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Distributional Implications of Electricity Taxation: An Assessment using Household Survey Data from 11 OECD countries*

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Abstract

This paper assesses the distributional implications of electricity taxation, using data from a 2011 survey of households in 11 OECD countries. Demand elasticities are estimated separately for the following household categories: income terciles, household location, type of residence, home ownership status and major heating source. Subsequently, change in dispersion of net (of electricity expenditure) income is computed and used as a summary measure of welfare change. The key results of the analysis are as follows. Welfare reduction due to electricity taxation, conceptualised as proportional tax scenarios of 2% and 5%, is very modest, and does not substantially increase when household demand is allowed to be heterogeneous across the above mentioned categories.

Keywords: electricity tax, regressivity, income distribution, price elasticity

JEL Classification: Q41, Q52, D60, D12

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1 Introduction

Energy-related taxes, on a variety of intermediate and final goods, are a common feature of virtually all developed economies for a variety of reasons. The importance of addressing climate change has led many developed economies, particularly the Kyoto Protocol signatories, to view taxes on carbon as a possible (additional) tax. Indeed, some form of taxation of carbon already exists within the EU: certain sectors are taxed under the ETS that is supplemented, in many countries, with a separate tax on sectors not covered under the ETS. A key concern in many energy- and carbon-related taxation relates to differential impact of policies upon different household types. These concerns are acute in the case of many energy sources, including electricity, given the essential nature of certain types of electricity-using consumption activities (e.g., winter heating, summer cooling, and lighting).

In particular, the effect on households of different characteristics are of some importance. For instance, it is plausible that households with larger number of people need a higher minimum quantity of electricity and, given the same household size, lower income households might be more adversely affected by electricity taxation. Households located in smaller aggregations, such as village and isolated dwellings, may face higher costs, given similar income levels and household sizes for a variety of reasons. An assessment of welfare differences across households of different types is thus necessary in order to understand the distributional consequences of price changes and to design policies mitigating some of the adverse consequences.

Given that taxes on residential electricity consumption are common in many countries, it is to be anticipated that concerns on the distributional implications of these taxes are of comparable importance to those of carbon and motor fuel (henceforth "fuel") taxes. Nonetheless, while there is by now a sizeable literature on the distributional implications of carbon and fuel taxes, there appear to be very few studies focused on assessing similar concerns in relation to taxation of household electricity consumption.

This paper makes a contribution to the (rather sparse) literature on assessing the distributional implications of taxing residential electricity. The main objective of the paper is an empirical assessment of the welfare implications of taxing residential electricity consumption when households of different types are allowed to be heterogeneous in demand behaviour. The assessment of welfare in our study is counterfactual rather than historical i.e. this study provides estimates of counterfactual taxation scenarios, exploring the welfare implications of imposing (additional) proportional taxes rather than assessing the incidence of existing taxes. It also illustrates a relatively straightforward, yet rigorous, way of quantifying the differential impact of electricity policies (e.g. any tax on marginal price) on households of differing attributes, including income levels. This approach uses ideas from the empirical literature on consumption taxation, drawing upon a major advantage of the OECD's Environmental Policy and Individual Behaviour Change (EPIC) surveys, the presence of consumption and price data.

It is important to emphasize that the welfare impact of economy-wide electricity price (or tax) increases operate through two channels, a direct channel, the one considered here, and an indirect channel, through changes in prices of other goods and services. The traditional approach to computing welfare impacts of such changes are through economy-wide models such as Computable General Equilibrium (CGE) models. In this study, on the other hand, interest centers upon changes in welfare, in particular on the distributional implications, consequent to price changes solely on household electricity consumption. The focus on a single consumption good implies that it is permissible, to a first-order at least, to ignore effects through the indirect channel. Alternatively, the welfare estimates provided here may be viewed as upper bounds on the direct welfare effects from an economy-wide change in electricity prices.

The data used for the analysis are drawn from the 2011 round of the EPIC survey. The empirical analysis is approached in an exploratory spirit, in that an attempt is made to explore different (potential) dimensions, in addition to income, along which disparity in net (of electricity expenditures) income ("net income") is large, with a view to instituting policy measures to counteract this increase in disparity.

The structure of the paper is as follows. Section 2 places the current study in the context of relevant literature on fuel and carbon taxes. Section 3 provides a brief review of alternative empirical approaches for assessing the welfare implications of taxation scenarios, along with a formal welfare framework for the approach used here. Section 4 discusses the survey on which the analysis is based. Demand analysis with the EPIC 2011 data is carried out in section 5 while estimates of the welfare changes using the estimated demand elasticities are presented and discussed in section 6. Section 7 summarises the implications of our analysis and provides a discussion of the interpretation and policy significance of our welfare estimates (as well as implications for the EPIC data gathering exercise). We note that although the title states "Energy Policies", the approach is applicable to water (or in principle, any consumption good) policy; the only change is the method used for demand estimation.

2 Related Literature and Context

Although our analysis is focused on taxation of residential electricity, for both methodological and contextual reasons there is some overlap with the large literature on distributional effects of fuel and carbon taxation and, in general, environmental taxation. We briefly touch upon overlapping areas, chiefly with a view to placing our study in the proper context, and subsequently cover other, more directly related, studies. In view of these objectives, our coverage of the literature will necessarily focus on broad outcomes rather than a detailed consideration of the various aspects of different studies. Our coverage will focus mainly on empirical, partial equilibrium, analysis, but we will subsequently briefly touch upon a strand of the literature that combines CGE models with more partial equilibrium, often empirical, micro-simulation models.

Readers interested in the details of empirical frameworks to which we relate our study are referred to excellent recent summaries of literature in e.g. Callan et al. (2009, §2), Zhang and Baranzini (2004) (or an earlier summary in Speck (1999)) for carbon taxes, to Sterner (2012) (as well as a collection of studies on the issue in Sterner (2011)) for fuel taxes, and to the collection of essays on a variety of issues related to environmental taxation in Johnstone and Serret (2006), with particular reference to Kriström (2006). This last study, which provides both a survey of the empirical literature and a clear delineation of the issues involved in taxation of different types of (energy-related, among others) commodities, will also be used to organise our discussion.

Carbon taxes affect the prices of both production and consumption goods, and there is by now a large literature exploring the implications of these taxes. The overall finding of the empirical strand of this literature can be summarised broadly as one of modest regressive effect, with the degree of regressivity depending upon a variety of factors such as country, measure of income etc., with a few studies even finding a progressive effect. Many of these studies use some form of demand elasticity, while a few estimate this elasticity using a demand system. Turning next to fuel taxes, with a particular focus on petrol, the range of outcomes here, for most developed countries, is as broad, ranging from weakly progressive to regressive. Most studies in this literature do not explicitly estimate demand systems, and assume varying degrees of demand elasticity; welfare assessment and demand estimation are not frequently carried out together. Overall, the findings in the literature on carbon and fuel taxes may be broadly summarised as follows: these taxes are only moderately regressive, with the degree depending upon the context and details, as also reflected in the diversity of outcomes detailed in e.g. Kriström (2006, Table 3.1).

To our knowledge, only one study, Halvorsen and Nesbakken (2002), deals explicitly with electricity taxation. This paucity of studies is particularly surprising since many countries (e.g. most EU countries) tax residential electricity consumption; in our sample, six of the 11 countries tax residential electricity consumption (see table 1). Unlike taxes on carbon, which are economy-wide, taxes on electricity and on some fuels (e.g. petrol, used primarily for personal transport) have weak linkages to other sectors (although linkages to the market for heating fuels can be strong). This facet permits restricting distributional impacts to this particular good, as also noted in Kriström (2006) for the case of petrol. Turning next to the details, the study of Halvorsen and Nesbakken (2002) reports welfare impacts of five different electricity tax schemes, two proportional and three progressive, across three income groups, by estimating a demand system allowing for household heterogeneity. Overall, the main findings are of a very small regressive effect, with demand heterogeneity not leading to substantial changes in welfare (see section 6.2 for a slightly detailed comparison of results). The discussion of a few other studies which are only methodologically related to ours, as well as a brief consideration of the issues related to measures of income–which are of some importance to computed distributional effects–, is deferred to the next section.

