binary variable indicating if the household lives in rural residential area.<sup>79</sup> Dwelling size, number of electric appliances, and type of heating system are used as additional control variables in the equations for electricity and gas emissions. Numbers of old and new cars are used as controls in the equation for car fuels emissions.

One relevant issue is addressed in this paper: the cohort effects of other household members (not just the household leader) are analysed. There can be persons from different cohorts living in the same household and the energy consumption (and emissions) is then blurred by the consumption activities of several birth cohorts. Previous literature has totally disregarded the presence of other birth cohorts in the household and focused only on the effect of the leader's birth cohort on emissions. Therefore, instead of household size, I include the number of household members belonging to a specific birth cohort as controls,

$$\ln(E_i)^{apc} = \alpha_{ai} + \pi_{pi} + \gamma_{ci} + \alpha_{0i}rescale(a) + \gamma_{0i}rescale(c) + \beta_{0i} + \sum_{c=1908}^{1988} \mu_{ci}n_c + \beta_{2i}educ2 + \beta_{3i}educ3 + \beta_{4i}\ln(ydisp) + \beta_{5i}rural + \varepsilon_i, \quad (3.9)$$

where  $n_c$  stands for the number of household members belonging to particular cohort  $c$  and  $\mu_{ci}$  is the cohort effect, coming from that particular household member, on emissions.

To examine the changes in characteristics and energy consumption of the average German household, Table 3.1 includes the summary statistics of the main variables of interest, weighted for the whole German population. The average German household got smaller, older, and richer between 1993 and 2013. The leaders of the households tend to be more educated: while in 1993 only 8.3 percent had completed high school or other specialized education in 2013 this number is up to 11.1 percent (*educ2*); the proportion of leaders with university or higher education also increased (*educ3*). The average household tends to own more electric appliance and to live in bigger dwellings in 2013 in comparison to earlier

<sup>78</sup> Date of birth (birth cohort), age, and education are defined for the leader of the household, who is the main income earner in the family. Many studies that investigate cohort effects among households make such an assumption (Chancel (2014), Sànchez-Peña (2013), and Segal (2013)).

<sup>79</sup> Some variables are logged and others are binary indicators so that to make the interpretation of the coefficients easier. Chancel (2014) also measures income in logs so that to obtain the income elasticity of emissions.

**Table 3. 1 Descriptive statistics**

Variable	1993		1998		2003		2008		2013	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
<i>adults</i>	1.887	0.820	1.834	0.802	1.804	0.804	1.758	0.789	1.727	0.778
<i>children</i>	0.424	0.819	0.359	0.757	0.334	0.734	0.298	0.692	0.281	0.682
<i>age</i>	50.479	16.297	51.267	16.447	51.650	16.627	51.693	16.516	52.464	17.145
<i>ydisp</i>	28708.220	16807.470	31426.280	18937.680	33898.480	20528.100	34692.720	21922.690	36805.630	22777.440
<i>educ1</i>	0.649	0.477	0.700	0.458	0.684	0.465	0.647	0.478	0.653	0.476
<i>educ2</i>	0.083	0.275	0.108	0.310	0.118	0.322	0.122	0.327	0.111	0.314
<i>educ3</i>	0.114	0.318	0.127	0.333	0.142	0.349	0.131	0.337	0.150	0.357
<i>TVs</i>	1.227	0.641	1.419	0.751	1.474	0.843	1.483	0.869	1.675	0.964
<i>PCs and notebooks</i>	0.249	0.498	0.463	0.656	0.866	0.893	1.224	1.080	1.810	1.342
<i>refrigerators and freezers</i>	1.717	0.755	1.994	0.739	1.917	0.831	1.796	0.888	1.269	0.535
<i>dishwashers</i>	0.313	0.466	0.461	0.505	0.583	0.507	0.643	0.497	0.752	0.465
<i>washing machines and driers</i>	1.112	0.537	1.236	0.582	1.322	0.608	0.386	0.491	1.441	0.627
<i>dwelling size</i>	85.808	38.192	89.785	40.927	92.665	42.002	92.316	41.748	92.809	42.366
<i>cars new</i>	0.446	0.586	0.432	0.587	0.410	0.578	0.367	0.561	0.431	0.607
<i>cars old</i>	0.478	0.641	0.535	0.677	0.605	0.710	0.625	0.716	0.669	0.758
<i>distant heating</i>	0.179	0.384	0.154	0.361	0.153	0.360	0.163	0.369	0.168	0.374
<i>central heating</i>	0.636	0.481	0.740	0.439	0.776	0.417	0.771	0.420	0.773	0.419
<i>quantity of electricity</i>	3879.428	2876.294	3644.427	2734.130	3880.870	2898.537	3144.112	2462.313	3136.729	2534.392
<i>quantity of gas</i>	21325.060	16043.200	20614.440	22579.500	17434.150	20917.880	15345.200	22644.410	12967.130	22570.810
<i>quantity of car fuels</i>	904.344	855.088	1047.388	1000.752	958.891	901.726	847.734	842.634	792.499	787.780



**Table 3. 1 (Continued)**

Variable	1993		1998		2003		2008		2013	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
<i>electricity related emissions</i>	2.165	1.605	2.034	1.526	2.166	1.617	1.754	1.374	1.750	1.414
<i>gas related emissions</i>	8.935	6.722	8.637	9.461	7.305	8.765	6.430	9.488	5.433	9.457
<i>car fuels related emissions</i>	2.170	2.052	2.514	2.402	2.301	2.164	2.035	2.022	1.902	1.891
<i>total energy emissions</i>	13.270	7.561	13.185	10.342	11.772	9.749	10.219	10.345	9.086	10.255
<i>electricity price</i>	0.143	0	0.143	0	0.155	0	0.221	2.78E-17	0.268	0
<i>gas price</i>	0.031	0	0.031	0	0.048	0	0.071	0	0.071	0
<i>car fuels price</i>	0.668	0	0.737	0	1.033	0	1.385	0	1.551	0
<i>observations</i>	38376		47747		41046		42315		50342	

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education.

periods, which consequently requires more electricity and space heating. Germans also own a higher proportion of older cars in comparison to new, which adds to the consumption of car fuels because the older cars are less energy efficient. The data shows that households that own old cars have on average six percent higher consumption of car fuels than households that own new cars.

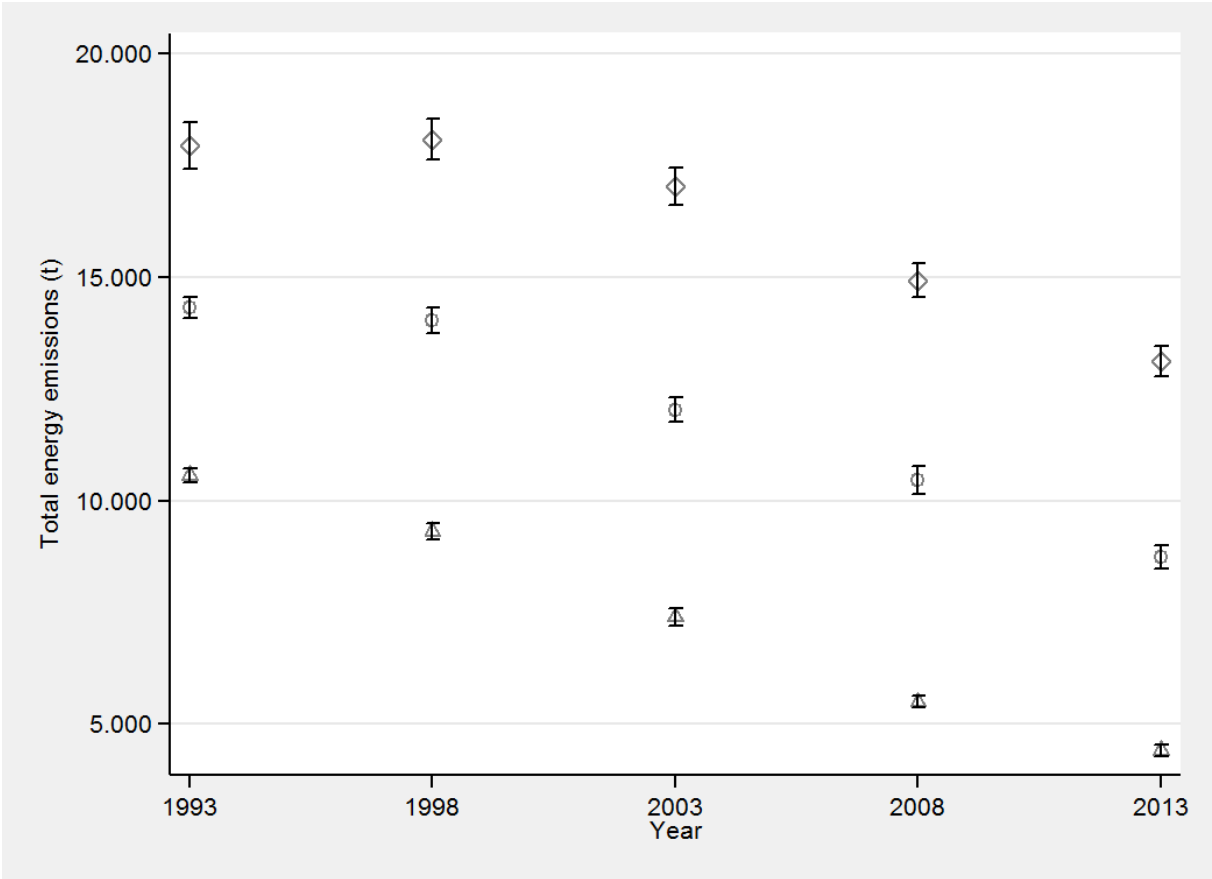
Table 3.1 reveals no clear trend in the consumption of electricity and the related emissions, but it appears that consumption is much lower in 2013 than it was in 1993 (consumption decreased by 19.2 percent). The decrease in electricity consumption is mainly due to higher electricity prices (which almost doubled during the period) and partially due to more energy efficient electric appliances (which is difficult to measure given the dataset). Concerning heating of their homes, the German households rely increasingly on central heating, which is usually gas operated. But gas consumption has also decreased by around 39.2 percent during the period whereas the gas price has more than doubled. Similarly, the consumption of car fuels and the related emissions have decreased by 12.4 percent. So, also the total direct energy related CO<sub>2</sub> emissions for the average German household have declined during the last twenty years of the IES data. The drop could be a consequence of the decrease in the average household size and the increase of energy prices but potentially also due to the economic crisis.

In order to investigate the emissions inequality between the poor – low income and the rich – high income households in Germany (determined by the level of equivalent income: disposable income divided by modified OECD scale), the emissions for each equivalent income decile are computed separately. The development of total energy related CO<sub>2</sub> emissions over time for the first (empty triangles), fifth (empty circles), and tenth decile (empty diamonds) of equivalent disposable income is provided in Figure 3.1.<sup>80</sup> The figure also includes the upper and lower 95 percent confidence intervals. The low income households emitted 10.6 tons of CO<sub>2</sub> in 1993 and only 4.4 tons of CO<sub>2</sub> in 2013. The CO<sub>2</sub> emissions of the high income German households have increased slightly from 1993 to 1998, then declined to 17.0 tons in 2003 and further to 13.1 tons of CO<sub>2</sub> in 2013 (overall they decreased by 26.7 percent). The fifth (middle) decile exhibits similar pattern to the tenth decile, only with smaller magnitude. The emissions inequality according to income levels is quite evident in Germany. Figure 3.1 further shows that in 1993 the rich emitted 68.9 percent

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<sup>80</sup> Table 3.4 in the Appendix includes the total energy related CO<sub>2</sub> emissions for each year and each decile separately.

more emissions than the poor while in 2013 even 196.8 percent more emissions<sup>81</sup>. Thus, the income emissions inequality has further widened during the period 1993–2013 but one has to be cautious since this evidence comes from raw data without controlling for any other relevant variables which might partly explain the difference. Rich and poor households differ in household size, age, and education levels. Richer households are likely to be older (age is usually related to higher energy consumption) and more educated while poorer households are likely to be bigger in size, all of which could partly explain the emissions inequalities between the two groups. Moreover, low income households are also less likely to own a car or electric home appliances and are more likely limit their consumption of other energy goods due to budget limitations.

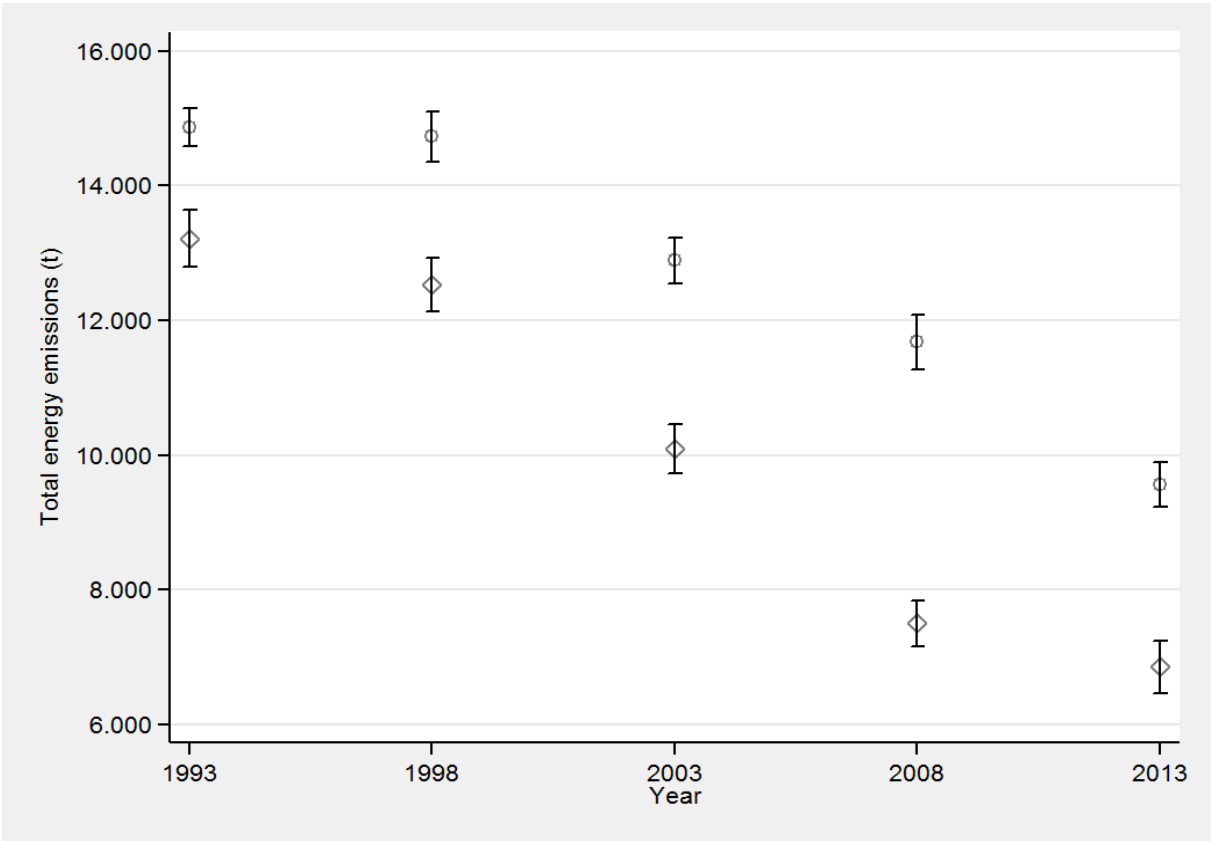


**Figure 3. 1 Development of total CO<sub>2</sub> emissions for the first, fifth and tenth equivalent income decile over time**

*Note.* Database is IES 1993–2013. Empty triangles denote the first, empty circles denote the fifth decile, and empty diamonds denote the tenth equivalent income decile. Line segments indicate the 95 percent confidence intervals.

<sup>81</sup> As mentioned in the literature review, rich households in the U.S., France (Chancel (2014)), and U.K. (Hargreaves et al. (2013)) are also found to emit around three times more CO<sub>2</sub> than the poor households.

Figure 3.2 presents the total energy related emissions of rural (empty circles) and urban (empty diamonds) households during the period 1993–2013. Rural households are defined as households living in areas with less than 100,000 inhabitants.<sup>82</sup> The gap between the rural and urban households’ emissions has widened during the period, despite the decreasing trend in direct CO<sub>2</sub> emissions (for the rural households this trend starts only after 1998). In 1993, the average urban household emitted 13.2 tons while the rural emitted 14.9 tons total direct energy related CO<sub>2</sub> emissions; the difference was 12.9 percent. However, by 2008 the gap widened further to 27.7 percent and by 2013 to 39.1 percent with urban and rural households emitting 6.9 and 9.6 tons of CO<sub>2</sub> respectively. Other differences between the rural and urban households, which might clarify the place of residence emissions inequalities, include household size, age, income, and education (see Table 3.3 in the Appendix). Rural households are found to be bigger, older and richer while urban households are found to be more educated – higher education is usually associated with higher environmental consciousness and thus lower emissions.

