ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

ESRI Working Paper No. 727

June 2022

Diminishing deadweight loss through energy subsidy cost recovery

Niall Farrell[1,2*] & Harry Humes[1]

a) Economic and Social Research Institute, Dublin, Ireland
b) Trinity College Dublin, Dublin, Ireland

*Corresponding Author:
Dr Niall Farrell
Economic and Social Research Institute,
Whitaker Square, Sir John Rogerson's Quay,
Dublin, Ireland
Email: Niall.Farrell@esri.ie

Diminishing deadweight loss through energy subsidy cost recovery

Niall Farrell*[1,2], Harry Humes[1]

[1]Economic and Social Research Institute, Whitaker Square, Sir John Rogerson's Quay, Dublin
[2]Trinity College, Dublin, Ireland

June 24, 2022

Abstract

Energy subsidies are common. Costs are commonly recovered via an often arbitrarily set uniform consumer levy or electricity price surcharge. We show that an electricity price surcharge is optimal for an Irish case study, despite obvious price distortions. The outcome holds across both first and second-best subsidy applications. When financing first-best energy subsidies (e.g. innovation grants), lost consumer surplus is outweighed by distributional benefits. Energy subsidies are often used as second-best policy to mitigate emissions. We show that an electricity price surcharge is most efficient should there be uninternalised emissions, as the social cost of avoided emissions exceeds the deadweight loss of the policy. This is also less regressive than a uniform consumer levy. We demonstrate these general findings through an Irish case study and quantify the expected magnitude of resulting effects. An electricity price surcharge increases lost consumer surplus by up to 3.3%. Distributional implications are also quantified for Ireland using 2015/16 data; households in the first quintile pay €8.65 less per annum, on average, while households in the fifth quintile pay €7.07 more per annum, on average. These impacts will grow with the total subsidy burden.

*Corresponding author: niall.farrell@esri.ie

1 Introduction

According to the first fundamental theorem of welfare economics, efficient emissions mitigation in a market economy occurs when one prices carbon at a rate equal to social cost [70, 63, 65]. Second-best renewable energy subsidies persist, often motivated by binding institutional or political economy constraints [6, 47, 48, 51, 53]. Subsidies can be among the first-best solutions for other market failures: research grants or tax breaks have been shown to be a cost-effective solution to an under-supply of innovation by the market [54, 3, 43]. This paper shows that when a subsidy is put in place, the method of cost-recovery is important. An electricity price surcharge is the most efficient policy in the majority of first-best and second-best policy scenarios, conditional on expected societal preferences for equity relative to efficiency. We quantify the magnitude of effects using an Irish case study.

Electricity-related surcharges are the most common method of energy subsidy cost-recovery [34, 15, 41] and two structures are common: a uniform (i.e. flat-rate) consumer levy [e.g. 32]; or an electricity price surcharge [e.g. 15, 79, 41]. We show that an electricity price surcharge is most efficient if the purpose of the subsidy is to internalise emissions, as the social cost of avoided emissions exceeds the deadweight loss of the policy. This is less regressive than a uniform consumer levy. An electricity price surcharge creates a loss of consumer surplus if the subsidy has an alternate purpose, such as a support for innovation or capital investment in energy efficiency. However, this loss of consumer surplus is less than the distributional benefits of the surcharge under expected societal preferences for equity relative to efficiency. These results are related to the extensive literature on the equity and efficiency implications of financing public expenditure through general taxation [e.g. 5, 26, 27].

This paper considers an Irish case study, where energy subsidy surcharges were equivalent to a gross annual loss in consumer surplus of €112m in 2015/16 through a uniform consumer levy. This paper identifies that the introduction of a electricity price surcharge would increase this lost consumer surplus by up to 3.3%. However, this loss in consumer surplus is counteracted by a more equitable distribution of cost. An electricity price surcharge shifts the burden from those with lower incomes (households in the first decile pay €8.65 less per annum, on average) towards those with higher incomes (households in the fifth decile pay €7.07 more per annum, on average). In aggregate, we show that the distributional benefits of an electricity price surcharge outweigh the losses in consumer surplus given expected societal preferences for equality and the magnitude of cost given the current Irish case study. Should the subsidy burden increase a uniform consumer levy is preferred in a greater number of scenarios. This preference is isolated to the scenarios where price elasticity of demand is in the upper end of the expected range and where society values equity less than that predicted by empirical evidence.