Our analysis, while influenced by that of Halvorsen and Nesbakken (2002), nonetheless differs from it in many respects. First, our data are very different, with many countries and only a single source of energy, electricity. Second, the dimensions across which households are allowed to differ are enlarged, to include ownership status, location and major space-heating source, in addition to income terciles. This exploration is motivated by some of the existing literature (e.g., Callan et al. (2009) and Kriström (2006)) that postulates many of these aspects as being of importance. Thirdly, we use different summary measures of dispersion (inequality), measures which are more robust and are commonly used in related, applied, literature; these are also related to measures of dispersion used for similar analyses for different energy (e.g. Sterner (2012)) and non-energy (Yitzhaki and Wodon (2002)) goods. Finally, we also provide a rigorous welfare framework for the summary measures of inequality used, allowing an interpretation of dispersion in net income as welfare.

We briefly relate our study to the sparse literature combining empirical (partial equilibrium) and CGE approaches, particularly for the case of carbon taxes, and refer the reader to the influential study of Labandeira et al. (2009) for more details. As observed in Labandeira et al. (2009), CGE models are often used for analysing the economy-wide ("efficiency") aspects of policies while microeconomic models tend to be commonly used for analysing the distributional ("equity") aspects of policies. Only a few studies have been able to combine a truly empirical household-data-based framework for assessing distributional impacts with a comprehensive model of different sectors of the economy; see e.g, Labandeira et al. (2009); Chitiga et al. (2010); Vandyck and Van Regemorter (2014). Although the findings vary, overall, these studies report substantial distributional effects of energy- and carbon-taxes that affect many goods. Extension of the empirical approach used here to explore the distributional effects of electricity taxation to include sectoral and relative price changes is left for future research.

Our sample of 11 countries is varied, as regards key electricity sector policies, particularly prices and taxes. These countries have relatively complicated residential consumer pricing schemes.[1] Similar to case of fuel, taxation of residential electricity has been a common feature of many developed economies[2]; indeed, six of the 11 countries in our sample tax residential electricity consumption. It is sometimes relatively difficult to provide a single summary tax figure for many countries, given the many layers of taxes and subsidies (a point also noted in Sterner (2012) for fuel taxes). A brief and broad overview of the two types of taxes levied on electricity in the sample of countries considered here is presented in table 1. In view of the fact that our analysis is not at the country level, the proper interpretation of our welfare assessment is as simulations of counter-factual tax scenarios. This is also the view taken by many studies of carbon taxes, particularly those simulating/assessing the effect of a tax prior to the introduction of one (e.g., Callan et al. (2009)).

Table 1: Taxation of Electricity for countries in the EPIC 2011 survey.

	Tax on		**Remarks**
	Consumption	*inputs*	
Australia	No	No	
Canada	No	No	
Chile	No	No	
France	Yes	No	
Israel	No	Yes	
Japan	Yes	Yes	375Yen/mWh
Netherlands	Yes	Yes	Decreasing-block system
South Korea	No	Yes	
Spain	Yes	No	
Sweden	Yes	Yes	283 SEK/MWH (187 for Northern Sweden)
Switzerland	Yes	Yes	0.009 CHF/kWh

Notes: "inputs" refers to taxes on energy sources (e.g. coal) used to produced electricity. Details on consumption tax structure for Spain and France were unavailable. Tax structure and rates refer to those in effect on 1 April 2012.
Source: OECD (2013)

[1]For instance, the block-pricing structure in South Korea is sophisticated, with non-linear block-pricing for low- and high-voltage consumers while for Japan, block-pricing schemes depend upon Ampere contracted, time-of-day, and a so called "fuel cost adjustment" that varies by month. Finally, in Australia, pricing of electricity is complex (e.g., rebates are available for certain types of consumers).

[2]Unlike for fuel-related taxes, which appear for some countries at least to be partly influenced by environmental considerations (see the discussions in e.g. Sterner (2012, 2011), we are unaware that environmental considerations play any part in policies taxing residential electricity consumption, except indirectly via reduced consumption.

3 Assessing Welfare Implications of Price Changes

3.1 Overview of Approaches

We briefly review two approaches available to empirically estimate welfare changes of price increases using household data. The methods outlined next, although different in many respects, have a common origin: demand estimation. With data in hand on consumption and marginal price[3] at the household level, demand estimation proceeds by estimating the parameters of a functional form for demand.[4] Once a consistent framework for demand estimation is chosen, two alternatives exist for quantifying welfare implications. In the first, the welfare framework is based upon the (indirect) utility function which follows from the demand estimation framework (following Hausman (1981) and Hausman and Newey (1995)). This utility function can be used to obtain a measure of welfare for a given price change, typically the Compensating Variation (CV) or Equivalent Variation (EV). Subsequently, some summary by (say) income groups–quartiles, terciles etc.–of the welfare measure provides the needed distributional interpretation. In the second approach, a summary measure of the dispersion (as in the poverty and inequality literature) of net income pre- and post-price-change is computed—using a suitable demand estimation framework– and the change in dispersion is interpreted as a measure of welfare.[5]

We outline next a few details of these approaches, and provide some commentary about their applicability. The first approach can be called *utility-based* welfare evaluation. In this framework (following Hausman (1981)) the idea is conceptually straightforward: a given demand function implies a certain form for the indirect utility function. Once the form of the utility function is known, with parameters estimated from the demand function, it is straightforward to compute a measure of welfare change, say the EV, based on estimated changes in consumption due to the price change.[6] If demand estimation is carried independently for each income tercile, say, then EV can be computed for each group and these income groups can be ordered based on the EV, with groups with higher EV more affected by the policy (see Hausman (1981) for two illustrative applications). Observe that welfare here is based on changes in expenditure, pre- and post-tax, with the magnitudes de-

[3] In the absence of marginal price, average price data can be used, with appropriate caveats, as illustrated in Krishnamurthy and Kriström (2015a) for the EPIC 2011 data.

[4] If, as here, the demand function is allowed to differ across many dimensions of the household, then demand estimation maybe carried out either independently across these dimensions, as we do, or jointly, as in Halvorsen and Nesbakken (2002).

[5] There is yet a third alternative, that used in Stoker (1986). This method is similar to the one in Hausman (1981)—at least conceptually—and differs in that it uses a specific demand system, the Jorgenson-Lau-Stoker (J-L-S). See Stoker (1986) for more details.

[6] If price changes are non-linear e.g. consumption dependent tax-rates, such as those increasing with consumption, computation of the new expenditures are more involved but the framework presented here is substantively unaltered, provided marginal prices are constant i.e. there is no increasing-block-structure to marginal prices. Policies for which this approach is ideally suited are proportional tax schemes, with every unit of consumption taxed at a fixed and constant tax rate.

pending substantially on the functional form (for demand estimation) used. It is important to note that this particular step, of deriving dispersion in some measure computed (EV or net EV—the last following Stoker (1986)), unlike the computation of individual welfare, has no particular theoretical justification or welfare interpretation.

The second approach can be called *expenditure-based* welfare evaluation, and is the approach used in our study. In this framework, the idea is that welfare is represented by net consumption possibilities. In more detail, net consumption possibilities are a proxy for unmeasurable individual welfare; thus, changes in net consumption possibilities are a proxy for welfare changes. Provided data on all categories of energy expenditure are available, one measure of net consumption possibility is household income net of expenditure on energy (electricity and its substitutes e.g. gas), an approach used in Halvorsen and Nesbakken (2002). Thus, once demand estimation is carried out, post-tax net household income is computed. Subsequently, some measure of the change in dispersion of net income is computed for both pre- and post-tax expenditure and the change in this measure of dispersion yields the sign of the welfare change.

Two points of comparison between the two approaches are worth noting. First, estimates from the expenditure-based approaches are more likely to be numerically stable.[7] A second, related, issue is that the expenditure-based framework (while theoretically less appealing) is not so closely tied to a specific functional form for demand. Note that in section 3.2 a basic welfare formulation and interpretation for the expenditure-based approach is provided, mitigating one of its drawbacks.

We note that alternative empirical approaches have been used to summarise the distributional implication of fuel and carbon taxes, based usually on household budget survey data (e.g. Sterner (2012), Brännlund and Nordström (2004), and other studies cited in Kriström (2006, Table 3.1)) or, in addition, detailed tax data (Hassett et al. (2011)). These approaches are infeasible in our case due to data limitations. That said, the broad outlines of our analysis are similar to a recent study of Sterner (2012), in that in both cases, summary measures of disparity are computed based upon some measure of income.[8]

At this stage, it is also pertinent to discuss a methodological issue that is commonly debated in the literature on assessing distributional effects, the choice of the measure of "income". The debate

[7]This is easily seen from the fact that the estimated parameters are used directly to compute utility, implying substantial sensitivity to parameters. A second drawback is the inherent difficulty in accommodating specific parameter values for different functional forms; for instance, for the commonly used double log functional form, a utility representation does not exist when income or price elasticity are close to unity.