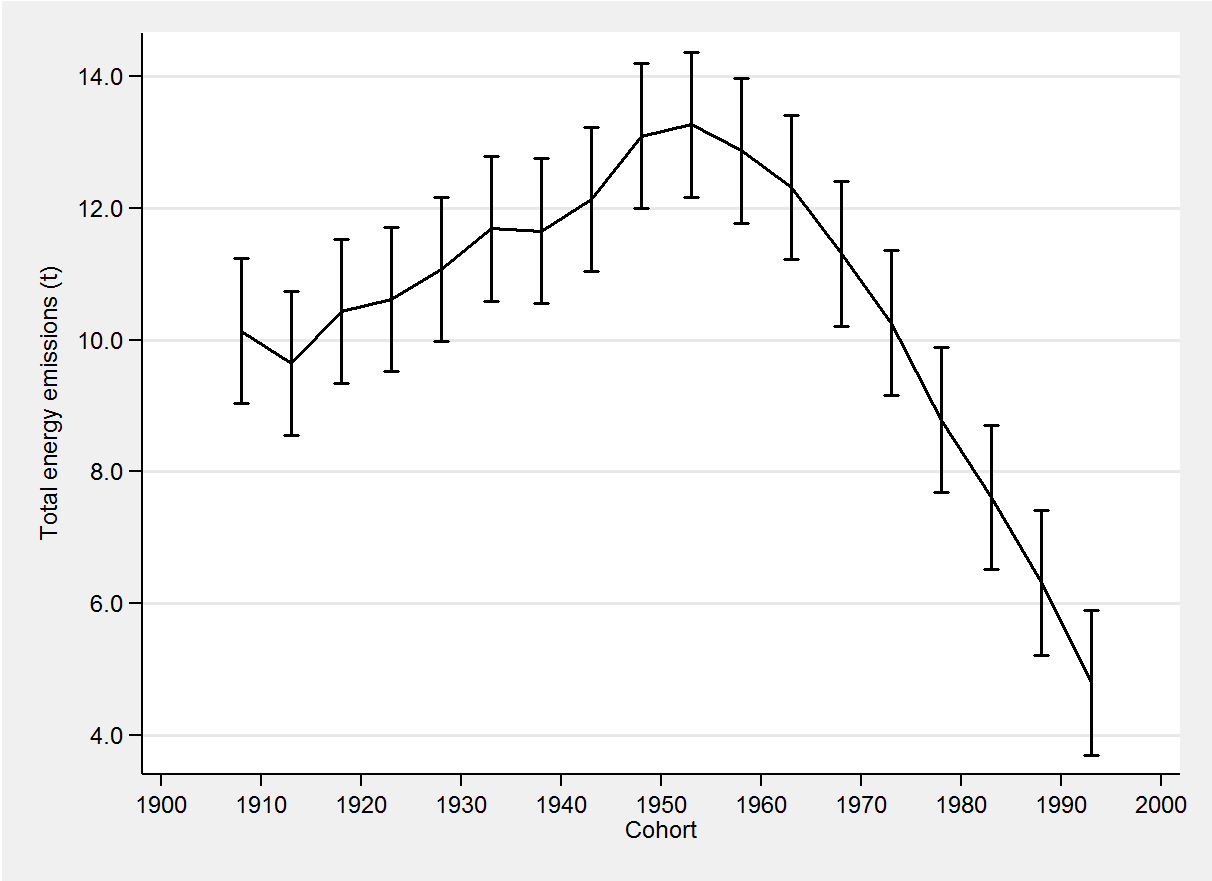


**Figure 3. 2 Differences in emissions levels between rural and urban households**

*Note.* Database is IES 1993–2013. Empty circles denote the urban and empty diamonds denote the rural households. Line segments indicate the 95 percent confidence intervals.

<sup>82</sup> Using an alternative specification of rural as households living in areas with below 50,000 inhabitants, demonstrates that the gap between urban and rural households is even wider.

For the emissions inequality according to year of birth (birth cohort), I have prepared Figure 3.3. The figure shows sort of an inverted u-shaped relationship between total energy related emissions and the birth cohort of the household leader. It can be seen in Figure 3.3 that the households which have a household leader born between 1933 and 1963 emit around 8.8 percent more CO<sub>2</sub> than the average German household. The highest emitters appear to be the cohort born in 1953, with 16.1 percent higher than average emissions. The households with leaders born 1908–1923 and 1968–1993 have lower than average emissions. As extreme cases, the cohorts born 1993 and 1995 have 44.8 percent and 58.1 percent lower emissions than the average German household.



**Figure 3. 3 Birth cohorts and total emissions**

*Note.* Database is IES 1993-2013. Line segments indicate the 95 percent confidence intervals.

Once again, other household’s characteristics could also explain such large differences in emissions levels.<sup>83</sup> Namely, household size is 5.9 percent larger than average among the households with leaders born 1953–1978. Moreover, households with leaders from birth

<sup>83</sup> Table 3.5 in the Appendix summarizes the variables of interest according to birth cohort of the household’s leader.

cohorts 1933–1963 live in 6.4 percent larger dwellings. Furthermore, if the households has a leader born between 1948 and 1978, income tends to be 6.7 percent higher. Hence, overall energy consumption appears to be highest among cohorts 1933–1963. Energy taxes on electricity would be more effective in reducing emissions if imposed on the generations 1933–1988 and energy taxes on gas should be imposed on the generations 1913–1963. Also, households with leaders from certain birth cohorts tend to have larger number of household appliances: cohorts 1943–1963 own 7.2 percent higher number of TVs, cohorts 1948–1993 own 12.6 percent higher number of PCs and notebooks, cohorts 1928–1958 own 6.5 percent higher number of refrigerators and freezers, cohorts 1943–1993 own 11.2 percent higher number of dishwashers, and cohorts 1943–1963 own 6.1 percent higher number of washing machines and driers. In addition, the cohorts 1948–1993 possess 10.8 percent larger than average number old cars, and the cohorts 1928–1958 possess 7.1 percent larger than average number of new cars. Increasing car fuels tax for the cohorts born before 1953 would affect emissions by less than if imposed on the cohorts born after 1953.

### 3.5 Empirical results

#### 3.5.1. Total energy related emissions

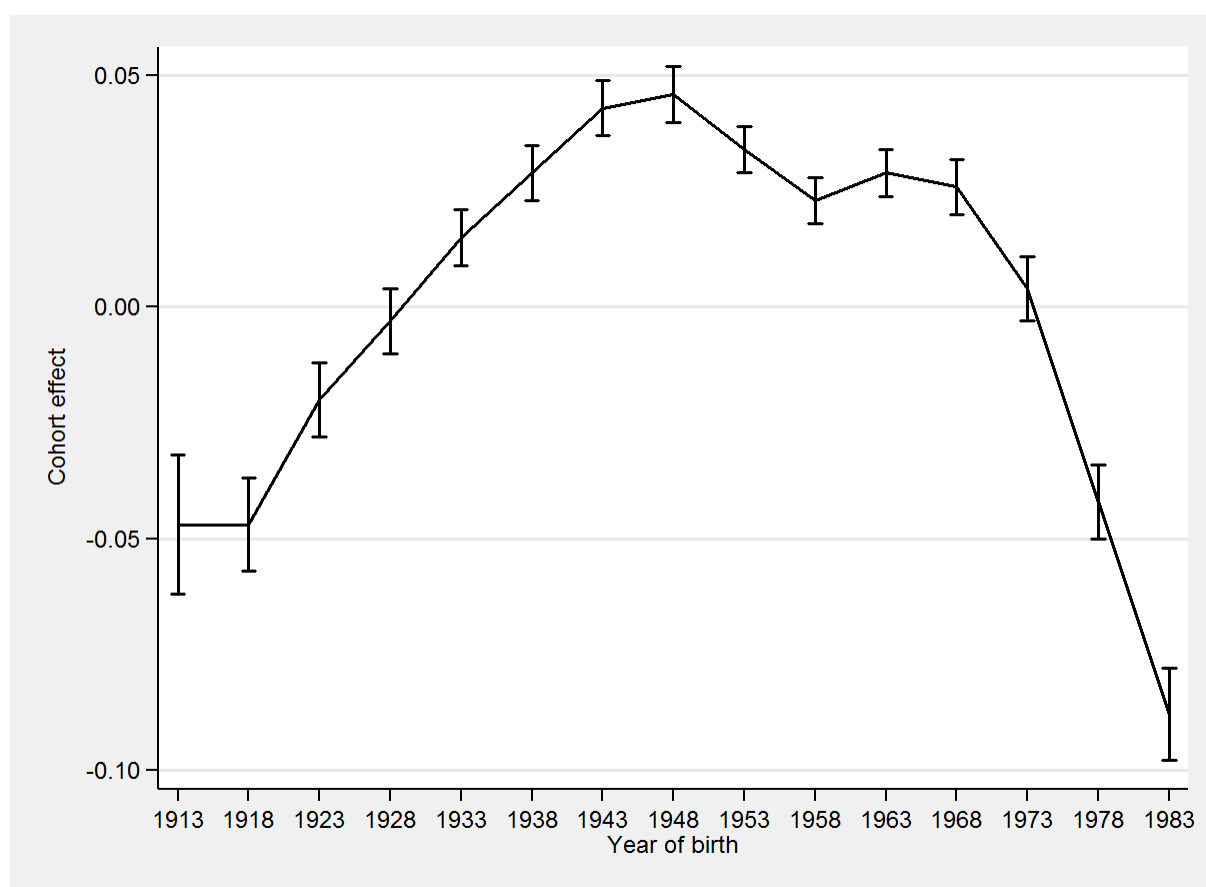
The results from the APCD specification, where only age, period, and cohort are included as explanatory variables, show that the households with leaders born between 1933 and 1973 have a stronger tendency to emit CO<sub>2</sub> than the households with leaders born before 1933 and after 1973 (see Figure 3.4). All the cohort effects are statistically significant<sup>84</sup> indicating that birth cohorts are important determinant of energy related emissions in Germany. So, the total energy emissions of German households exhibit sort of an inverted u-shaped relationship with the birth cohort of the household's leader. The cohorts born 1933–1973 emit more CO<sub>2</sub> than the average German household, holding everything else constant. Figure 3.4 also shows that the households whose leader is born in 1913, 1918 or 1983 emit less emissions than the average household probably due to lower demand for energy goods (for instance demand for car fuels among the earlier generations). The existence of strong generational emissions inequalities in Germany could be explained by the fact that baby boomers are wealthier, live in energy inefficient dwellings, and have certain types of habits

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<sup>84</sup> With exception of the cohorts 1923 and 1973. Table 3.6 in the Appendix shows the details on the estimated coefficients of the model without additional controls, with controls, and with other cohorts' effects.

and life styles. The estimates from the APCD model overlap with the descriptive evidence (see Figure 3.3 in Section 3.4), which shows the households with leaders born 1933–1963 to be the highest emitters (irrespective of age, period, and other characteristics). So, controlling for age, period, and cohort effects helped to explain part of the inter-generational emissions gap found in the data.

The generational effect is still present once income, education, other socioeconomic, demographic, and life style variables are included in the model. Figure 3.5 shows the effect of birth cohort of household's leader on CO<sub>2</sub> emissions with additional explanatory variables and number of household members of certain cohorts (except of the household's leader), as described by equation (3.9).<sup>85</sup> This specification significantly improved the model fit and



**Figure 3. 4 Cohort effects of household's leader on total energy CO<sub>2</sub> emissions without controls**

*Note.* Database is IES 1993–2013. Line segments indicate the 95 percent confidence intervals.

also allowed for analyses of the influence of household's members (potentially belonging to a different birth cohort from the leader) on emissions. The results reveal that generations born between 1943 and 1973 have higher CO<sub>2</sub> emissions than the average German household and

<sup>85</sup> Household size (number of adults and children) as control is included in the second specification (equation (3.8)). See the third column in Table 3.6 in the Appendix for the results.

most of the cohort effects are statistically significant.<sup>86</sup> Households whose leader belongs to the 1963 birth cohort are the highest CO<sub>2</sub> emitters. It seems that the 1943–1973 cohorts have difficulties in adapting to more energy efficient consumption patterns and lifestyles. The households' leader belonging to the generations born before 1943 and after 1973 have lower tendency to emit CO<sub>2</sub>. Chancel (2014) claims that the sign of the cohort effects is more important than the actual magnitude. The cohort effects for Germany are comparable to the results of Chancel (2014) for France, where the cohorts born between 1930 and 1955 are the highest CO<sub>2</sub> emissions emitters (using data for the period 1980–2000), and overlap also with the results of Menz and Küling (2011) for OECD countries (using data for the period 1970–2000), where people born before 1960 are found to have lower SO<sub>2</sub> emissions). Sánchez-Peña (2013) finds that in Mexico, the cohorts born between 1923 and 1968 consume more energy (and therefore emit more CO<sub>2</sub> emissions) than the average household. The results of Menz and Welsch (2012) demonstrate that people born 1920 and earlier, and between 1941 and 1960 emit significantly less CO<sub>2</sub> than people born after 1960.<sup>87</sup>

As explained before, including the number of other household members belonging to a certain birth cohort (see equation (3.9)) as control variables, allowed for the examination of the impact of the birth cohorts of other household members on energy emissions, which has not been done in earlier studies. The cohort effect of the household members born between 1918 and 1988 is positive and statistically significant. Only the cohort effect of the household members born in 1908 is negative but insignificant (Figure 3.9 and Table 3.5 in the Appendix). Having an additional household member, who belongs to the birth cohorts 1923, 1928, 1933, 1938, 1943, 1948, 1953, 1958, 1963 or 1968, increases energy related CO<sub>2</sub> emissions. Additional members from the cohort 1943 have highest effect on emissions. Interestingly enough, the results indicate that having either a households leader or at least one household member from the birth cohorts 1943–1968<sup>88</sup> leads to higher energy consumption and tendency to emit more CO<sub>2</sub>.

The results of the APCD model with controls and other household members cohorts' controls provide several further details about the determinants of energy related emissions, besides the birth cohorts of the leader and other members. The effect of dwelling size on total energy emissions is positive and statistically significant. High school or university education

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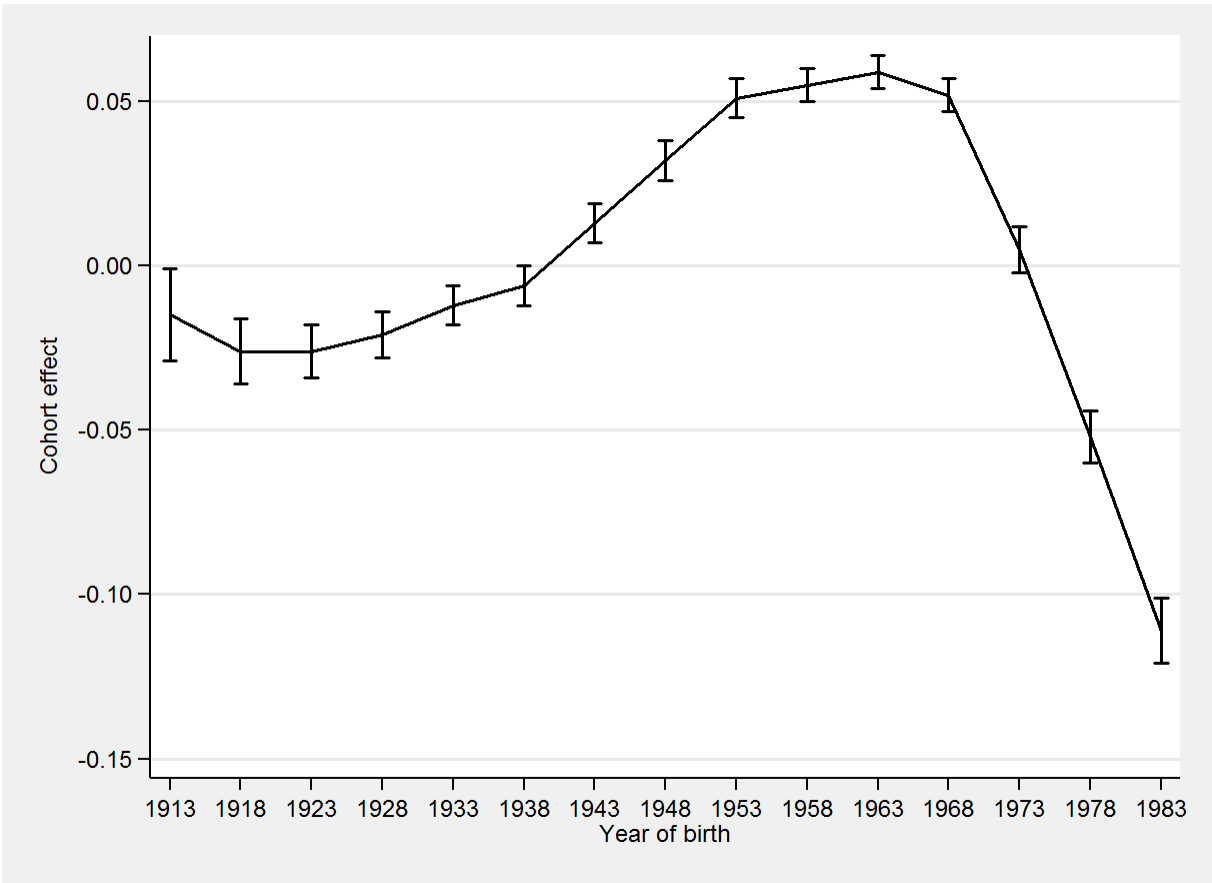
<sup>86</sup> For details on the estimated coefficients and their standard errors, please refer to Table 3.6 in the Appendix. The cohort effects of household's leader on emissions are insignificant only for the cohorts born 1913, 1938, and 1973.