We illustrate that the choice of cost-recovery can mitigate welfare losses associated with second-best climate policy. While an energy price surcharge reduces consumer surplus, it also reduces carbon emissions. Isolating the deadweight loss component of any change in consumer surplus, we show that the value of avoided emissions exceeds the welfare losses to society. While this is less than the outcome under a carbon price that reflects the social cost of carbon, it is welfare-enhancing relative to a uniform consumer levy.

This paper provides evidence for more informed policy. In practice, the motivation for choosing a particular energy subsidy cost-recovery method has been unclear. For instance, the Irish Public Service Obligation levy is a uniform consumer levy. While allocation among consumer groups is calculated based on each user group's contribution towards peak demand, the method of household-level cost-recovery is unmotivated in the public documentation [21, 20]. In the UK, the impact of retail competition has motivated a supplier obligation for energy efficiency investment, a cost that is passed through to consumers by suppliers via an electricity price surcharge. The choice of an electricity price surcharge has not been motivated on grounds of maximising consumer welfare, but through a profit maximising decision by suppliers.[1]

[1] In the UK, Environmental and Social Obligations are financed by retail suppliers. This has been motivated on the grounds that, as suppliers must pass these costs through to consumers, they will do so at minimum cost due to competitive constraints from other suppliers, efficiently delivering environmental policy [25, 60]. This, of course, relies on the assumption that the retail market is sufficiently competitive to

There are a number of contributions to the academic literature provided by this paper. This is the first applied analysis to consider the welfare losses due to second-best climate policy at the household level. Much research has focussed on the aggregate implications of second-best climate policy. [48] find that if carbon pricing is permanently missing, mitigation costs increase by multiples, with a combination of carbon pricing and subsidies minimising welfare losses in a second-best world. [40] explore the required second-best carbon pricing policy when no subsidies are available to support innovation. [70] show that second-best subsidies can achieve decarbonisation at a similar cost to the first-best solution should there be credible public commitment. [62] explore the welfare loss created by distorting taxes to finance subsidies.

Secondly, this is the first paper to consider the importance of cost-recovery methods in counteracting uninternalised externalities and the relative balance of efficiency and equity in choice of cost-recovery method. In doing so, we draw on strands of the literature discussing both the household-level equity and efficiency implications of energy surcharges and tariff design. The classical literature of the early 20t̂h century has attempted to identify the optimal tariff design for a utility with high fixed costs, resulting in an inability to apply the traditional marginal cost pricing rule. [68] and [9] advocate a markup that is inversely proportional to the price elasticity of demand, while [44] and [52] advocate for fixed cost recovery through taxation. The two-part structure proposed by [16] has become the dominant solution, guiding the tariff structure adopted by many utilities today.

Much applied literature exists to examine the implications of deviating from the Coasian tariff structure. While much attention has been paid to the inefficiencies associated with electricity tariff structures, the impact of subsidy-related surcharges has not been addressed. [33] demonstrates that 'ignoring Coase' in British electricity tariff design has resulted in losses in consumer surplus equivalent to between 6-18% of domestic consumption value. Similar effects were observed in the US natural gas industry. [23] find that volumetric

incentivise price competition. While this explains the choice of electricity-consumer related cost-recovery, the choice of consumption surcharge as opposed to a uniform consumer levy is presumably that which maximises profits. As volumetric prices in the UK exceed marginal cost, and standing charges are below each consumer's share of fixed costs [33], this suggests that costs are recovered via an electricity price surcharge.

prices are significantly higher than marginal cost, resulting in an estimated US$ 2.7billion welfare loss per annum. [10] find slightly lower estimates for markups, with natural gas volumetric prices approximately 30% higher than marginal cost, resulting in a consumer welfare loss. The welfare loss associated with water utility pricing has been the subject of a further strand in the literature (e.g. [18, 77, 69]. [66] finds that French water customers face prices on average 8% greater than marginal costs, resulting in a welfare loss of approximately €8 million.