[8]Sterner (2012), using household budget survey data from seven countries in Europe, provides a summary measure of progressivity of taxes across the income distribution, the Suits index. Given that our data set is rather limited (e.g. tax data are unavailable) and that we are interested in a broader set of dimensions along which disparities exist (home ownership, location and heating fuel used, in addition to income terciles), this approach is not directly applicable to our case.

centers on the choice between expenditure (on energy or all goods) and current income as the best measure of ability to pay taxes; see e.g. the brief discussion in Speck (1999, p.662-63), Kriström (2006, §2.3.1) and Sterner (2012, p.78) (and references therein). Overall, there appears to be no consensus on the best measure of income to use.[9] The measure we use, income net of electricity expenditures, is similar (although not identical) to one of the two used in Sterner (2012), annual disposable income. However, in keeping with the exploratory spirit, we also assess if the distributional implications obtained here are altered when we use electric expenditure share of income (henceforth "shares"). The use of this additional measure ensures that our assessment of distributional impacts is not completely dependent upon any one measure of income.

Finally, it is also important to mention here that differences across household categories, in our analysis, are accounted for by allowing the demand functions for the categories to differ. Using the presumably distinct demand functions, a single measure of welfare (inequality in net income), is computed for every categorisation and scenario (e.g. a 5% tax increase). In other words, welfare computation does not indicate whether e.g. home owners are affected less (or more) than renters i.e. the framework above is not used to provide differential welfare impacts across chosen categories, primarily for data-related reasons. See also section 7.

3.2 Welfare framework

As already pointed out, in the expenditure-based approach there is no welfare framework in which to either interpret the increase in inequality as welfare reducing or to quantify the trade-off between the level of outcome ("efficiency"), say income, and distributional implications ("equity") of a given policy. This is the task undertaken next.

Consider the following social welfare function, whose interpretation is considered later

$$W = \mu (1 - G), \tag{1}$$

where μ, G refer respectively to a "mean" outcome over the population of interest (e.g. net income) and the Gini coefficient of the outcome. This form of a (social) welfare function quantifies explicitly the trade-off between increased "level " of a social outcome and the change in distribution of this outcome over the population of interest. To illustrate, consider a policy measure which leads to increased average level of an outcome while also increasing inequality. The effect upon welfare of

[9] The importance of this aspect to the overall conclusion of the body of literature is summarised in Kriström (2006, p.88), as "conclusions about the distributional aspects of environmental policy are not necessarily robust towards the used concept of income".

this measure is easily seen to be, with μ_2 and $\mu_1$representing mean outcomes after and before the policy (similarly for the Gini coefficient and Welfare), $\Delta\mu = \mu_2 - \mu_1$ and $\Delta W = W_2 - W_1$,

$$\Delta W = \Delta\mu + (\mu_1 G_1 - \mu_2 G_2) .$$

With $\mu_2 > \mu_1$ and $G_2 > G_1$, change in welfare evidently depends upon the magnitude of the increase in level and in Gini (since $\Delta\mu > 0$ and the term in parenthesis is negative). When, however, a policy is considered—such as here—which has only a marginal impact upon the society-wide mean outcome (alternatively, it does not directly affect the "efficiency" of the economy) but can have distributional effects, then the implication for welfare is quite clear: welfare is increasing whenever inequality (dispersion) is decreasing (easily seen since, in this case, $\Delta W = \mu (G_1 - G_2)$).

In the present case, marginal increases in existing electricity taxes do not (arguably) substantially alter the level of the outcome of interest (net household income) on average across the population (alternatively, these changes are "small" and may be ignored), and thus, one can focus attention exclusively on changes in distributional aspects, represented here by the Gini coefficient. [10] This approach is elaborated in Yitzhaki (2001), and illustrated for a few applications in Yitzhaki and Wodon (2002, §2.5), and the reader is directed to these sources for details regarding important implications of this framework.[11]

An important caveat with the two approaches to welfare comparison outlined here is that with only one source of energy, electricity, considered here, estimated welfare effects are likely larger than actual (see Stoker (1986) for a detailed discussion of this point). This over-estimation results from ruling out substitution across sources of energy, and is an inherent limitation of using only one source of energy in demand analysis when in reality many sources are used. As a result, computations of net income using only expenditure on electricity can understate the true dispersion in net consumption possibilities.[12] However, given that policy makers are likely interested in perceived changes in

[10]We note that the two inequality measures used in this study, the Gini coefficient and the Atkinson index (defined in section 6.1), both yield a formal welfare interpretation, based upon a welfare function such as that in eq. (1). For brevity, and since the Atkinson index has not been used in this context in the applied literature, we only elaborate on the welfare framework using the Gini coefficient and direct the reader to Creedy (2014, §4) for an analogous treatment of welfare using the Atkinson index.

[11]In the interest of completeness, we mention the major implications here. The social welfare function represented in eq. (1) does not admit a representation as a additive, utilitarian social welfare function i.e. it cannot be derived from individual utility functions as an additive representation, the most common representation of social welfare functions. Nonetheless, it enjoys certain advantages, including an ability to completely rank all possible distributions of the outcomes of alternative policies and respects all commonly used postulates of welfare functions. In addition, this form of the welfare function can also be interpreted as reflecting preferences of individuals/households whose utility is derived from relative comparisons (reflecting the theory of relative deprivation) i.e. individual/household welfare is derived from comparing their consumption (income) to those of others. Finally, note that while other (bounded) inequality indices can be used instead of the Gini in eq. (1), use of the Gini provides certain advantages.

[12]To understand this aspect, consider two households which are identical except for the fact that one has access to an alternative heating source (e.g. gas) while the other does not. In case of an increase in price of electricity, it is very likely

welfare as a result of taxes on electricity (which relate directly to electricity expenditure), and since a major part of the sample does not have access to alternative sources of energy for space heating, it is evident that the use of income net of electricity expenditure as the measure of net consumption is appropriate, provided the resultant dispersion, and reduction in social welfare, is seen as an upper bound on the actual reduction in welfare.[13]

4 Data

Data for the analysis was drawn from the OECD's project on *Greening Household Behaviour*, as part of which a periodic survey on EPIC, covering a number of countries and areas, is carried out. The second survey was conducted in 2011 and included 11 countries: Australia, Canada, Chile, France, Israel, South Korea, Japan, the Netherlands, Spain, Sweden and Switzerland. We provide a very brief description of the survey and refer to sections 3.1 and 3.2 of Krishnamurthy and Kriström (2015a) for details on the data and summary statistics, and to Annexes A and B of OECD (2014) for survey questions and methodological details respectively.

About 1000 individuals in each country were surveyed using an internet-based questionnaire, for a total sample size of $12,200$ households. The questionnaire collected information regarding household behaviours in five distinct areas (apart from household characteristics and environmental attitudes): residential energy use, waste generation and recycling, food consumption, personal transport, and water consumption. The present analysis uses data from the energy section.We note that individuals were requested to provide data on their electricity bill (annual) and quantity consumed in kWh (annual). Very few individuals provided billing data, and of those, a few provided quantity data, allowing computation of the average price. As a result, the final sample size, of about 1400, is a fraction of the usable responses of approximately $11,000$ households. It is important to point out that there is no marginal price data provided in the survey; as a result, average prices are derived based upon expenditure (in euro) and consumption (in kWh), as already mentioned.

that for the household with access to gas, expenditure on electricity will fall for two reasons, own price effect as well as a substitution towards gas, while expenditure on gas will correspondingly rise. Excluding expenditure on gas in computing net income, therefore, will evidently overstate consumption possibilities for this household, and bias the dispersion measure in an unknown direction. Since a sizeable part of the sample has access to alternative sources of energy for space heating, exclusion of expenditure on these is likely to affect the magnitude and direction of computed welfare change.

[13]Evidently, this interpretation as an upper bound is only valid as a first approximation, since there are essentially two opposing effects. On the one hand, consideration of alternative goods, e.g. gas, will strengthen the upper bound interpretation offered here. On the other, however, there is an arguable second-order effect on all relative prices in the economy that can amplify the reduction in welfare resulting from a tax. Depending upon which of these effects is stronger, the full effect will be higher or lower than that estimated here.