<sup>87</sup> The data used in Sánchez-Peña (2013), and Menz and Welsch (2012) cover the period 1992–2008 (in 4 years gaps) 1960–2005 respectively.

<sup>88</sup> This is the overlap of the results of Figures 3.6 and 3.11.



of the household’s leader appears to have small but negative effect on total emissions. Households which have a leader aged between 50 and 75 are found to emit more CO<sub>2</sub> than the average German household. In France, households with leaders aged above 60 emit more CO<sub>2</sub> than the average household (Chancel (2014)). The age of the household’s leader has been associated with the life cycle of the household. Households that are at later stages of their life cycle usually increase their consumption net of other effects (Pachauri, 2004). Indeed in some developed countries, age is found to be positively related with higher residential energy consumption (see for instance Rehdanz (2007), Liddle and Lund (2010), and O’Neill and Chen (2002)).



**Figure 3. 5 Cohort effects of household’s leader on total energy CO<sub>2</sub> emissions with control variables and other cohorts effects**

*Note.* Database is IES 1993–2013. Line segments indicate the 95 percent confidence intervals.

To examine the effect of income on emissions and to confirm the presence of income emissions inequalities among German households, the sign and statistical significance of the coefficient of income in equation (3.9) are important. The results demonstrate that income has positive and significant effect on emissions – comparing two households with same characteristics but with different income levels, the households with higher income is

expected to have higher energy related emissions. Weber and Matthews (2008), find that 10 percent increase in the income of US households leads to 3.5 to 5.2 percent increase in the carbon footprint.<sup>89</sup> Similarly, to confirm the presence of place of living inequalities, the coefficient on the rural variable should be significant.<sup>90</sup> A household living in rural area in Germany is expected to have higher total energy related emissions than a household living in urban residential area, holding everything else constant.

### 3.5.2 Emissions from the separate sources: electricity, gas, and car fuels

The cohort effects for the separate energy related emissions<sup>91</sup> (electricity, gas, and car fuels) are displayed in Figure 3.6. The effects represented on the graph are coming from the model with additional control variables and other cohorts' effects.<sup>92</sup> For electricity related emissions, the households with leaders born between 1948 and 1978 are highest CO<sub>2</sub> emitters. Having an additional household member from the cohorts 1933–1953 increases electricity related emissions (see Table 3.7 in the Appendix). The household with leader born between 1928 and 1968 are responsible for more gas related CO<sub>2</sub> emissions than the average household. Gas related emissions are higher if the household has an additional member from the cohorts 1928–1953. The cohort effects of the household's leader for car fuels related emissions demonstrate that the cohorts 1958–1973 are the highest emissions emitters. Having an additional household member from the cohorts 1938–1963 leads to higher than average car fuels related emissions. Households with either a household's leader or member from birth cohorts 1948–1953, 1928–1953, and 1938–1963 have propensity to emit more electricity, gas, or car fuels related emissions respectively.

The outcomes from the APCD further provide evidence of income related emissions inequalities for electricity, gas, and car fuels related emissions.<sup>93</sup> So, a positive relationship between income and total energy related CO<sub>2</sub> emissions is reconfirmed for the emissions coming from separate energy sources, as was also found in Brännlund and Ghalwash (2008). Table 3.7 in the Appendix also presents evidence of area of residence emissions inequalities for CO<sub>2</sub> emissions coming from gas and car fuels. Rural households are expected to have

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<sup>89</sup> The authors consider the carbon footprint across all goods categories (not just energy) and consider both domestic and emissions included in imported goods and services.

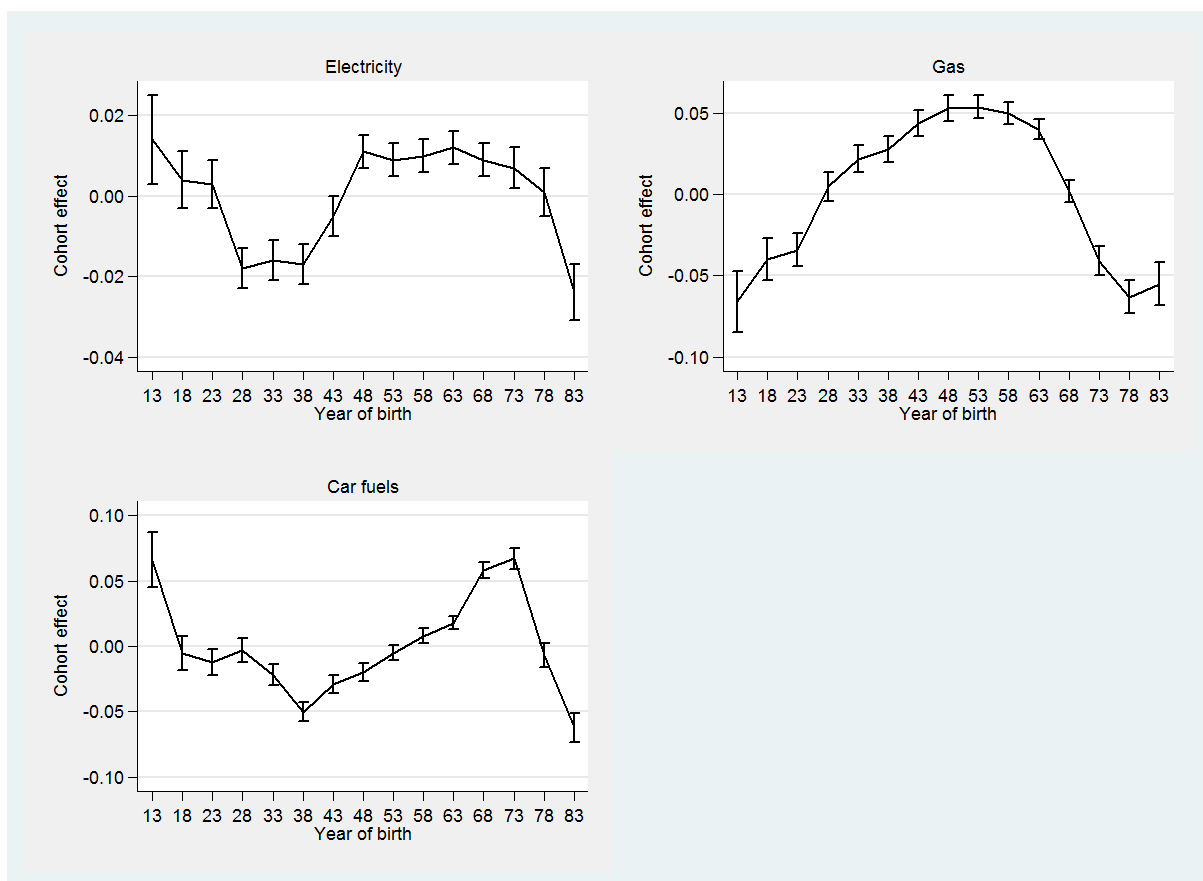
<sup>90</sup> See Table 3.5 in the Appendix for details on estimated coefficients for income and rural place of residence. The descriptive evidence from Figures 3.1 and 3.2 is in line with the empirical results included in Table 3.5.

<sup>91</sup> For details on the estimates, please refer to Table 3.7 in the Appendix.

<sup>92</sup> For the pure cohort effects, without controls, please check Figure 3.10 in the Appendix. They are comparable to Figure 3.6 but slightly larger in absolute value.

<sup>93</sup> Please refer to Table 3.7 in the Appendix.

higher gas related emissions and higher car fuels related emissions, probably due to more travel necessary for everyday life. As expected, there is no difference between rural and urban households in CO<sub>2</sub> emissions related to electricity.



**Figure 3. 6 Cohort effects of household leader on different energy CO<sub>2</sub> emissions sources, with additional control variables and other cohorts effects**

*Note.* Database is IES 1993–2013. Years 13–83 stand for 1913–1983. Line segments indicate the 95 percent confidence intervals.

The results have several policy implication concerning which groups of the population should be targeted in order to achieve highest CO<sub>2</sub> emissions savings. In Germany, rural and high income households have higher electricity, gas, and car fuels related emissions. Carbon taxes would decrease emissions more for the rural and rich than for the urban and poor households.<sup>94</sup> Energy taxes on gas would be more effective in reducing emissions if imposed on the generations 1928-1968, and energy taxes on electricity should be imposed on the generations 1948-1973. Increasing car fuels tax for the cohorts 1953-1973 would affect emissions more than if imposed on the cohorts born before 1953 or after 1973. So for the

<sup>94</sup> This also depends on the price elasticities of demand of the respective groups, and for instance in Chapter 2, I have shown that low income households have higher elasticity for electricity demand than the high income households.

earlier cohorts, energy taxes on domestic energy would be more efficient than taxes on transport. Having higher emissions from gas or electricity than from car fuels can indicate that taxes on car fuels will not be as effective in reducing emissions for that part of the population. Hence, mitigation policies need to be scrutinized for the separate emission domains in order to assure fairness. Moreover changes in lifestyles can also contribute to lowering residential energy related emissions in Germany. Living in bigger household size and smaller (energy efficient) dwellings, lower number or more efficient electric appliances and cars can all bring CO<sub>2</sub> savings.

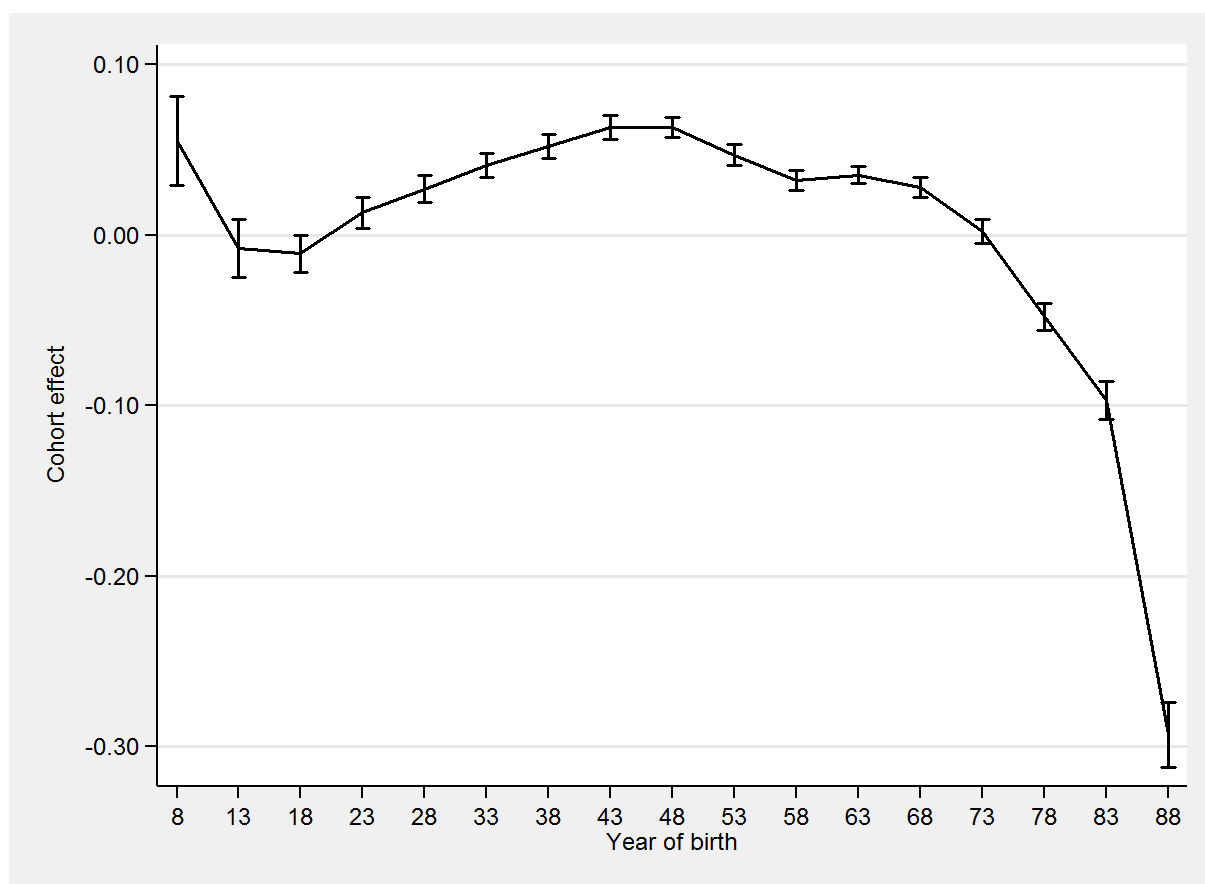
### 3.6 Consistency checks and methodological issues

The Age Period Cohort Intrinsic Estimator (APC-IE) model<sup>95</sup> is estimated to check the robustness of the APCD results. The estimates from the APC-IE reconfirm the inverted u-shape of residential energy emissions in Germany but as the estimates are expected to include some bias, the predicted coefficients should be interpreted with caution. Figure 3.7 includes the cohorts' effects of the household's leader on total energy emissions as predicted by the APC-IE model without controls. The figure demonstrates that households with leader from the birth cohorts 1923–1973 have higher emissions whereas the 1943 and 1948 cohorts are found to have highest tendency to emit CO<sub>2</sub>. This was also the case in the APCD model without controls: 1948 cohort is the highest emitter, and the cohorts 1933–1973 emitting more CO<sub>2</sub> than the average household.

Figure 3.8 shows the birth cohort effects from the APC-IE model with controls and other household members cohorts' effects. On this figure, it can be seen that the households with leaders belonging to birth cohorts 1933–1973 emit more CO<sub>2</sub>, and the leaders belonging to 1963 cohort emit more CO<sub>2</sub> than the average household. APCD also predicted households with leaders from the 1963 birth cohort as highest emitters and positive and significant cohort effect on emissions if the leader is from the birth cohorts 1943–1973. The APC-IE cohort effects of other household's members indicate that household's members belonging to cohorts 1928–1963 raise energy consumption and CO<sub>2</sub> emissions.<sup>96</sup>

<sup>95</sup> For details on model specifications, please refer to Yang et al. (2004 and 2008), Yang and Land (2006), Rutherford et al. (2010), Sasieni (2012), and Schulhofer-Wohl and Yang (2006). Detailed results from the German data are provided in Table 3.8 and Figure 3.11 in the Appendix.

<sup>96</sup> The cohorts' effects of other household members from APC-IE are very similar to APCD estimates (compare Figures 3.10 and 3.11 in Appendix).