5 Demand Estimation

5.1 Empirical Framework

Our empirical analysis is based upon the demand estimation framework used in Krishnamurthy and Kriström (2015a). We provide here a brief description of the regression framework and direct the readers to that study for further details, including on computation of standard errors. Denoting by E_j, Q_j the (annual) expenditure (euro) and consumption (kWh) of the j^{th} household, with (annual) income I_j (euro), facing an average electric price of P_j (euro), the demand function (in kWh) can be written for the quadratic-in-prices-and-income, heuristically referred to as the "trans log", functional form, as:

$$\log(Q_{i,j}) = \alpha_i + \Gamma X_{i,j} + \beta_0 \ln(I_{i,j}) + \gamma_0 \ln(P_{i,j}) + \beta_1 \left(\ln(I_{i,j})^2\right) + \gamma_1 \left(\ln(P_{i,j})^2\right) + \delta\left(\ln(P_{i,j}) \times \ln(I_{i,j})\right) + \eta_{i,j}. \quad (2)$$

$X_{i,j}$ is a matrix of covariates (excluding price and income) that influence electricity consumption and includes key variables such as home size, number of individuals living in the home, socio-economic characteristics of the respondent (age, gender, location, number of appliances owned), and characteristics of the home (indicator variables for location of home, electric heating/cooling, home ownership and the number of energy efficient appliances). α_i refers to the country-specific fixed effect, for country $i = 1, 2, \ldots 11$, whose inclusion is intended to account for the effect of factors varying at the country level (e.g. energy and climate policies). Country indices are henceforth suppressed in the interest of notational simplicity, and also since our analysis is at the aggregate, rather than at the country, level (unlike in Krishnamurthy and Kriström (2015a))

For the translog functional form in eq. (2), price and income elasticities, denoted ε_j^P and ε_j^I respectively, are: $\varepsilon_j^P = \gamma_0 + 2\gamma_1 \ln(P_j) + \delta \ln(I_j)$ and $\varepsilon_j^I = \beta_0 + 2\beta_1 \ln(I_j) + \delta \ln(P_j)$. The key point regarding eq. (2) is that the demand function, and therefore elasticity, differs for each household but not (systematically) over any specific group. This is what we term below the "base specification" for which we report mean elasticities (table 2 in section 5.2). More precisely, what we report for the base specification are[14]:

$$\overline{\varepsilon^P} = \frac{\sum_{j=1}^{N} (\gamma_0 + 2\gamma_1 \ln P_j + \delta \ln I_j)}{N} = \frac{\sum_{j=1}^{N} \varepsilon_j{}^P}{N}$$

and

$$\overline{\varepsilon^I} = \frac{\sum_{j=1}^{N} (\beta_0 + 2\beta_1 \mathrm{lnI}_j + \delta \mathrm{lnP}_j)}{N} = \frac{\sum_{j=1}^{N} \varepsilon_j{}^I}{N}.$$

However, interest in our analysis centres on whether, and how much, the average elasticity varies across households with specific characteristics. To address this question, we use the strategy of allowing *all* coefficients in eq. (2) to differ across these characteristics. In essence, we postulate that the demand function for a household is systematically different across certain household characteristics. For instance, if the characteristic of interest is home ownership—with two categories, owners and renters—, we assume in our estimation that the demand function in eq. (2) differs between home owners and renters. Thus, it is evident that ε_j^P and ε_j^I (and therefore, $\overline{\varepsilon^P}$ and $\overline{\varepsilon^I}$) are now distinct for home owners and renters, where j is now the individual household in respective category.[15] Thus, we obtain as many values for $\overline{\varepsilon^P}$ and $\overline{\varepsilon^I}$ as there are categories of the variable along whose dimension we assume they differ, and these are the values reported in table 2. In the case of home ownership, owners and renters have distinct values of price and income elasticity.

The key characteristics across which we wish to estimate differences in elasticity are: income terciles, home ownership (owner and renter), electrically heated/cooled homes (versus not) and location of household (cities, suburbs and small towns/isolated regions).[16] Essentially, the base specification (row labelled "base" in table 2) assumes that all the characteristics above (except income terciles) result in a shift of the demand function intercept for households in that category. The other regressions differ from the base in that households in each category are assumed to have a demand function with

[14]Note that the measure of average elasticity reported here is not the same as that in Krishnamurthy and Kriström (2015a), wherein country-specific price elasticity and aggregate income elasticity are reported. However, the overall elasticity reported there (Table 4, p.80), being an aggregate across the sample, is identical to the price elasticity reported here for the base specification in table 2. The income elasticity in Krishnamurthy and Kriström (2015a) for the trans log specification (not reported in the tables there), being an average across the sample, is very similar to the one here .

[15]To be more formal, let N_O and N_R denote the sample sizes for owners and renters; then estimated price elasticity for each category can be written as $\varepsilon^P_{j_O}$ and $\varepsilon^P_{j_R}$, with $j_O = 1,2,....,N_O$ and $j_R = 1,2,....,N_R$. Continuing along similar lines, the average (across category) price elasticities therefore are $\overline{\varepsilon_O{}^P} = \frac{\sum_{j=1}^{N_O} \varepsilon_j{}^P}{N_O}$ and $\overline{\varepsilon_R{}^P} = \frac{\sum_{j=1}^{N_R} \varepsilon_j{}^P}{N_R}$ where "O" and "R" indicate Owner and Renter respectively. Income elasticities are computed similarly.

[16]Household location is ascertained from the response to a question (Q.18, OECD (2014, Annex A)) asking the respondents "How would you describe best the area in which you live", with choices "Major town/city", "Suburban (fringes of a major town/city)", "small town or village" and "Isolated dwelling". Similarly, information regarding whether households owned the home they lived in and whether the major space heating source was electricity was elicited using explicit questions in the survey (Q.16 and Q.67 respectively of OECD (2014, Annex A)).

differing parameters obtained by estimating the regression in eq. (2) separately for each category.

Before proceeding to the results of the demand estimation detailed here, we remark on a few features of the estimation framework. Krishnamurthy and Kriström (2015a) estimate country-specific price and aggregate income elasticity using two functional forms, the double log and the trans log, and find that while the double log function yields slightly higher price elasticity, both functional forms provide elasticity estimates which are quantitatively very similar. As noted there, the trans log functional form is more appealing due to its better theoretical properties; in addition, for the EPIC 2011 data set, they also found that statistical tests indicated that the trans log–nesting the double log–was the preferred functional form. These factors motivate the choice of trans log functional form for the analysis here.

In addition, unlike in Krishnamurthy and Kriström (2015a), who provide country-specific elasticities, we do not analyse the distributional implications over country and attribute. While important policies which affect the analysis (e.g. tax and housing) vary at the country level, and country-specific distributional analyses are of much interest, the very small country-specific sample sizes (varying from 85 for Australia to 213 for Sweden) precludes the possibility of carrying out our analyses at the country-level. Presumably, data from future rounds of the EPIC survey (the next round is scheduled to commence early this year) can be used to extend the analysis carried out here to the country-level.

5.2 Demand Elasticities

We present, in table 2, mean price and income elasticity across different categories considered (along with sample sizes for each category), estimated using the framework detailed above.[17] Note that the full regression results are reported in table A.1 in Appendix A and all regressions passed a goodness-of-fit test, similar to that used (and discussed) in Krishnamurthy and Kriström (2015a); we do not report these results here. Turning to the elasticities, the (absolute value of the) average price elasticity in the "base specification", at 0.68, is very high when compared to current estimates in the literature, which are generally lower than 0.4 (see Krishnamurthy and Kriström (2015a) for a discussion of specific ranges for price and income elasticities), while the (average) income elasticity, at 0.048, is insignificant. Turning now to the category-specific price and income elasticity, we note that—except for electric space heating/cooling and income terciles—a priori we have no particular

[17] All regressions were estimated, and welfare computations were carried out, using the stata 12™ package. The stata code and the data set used are available from the author upon request, subject to OECD data release policies, for purposes of replication.

Table 2: Price and Income elasticity by category.