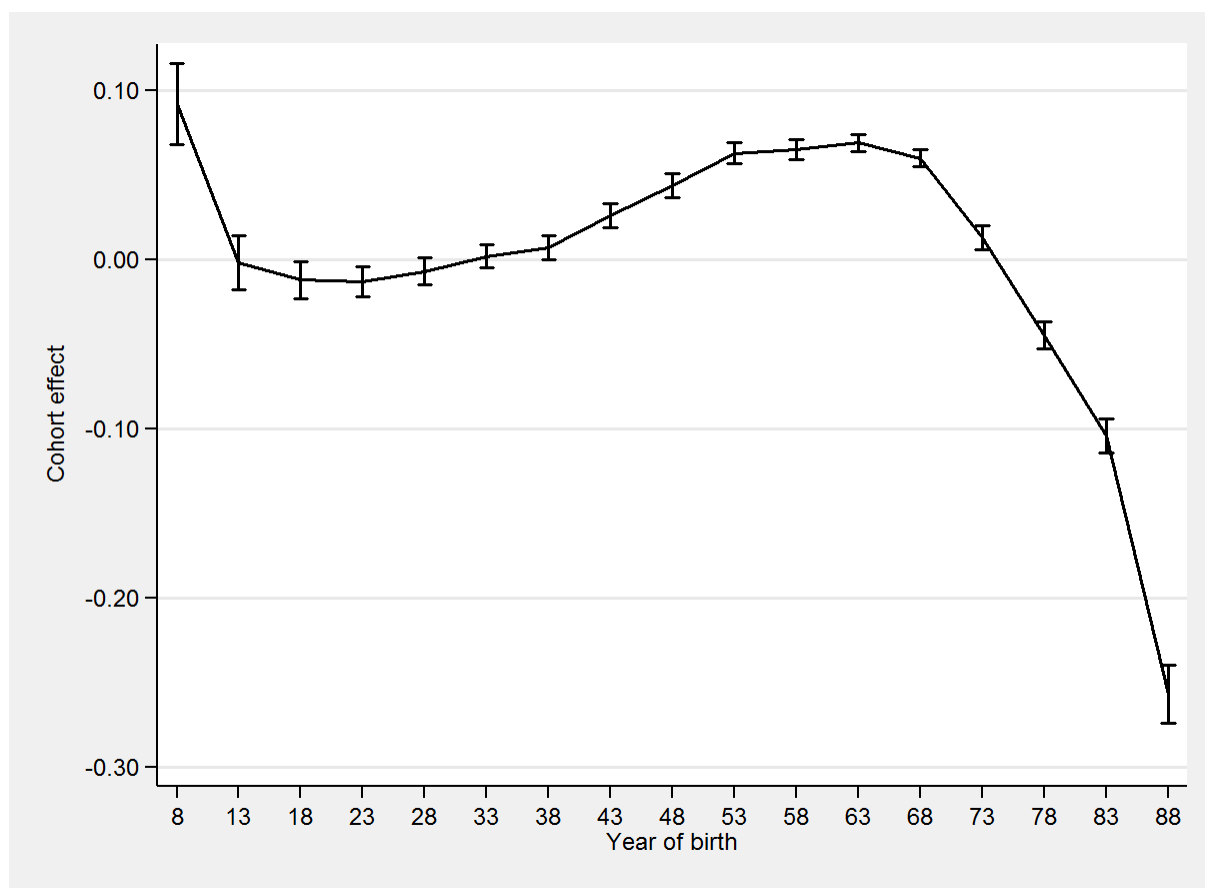


**Figure 3. 7 Cohort effects of household's leader from the APC-IE model without controls**

*Note.* Database is IES 1993–2013. Years 13–83 stand for 1913–1983. Line segments indicate the 95 percent confidence intervals.

The only big difference between the APCD and the APC-IE estimates (both including additional controls and other cohorts' effects as in equation (3.9)) is that the latter model has higher cohort effects overall and identifies the 1933–1973 birth cohorts as the highest emitters while the APCD identifies the cohorts 1943–1973 as the highest CO<sub>2</sub> emitters. The APC-IE model also includes two more cohorts (1908 and 1998) and has larger 95 percent confidence intervals in comparison to the APCD, which cuts the corner cohorts, leading to large improvement in the efficiency of the estimates. The results from APC-IE also confirm the presence of intra-temporal emissions inequalities in Germany. Emissions are higher among households with higher income levels and households that live in rural area.

The comparison of the results from the two different estimation methods support the idea of the robustness of both the cohort trends and the overall estimations. As mentioned earlier, the trend is also more relevant than the actual magnitude of the cohort coefficients. So, the results should still be carefully interpreted even if the de-trended estimator is more appropriate than the intrinsic estimator.



**Figure 3. 8 Cohort effects of household's leader from the APC-IE model with additional controls and other cohort effects**

*Note.* Database is IES 1993–2013. Years 13–83 stand for 1913–1983. Line segments indicate the 95 percent confidence intervals.

There can be potentially other factors, such as behavioral, housing, and income, behind the cohort trends.<sup>97</sup> The number and type of household appliances, or the number and type of cars, and the frequency of their usage could be interpreted as behavioral as well as income determined factors. The cohorts 1933–1963 own larger than average number of household appliances, the cohorts 1948–1993 own larger than average number of old cars, and the cohorts 1928–1958 own larger than average number of new cars. Some of the electric appliances owned by generations born after 1973 might be more energy efficient but it also might be the case that the latter generations use the appliances less frequently due to environmental concerns or different habits.<sup>98</sup> Similarly, newer cars could be more energy

<sup>97</sup> The issue of inter-generational emissions gaps was already touched upon at the end of Section 3.4 (and Table 3.5 in the Appendix).

<sup>98</sup> Lighting and heating requirements are also very different for a retired person who spends significant amount of time at home and a student who spends significant amount of time at the university buildings.

efficient and different birth cohorts could have different behavioral patterns.<sup>99</sup> Households with leaders born between 1933 and 1963 live in larger dwellings, which requires more lighting and heating and represents the housing factor. Unfortunately, data on type of dwelling and year of construction was not available for all the waves of the IES data.

The household size and type of heating system are also determined by both behavior and income. For example, household size is higher than average among the households with leader born 1953–1978. Households with leaders born 1958–1993 rely more on central heating, which is usually gas operated. The income factor is clearly present and income is higher than average among the households with leader born 1948–1978. This could indicate that the younger generations as well as pensioners are more resources restricted, which in turn is reflected in lower energy consumption and emissions. It is worth to note that all three factors overlap for the generations 1953 and 1958, which are also identified as higher emitters by the APCD.

An additional concern might be that the only direct energy emissions of households are included in the analyses. According to some studies, the indirect energy emissions (which are incorporated in the goods and services purchased by the households) account for 40-50 percent of total households' emissions (see Chancel, 2014). In addition, the emissions levels in this paper are measured based on energy expenditures, assuming that all households pay the same price for specific energy good in a given year. Consequently, higher energy consumption levels might be assigned to a household that pays higher energy price per unit of energy good, hence overstating their emissions. So, surveys that collect data on both energy quantity (consumption) and price might be more suitable for analyses in the future. Another potential reason for caution with the results' interpretation is that the APCD requires that age and cohort variables to be equality spaced with the frequency of the data collection ( which in the case of the German IES is five years). So actual age and year of births were converted to an interval: for instance if the leader was born in 1976 and was aged 38 in 2013, he or she will be assigned to the birth cohort 1973–1978 and age of 40. This might slightly alter the predictions on the size of cohorts and age effects.

### **3.7 Interim conclusion**

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<sup>99</sup> For instance, the student might opt out for using a bicycle or public transport whereas a pensioner might choose to drive the car.

The goal of this paper is to investigate energy related emissions inequalities and their underlying causes. For that purpose, first the direct residential CO<sub>2</sub> emissions are derived from German households data. Secondly, two types of emissions inequalities among German households are identified: i) intra-generational – a) poor versus rich and b) rural versus urban inequalities, and ii) intergenerational – birth cohort inequalities. The descriptive evidence demonstrates that the high income German households emit around 200 percent more CO<sub>2</sub> than low income households in 2013. Also the gap between the rural and poor households' emissions is large, with rural emitting 40 percent more CO<sub>2</sub> than urban households in 2013. Some of the intra-generational emissions inequalities could be potentially explained by differences in household size and composition, age, education, income, and area of residence. An inverted u-shaped relationship is found between total energy related emissions and the birth cohort of the household's leader. The emissions are highest for the households that have a leader born between 1933 and 1963. The cohorts born 1908–1928 and 1968–1993 have lower than the average emissions. The younger (later) German generations appear to be more environmentally conscious as well as resources restricted and this could partly explain the intergenerational CO<sub>2</sub> emissions inequality.

Thirdly, the analyses focuses the role of year of birth in driving emissions by applying a De-trended Age Period Cohort (APCD) model. The estimates indicate the presence of clear cohort effects on residential energy related CO<sub>2</sub> emissions. The households with leaders born 1933–1973 (in 5 years gaps) are found to be the highest CO<sub>2</sub> emitters. Adding additional controls to the model demonstrates that the generational effect is still present, statistically significant, and might be a reflection of both large and energy inefficient infrastructures as well as higher number of motor vehicles used by earlier generations. The German households with leaders born 1943–1973 emit more CO<sub>2</sub> than their predecessors or followers. The estimates confirm the presence of intra-temporal, namely income- and area of residence-related emissions inequalities in Germany. Households in rural areas and richer households have higher energy related emissions.

This paper tackles a crucial issue: estimating the birth cohort effects of additional household members on emissions. The cohort effects of other household members prove that additional household members born between 1913 and 1988 have positive and statistically significant effect on emissions. Household's members belonging to the birth cohorts 1923, 1928, 1933, 1938, 1943, 1948, 1953, 1958, 1963 or 1968 add more to emissions than the average household member.



The results demonstrate solid evidence that birth cohort effects (both of household's leader and household's members) are significant in explaining residential energy related pollution in Germany. The cohort compositional differences provide knowledge about the creation of environmental practices of households and can be useful in creating improved environmental policies, which would target specific birth cohorts in the population. The cohort effects partly explain the durability of energy practices of German households and maybe in the future lower pollution levels will be achieved by cohort replacement.

The empirical outcomes have several policy implications on how to reduce emissions and to overcome emissions inequalities. Carbon or energy taxes would decrease emissions more if imposed/increased for the rural and the high income households. Taxes could reduce emissions by larger amounts if imposed on the households leaders or members from the generations 1943–1968. Also for the earlier (older) cohorts taxes on domestic energy would be more effective than taxes on car fuels. Fahmy et al. (2011) also recommend policies which aim at reduction of energy consumption among the groups which are “overconsuming” relative to the population (for instance taxing private vehicle and aviation transport among the rich households). Last but not least, changes in lifestyles such as smaller (energy efficient) dwellings, bigger household size, less or more efficient cars, and electric appliances can play an important role in lowering residential energy related emissions in Germany.

There are several possibilities for future research. The empirical analyses could be repeated for actual consumption (including other domestic fuels besides gas) or emissions data when such dataset becomes available for an extended period of time. The analyses can be conducted for other pollutants like sulfur dioxide (SO<sub>2</sub>) or nitrogen oxides (NO<sub>x</sub>). Similarly, the examination of the presence of cohort effects of the household's leader and other household's members in other countries of the European Union (E.U.) might be worthwhile to identify potential target groups for more effective mitigation policies.

### 3.8 Appendix

**Table 3. 2 Relevant studies and their contribution to literature**

Study	Country, and time period	Energy/ Resources inequality	Determinants of energy consumption/ emissions	Age-Period-Cohort model	Cohort effects of household's leader/members	Age effects	Income effects	Rural (Urbanization effects)
Ghalwash (2007)	Sweden, 1984–1996	Yes	No	No	No/No	No	Yes	No
Aguiar and Hurst (2013)	U.S., 1980–2003	No	Yes (with behavioral responses)	No	Yes/No	Yes	Yes	No
Segall (2013)	U.S., 1980–2003	Yes	Yes (with behavioral responses)	Yes	Yes/No	Yes	Yes	No
Deutsch and Timpe (2012)	Germany, 2008	Yes	Yes	No	No/No	Yes	No	No
Sánchez-Peña (2013)	Mexico, 1992–2008	Yes	Yes	Yes	Yes/No	Yes	Yes	No
Chancel (2014)	France, US, 1980–2000	Yes	Yes	Yes	Yes/No	Yes	Yes	No
Papathanasopoulou and Jackson (2009)	U.K., 1968–2000	Yes	No	No	No/No	No	Yes	No
Papathanasopoulou (2007)	Greece, 1990–2006	Yes	Yes	No	No/No	No	No	No
Fahmy et al. (2011)	U.K., 2002–2008	Yes	Yes	No	No/No	Yes	Yes	Yes
Hargreaves et al. (2013)	G.B., 2004–2007	Yes	Yes	No	No/No	Yes	Yes	Yes
Büchs and Schnepf (2013)	U.K., 2006–2009	Yes	Yes	No	No/No	Yes	Yes	Yes
Pampel and Hunter (2012)	U.S., 1973–2008	No	Yes (environmental spending)	Yes	Yes/No	Yes	Yes	No
Weber and Matthews (2008)	U.S., 2004	Yes	Yes	No	No/No	No	Yes	No
Weber and Perrels (2000)	West Germany, Netherlands, and France, 1990	No	Yes	No	No/No	Yes	Yes	No
Rehdanz (2007)	Germany, 1998–2003	No	Yes	No	No/No	Yes	Yes	No
Jamasb and Meier (2010)	U.K., 1991–2007	No	Yes	No	No/No	No	Yes	Yes
Meier and Rehdanz (2010)	U.K., 1991–2005	No	Yes	No	No/No	Yes	Yes	No

**Table 3. 2 (Continued)**

Study	Country, and time period	Energy/ Resources inequality	Determinants of energy consumption/ emissions	Age-Period-Cohort model	Cohort effects of household's leader/members	Age effects	Income effects	Rural (Urbanization effects)
Bin and Dowlatabadi (2005)	U.S., 1997	No	Yes	No	No/No	No	No	No
Xu et al. (2016)	China, 2011	Yes	Yes	No	No/No	Yes	Yes	Yes
O'Neill and Chen (2002)	U.S., 1993–1994	No	Yes	No	No/No	Yes	Yes	Yes
Räty and Carlsson-Kanyama (2009)	Germany, 2003; Norway, 2001–2003; Greece, 2004–2005; Sweden, 2003–2005	Yes	Yes	No	No/No	Yes	Yes	No
Chancel and Piketty (2015)	Worldwide, 1998–2013	Yes		No	No/No	No	Yes	No
Grunewald et al. (2016)	158 countries, 1980–2008	Yes (income inequality)	Yes	No	No/No	No	Yes	No
Menz and Küling (2011)	25 OECD countries, 1970–2000	Yes	Yes	No	Yes/No	Yes	Yes	Yes
Menz and Welsch (2012)	26 OECD countries, 1960–2005	Yes	Yes	No	Yes/No	Yes	Yes	Yes
Ravallion et al. (2000)	42 countries, 1975–1992	Yes (income inequality)	Yes	No	No/No	No	Yes	Yes

*Note.* All necessary information is taken from the respective studies.

**Table 3. 3 Summary statistics of rural and urban households**

Variable	Rural		Urban		All	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
<i>adults</i>	1.886	0.822	1.638	0.730	1.955	0.811
<i>children</i>	0.388	0.789	0.239	0.620	0.447	0.836
<i>age</i>	51.699	16.251	51.296	17.338	52.470	15.019
<i>ydisp</i>	35182	20845	29762	19703	39184	21647
<i>educ1</i>	0.700	0.458	0.606	0.489	0.615	0.487
<i>educ2</i>	0.106	0.308	0.114	0.317	0.145	0.352
<i>educ3</i>	0.111	0.314	0.175	0.380	0.171	0.376
<i>TVs</i>	1.500	0.851	1.405	0.816	1.548	0.874
<i>PCs and notebooks</i>	0.980	1.133	0.912	1.082	1.075	1.135
<i>refrigerators and freezers</i>	1.803	0.821	1.587	0.730	1.797	0.828
<i>dishwashers</i>	0.600	0.506	0.486	0.511	0.636	0.499
<i>washing machines and driers</i>	1.158	0.681	1.033	0.681	1.174	0.678
<i>dwelling size</i>	99.274	43.061	75.220	32.307	98.509	42.263
<i>cars new</i>	0.448	0.604	0.361	0.545	0.479	0.615
<i>cars old</i>	0.653	0.735	0.462	0.634	0.634	0.729
<i>distant heating</i>	0.109	0.312	0.263	0.440	0.150	0.357
<i>central heating</i>	0.793	0.405	0.647	0.478	0.742	0.438
<i>quantity of electricity</i>	3778	2895	3036	2280	3801	2844
<i>quantity of gas</i>	18603	24021	15126	15659	18780	22650
<i>quantity of car fuels</i>	1038	914	672	777	1073	923
<i>total energy emissions</i>	12.394	10.888	9.644	7.522	2.121	1.587
<i>observations</i>	147922		71904		219826	

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education.

**Table 3. 4 Total energy related emissions across the deciles**

Decile/ Year	1	2	3	4	5	6	7	8	9	10
	Mean CO <sub>2</sub> emissions (in tons)									
	Germany									
1993	10.562	12.258	13.086	13.793	14.312	14.878	15.598	16.032	17.940	17.346
1998	9.311	11.241	12.311	13.089	14.025	14.833	15.676	16.351	18.083	16.682
2003	7.393	9.150	10.373	11.122	12.032	12.810	13.710	14.301	17.029	15.160
2008	5.496	7.294	8.360	9.552	10.463	11.427	11.919	12.948	14.922	13.708
2013	4.415	5.996	6.914	8.079	8.746	9.645	10.585	11.116	13.120	11.824

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population.

**Table 3. 5 Summary statistics of households according to birth cohort of household's leader**

Cohorts	All cohorts	1908	1913	1918	1923	1928	1933	1938	1943	1948	1953	1958	1963	1968	1973	1978	1983	1988	1993
Variable	Mean																		
<i>adults</i>	1.798	1.272	1.329	1.389	1.431	1.565	1.722	1.735	1.808	1.992	2.094	2.039	1.942	1.805	1.711	1.601	1.562	1.535	1.487
<i>children</i>	0.336	0.000	0.001	0.004	0.004	0.008	0.009	0.015	0.042	0.134	0.320	0.535	0.684	0.719	0.696	0.573	0.360	0.153	0.070
<i>age</i>	51.557	85.000	82.898	80.134	76.318	73.679	70.572	66.902	62.571	56.458	51.614	47.032	42.207	38.017	35.246	31.735	28.604	25.359	22.477
<i>ydisp</i>	33274	16809	17935	21025	22560	25457	28512	30133	32864	36178	37838	38071	37337	36486	36362	34200	30863	26327	21403
<i>educ1</i>	0.667	0.626	0.683	0.686	0.674	0.663	0.652	0.672	0.687	0.680	0.671	0.671	0.688	0.686	0.681	0.621	0.584	0.587	0.473
<i>educ2</i>	0.109	0.026	0.049	0.050	0.071	0.099	0.104	0.117	0.118	0.119	0.114	0.114	0.110	0.114	0.110	0.121	0.113	0.088	0.037
<i>educ3</i>	0.134	0.053	0.045	0.069	0.083	0.110	0.132	0.121	0.125	0.142	0.156	0.155	0.142	0.135	0.131	0.155	0.165	0.141	0.046
<i>TVs</i>	1.467	0.979	1.048	1.096	1.194	1.265	1.406	1.457	1.541	1.633	1.636	1.577	1.491	1.418	1.410	1.390	1.450	1.452	1.643
<i>PCs and notebooks</i>	0.956	0.002	0.010	0.054	0.091	0.233	0.456	0.661	0.895	0.982	1.075	1.143	1.126	1.162	1.262	1.354	1.516	1.646	1.736
<i>refrigerators and freezers</i>	1.727	1.413	1.517	1.651	1.770	1.854	1.888	1.842	1.821	1.902	1.876	1.808	1.726	1.642	1.524	1.406	1.351	1.276	1.256
<i>dishwashers</i>	0.560	0.070	0.098	0.166	0.229	0.341	0.457	0.526	0.587	0.630	0.633	0.637	0.626	0.618	0.612	0.586	0.580	0.597	0.740
<i>washing machines and driers</i>	1.114	0.782	0.868	0.988	1.029	1.068	1.096	1.080	1.180	1.234	1.204	1.189	1.175	1.066	1.036	0.956	0.985	0.953	1.443
<i>dwelling size</i>	90.808	71.976	73.115	77.047	82.304	86.627	91.596	92.699	94.662	97.167	98.587	97.955	94.849	90.789	89.398	82.942	75.328	65.578	58.137
<i>cars new</i>	0.418	0.144	0.161	0.251	0.336	0.425	0.486	0.512	0.504	0.523	0.489	0.447	0.384	0.348	0.328	0.293	0.297	0.312	0.428
<i>cars old</i>	0.586	0.079	0.110	0.136	0.183	0.257	0.366	0.441	0.557	0.629	0.696	0.695	0.705	0.725	0.724	0.710	0.698	0.635	0.668
<i>distant heating</i>	0.163	0.212	0.159	0.182	0.175	0.181	0.186	0.195	0.185	0.170	0.171	0.157	0.144	0.131	0.128	0.140	0.170	0.180	0.165
<i>central heating</i>	0.742	0.521	0.638	0.654	0.665	0.697	0.706	0.715	0.727	0.749	0.741	0.750	0.757	0.773	0.793	0.783	0.772	0.763	0.767
<i>quantity of electricity</i>	3517	3039	2926	3083	3231	3380	3545	3552	3662	3955	4092	3963	3747	3462	3201	2925	2579	2125	1885
<i>quantity of gas</i>	17379	19527	18224	19436	19224	19354	19678	19152	19369	20155	19829	18975	17821	15950	13804	11126	9595	7983	5730
<i>quantity of car fuels</i>	909	108	156	239	316	450	610	686	824	1020	1116	1130	1151	1123	1120	1038	897	743	559

**Table 3. 5 (Continued)**

Cohorts	All cohorts	1908	1913	1918	1923	1928	1933	1938	1943	1948	1953	1958	1963	1968	1973	1978	1983	1988	1993
Variable	Mean																		
<i>electricity emissions</i>	1.963	1.696	1.633	1.720	1.803	1.886	1.978	1.982	2.043	2.207	2.283	2.211	2.091	1.932	1.786	1.632	1.439	1.186	1.052
<i>gas emissions</i>	7.282	8.182	7.636	8.144	8.055	8.109	8.245	8.025	8.116	8.445	8.308	7.950	7.467	6.683	5.784	4.662	4.020	3.345	2.401
<i>car fuels emissions</i>	2.182	0.259	0.374	0.574	0.757	1.079	1.465	1.647	1.977	2.447	2.678	2.712	2.762	2.695	2.688	2.490	2.152	1.783	1.341
<i>total emissions</i>	11.426	10.137	9.643	10.438	10.615	11.075	11.689	11.654	12.136	13.099	13.269	12.873	12.320	11.309	10.258	8.784	7.612	6.314	4.794

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education.

**Table 3. 6 Coefficient estimates of the APCD model**

$\ln(E_{total})$	Without additional controls		With additional controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>cohort</i> 1913	-0.047	0.015	-0.026	0.014	-0.015	0.014
<i>cohort</i> 1918	-0.047	0.010	-0.033	0.009	-0.026	0.010
<i>cohort</i> 1923	-0.020	0.008	-0.028	0.008	-0.026	0.008
<i>cohort</i> 1928	-0.003	0.007	-0.012	0.007	-0.021	0.007
<i>cohort</i> 1933	0.015	0.006	0.001	0.006	-0.012	0.006
<i>cohort</i> 1938	0.029	0.006	0.004	0.006	-0.006	0.006
<i>cohort</i> 1943	0.043	0.006	0.021	0.006	0.013	0.006
<i>cohort</i> 1948	0.046	0.006	0.031	0.005	0.032	0.006
<i>cohort</i> 1953	0.034	0.005	0.048	0.005	0.051	0.006
<i>cohort</i> 1958	0.023	0.005	0.050	0.005	0.055	0.005
<i>cohort</i> 1963	0.029	0.005	0.051	0.005	0.059	0.005
<i>cohort</i> 1968	0.026	0.006	0.039	0.005	0.052	0.005
<i>cohort</i> 1973	0.004	0.007	0.007	0.007	0.005	0.007
<i>cohort</i> 1978	-0.042	0.008	-0.045	0.007	-0.052	0.008
<i>cohort</i> 1983	-0.088	0.010	-0.107	0.009	-0.111	0.010
<i>age</i> 25	-0.214	0.009	0.023	0.009	0.013	0.009
<i>age</i> 30	-0.143	0.006	-0.012	0.006	0.000	0.006
<i>age</i> 35	0.015	0.005	-0.035	0.005	-0.012	0.005
<i>age</i> 40	0.087	0.005	-0.064	0.005	-0.045	0.005
<i>age</i> 45	0.141	0.005	-0.037	0.005	-0.033	0.005
<i>age</i> 50	0.150	0.005	0.010	0.005	-0.002	0.005
<i>age</i> 55	0.141	0.005	0.049	0.005	0.027	0.005
<i>age</i> 60	0.086	0.006	0.067	0.005	0.042	0.005
<i>age</i> 65	-0.008	0.006	0.058	0.005	0.038	0.005
<i>age</i> 70	-0.042	0.006	0.044	0.005	0.034	0.005
<i>age</i> 75	-0.012	0.006	0.016	0.006	0.019	0.006
<i>age</i> 80	-0.059	0.008	-0.023	0.007	-0.008	0.007
<i>age</i> 85	-0.141	0.010	-0.097	0.009	-0.072	0.009
<i>period</i> 1993	-0.046	0.002	-0.021	0.002	-0.024	0.002
<i>period</i> 1998	0.013	0.003	-0.001	0.003	0.000	0.003
<i>period</i> 2003	0.060	0.003	0.032	0.003	0.033	0.003
<i>period</i> 2008	0.025	0.003	0.025	0.003	0.029	0.003
<i>period</i> 2013	-0.052	0.002	-0.034	0.002	-0.038	0.002

**Table 3.6 (Continued)**

$\ln(E_{total})$	Without additional controls		With additional controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>rescacoh</i>	-1.766	0.014	-1.905	0.013	-2.002	0.016
<i>rescaage</i>	-0.870	0.007	-0.949	0.007	-1.016	0.008
$\ln(ydisp)$			0.303	0.004	0.277	0.004
<i>hsize</i>			0.066	0.002		
<i>n1908</i>					-0.050	0.046
<i>n1913</i>					0.017	0.031
<i>n1918</i>					0.046	0.017
<i>n1923</i>					0.076	0.012
<i>n1928</i>					0.116	0.010
<i>n1933</i>					0.149	0.008
<i>n1938</i>					0.150	0.007
<i>n1943</i>					0.192	0.007
<i>n1948</i>					0.178	0.006
<i>n1953</i>					0.171	0.006
<i>n1958</i>					0.141	0.006
<i>n1963</i>					0.104	0.006
<i>n1968</i>					0.015	0.003
<i>n1973</i>					0.029	0.003
<i>n1978</i>					0.050	0.003
<i>n1983</i>					0.069	0.004
<i>n1988</i>					0.117	0.004
$\ln(h_{qm})$			0.358	0.005	0.356	0.005
<i>educ2</i>			-0.010	0.004	-0.008	0.004
<i>educ3</i>			-0.024	0.004	-0.019	0.004
<i>rural</i>			0.048	0.003	0.047	0.003
<i>weight</i>	-0.189	0.002	-0.014	0.002	-0.015	0.002
<i>constant</i>	2.402	0.003	-2.685	0.033	-2.380	0.035
<i>AIC</i>		2.177		1.978		1.972
<i>BIC</i>		-2548613		-2568754		-2569055
<i>observations</i>		216578		216578		216578

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education. *n1908* – *n1988* indicate number of household members from these birth cohorts. *h<sub>qm</sub>* is dwelling size. *AIC* and *BIC* stand for Akaike and Bayesian Information Criterion.



**Table 3. 7 Estimates from APCD with additional controls for electricity, gas, and car fuels**

$\ln(E_i)$	Electricity				Gas				Car fuels			
	With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>cohort</i> 1913	-0.001	0.010	0.014	0.011	-0.067	0.018	-0.066	0.019	0.006	0.020	0.066	0.021
<i>cohort</i> 1918	-0.007	0.007	0.004	0.007	-0.039	0.012	-0.040	0.013	-0.035	0.012	-0.005	0.013
<i>cohort</i> 1923	-0.006	0.006	0.003	0.006	-0.034	0.010	-0.034	0.010	-0.026	0.010	-0.012	0.010
<i>cohort</i> 1928	-0.016	0.005	-0.018	0.005	0.010	0.009	0.005	0.009	0.000	0.008	-0.003	0.009
<i>cohort</i> 1933	-0.003	0.004	-0.016	0.005	0.029	0.008	0.022	0.008	0.001	0.007	-0.022	0.008
<i>cohort</i> 1938	0.001	0.004	-0.017	0.005	0.033	0.007	0.028	0.008	-0.012	0.006	-0.050	0.007
<i>cohort</i> 1943	0.013	0.004	-0.005	0.005	0.047	0.007	0.044	0.008	0.013	0.006	-0.029	0.007
<i>cohort</i> 1948	0.023	0.004	0.011	0.004	0.050	0.007	0.053	0.008	0.017	0.006	-0.020	0.007
<i>cohort</i> 1953	0.014	0.004	0.009	0.004	0.047	0.006	0.054	0.007	0.026	0.005	-0.005	0.006
<i>cohort</i> 1958	0.007	0.003	0.010	0.004	0.041	0.006	0.050	0.007	0.030	0.005	0.008	0.006
<i>cohort</i> 1963	0.002	0.003	0.012	0.004	0.029	0.006	0.040	0.006	0.022	0.005	0.018	0.005
<i>cohort</i> 1968	-0.005	0.004	0.009	0.004	-0.007	0.007	0.002	0.007	0.039	0.006	0.058	0.006
<i>cohort</i> 1973	0.003	0.005	0.007	0.005	-0.040	0.009	-0.041	0.009	0.045	0.007	0.067	0.008
<i>cohort</i> 1978	0.001	0.006	0.001	0.006	-0.054	0.010	-0.063	0.010	-0.032	0.008	-0.007	0.009
<i>cohort</i> 1983	-0.025	0.007	-0.024	0.007	-0.044	0.013	-0.055	0.013	-0.093	0.011	-0.062	0.011
<i>age</i> 25	0.021	0.006	0.004	0.007	0.059	0.011	0.052	0.011	-0.017	0.010	-0.041	0.010
<i>age</i> 30	-0.021	0.004	-0.018	0.004	0.004	0.008	0.009	0.008	-0.021	0.006	-0.020	0.006

**Table 3. 7 (Continued)**

$\ln(E_i)$	Electricity				Gas				Car fuels			
	With controls and <i>hhsiz</i> e		With controls and other cohorts effects		With controls and <i>hhsiz</i> e		With controls and other cohorts effects		With controls and <i>hhsiz</i> e		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>age 35</i>	-0.033	0.004	-0.020	0.004	-0.015	0.006	-0.005	0.007	-0.052	0.005	-0.040	0.005
<i>age 40</i>	-0.036	0.004	-0.021	0.004	-0.031	0.006	-0.022	0.006	-0.079	0.005	-0.064	0.005
<i>age 45</i>	-0.014	0.003	-0.006	0.004	-0.022	0.006	-0.018	0.006	-0.026	0.005	-0.016	0.005
<i>age 50</i>	0.018	0.004	0.018	0.004	-0.015	0.006	-0.018	0.006	0.039	0.005	0.042	0.005
<i>age 55</i>	0.031	0.004	0.024	0.004	-0.002	0.006	-0.010	0.007	0.090	0.005	0.087	0.006
<i>age 60</i>	0.048	0.004	0.038	0.004	0.004	0.007	-0.007	0.007	0.108	0.006	0.101	0.006
<i>age 65</i>	0.040	0.004	0.031	0.004	-0.012	0.007	-0.021	0.007	0.093	0.006	0.086	0.006
<i>age 70</i>	0.023	0.004	0.017	0.004	-0.003	0.007	-0.008	0.007	0.063	0.006	0.058	0.006
<i>age 75</i>	-0.006	0.004	-0.007	0.004	-0.009	0.008	-0.011	0.008	0.019	0.007	0.020	0.007
<i>age 80</i>	-0.021	0.005	-0.018	0.005	0.010	0.009	0.015	0.009	-0.065	0.009	-0.060	0.009
<i>age 85</i>	-0.050	0.007	-0.041	0.007	0.030	0.012	0.043	0.012	-0.151	0.012	-0.152	0.012
<i>period 1993</i>	0.021	0.002	0.019	0.002	-0.054	0.003	-0.048	0.003	-0.078	0.002	-0.088	0.003
<i>period 1998</i>	-0.062	0.002	-0.066	0.002	0.156	0.003	0.152	0.004	0.100	0.003	0.106	0.004
<i>period 2003</i>	0.057	0.002	0.064	0.003	0.051	0.004	0.044	0.004	0.022	0.003	0.030	0.004
<i>period 2008</i>	-0.012	0.002	-0.006	0.003	-0.354	0.003	-0.353	0.004	-0.032	0.003	-0.027	0.003
<i>period 2013</i>	-0.004	0.002	-0.011	0.002	0.201	0.003	0.204	0.003	-0.012	0.002	-0.021	0.003
<i>rescacoh</i>	-0.568	0.012	-0.571	0.014	-2.224	0.017	-2.223	0.021	-0.701	0.016	-0.777	0.019
<i>rescaage</i>	-0.207	0.006	-0.230	0.007	-0.986	0.009	-1.007	0.011	-0.708	0.008	-0.738	0.009