	Price elasticity	**Income Elasticity**	**N**
base	-0.685	0.048	1420
Income terciles			
I Tercile	-0.685	0.030	420
II Tercile	-0.740	**0.770**	469
III Tercile	-0.641	0.375	531
Home Ownership			
Renter	-0.753	0.125	344
Owner	-0.708	0.001	1076
Location			
City	-0.656	0.039	514
Suburb	-0.648	0.118	319
Town	-0.980	0.106	518
Isolated	-0.830	0.400	74
Electric heating/cooling			
Others	-0.962	0.108	629
El_Heat	-0.524	0.017	791

Notes: Average (over category sample size) price and income elasticity; see text for category definitions. All price elasticities, and income elasticities in **bold**, are significant at the 1% level. Each row represents a particular categorisation of the data, and demand elasticity for each row is computed using a separate regression. All regressions included country-specific fixed effects and accounted for sampling weights.

expectation regarding the differences across household categories/types; there is also little analysis of differences in elasticities along these dimensions in the literature. As regards electric heating, it is plausible that households which do not have electric heating/cooling are likely to have greater freedom in reducing consumption. The relationship between price elasticity and income is more involved. Empirically, evidence appears ambiguous; as reported in a survey of the few available empirical studies in Kriström (2006, §3.2), there is scattered evidence for price elasticities to both increase and decrease with income for different goods (e.g. food consumption and petrol), as well as for only very small differences across income. Overall, there does not appear to be robust empirical evidence for a relationship in any direction between price elasticity and income.

The only study to our knowledge that estimated household-specific price and income elasticity for electricity, Reiss and White (2005), provides some evidence to the effect that lower income households have higher price elasticity. Our findings are somewhat similar; we report higher price elasticity for households in the first two terciles than in the highest (at 0.64) and the differences, while non-trivial, are not very large. Income elasticity, on the other hand, varies widely, from almost 0 for households in the first tercile to a very high 0.7 for those in the second and about half as large, yet substantial, 0.375 for those in the third. Income elasticity of households in the last two terciles is very much higher than typically reported in the literature, with the caveat that the only significant elasticity is for households in the second tercile. Overall, we find households in second tercile having the highest price and income elasticity.

While we do not find any difference in price elasticity between home owners and renters, we do however find substantial differences in income elasticity between the two groups, with renters' elasticity, at 0.125, two orders of magnitude larger than that of the owners' (at 0.001). Such a large, albeit statistically insignificant, difference is likely a reflection of the correspondingly large difference in income between the two groups, as well as the substantial differences in sample size (owners tend to be over-sampled in such surveys, relative to renters).[18] Turning next to differences in households depending upon their location, we note that households located in towns are very highly price-elastic, with a unitary elasticity, while those in the cities have the lowest elasticity, at 0.65 (which is nonetheless very high, when compared to the existing literature). This essentially reflects consumption patterns, with city-residents having the lowest total consumption and a similar number of appliances to the other categories (data not reported). Income elasticities, while not significant, vary across household locations, with households in isolated dwellings and villages having the largest elasticity, at 0.4, a pattern which follows the income distribution, with this category reporting the smallest income (not reported). Finally, non-electrically heated households are, as anticipated, highly price-elastic, with a almost unitary price elasticity, close to double that of households with electric heating. Non-electrically heated households also have a substantially higher income elasticity than those with electric heating, at 0.1, albeit not significant.

Overall, we note that households in our analysis are highly price-elastic, with elasticity varying in a wide range across different household categories. More importantly, from a welfare perspective, elasticity estimates as high as those obtained here provide indications that moderate price (tax) increases are unlikely to lead to sizeable increases in expenditure. Indeed, for many households in certain categories (e.g. non-electrically heated homes), depending upon other covariates, there are likely to be reductions in expenditure consequent to certain price (tax) increases. This aspect of our analysis is in contrast with many existing studies on energy taxes which implicitly assume low (or no) price elasticity; see, for instance, the discussion in Callan et al. (2009, §2) and Kriström (2006, §3.2.2).

[18] Krishnamurthy and Kriström (2015b) explore the OECD EPIC 2011 data along with ownership dimension in order to analyse the energy efficiency incentives; see this study for data summaries along the owner and renter dimensions.

6 Distributional Implications of tax scenarios

6.1 Computational Details

We next elaborate on the framework used for computing expenditure changes and subsequently detail the measures of dispersion used. For household j facing a price P_j, let $t_j = \Delta P_j$ denote the proportional tax on electricity; thus, the “new price” of electricity is $P_j + \Delta P_j$. Given that we are ultimately interested in computing the post-tax expenditure on electricity, the first step is to compute the change in consumption resulting from this change in price. Using the standard expression for the relationship between elasticity and marginal effects leads to the following expression for change in quantity: $\Delta Q_j \cong \left(\widehat{\frac{\partial Q_j}{\partial P_j}}\right)\Delta P_j$. Thus, post-tax consumption can be written as $\widehat{Q}_{new,j} = Q_j + \Delta Q_j$, from which post-tax expenditure is easily seen to be

$$\widehat{E}_{new,j} = \widehat{Q}_{new,j}\,(P_j + \Delta P_j)\,. \tag{3}$$

For the base scenario, wherein elasticities are not allowed to systematically differ across any household category, given a change in price, ΔP_j, it is straight forward to compute the new consumption and expenditure for all households using the expression in eq. (3), obtaining the vector $\widehat{E}_{new} = \left[\widehat{E}_{new,1}, \widehat{E}_{new,2}, \ldots, \widehat{E}_{new,N}\right]$ where $1,2,\ldots,N$ evidently are households. The procedure to compute $\widehat{E}_{new}$ when elasticities are allowed to differ across categories is best understood with an example. Consider the case when elasticities are allowed to differ across households based on their income i.e. eq. (2) is estimated separately for households belonging to each income tercile. Subsequently, $\widehat{E}_{new,j}$ is computed for each household in a given tercile, obtaining $\widehat{E}^k_{new} = \left[\widehat{E}^k_{new,1}, \widehat{E}^k_{new,2}, \ldots, \widehat{E}^k_{new,N_k}\right]$ where $k = I, II, III$ refers to the tercile and N_k is the number of households in the k^{th} tercile. These computations are repeated for each tercile and a vector for $\widehat{E}_{new} = \left[\widehat{E}^I_{new}, \widehat{E}^{II}_{new}, \widehat{E}^{III}_{new}\right]$ obtained.

Our measure of the “effect” of a given tax scenario is the change in dispersion of net income before and after the tax. Denote, for each categorisation, C, of the sample, by G_C the corresponding dispersion measure computed using derived net income $\tilde{I}_j = I_j - E_j$. Thus, we obtain $G_C\left(\tilde{I}, \widehat{\tilde{I}}^C_{new}\right)$ where $\widehat{\tilde{I}}^C_{new}$ corresponds to the computed net income for a given price change when elasticities are assumed to differ across categorisation C. In the case of our example using the income tercile categorisation, $\widehat{\tilde{I}}^C_{new} = \left[\widehat{\tilde{I}}^I_{new}, \widehat{\tilde{I}}^{II}_{new}, \widehat{\tilde{I}}^{III}_{new}\right]$. We report dispersion using two measures: the Gini coefficient and the Atkinson index, whose definition we take up next.

We only provide brief details regarding the Atkinson index, and direct the reader to Lambert

(2001) for further details on the Gini coefficient (and the Atkinson index). Using notation from before, the Atkinson index is computed as

$$A(\varepsilon) = \begin{cases} 1 - \frac{1}{\bar{\tilde{I}}} \left\{ \frac{1}{N} \sum_{j=1}^{N} \tilde{I}_j^{1-\varepsilon} \right\}, & \varepsilon \neq 1 \\ 1 - \frac{1}{\bar{\tilde{I}}} \left(\prod_{j=1}^{N} \tilde{I}_j \right)^{\frac{1}{N}}, & \varepsilon = 1 \end{cases},$$

with $\bar{\tilde{I}} = \frac{\sum_{j=1}^{N} \tilde{I}_j}{N}$ the sample mean. The Atkinson Index is bounded (between 0 for perfectly equal and 1 for completely unequal distribution) and easily interpretable. Indeed, it is derived from a welfare representation, and therefore, as already referred to in footnote 10, has a direct welfare interpretation. We note that the choice of the parameter ε indicates the degree to which the analyst is 'inequality averse', with higher values indicative of increasing inequality aversion. Following convention in the applied literature, we report values of the Atkinson index for two reasonable values of ε, 0.5 and 1, indicating only moderate aversion to inequality. The third measure we use, the Gini coefficient, is commonly used to measure income inequality, and varies between 0 and 1.

We can summarise our procedure for computing the measures of dispersion as follows: first, we compute the dispersion of the pre- and post-price-increase net income and second, we compute the change in the inequality measure, expressed as a percentage.