**Table 3. 7 (Continued)**

$\ln(E_i)$	Electricity				Gas				Car fuels			
	With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
$\ln(ydisp)$	0.144	0.003	0.124	0.003	0.109	0.005	0.097	0.005	0.445	0.004	0.423	0.004
<i>hsize</i>	0.111	0.001			0.035	0.002			0.052	0.002		
<i>n1908</i>			0.165	0.034			-0.051	0.060			-0.103	0.049
<i>n1913</i>			0.129	0.023			0.051	0.040			-0.121	0.036
<i>n1918</i>			0.171	0.013			0.106	0.023			-0.036	0.020
<i>n1923</i>			0.147	0.009			0.089	0.015			0.003	0.014
<i>n1928</i>			0.163	0.007			0.082	0.012			0.045	0.011
<i>n1933</i>			0.186	0.006			0.104	0.010			0.074	0.008
<i>n1938</i>			0.202	0.005			0.094	0.009			0.122	0.007
<i>n1943</i>			0.220	0.005			0.113	0.009			0.161	0.007
<i>n1948</i>			0.209	0.005			0.093	0.008			0.161	0.007
<i>n1953</i>			0.198	0.005			0.080	0.008			0.158	0.006
<i>n1958</i>			0.167	0.004			0.062	0.008			0.146	0.006
<i>n1963</i>			0.138	0.004			0.037	0.007			0.119	0.006
<i>n1968</i>			0.085	0.002			0.009	0.004			0.030	0.003
<i>n1973</i>			0.096	0.002			0.026	0.004			0.023	0.003
<i>n1978</i>			0.089	0.002			0.039	0.004			0.029	0.003
<i>n1983</i>			0.102	0.003			0.036	0.004			0.042	0.004

**Table 3. 7 (Continued)**

$\ln(E_i)$	Electricity				Gas				Car fuels			
	With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects		With controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>n1988</i>			0.133	0.003			0.043	0.005			0.081	0.004
<i>educ2</i>	-0.055	0.003	-0.053	0.003	-0.017	0.005	-0.015	0.005	-0.007	0.004	-0.003	0.004
<i>educ3</i>	-0.089	0.003	-0.085	0.003	-0.001	0.005	0.002	0.005	-0.035	0.004	-0.030	0.004
$\ln(h\_qm)$	0.363	0.004	0.362	0.004	0.486	0.006	0.485	0.006				
<i>distant</i>	-0.446	0.005	-0.444	0.005	0.296	0.008	0.298	0.008				
<i>central</i>	-0.345	0.004	-0.342	0.004	0.406	0.008	0.409	0.008				
<i>TVs</i>	0.019	0.001	0.017	0.001								
<i>PCs and notebooks</i>	0.008	0.001	0.010	0.001								
<i>refrigerators and freezers</i>	0.049	0.002	0.046	0.002								
<i>dishwashers</i>	0.064	0.003	0.066	0.003								
<i>washing machines and driers</i>	0.062	0.002	0.064	0.002								
<i>cars new</i>									0.203	0.003	0.198	0.003
<i>cars old</i>									0.228	0.003	0.225	0.003
<i>rural</i>	-0.001	0.002	-0.002	0.002	0.055	0.004	0.054	0.004	0.145	0.003	0.145	0.003
<i>weight</i>	0.015	0.002	0.017	0.002	0.003	0.003	0.005	0.003	-0.016	0.003	-0.017	0.003
<i>constant</i>	-2.722	0.026	-2.423	0.027	-1.871	0.044	-1.727	0.046	-4.372	0.039	-4.107	0.040
<i>AIC</i>	1.376		1.371		2.289		2.288		1.991		1.987	
<i>BIC</i>	-2569152		-2569226		-2035358		-2035278		-2166322		-2166480	

**Table 3. 7 (Continued)**

	Electricity		Gas		Car fuels	
	With controls and <i>hsize</i>	With controls and other cohorts effects	With controls and <i>hsize</i>	With controls and other cohorts effects	With controls and <i>hsize</i>	With controls and other cohorts effects
<i>observations</i>	213440	213440	176933	176933	185188	185188

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education. *n1908* – *n1988* indicate number of household members from these birth cohorts. *h\_qm* is dwelling size. *AIC* and *BIC* stand for Akaike and Bayesian Information Criterion.

**Table 3. 8 Consistency check: Estimates from the APC-IE model**

$\ln(E_{total})$	Without additional controls		With controls and <i>hsize</i>		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
$\ln(ydisp)$			0.305	0.004	0.280	0.004
<i>hsize</i>			0.066	0.002		
<i>n1908</i>					-0.039	0.042
<i>n1913</i>					0.030	0.028
<i>n1918</i>					0.044	0.017
<i>n1923</i>					0.076	0.012
<i>n1928</i>					0.116	0.010
<i>n1933</i>					0.149	0.008
<i>n1938</i>					0.150	0.007
<i>n1943</i>					0.191	0.007
<i>n1948</i>					0.178	0.006
<i>n1953</i>					0.171	0.006
<i>n1958</i>					0.142	0.006
<i>n1963</i>					0.105	0.006
<i>n1968</i>					0.015	0.003
<i>n1973</i>					0.028	0.003
<i>n1978</i>					0.050	0.003
<i>n1983</i>					0.070	0.004
<i>n1988</i>					0.118	0.004
$\ln(h_{qm})$			0.359	0.005	0.358	0.005
<i>educ2</i>			-0.010	0.004	-0.008	0.004
<i>educ3</i>			-0.025	0.004	-0.020	0.004
<i>rural</i>			0.049	0.003	0.048	0.003
<i>weight</i>	-0.187	0.002	-0.012	0.002	-0.013	0.002
<i>age 25</i>	-0.207	0.011	0.032	0.010	0.033	0.010
<i>age 30</i>	-0.136	0.007	-0.005	0.006	0.017	0.006
<i>age 35</i>	0.021	0.006	-0.030	0.005	0.001	0.005
<i>age 40</i>	0.091	0.005	-0.061	0.005	-0.036	0.005
<i>age 45</i>	0.144	0.005	-0.036	0.005	-0.028	0.005
<i>age 50</i>	0.152	0.005	0.010	0.005	-0.001	0.005
<i>age 55</i>	0.141	0.005	0.048	0.005	0.026	0.005
<i>age 60</i>	0.085	0.006	0.066	0.005	0.039	0.005
<i>age 65</i>	-0.011	0.006	0.056	0.005	0.032	0.006

**Table 3.8 (Continued)**

$\ln(E_{total})$	Without additional controls		With controls and <i>hhsiz</i> e		With controls and other cohorts effects	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
<i>age</i> 70	-0.045	0.006	0.041	0.006	0.025	0.006
<i>age</i> 75	-0.018	0.007	0.011	0.006	0.007	0.006
<i>age</i> 80	-0.067	0.008	-0.029	0.007	-0.023	0.007
<i>age</i> 85	-0.150	0.011	-0.104	0.010	-0.090	0.010
<i>period</i> 1993	0.241	0.003	0.293	0.003	0.309	0.004
<i>period</i> 1998	0.157	0.003	0.156	0.003	0.167	0.003
<i>period</i> 2003	0.060	0.003	0.032	0.003	0.033	0.003
<i>period</i> 2008	-0.119	0.003	-0.132	0.003	-0.138	0.003
<i>period</i> 2013	-0.339	0.003	-0.348	0.003	-0.372	0.003
<i>cohort</i> 1908	0.055	0.026	0.095	0.023	0.092	0.024
<i>cohort</i> 1913	-0.008	0.017	-0.002	0.015	-0.002	0.016
<i>cohort</i> 1918	-0.011	0.011	-0.010	0.010	-0.012	0.011
<i>cohort</i> 1923	0.013	0.009	-0.007	0.008	-0.013	0.009
<i>cohort</i> 1928	0.027	0.008	0.007	0.007	-0.007	0.008
<i>cohort</i> 1933	0.041	0.007	0.018	0.007	0.002	0.007
<i>cohort</i> 1938	0.052	0.007	0.019	0.006	0.007	0.007
<i>cohort</i> 1943	0.063	0.007	0.035	0.006	0.026	0.007
<i>cohort</i> 1948	0.063	0.006	0.043	0.006	0.044	0.007
<i>cohort</i> 1953	0.047	0.006	0.058	0.005	0.063	0.006
<i>cohort</i> 1958	0.032	0.006	0.058	0.005	0.065	0.006
<i>cohort</i> 1963	0.035	0.005	0.057	0.005	0.069	0.005
<i>cohort</i> 1968	0.028	0.006	0.043	0.005	0.060	0.005
<i>cohort</i> 1973	0.002	0.007	0.009	0.007	0.013	0.007
<i>cohort</i> 1978	-0.048	0.008	-0.044	0.008	-0.045	0.008
<i>cohort</i> 1983	-0.097	0.011	-0.109	0.010	-0.104	0.010
<i>cohort</i> 1988	-0.293	0.019	-0.270	0.017	-0.257	0.017
<i>constant</i>	2.383	0.004	-2.735	0.033	-2.428	0.034
<i>AIC</i>		2.183		1.982		1.977
<i>BIC</i>		-2578843		-2599493		-2599803
<i>Observations</i>		218998		218998		218998

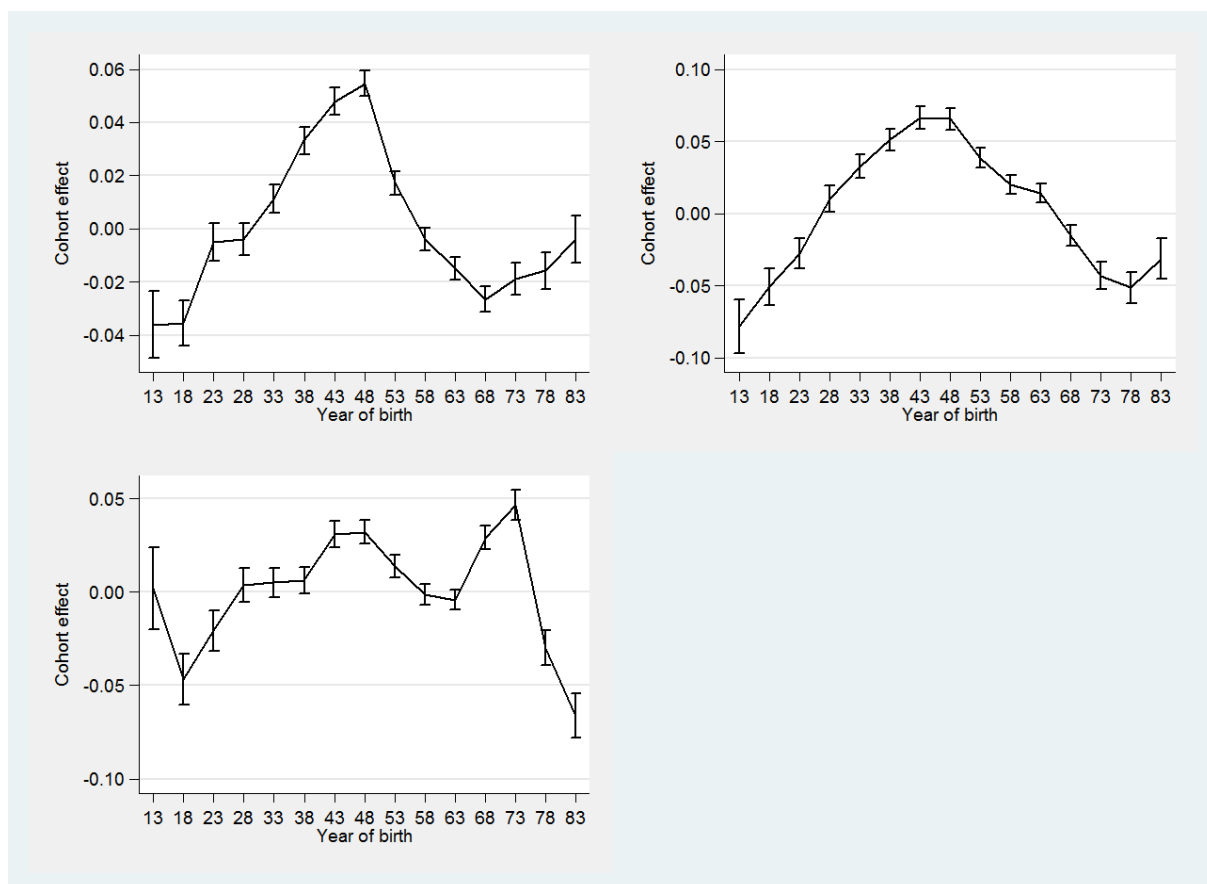
*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *ydisp* stands for disposable income, *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education. *n1908* – *n1988* indicate number of household members from these birth cohorts. *h<sub>qm</sub>* is dwelling size. *AIC* and *BIC* stand for Akaike and Bayesian Information Criterion.



**Figure 3. 9 Cohorts effects of other household members on total energy CO<sub>2</sub> emissions with control variables**

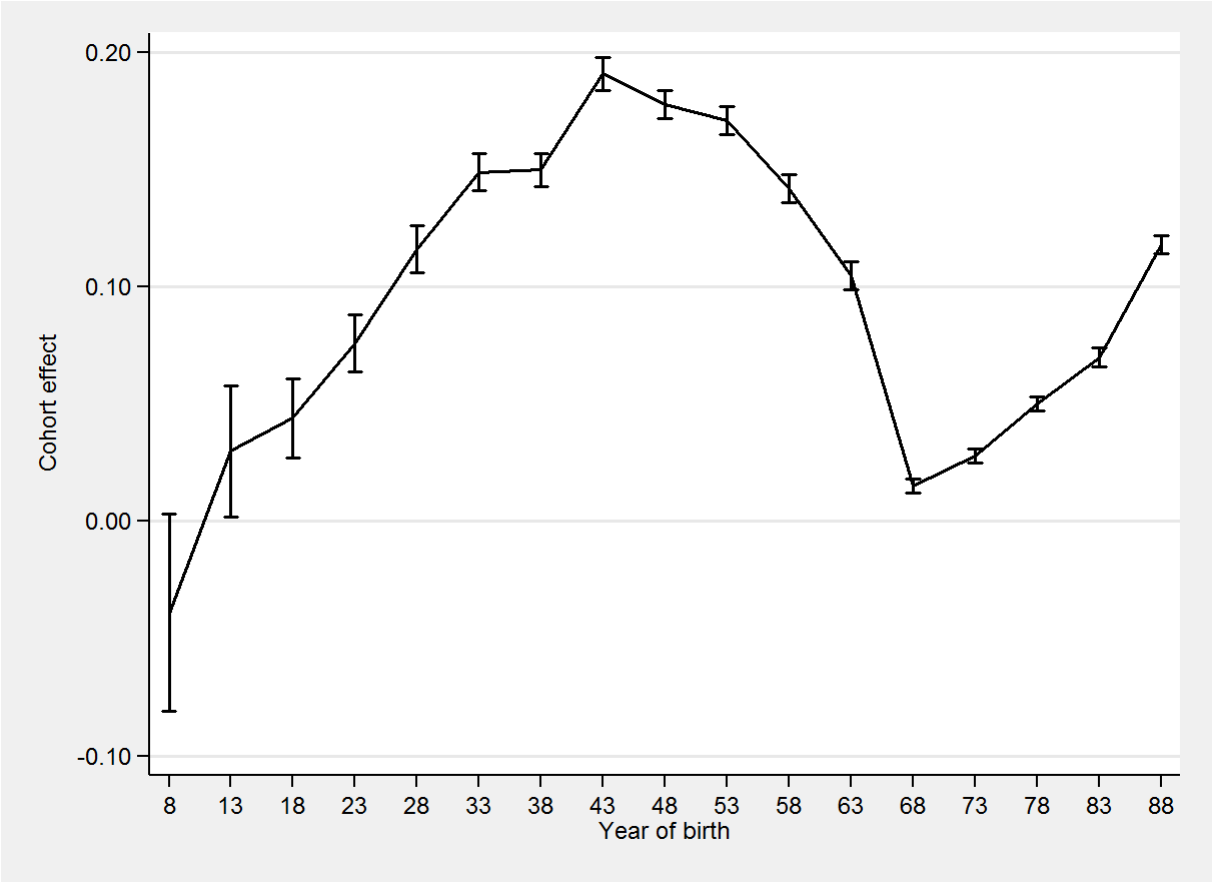
*Note.* Database is IES 1993–2013. Line segments indicate the 95 percent confidence intervals.





**Figure 3. 10 Cohort effects of the household leader on different energy CO<sub>2</sub> emissions sources, without controls**

*Note.* Database is IES 1993–2013. Years 13–83 stand for 1913–1983. Line segments indicate the 95 percent confidence intervals.



**Figure 3. 11 Other household members’ cohort effects from the APC-IE model**

*Note.* Database is IES 1993–2013. Line segments indicate the 95 percent confidence intervals.



## Concluding Remarks

Environmental and energy taxes are crucial components behind the policies aiming at pollution reduction from the residential sector. As in many other E.U. countries, the car fuels tax in Germany is imposed with the goal to limit energy consumption: 0.53 euros are levied on the final consumers for every purchased liter of gasoline, leading to around 40 percent higher relative consumer prices. The price elasticity of gasoline demand determines the potential for reductions in consumption and CO<sub>2</sub> emissions. Despite their desirable environmental effects, those taxes usually also influence households' budgets (after-tax income), and hence both the consumer welfare and the income distribution. Since the consumption of particular energy good serves as the tax base, the tax can have regressive effects, which might offset any policy efforts to reduce income inequality.

The first paper proposed and employed a framework which relies on estimates from Demographically-scaled Quadratic Almost Ideal Demand System (DQUAIDS). Such framework has allowed for thorough investigation of the potential trade-offs between CO<sub>2</sub> emissions, income distribution, and welfare targets. Clear emissions–inequality and emissions–welfare trade-offs are identified. If the car fuels tax is increased by 5 percent, this indicates emissions reduction of 0.9 percent, inequality increase of 0.04 percent, and welfare reduction of 35 euros (0.24 percent of income).

Similarly, the EEG surcharge as part of the electricity price, is imposed in Germany with the goal to finance electricity production from renewable energy sources. The EEG surcharge has led to substantial electricity price increases, which affect certain types of households more than others. In particular, higher energy prices are expected to hurt poor households, making them to restrict their heating consumption (leading to health problems) or to ration their other budgets (like food). The above mentioned factors have led to tripling of energy poverty (inadequate amount of energy services) among German households between 1993 and 2013. Being income poor, unemployed, or living in rural residential area are all associated with higher probability of being energy poor.

The estimates show that electricity is a necessity good in Germany, with relatively low elasticity of demand (-0.235), demonstrating that price change policies will not be very effective tools in managing electricity consumption. Also electricity and other fuels are found to be complementary goods with food, indicating a heat or eat behavior. Abolishing the EEG

surcharge would make electricity related emissions higher but still energy poverty will decrease by around 10 percent and income poverty will decrease by around 2 percent. Such policy reform would help the poorest and single parent household by lowering their energy tax burdens. Abolishing both the CFT and the EEG surcharge, increases emissions by 12.3 percent while income and energy poverty are 7.2 percent and 65 percent lower respectively. Hence, I identify a positive link between poverty and energy taxes is i.e. higher levels of EEG surcharge or CFT are associated with higher levels of income and energy poverty in Germany.

My results indicate a potential policy reform which would decrease energy poverty while increasing energy related emissions only slightly. The EEG surcharge could be abolished and the CFT could be increased by 25 percent. This change in energy policy is expected to bring limited environmental damage and minimal revenue loss for the government. The groups of people expected to have highest benefit are: unemployed people, single parent households, and larger families.

The final paper investigated the sources of residential energy related emissions inequalities. Two types of emissions inequalities are identified among German households: i) intra-generational – a) poor versus rich and b) rural versus urban inequalities, and ii) intergenerational – birth cohort inequalities. I find that high income (rich) households emitted around 200 percent more CO<sub>2</sub> than low income (poor) households; and rural emitted 40 percent more CO<sub>2</sub> than urban households in 2013. An inverted u-shaped relationship is found between total energy related emissions and the birth cohort of the household's leader. The estimates from a De-trended Age Period Cohort (APCD) model demonstrate the presence of clear birth cohort effects in explaining emissions. The German households with leaders born between 1943 and 1973 emit more CO<sub>2</sub> than their predecessors or followers. The results confirm the presence of intra-temporal, namely income- and area of residence-related emissions inequalities in Germany. Households in rural areas of residence have 5 percent higher emissions while each additional percentage of income adds 0.3 percent to energy related emissions.

This paper investigates an imperative question which was disregarded by previous studies: the effect of the presence of other persons, potentially from different birth cohorts, on carbon emissions. The estimates reveal that each additional household member who belongs to the birth cohorts 1923 to 1968 increases emissions by more than the average member, who increases emissions by 7 percent. The results confirm the significance of birth cohort effects in explaining energy related CO<sub>2</sub> emissions of German households and provide potential sources on how to reduce emissions and to overcome emissions inequalities. The evidence

presented in this paper can be used in creating birth cohort specific (targeted) environmental policies. For instance, carbon or energy taxes would be more effective in reducing emissions if imposed on the household's leaders or members from the generations 1943–1968. Also for the earlier cohorts taxes on domestic energy would be more effective than taxes on car fuels. Such taxes could lead to larger emissions's reductions if imposed on the rural and the high income households. In addition, changes in habits and lifestyles such as bigger household size, smaller dwellings, lower number of cars and electric appliances, can lead to lower emissions inequality and lower energy related CO<sub>2</sub> emissions in Germany.



## **Appendix A: Separate Analyses for Schleswig-Holstein**

As mentioned already, Germany is a leader in Europe when it comes to energy production from Renewable Energy Sources (RES). In particular, the federal state Schleswig-Holstein (SH) has been a pioneer in harnessing renewable energy, especially on- and off-shore wind energy. It is expected that in the foreseeable future electricity consumption could be covered by generation from wind turbines, but grid stability could be compromised with the decommissioning of the three nuclear power plants in the region. As SH supplies energy for other states in Germany, demand will play a big role both in SH as well as throughout the country. Hence, it is crucial to understand the residential energy demand for better and sustainable energy policy design. On the demand side, the costs for the household of supporting the financing of RES (through the Renewable Energy Act surcharge-EEG Umlage) can possibly impact the public acceptance of certain policies. Similarly, the households in this region can be affected by increased environmental taxes (such as the car fuels tax) and determining the tax burden and the tax effects on income inequality and poverty is essential.

Predicting the household energy consumption in this federal state could help in designing better energy and environmental policies, with the aim of decreasing carbon dioxide (CO<sub>2</sub>) emissions, and circumventing usage of fossil fuels in power generation. The vast possibilities of biofuels, given that a large share of the industry in Schleswig-Holstein is agriculture, need to be incorporated in power and heat generation both on a large and small scale which also leads to unification of policies for household energy usage as well as industry. Adjustment of household energy consumption models will keep SH on the path to meeting the emissions requirements beyond the Kyoto protocol and set an example for the rest of the German federal states.

Data from the German Income and Expenditure Survey for the federal state of Schleswig-Holstein is used to analyse energy demand and energy related emissions. IES data is combined with data of consumer prices, also provided by the German Federal Statistical Office. For detailed data description, please refer to Section 1.3 in Chapter 1. Around 6,664 (8,697) households are observed in Schleswig-Holstein during the years 1993–2008 (1993–2013).

Using IES data for SH for the period between 1993 and 2008, I find electricity, car fuels, and other fuels to be necessity goods and price inelastic in the federal state Schleswig-Holstein.



The existence of emissions–inequality and emissions–welfare trade-offs is also confirmed for SH. The higher is the car fuels tax, the lower are the emissions, but the higher is the welfare loss and inequality in the post-tax income distribution.

The results from the energy demand system for the period 1993–2013 indicate that electricity has a relatively low elasticity of demand in the federal state Schleswig-Holstein. Households in Schleswig Holstein are least vulnerable to price increases in electricity (and have lower than average increases in income poverty and energy poverty) so in this federal state it might be a good idea to enforce higher prices so that to generate more tax revenues.

The factors behind inter- and inter-generational emissions inequalities are also investigated for the federal state of Schleswig-Holstein. Birth cohort of the household's leader is not significant in explaining energy related CO<sub>2</sub> emissions for Schleswig-Holstein. However, birth cohorts of the other household's members are important determinants of emissions' levels. So, inter-generational emissions inequalities are confirmed by the results. Income- and rural-related emissions inequalities (both being intra-generational) are also established for SH.

## A1 Car fuels tax

Using the estimates from a Demographically-scaled Almost Ideal Demand System (DAIDS) on data from the Income and Expenditure Survey (IES) for Schleswig-Holstein for the period 1993–2008, the price and income elasticities of demand are obtained for this federal state. Table A1 summarizes those elasticities. It appears that car fuels are necessary good among households in Schleswig-Holstein: for one percent increase in income, demand for car fuels will decrease by 0.795 percent. Food, electricity, and other fuels are also necessary goods. Demand for car fuels is also price inelastic: for one percent increase in the price, demand will go down by 0.261 percent. Electricity demand is also relatively price inelastic, with elasticity of  $-0.104$ . Throughout Germany, electricity demand is more price elastic ( $-0.787$ ) and car fuels demand is less price elastic ( $-0.165$ ). This is indicative that price instruments (through managing the energy tax) will be more effective in managing electricity demand in Germany and car fuels demand in Schleswig-Holstein. The cross price elasticities show that car fuels are complementary goods with food and electricity, demonstrating the “drive or eat behavior” and the “heat or eat behavior” where consumers are rationing their other budgets (like food) due to increase in energy price.

Two different policy change scenarios are considered for Schleswig-Holstein: doubling of the car fuels tax (CFT) and abolishing of the CFT, leading to 52 percent increase and decrease in the car fuels price respectively (see Table A2). Under the first scenario, car fuels related emissions will be 18.9 percent lower and electricity related emissions will be 5.7 percent lower, or total energy related emissions will be 24.5 percent lower than the status quo: the situation as it was in 2008. The compensating variation and equivalent variation, as measures of consumer welfare, indicate a welfare loss of 656 euros and 642 euros (both representing around 1.7 percent of income). Tax burden is 382 euros higher than under the status quo and represents 0.987 percent of income and the inequality in the post-tax income distribution increases, as measured by the Gini index. If the CFT is abolished, total energy related emissions will be 35.6 percent higher than under the status quo. The equivalent and compensating variation both show welfare gain, which is approximately 2 percent of income. The tax burden in this case is 604 euros lower and the inequality in the post-tax income distribution decreases by 0.666 percent. The results indicate the presence of the emissions–inequality and emissions–welfare trade-offs in SH. Those

trade-offs provide evidence for policy makers about balancing environmental with income inequality and consumer welfare concerns.

**Table A. 1 Income and price elasticities (uncompensated) in Schleswig-Holstein**

	Income elasticities		Price elasticities									
		SE	Food	SE	Electricity	SE	Other fuels	SE	Car fuels	SE	Other goods	SE
Food	0.5043	0.0027	-0.9175	0.0004	0.0851	0.0007	-0.1397	0.0001	-0.1671	0.0001	-0.0044	0.0000
Electricity	0.5244	0.0038	0.0150	0.0001	-0.1043	0.0067	-0.0002	0.0000	-0.1193	0.0001	-0.0284	0.0000
Other fuels	0.8213	0.0001	-0.0216	0.0001	0.0107	0.0001	-0.6936	0.0002	0.3061	0.0002	-0.0273	0.0000
Car fuels	0.7947	0.0004	-0.0313	0.0001	-0.1686	0.0013	0.3230	0.0002	-0.2614	0.0006	-0.0427	0.0000
Other goods	1.1399	0.0000	0.4512	0.0024	-0.3473	0.0024	-0.3108	0.0002	-0.5530	0.0005	-1.0371	0.0000

*Note.* Database is IES, 1993-2008.

**Table A. 2 Results of policy change scenarios in Schleswig-Holstein**

	Doubling of CFT		Abolishing of CFT	
	Mean	Std. Dev.	Mean	Std. Dev.
Electricity emissions (% change)	-0.0565	0.0209	0.1144	0.0530
Car fuels emissions (% change)	-0.1886	0.0260	0.2411	0.0520
Total emissions (% change)	-0.2450	0.0444	0.3555	0.0723
CV	656.5212	327.8904	-804.0259	403.0891
CV (% of income)	1.7019	0.5558	-2.0836	0.6859
EV	642.6838	321.5386	-824.4658	412.3253
EV(% of income)	1.6652	0.5436	-2.1385	0.7047
Tax burden (% change)	381.6311	203.7450	-604.0883	291.2950
Tax burden change (% of income)	0.9872	0.3565	-1.5672	0.4830
Gini index (% change)	0.3858	0.0000	-0.6661	0.0000

*Note.* Database is IES, 2008.

## A2 EEG surcharge

Applying the separate IES data for Schleswig-Holstein for the period 1993–2013, I was able to obtain estimates from the Demographically-scaled Quadratic Almost Ideal Demand System (DQUAIDS). The elasticities obtained from this demand system are included in Table A3. The expenditure elasticities indicate that electricity is a necessity good and the households in SH are extremely unresponsive (almost price inelastic) to electricity price changes: for 1 percent price increase, demand will decrease by only 0.021 percent. This indicates that as electricity price goes up or down, the quantity demanded will change by very little amounts, proving that energy or environmental policies (which are price related) will not be very effective in SH. The expenditure elasticity of electricity shows that electricity is normal good among households in Schleswig-Holstein: for 1 percent increase in expenditures, households would increase their electricity consumption by 0.766. Car fuels are found to be a luxury good within this federal state (expenditure elasticity is 1.298). Demand for other fuels is also price inelastic: for 1 percent price increase consumption would go down by 0.316 percent and by 0.377 in Germany and Schleswig-Holstein respectively.

Several scenarios with changes in the Renewable Energy Act Surcharge (EEG surcharge) are considered for SH – S5: the EEG is doubled; S6: abolishing of the EEG; S7: doubling of both the EEG and the Car Fuels Tax (CFT); and S8: abolishing of both the EEG and the CFT. The results are summarized in Table A4. I compare all relevant variables with their values in the status quo (the situation in 2013) in order to calculate the percentage change in tax burdens, emissions or poverty. If the EEG surcharge is doubled, the electricity tax burden will be 184 euros lower in Schleswig-Holstein, which represents almost 0.5 percent of average income. Income and energy poverty will increase by 1.2 and 11.3 percent respectively. Electricity related emissions will be 4.5 percent lower than under the status quo. Under this scenario, the emissions' reduction in Schleswig-Holstein is much smaller than in Germany (7.5 percent), and the increase in poverty is also smaller. Under S6, tax burden is 203 euros lower in SH and energy poverty will decrease by 14.2 percent. Households in SH increase their electricity's consumption (and emissions) by much less than households in Germany when the EEG surcharge is abolished. They also experience much smaller reduction in income poverty due to such policy reform (0.6 percent in SH versus 2.1 percent in Germany).

If both the EEG surcharge and the CFT are doubled (S7), the electricity tax burden for households in Schleswig-Holstein will be 148 euros (0.4 percent of income) higher than the status quo. The tax burden change is lower under S7 than under S5 due to the fact that electricity and car fuels are found to be complementary goods: as price of electricity increases demand for car fuels goes down and also as car fuels price goes up demand for electricity goes down. Residential CO<sub>2</sub> emissions in SH will decrease by 11.8 percent but income and energy poverty will increase by 4.3 and 45.9 percent respectively. The emissions reductions in SH are more pronounced in SH than in Germany while the poverty indicators are more responsive in Germany than in SH alone. Under S8, the reduction in electricity tax burden and increase in electricity related emissions is more pronounced in SH than in Germany. Income poverty and energy poverty will decrease by 5.8 and 67.3 percent in SH respectively. Throughout Germany, income and energy poverty decrease by 7.2 and 65 percent. Scenarios 5 and 7 are efficient in reducing emissions while scenarios 6 and 8 are effective in reducing income poverty and energy poverty in Schleswig Holstein.

Alternatively, a ninth scenario (S9) leads to lower income and energy poverty while energy related CO<sub>2</sub> emissions (both from electricity and car fuels) are only slightly increased. Those effects would occur if the EEG surcharge is abolished whereas the car fuels tax is increased by 25 percent. Such policy reform should be considered by policy makers in Germany, and hence be implemented at the federal level, not just in Schleswig-Holstein.

**Table A. 3 Elasticities and expenditure shares Schleswig-Holstein versus Germany**

	Price elasticities					Expenditure elasticities					Expenditure shares (% of total expenditures)				
	Food	Electricity	Other fuels	Car fuels	Other goods	Food	Electricity	Other fuels	Car fuels	Other goods	Food	Electricity	Other fuels	Car fuels	Other goods
Schleswig-Holstein	-1.004	-0.021	-0.822	-0.377	-1.024	0.899	0.766	0.762	1.298	1.039	17.048	3.060	4.058	4.396	71.438
SE	0.002	0.015	0.004	0.019	0.001	0.013	0.012	0.013	0.047	0.001	0.069	0.020	0.040	0.036	0.088
Germany	-1.003	-0.235	-0.657	-0.316	-1.136	0.488	0.496	0.770	0.994	1.149	17.044	3.231	4.030	4.183	71.513
SE	0.001	0.008	0.001	0.005	0.000	0.005	0.003	0.001	0.008	0.000	0.075	0.023	0.043	0.039	0.095

Note. Own calculations. Dataset is IES 1993–2013.