6.2 Assessment of the Distributional implications

We turn next to discussing the distributional implications of two electricity tax scenarios, 2% and 5%. Choice of the tax increases are motivated by the exploratory spirit already alluded to, as well as by the limitations of the framework–in that only moderate tax changes are likely plausible.[19] Before we do so, however, we briefly turn to understanding how predicted expenditure–the key driver of our analysis–varies across the different categorizations chosen. These are presented as a figure, fig. 1, for the 5% scenario, a few features of which are worth commenting upon.[20] First, compared to the raw data, there are more extreme values in the computed expenditure.[21] In addition, there is no

[19] We note that alternative scenarios, in particular 1% and 10% tax increases, yielded results qualitatively identical and quantitatively very similar to those considered here.

[20] Similar patterns are discerned in the 2% tax increase scenario, the figure for which is not presented for brevity.

[21] Note that negative predicted values of expenditure, along with outlier data points, have been omitted from fig. 1 for all categorisations to assist in visualisation; the figure with outliers included is provided in Appendix A. Given that there have

Table 3: Welfare effects of electricity taxation.

	Gini	A(0.5)	A(1)	Gini	A(0.5)	A(1)	
	Changes from raw data			*raw values*			
Base	0.143	0.217	0.131	0.331	0.092	0.191	2% tax increase
Income terciles	0.147	0.237	0.163	0.331	0.092	0.191	
Ownership	0.149	0.221	0.130	0.331	0.092	0.191	
Location	0.143	0.232	0.166	0.331	0.092	0.190	
El. space heating	0.143	0.198	0.105	0.332	0.093	0.192	
Base	-0.019	-0.143	-0.264	0.332	0.092	0.191	5% tax increase
Income terciles	-0.048	-0.147	-0.221	0.331	0.092	0.191	
Ownership	-0.044	-0.186	-0.303	0.331	0.092	0.191	
Location	0.003	-0.066	-0.140	0.331	0.092	0.190	
El. space heating	0.007	-0.081	-0.194	0.332	0.093	0.191	

Notes: Columns under "Changes from raw data" provide percentage change in dispersion of net income following specified tax increases (indicated in the final column). Positive sign on an entry indicates increase in inequality (welfare reduction). "A(0.5)", "A(1)" are respectively the Atkinson index with $\varepsilon = 0.5$ and $\varepsilon = 1$. Columns under "raw values" refer to the (respective) inequality indices computed using the raw data.

Table 4: Expenditure Share changes resulting from electricity taxation.

		2% increase	5% increase	Raw Share
Base		4.859	-4.655	2.850
Terciles	T1	**12.031**	2.641	4.731
	T2	-0.706	-11.615	2.676
	T3	-1.182	-9.789	1.628
Ownership	Renter	**16.507**	7.096	2.573
	Owner	0.483	-10.153	2.971
Location	City	**22.333**	15.315	2.264
	Suburb	-3.140	-11.576	2.862
	Town	-5.060	-20.474	3.418
	Isolated	-7.961	-18.946	3.823
El. space heating	Other	5.544	-9.051	2.268
	El. heated	**5.900**	-0.891	3.154

Notes: Entries in columns labelled "2% increase" and "5% increase" refer to percentage change in income share of expenditure on electricity, pre- and post-tax, for specified tax increases. Positive sign on an entry indicates increased expenditure share following a tax increase. Entries under the column labelled "Raw share" refer to the income share of original electricity expenditure, in %. Entries in **bold** are statistically significant, based on a (one-sided) test of proportions.

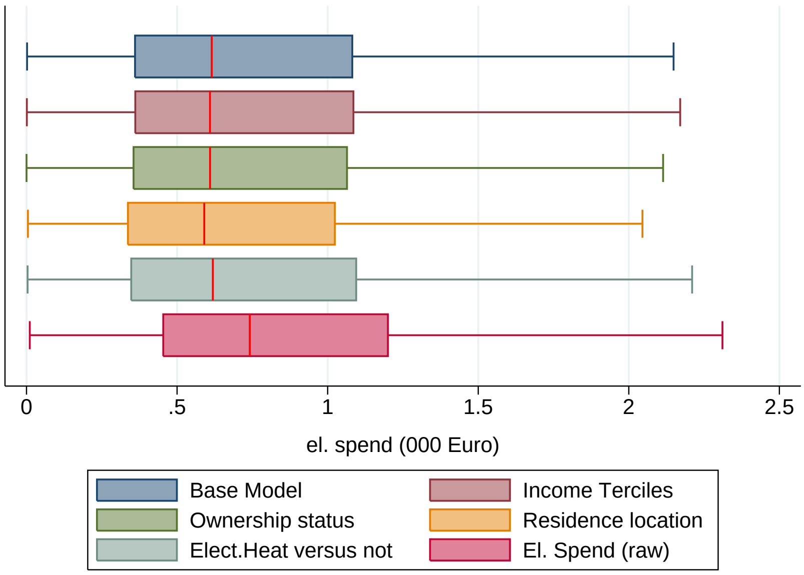

Figure 1: Computed versus raw expenditure for different categories.

significant difference in fit across the different categorisations over which elasticities are computed (since no one figure has a substantially different pattern of outliers from the others—see also fig. 2). The second point worth mentioning is the substantial dispersion in expenditure in the raw (survey) data, with a few obvious outliers. For our analysis, we have attempted no particular data cleaning exercises, and do not anticipate any changes should reasonable ways of addressing them be used.[22] Overall, we note that the computed expenditure, across different dimensions along which demand is postulated to differ, are similar to one another—in broad pattern—and quite plausible.

We turn now to the focal point of our analysis, understanding changes in the dispersion of net income given a tax increase. Given our definitions, increase in dispersion is indicated by a positive sign and is welfare reducing. We detail the distributional effects of the two hypothetical tax increases already indicated in table 3. The entries in table 3 correspond to changes in dispersion after tax (relative to before tax), the rows correspond to a particular categorisation and the columns to measures of inequality. For instance, for the "base scenario"—with demand functions estimated for the whole sample—applying a price change of 2% leads to an increase in dispersion by 0.14%, 0.21% and 0.13% as measured (respectively) by the Gini coefficient and the Atkinson index with $\varepsilon = 0.5$ and $\varepsilon = 1$.

been no restrictions imposed on the estimation framework, negative predicted values are not unexpected, irrespective of the quality of fit. Negative predicted values are few in number for all characterisations and do not exhibit any particular pattern across the different characterisation of our data.

[22] Krishnamurthy and Kriström (2015a) show that price elasticities obtained when winsorsing the data—both income and expenditure–are very similar, and are only marginally lower.

Two points are evident from table 3. First, allowing heterogeneity of demand across a variety of dimensions (income terciles, home ownership status, location and heating source) does not lead to sizeable differences in changes in dispersion (since changes across these categorisations are very similar to those in the base), irrespective of the measure of dispersion used and for both tax increases considered (changes for the 5% increase scenario are only very moderately higher, and indistinguishable from a practical perspective). Second, both inequality indices provide similar direction and magnitudes of effect. In more detail, for the 2% tax increase scenario, there is a very low increase in inequality, in all cases below 1%. With the 5% tax increase scenario, there is an even smaller reduction in inequality in net income.[23]

In order to evaluate whether welfare effects are significantly altered when using more intuitive and commonly applied measures, we turn next to comparing changes in the expenditure share of income as a result of the tax. The use of shares is well established in economics, with the interpretation that increases in shares for poorer households are, in a heuristic sense, welfare reducing. The computation of changes in expenditure share are presented in table 4. As also remarked in Sterner (2012), it is important to emphasize that unlike the use of summary inequality indices, changes in shares do not have a direct welfare interpretation and, in addition, are also likely to yield ambiguous results (e.g. some terciles' share increases while other's decrease, as also true in our case). They are presented here only to fully explore potential household dimensions along which changes are likely substantial. This approach also provides information additional to that yielded by the summary welfare measures.

We note that shares in the "base" specification increase by a relatively modest (and statistically insignificant) 4.9%, from 2.8%, and *fall* by a similar (and statistically insignificant) magnitude (4.7%), for the 2% and 5% tax scenarios respectively. Given that reduction in expenditure for certain price increases have already been indicated as quite likely (section 5.2), it is not surprising that large tax increases result in reduced expenditure share. Turning next to the effect of allowing for demand heterogeneity, we observe that households in the I income tercile experience statistically significant increase of 12%, fully three times the base effect, while the other two terciles experience insignificant changes. Similarly, households which rent their home, live in a city and use electric space heating experience relatively large changes in shares, of 16.5%, 22.3% and 5.9% (the first two from a smaller base). With a 5% tax, however, no statistically significant changes in shares are observed,

[23]We observe that while the high price elasticity already indicates that expenditure increases resulting from a moderate increase in price are low (and in many cases there are expenditure reductions, depending upon other covariates), the direction of the change in *dispersion* of net income is not a priori obvious. In other words, high price elasticity does not a priori indicate the direction of change in dispersion of net income pre- and post-tax.

although the four categories with significant changes in the 2% tax scenario nonetheless have higher increase in shares.

These increases in shares however are from a rather low base, of 2.8% aggregate; indeed, except for the case of households in the I income tercile and electrically heated households, with shares (the highest of all categories analysed) of 4.7% and (relatively higher) 3.1% respectively, the other two household categories experiencing significant increases, households renting their homes and those living in cities, have lower shares than relevant sub-category of households. Overall, two of the household categories experiencing sizeable increases (rented homes and homes located in cities) are those with a smaller-than-relevant-sub-category levels of share, while of the remaining two categories experiencing increases, electrically heated households and those in the I income tercile, households in the former have higher income than non-electrically heated ones.

To summarise, for the two tax scenarios considered, little evidence for increase in inequality in net income was found, a result which is unchanged when allowing for demand heterogeneity across household types. When considering expenditure share changes, the key household dimension across which increases in shares appear to warrant welfare concerns is income terciles, with an increase in share for households in the I tercile. Overall, the distributional implications of the considered tax scenarios are moderate. Further, these results are unaltered when factors which affect demand estimation and welfare interpretation, such as the inclusion of countries with non-linear marginal pricing, are accounted for.[24]

It is instructive to compare the results obtained here with those from the study most directly related, Halvorsen and Nesbakken (2002), providing a context to interpret the results obtained here. This study analyses the effects of five different electricity tax schemes across three income groups, and has already been briefly discussed in section 2. Overall, it reports (Table 4, p.12) very small welfare reduction (0.18 percentage points being the largest) with the proportional tax and modest increase in welfare for all progressive tax schemes (0.19 percentage points being the largest). In addition, and similar to our results, welfare changes are very little altered when heterogeneity in household price response is accounted for.

[24] The distributional implications when the sample is restricted to only countries with constant (independent of quantity) marginal price are presented in table A.3 and table A.4 in Appendix A. From table A.3, it is evident that for the 2% tax increase scenario, increases in inequality are of similar magnitude as for the full sample, with only minor variations. For the 5% tax increase scenario, the pattern of results–even lower changes in inequality–are identical with the full sample, the only change being the direction, with very low increases, instead of very low reduction, in inequality. The results in table A.4 indicate that households in only two of the previous four dimensions–I tercile and in the city–experience significant increases in expenditure share for the 2% tax scenario; for the 5% scenario, as with the full sample, share changes are smaller and insignificant.

7 Conclusions and Discussion

This paper presents the welfare implications of increases in electricity prices, couched in the form of proportional tax increases, across differing household types. The characteristics across which households are allowed to differ include, in addition to income terciles, home owning status, location, and use of electricity as primary space heating/cooling energy source. Contrary to a priori perceptions, tax increases of 2 and 5% lead only to moderate welfare reductions, irrespective of whether household heterogeneity in demand behaviour is allowed for, and the only households likely to experience economically significant increases in expenditure shares are those in the I income tercile. The data used are from a 2011 survey of households in eleven OECD countries. This is, to our knowledge, among a very few studies to provide distributional implications of electricity taxation, despite the prevalence of such taxation in many countries, and the first study to do so using demand estimates from a wide cross-section of countries.

We emphasize that, while suffering from a few drawbacks (detailed in section 3.1 and section 3.2), the main advantage of the framework used here is a relatively rapid and straightforward evaluation of the potential adverse distributional impact of (for instance) different climate policy measures. Many alternative methods of evaluating the distributional (typically income distribution) implications of climate change policies exist, as has already been discussed in section 2 and section 3.1. However, for a relatively rapid empirical evaluation in a multi-country context, they suffer from data-related drawbacks i.e. detailed data on tax receipts (e.g. Sterner (2012)), alternative energy sources (for demand system estimation e.g. Brännlund and Nordström (2004)) or the entire tax structure (e.g. Hassett et al. (2011)) etc. are required.

Studies addressing heterogeneity of households and household response to price changes are being increasingly undertaken by environmental economists, with a firm focus on equity aspects of environmental and energy policies. Our analysis is one among many in the recent past focused on evaluating the distributional implications of energy taxes. Our main result, of only a moderately regressive effect, is also consistent with that of some of the literature on carbon taxes cited in e.g., Callan et al. (2009), Kriström (2006), and with the study of Sterner (2012) on fuel taxes. Overall, these studies provide evidence to the effect that the distributional implications of energy taxes are relatively sensitive to the context but are, broadly, not very regressive.

We emphasise that our study is meant to be a broad first look at the distributional implications of electricity taxation over a range of countries. Detailed analyses at the country level, including a consideration of policies to mitigate the adverse distributional implications identified, will need richer data sets than those used here. They may, in addition, also need more appropriate frameworks, such as the combined micro-macro approach of Labandeira et al. (2009) mentioned in section 2, linking the supply side of the economy to the demand side analysed here. An investigation of these details is left for future work but in any case, partial equilibrium empirical analyses of the kind carried out here will help set a baseline for the more detailed studies.

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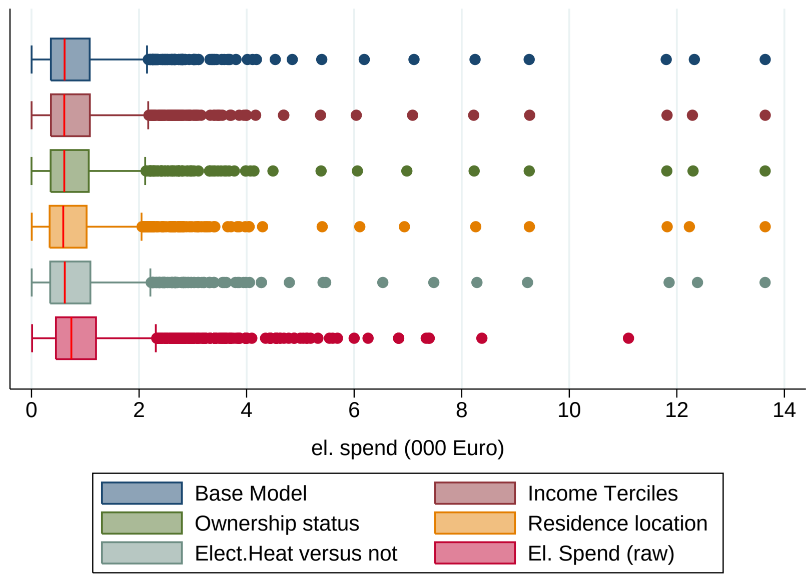

Figure 2: Computed versus raw expenditure for different categories (negative values removed).

Appendix A   Additional Tables and Figures

Table A.1: Full table of regression results.