**Table A. 4 Scenarios S5-S8 results Schleswig-Holstein versus Germany**

Scenarios	Electricity tax burden				Electricity emissions				Income poverty (HC ratio)		Energy poverty (TPR)	
	change in euros		% of income		change in tons		% change		% change		% change	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
S5–doubling of <i>EEG</i>												
<i>Schleswig-Holstein</i>	184.117	75.060	0.488	0.144	-0.072	0.078	-4.451	5.098	1.223	0.000	11.321	0.000
<i>Germany</i>	154.009	75.477	0.476	0.150	-0.118	0.060	-7.451	2.459	1.629	0.000	11.111	0.000
S6–abolishing of <i>EEG</i>												
<i>Schleswig-Holstein</i>	-202.791	74.551	-0.545	0.160	0.014	0.145	1.763	7.615	-0.612	0.000	-14.151	0.000
<i>Germany</i>	-180.681	84.038	-0.566	0.184	0.114	0.089	7.518	4.698	-2.123	0.000	-13.890	0.000
S7–doubling of <i>EEG</i> and <i>CFT</i>												
<i>Schleswig-Holstein</i>	147.488	57.568	0.393	0.114	-0.208	0.074	-11.789	2.871	4.281	0.000	45.912	0.000
<i>Germany</i>	146.118	70.284	0.454	0.144	-0.147	0.068	-9.132	1.960	5.117	0.000	48.700	0.000
S8–abolishing of <i>EEG</i> and <i>CFT</i>												
<i>Schleswig-Holstein</i>	-187.584	67.730	-0.506	0.149	0.362	0.124	20.431	3.958	-5.810	0.000	-67.296	0.000
<i>Germany</i>	-177.068	81.872	-0.555	0.181	0.197	0.096	12.299	3.404	-7.165	0.000	-65.050	0.000

Note. Own calculations. Dataset is IES 2013. *EEG* stands for the Renewable Energy Act Surcharge and *CFT* is the Car Fuels Tax.



### A3 Emissions inequalities

The socioeconomic and demographic characteristics of households are relevant factors in explaining residential energy consumption and energy related emissions. The characteristics of the households in Schleswig-Holstein (SH) differ slightly than the ones from the rest of the country. Around 9,000 observations are available for SH from the IES database, across five time periods (1993–2013). Households in SH tend to be slightly larger in size, older, wealthier, and more educated (see Table A5). They also possess larger number of electric appliances, old cars, and live in larger dwellings. Households in this state consume larger amounts of energy in comparison to the other states: electricity consumption is 4.7 percent larger, gas consumption is 10 percent larger, and car fuels consumption is 3.2 percent larger.

Both the emissions of the low and high income households in Schleswig-Holstein are larger than the German averages. Low income (first equivalent income decile) households emitted around 11 tons of CO<sub>2</sub> in 1993 and around 5 tons in 2013. High income (tenth equivalent income decile) households emitted 19.6 in 1993 and 12.5 tons of CO<sub>2</sub> in 2013. Hence, the gap between low and high income households has widened in SH, where high income households emitted 78 percent more CO<sub>2</sub> than the low income households in 1993 and 146.9 percent more by 2013 (Table A6). Hence, income-related emissions inequalities are confirmed by the data. Rural households in SH are also found to be higher emitters than urban households. While households in rural areas emitted 14.6 tons of CO<sub>2</sub>, households in urban areas emitted 11 tons of CO<sub>2</sub>. Area of residence-related emissions inequalities exist also in SH.

Inter-generational emissions inequalities are also investigated for households in SH. An inverted u-shaped relationship between the emissions and the birth cohort of the household leader is also identified for Schleswig-Holstein.<sup>100</sup> Similarly to the whole country, households in SH with a leader from the birth cohorts 1933–1963 have higher CO<sub>2</sub> emissions (7.6 percent higher). The cohort 1943 emits even 14.4 percent more CO<sub>2</sub> than the average household in Schleswig-Holstein.

A de-trended age period cohort (APCD) model is employed to separate the effects of birth cohort, age, and period on energy related CO<sub>2</sub> emissions. No birth cohort effects of the household's leader are identified for Schleswig-Holstein (they are statistically insignificant).<sup>101</sup>

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<sup>100</sup> See Figure A1.

<sup>101</sup> See Table A7 for the estimates of the APCD model for Schleswig-Holstein and Germany.

This has been also the case for households in the US, where cohort effects were also statistically insignificant (see Chancel, 2014). Birth cohorts of the other household members are important determinants of emissions' levels. Namely, additional household members belonging to 1918–1958 birth cohorts increase emissions by more than the average household member. Income- and rural-related emissions inequalities are confirmed by the APCD model for Schleswig-Holstein, with higher income and rural households emitting more CO<sub>2</sub>. Also households with leaders aged 65–75 are found to be higher emitters.

**Table A. 5 Summary statistics of rural and urban households in Schleswig-Holstein versus Germany**

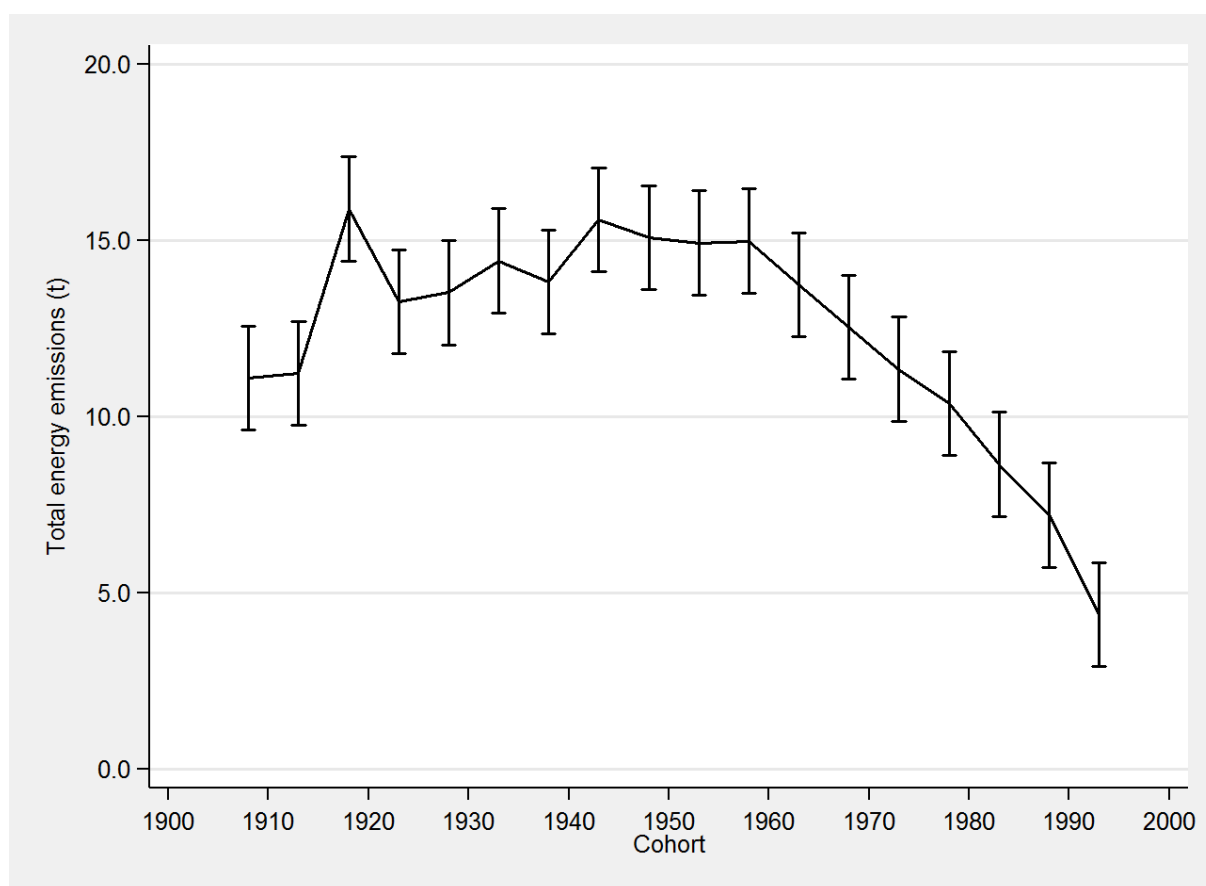
Variable	Schleswig-Holstein						Germany	
	Rural		Urban		All		All	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
<i>adults</i>	2.006	0.796	1.727	0.745	1.933	0.793	1.955	0.811
<i>children</i>	0.543	0.934	0.344	0.742	0.491	0.892	0.447	0.836
<i>age</i>	53.451	14.913	51.034	16.666	52.818	15.427	52.470	15.019
<i>ydisp</i>	42235	20515	33581	19787	39969	20679	39184	21647
<i>educ2</i>	0.168	0.374	0.145	0.352	0.162	0.368	0.145	0.352
<i>educ3</i>	0.130	0.337	0.172	0.378	0.141	0.348	0.171	0.376
<i>TVs</i>	1.715	0.958	1.531	0.900	1.667	0.946	1.548	0.874
<i>PCs and notebooks</i>	1.088	1.153	1.034	1.096	1.074	1.139	1.075	1.135
<i>refrigerators and freezers</i>	1.900	0.856	1.618	0.758	1.826	0.841	1.797	0.828
<i>dishwashers</i>	0.698	0.477	0.537	0.508	0.656	0.490	0.636	0.499
<i>washing machines and driers</i>	1.250	0.675	1.094	0.692	1.209	0.683	1.174	0.678
<i>dwelling size</i>	107.853	41.142	80.460	34.680	100.681	41.343	98.509	42.263
<i>cars new</i>	0.459	0.590	0.375	0.537	0.437	0.578	0.479	0.615
<i>cars old</i>	0.675	0.739	0.544	0.672	0.640	0.724	0.634	0.729
<i>distant heating</i>	0.147	0.354	0.400	0.490	0.214	0.410	0.150	0.357
<i>central heating</i>	0.824	0.381	0.573	0.495	0.758	0.428	0.742	0.438
<i>quantity of electricity</i>	4253	2976	3241	2676	3988	2934	3801	2844
<i>quantity of gas</i>	22100	22972	17389	17018	20867	21671	18780	22650
<i>quantity of car fuels</i>	1219	956	794	794	1108	938	1073	923
<i>total energy emissions</i>	14.559	10.635	11.000	8.239	2.225	1.637	2.121	1.587
<i>observations</i>	6420		2277		8697		219826	

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population. *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education.

**Table A. 6 Total energy related emissions in Schleswig-Holstein across the deciles**

Decile/ Year	1	2	3	4	5	6	7	8	9	10
	Mean CO <sub>2</sub> emissions (in tons)									
1993	10.979	12.382	14.376	15.263	16.715	16.196	17.387	17.821	18.493	19.631
1998	8.531	10.792	13.961	12.343	16.348	15.425	15.544	18.592	18.023	18.074
2003	7.602	10.143	12.416	12.162	12.903	15.559	15.675	14.556	18.581	20.377
2008	5.395	7.901	9.077	10.380	11.044	10.869	12.927	13.174	15.335	14.983
2013	5.066	7.503	8.498	8.223	10.554	9.712	13.073	12.470	12.710	12.506

*Note.* Database is IES 1993–2013. Weights used to assure representativeness of the German population.

**Figure A. 1 Birth cohorts and total emissions in Schleswig-Holstein**

*Note.* Database is IES 1993–2013. Line segments indicate the 95 percent confidence intervals.

**Table A. 7 Coefficient estimates of the APCD model for Schleswig-Holstein versus Germany**

$\ln(E_{total})$	Schleswig-Holstein		Germany	
	With controls and other cohorts effects			
	Coef.	Std. Err.	Coef.	Std. Err.
<i>cohort</i> 1913	0.112	0.061	-0.015	0.014
<i>cohort</i> 1918	-0.038	0.043	-0.026	0.010
<i>cohort</i> 1923	-0.083	0.038	-0.026	0.008
<i>cohort</i> 1928	-0.067	0.034	-0.021	0.007
<i>cohort</i> 1933	-0.053	0.031	-0.012	0.006
<i>cohort</i> 1938	0.020	0.029	-0.006	0.006
<i>cohort</i> 1943	-0.011	0.029	0.013	0.006
<i>cohort</i> 1948	-0.011	0.029	0.032	0.006
<i>cohort</i> 1953	0.058	0.027	0.051	0.006
<i>cohort</i> 1958	0.077	0.025	0.055	0.005
<i>cohort</i> 1963	0.090	0.023	0.059	0.005
<i>cohort</i> 1968	0.062	0.025	0.052	0.005
<i>cohort</i> 1973	-0.013	0.033	0.005	0.007
<i>cohort</i> 1978	-0.062	0.041	-0.052	0.008
<i>cohort</i> 1983	-0.080	0.049	-0.111	0.010
<i>age</i> 25	0.019	0.040	0.013	0.009
<i>age</i> 30	0.061	0.028	0.000	0.006
<i>age</i> 35	-0.001	0.024	-0.012	0.005
<i>age</i> 40	-0.069	0.022	-0.045	0.005
<i>age</i> 45	-0.042	0.022	-0.033	0.005
<i>age</i> 50	-0.019	0.023	-0.002	0.005
<i>age</i> 55	-0.017	0.024	0.027	0.005
<i>age</i> 60	0.000	0.026	0.042	0.005
<i>age</i> 65	0.042	0.026	0.038	0.005
<i>age</i> 70	0.029	0.025	0.034	0.005
<i>age</i> 75	0.035	0.027	0.019	0.006
<i>age</i> 80	-0.022	0.032	-0.008	0.007
<i>age</i> 85	-0.016	0.041	-0.072	0.009
<i>period</i> 1993	-0.015	0.012	-0.024	0.002
<i>period</i> 1998	-0.023	0.015	0.000	0.003
<i>period</i> 2003	0.079	0.016	0.033	0.003
<i>period</i> 2008	-0.029	0.015	0.029	0.003

**Table A. 7 (Continued)**

	Schleswig-Holstein		Germany	
	With controls and other cohorts effects			
$\ln(E_{total})$	Coef.	Std. Err.	Coef.	Std. Err.
<i>period</i> 2013	-0.012	0.011	-0.038	0.002
<i>rescacoh</i>	-1.956	0.075	-2.002	0.016
<i>rescaage</i>	-0.986	0.038	-1.016	0.008
$\ln(ydisp)$	0.309	0.018	0.277	0.004
<i>n1908</i>	-0.126	0.279	-0.050	0.046
<i>n1913</i>	0.142	0.135	0.017	0.031
<i>n1918</i>	0.130	0.083	0.046	0.017
<i>n1923</i>	0.124	0.057	0.076	0.012
<i>n1928</i>	0.102	0.051	0.116	0.010
<i>n1933</i>	0.156	0.037	0.149	0.008
<i>n1938</i>	0.099	0.034	0.150	0.007
<i>n1943</i>	0.177	0.032	0.192	0.007
<i>n1948</i>	0.165	0.032	0.178	0.006
<i>n1953</i>	0.127	0.031	0.171	0.006
<i>n1958</i>	0.110	0.028	0.141	0.006
<i>n1963</i>	0.049	0.027	0.104	0.006
<i>n1968</i>	0.017	0.013	0.015	0.003
<i>n1973</i>	0.041	0.013	0.029	0.003
<i>n1978</i>	0.024	0.015	0.050	0.003
<i>n1983</i>	0.029	0.018	0.069	0.004
<i>n1988</i>	0.089	0.017	0.117	0.004
$\ln(h_{qm})$	0.427	0.024	0.356	0.005
<i>educ2</i>	-0.004	0.019	-0.008	0.004
<i>educ3</i>	-0.029	0.020	-0.019	0.004
<i>rural</i>	0.038	0.016	0.047	0.003
<i>constant</i>	-2.935	0.161	-2.380	0.035
<i>AIC</i>	1.867		1.972	
<i>BIC</i>	-73576		-2569055	
<i>observations</i>	8533		216578	

*Note.* Database is IES 1993–2013. *educ2* indicates whether the household's leader has completed high school or other specialized school, *educ3* if she or he has a university or higher education. *n1908* – *n1988* indicate number of household members from these birth cohorts. *h<sub>qm</sub>* is dwelling size. *AIC* and *BIC* stand for Akaike and Bayesian Information Criterion.



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# Declaration

I hereby declare that I have produced my doctoral thesis " Essays on Energy Economics – Empirical Analyses Based on German Household Data" independently and without external assistance, and that I have made a significant contribution as co-author to other scientific articles. I have identified all word-for-word quotations of other authors, as well as comments based closely on other authors' ideas, and I have cited the sources according to the guidelines I received.

18 January 2017

Dragana Nikodinoska