		Income Terciles			Home Ownership		Residence Location				Electric Heat	
	Base	**I**	**II**	**III**	**Owner**	**Renter**	**City**	**Suburb**	**Town**	**Isolated**	**Yes**	**No**
log(income)	1.524	3.052	-18.15	15.67	-0.277	1.683	1.077	-0.628	1.345	-9.087	0.816	1.856
	(1.54)	(1.26)	(-0.29)	(1.19)	(-0.16)	(1.50)	(0.76)	(-0.37)	(0.85)	(-1.45)	(0.77)	(1.35)
log(price)	-1.870*	-1.182	-6.394	-4.086	-0.392	-2.284*	-2.166*	-0.531	-0.667	5.270	-1.587	-1.713*
	(-2.11)	(-0.86)	(-1.38)	(-0.94)	(-0.34)	(-2.13)	(-2.47)	(-0.27)	(-0.41)	(1.47)	(-1.54)	(-2.04)
$\log(\text{income}) \times \log(\text{price})$	0.0651	0.0112	0.491	0.266	-0.0663	0.0957	0.0917	-0.0463	-0.0119	-0.527	-0.00481	0.0766
	(0.78)	(0.08)	(1.09)	(0.67)	(-0.66)	(0.91)	(1.10)	(-0.25)	(-0.08)	(-1.66)	(-0.05)	(1.00)
$\log(\text{income})^2$	-0.0653	-0.157	0.953	-0.672	0.0140	-0.0718	-0.0427	0.0314	-0.0600	0.408	-0.0344	-0.0820
	(-1.36)	(-1.17)	(0.32)	(-1.16)	(0.17)	(-1.32)	(-0.62)	(0.36)	(-0.74)	(1.39)	(-0.62)	(-1.24)
$\log(\text{price})^2$	-0.137***	-0.106**	-0.142**	-0.139*	-0.0883*	-0.153***	-0.156***	-0.0991	0.0512	0.164	-0.183***	-0.107***
	(-4.85)	(-2.63)	(-3.20)	(-2.38)	(-2.11)	(-4.17)	(-4.66)	(-1.51)	(0.91)	(0.94)	(-5.96)	(-3.46)
Members in household	0.111***	0.119***	0.0910	0.132**	0.0386	0.147***	0.0747	0.170***	0.0861	0.0861	0.111***	0.110**
	(3.78)	(3.78)	(1.60)	(2.88)	(0.77)	(4.39)	(1.71)	(3.54)	(1.84)	(0.94)	(3.92)	(2.87)
Size of Residence	-0.000215	0.000610	0.00101	-0.00135	0.00270	-0.000821	-0.00127	-0.000683	0.00193*	-0.000188	0.00151*	-0.00116
	(-0.25)	(0.55)	(0.83)	(-1.18)	(1.66)	(-0.84)	(-0.66)	(-0.50)	(2.27)	(-0.11)	(2.06)	(-1.04)
Home Ownership (1=Owner)	-0.0370	0.0964	0.154	-0.289			-0.0496	0.0586	0.132	0.149	0.154	-0.161
	(-0.38)	(0.83)	(1.37)	(-1.47)			(-0.29)	(0.34)	(1.08)	(0.44)	(1.51)	(-1.26)
Home Type (1=Multi-dwelling)	-0.268*	-0.109	-0.123	-0.580*	-0.0422	-0.370*	-0.370	-0.336*	0.154	-0.758	-0.158	-0.338**
	(-2.50)	(-0.81)	(-1.20)	(-2.55)	(-0.32)	(-2.34)	(-1.85)	(-2.37)	(1.26)	(-1.22)	(-1.40)	(-2.72)
Urban Area (1=Urban)	-0.228**	-0.112	0.0124	-0.449***	-0.204*	-0.247*					-0.0294	-0.266*
	(-2.65)	(-1.18)	(0.12)	(-3.41)	(-2.16)	(-2.44)					(-0.39)	(-2.42)
Age of respondent	0.00773**	0.00383	0.00961**	0.00302	0.00707	0.0112**	0.00743	0.00873	0.00935*	0.00490	0.00850**	0.00843*
	(2.85)	(1.11)	(2.70)	(0.44)	(1.72)	(3.22)	(1.83)	(1.63)	(2.19)	(0.67)	(2.90)	(2.49)
Gender (1=Male)	0.0518	-0.0479	0.0188	0.176	0.0382	0.0322	0.150	-0.130	0.0744	-0.360	-0.158*	0.0978
	(0.79)	(-0.57)	(0.17)	(1.44)	(0.40)	(0.41)	(1.51)	(-1.14)	(0.74)	(-1.99)	(-2.14)	(1.12)
Years of Education	0.0126	-0.00893	0.0124	0.0100	-0.00500	0.0234	0.0201	0.00993	-0.0178	0.0742*	0.00364	0.0151
	(0.77)	(-0.54)	(0.40)	(0.35)	(-0.29)	(1.01)	(0.79)	(0.46)	(-0.66)	(2.07)	(0.25)	(0.76)
Member of Envt. Organization (1=Yes)	-0.121	-0.0465	0.109	-0.315	-0.0774	-0.186	-0.370	-0.0940	-0.0185	-0.372	0.0103	-0.251
	(-0.69)	(-0.34)	(1.01)	(-1.20)	(-0.50)	(-0.83)	(-1.18)	(-0.44)	(-0.18)	(-1.65)	(0.11)	(-1.04)
Energy Behaviour Index	-0.0330	-0.0821*	-0.0699***	-0.00163	-0.128***	-0.00127	-0.00939	-0.0433	-0.0862***	-0.0884	-0.0722***	-0.0310
	(-1.33)	(-2.52)	(-3.33)	(-0.04)	(-3.90)	(-0.05)	(-0.21)	(-1.28)	(-3.81)	(-1.44)	(-3.42)	(-1.06)
Energy Efficient Appliances (1=Yes)	-0.0370	-0.0445	-0.132	0.137	0.0344	-0.0590	-0.150	0.0312	0.0836	-0.264	-0.0309	0.0288
	(-0.56)	(-0.49)	(-1.21)	(1.14)	(0.34)	(-0.72)	(-1.58)	(0.26)	(0.73)	(-0.82)	(-0.39)	(0.33)
Number of Appliances	0.0175*	0.00898	0.0176	0.0177	0.0114	0.0206*	0.0268*	-0.0123	0.0207**	0.0468*	0.000672	0.0235**
	(2.32)	(0.95)	(1.96)	(1.41)	(0.98)	(2.46)	(2.04)	(-0.90)	(3.27)	(2.09)	(0.07)	(2.80)
Electric Space Heating (1=Yes)	0.279***	0.482***	0.186*	0.200	0.382***	0.245***	0.119	0.264*	0.427***	-0.0725		
	(4.34)	(5.18)	(2.12)	(1.58)	(3.36)	(3.52)	(1.28)	(2.31)	(4.40)	(-0.28)		
Observations	1420	420	469	531	344	1076	513	318	517	72	629	791

Notes: Each Column represents a regression, and regressions sharing similar characteristics are grouped together; for instance, "Terciles I, II and III" represent regressions carried out, separately, for Income terciles I, II and III. All indicator variables used as characteristics across which individuals are allowed to differ (Ownership, Residence location and Electric space heating/cooling) appear in the base regression as well as in regressions which are not specific to that category. In particular, this implies that regressions carried out separately by category (e.g. Ownership) do not have an indicator for that particular category (e.g. ownership). The variable "Education" refers to years of post-secondary education. All regressions include country fixed-effects and account for complex sampling design. Standard error computation is described in the text.

	Price elasticity	Income Elasticity	N
base	-0.875	0.081	1000
Income terciles			
I Tercile	-0.882	0.061	310
II Tercile	-0.790	0.147	339
III Tercile	-0.937	-0.084	351
Home Ownership			
Renter	-1.135	-0.191	214
Owner	-0.827	0.128	786
Location			
City	-0.958	0.084	333
Suburb	-0.625	0.141	188
Town	-0.946	0.084	434
Isolated	-1.163	0.402	65
Electric heating/cooling			
Others	-1.009	0.082	551
El_Heat	-0.703	0.044	449

Notes: Same as table 2 but for a sample excluding households in the following countries: Australia, Israel, Japan and South Korea.

Table A.2: Price and Income elasticity by category.

Table A.3: Welfare effects of electricity price increase.

	Gini	A(0.5)	A(1)	Gini	A(0.5)	A(1)	
	Changes from raw data			*raw values*			
Base	0.224	0.508	0.501	0.329	0.093	0.196	2% tax
Income terciles	0.243	0.539	0.534	0.330	0.093	0.196	2% tax
Ownership	0.214	0.491	0.488	0.329	0.093	0.196	2% tax
Location	0.204	0.476	0.469	0.330	0.093	0.196	2% tax
El. space heating	0.228	0.517	0.511	0.330	0.093	0.196	2% tax
Base	0.061	0.254	0.310	0.328	0.092	0.194	5% tax
Income terciles	0.114	0.343	0.402	0.327	0.092	0.193	5% tax
Ownership	0.037	0.213	0.279	0.328	0.092	0.194	5% tax
Location	0.100	0.331	0.400	0.328	0.092	0.194	5% tax
El. space heating	0.072	0.275	0.331	0.328	0.092	0.194	5% tax

Notes: Same as table 3 but for a sample excluding households in the following countries: Australia, Israel, Japan and South Korea.

Table A.4: Expenditure Changes resulting from electricity price increase.

		2% increase	**5% increase**	**Raw Share**
Base		7.517	-5.685	3.105
Terciles	T1	**17.750**	6.752	4.458
	T2	-2.315	-16.137	2.703
	T3	-6.439	-25.355	1.839
Ownership	Renter	24.083	7.385	3.181
	Owner	3.113	-9.439	3.083
Location	City	**25.533**	15.844	2.877
	Suburb	-2.186	-8.683	2.883
	Town	-1.933	-19.020	3.221
	Isolated	-12.377	-26.671	4.254
El. space heating	Other	7.711	-7.468	2.362
	El. heated	8.633	-1.820	3.796

Notes: Same as table 4 but for a sample excluding households in the following countries: Australia, Israel, Japan and South Korea.