This paper identifies the optimal surcharge design given, first, the policy objective and, second, the relative importance of equity and efficiency. Numerical analyses have focussed on estimating the distributional effects for a given context and have failed to consider the trade-off with efficiency. Equity was first incorporated into the literature on tariff structure by [35], who suggested that uniform consumer charge, such as that in a Coasian two-part tariff or a uniform consumer levy, is 'essentially a regressive head tax'. [34] discuss the distributional costs of alternative PSO levy structures in Ireland, finding that a uniform consumer levy is more regressive than an electricity price surcharge or a hybrid policy. A number of German studies estimate the regressive nature of their electricity price surcharge, the EEG Umlage, on consumption [e.g. 56, 41]. It is suggested that the magnitude of the regressivity can be partly attributed to exemptions made by the German government for certain energy-intensive industries, as this leaves more of the burden of financing RES-E to be shouldered by residential customers. Similar regressive effects were found for other European countries, such as in the case of Italy's A3 surcharge [79] and British environmental and social obligations levied on retail suppliers [15]. Furthermore, [55] find that a solar feed-in tariff policy in Australia is regressive.

Efficiency, however, is an important consideration. As noted by [61], policy must confront 'choices that offer somewhat more equality at the expense of efficiency, or somewhat more efficiency at the expense of equality,' with the work of [11] and [33] considering these trade-offs in relation to energy tariffs. [11] considers both efficiency and equity in the design of electricity tariffs, focussing on the distributional benefits, and efficiency losses, associated with non-linear tariffs. [33] considers the loss in consumer surplus associated with non-Coasian markup, showing that the consumer welfare gains of a Coasian reform outweigh the distributional losses. While this literature has explored tariff-related welfare losses, it has not explored welfare losses resulting from an energy subsidy-related markup.

The findings of this paper are identified using an Irish case study but sensitivities are explored to ensure general insight. Ireland is a developed country with rates of income inequality close to the median of all EU countries [30]. To provide general insight, we explore the sensitivity to the policy context and the magnitude of the policy burden. We consider two scenarios; (1) where the subsidy is used as first-best policy to incentivise innovation or energy efficiency investments and (2), where the subsidy is used as second-best policy to reduce carbon emissions.

This paper is structured as follows. Section 2 presents the institutional setting, while Section 3 outlines the empirical strategy and the data. Sections 4 present the results. Efficiency and equity effects are quantified for the Irish case study, in the context of both optimal and second-best subsidies. We apply a social welfare function to quantify the trade-off between equity and efficiency. Section 5 concludes.

2 Institutional setting

Energy subsidy cost-recovery relates to the policy imperative of decarbonisation: the global electricity sector must reach net-zero emissions by 2040 to achieve the commitments of the Paris Agreement [78, 2]. Market failures such as incomplete markets for emissions, innovation, and risk delay this process [65, 63, 54, 3, 43, 39, 75, 80]. While carbon tax is established as the first-best policy for internalising carbon emissions [63, 70], subsidies are often used for this purpose, alongside first-best applications such as incentives for innovation.

Energy subsidies are a public expenditure and there is a wide literature covering the least distortive method of raising such revenues. Taxes may be levied on income and labour, with the efficiency and equity implications well-established [17, 28, 42, 64]. Consumption decisions may be distorted if taxes are raised by altering the price of goods or services. Value-Added Tax (VAT) has been shown to be the least-distortionary method of raising public funds through such surcharges [26, 27]. VAT should be a single uniform rate unless there are distributional counter-arguments [24].

Despite this general rule, many markets impose a separate surcharge on electricity consumption to finance renewable energy subsidies and energy efficiency policy [15, 41, 34]. Following the guidance of [24], such deviation from a uniform VAT rate should consider the equity implications, and this has formed part of much policy and academic discussion [15, 56, 41, 34, 79, 57, 58, 59].[2] In addition to this, efficiency effects warrant examination not just in the context of distorting prices but also in the context of uninternalised environmental externalities. This is especially important should policy be constrained in its ability to impose a sufficiently high carbon price.

This paper considers the cost recovery of energy subsidies through the Irish Public Service Obligation (PSO) levy. Presently, the PSO funds price supports for renewable energy deployment only. The cost of financing these policies is the difference between market prices and the pre-agreed price guarantee. In the past, this levy has also funded indigenous peat generation and other capacity for security of supply purposes. This is similar to levies imposed in other markets such as Italy [79], the UK [15] and Germany [41]. [56] has shown that similar levies exist in 23 EU countries and in over 100 countries globally.

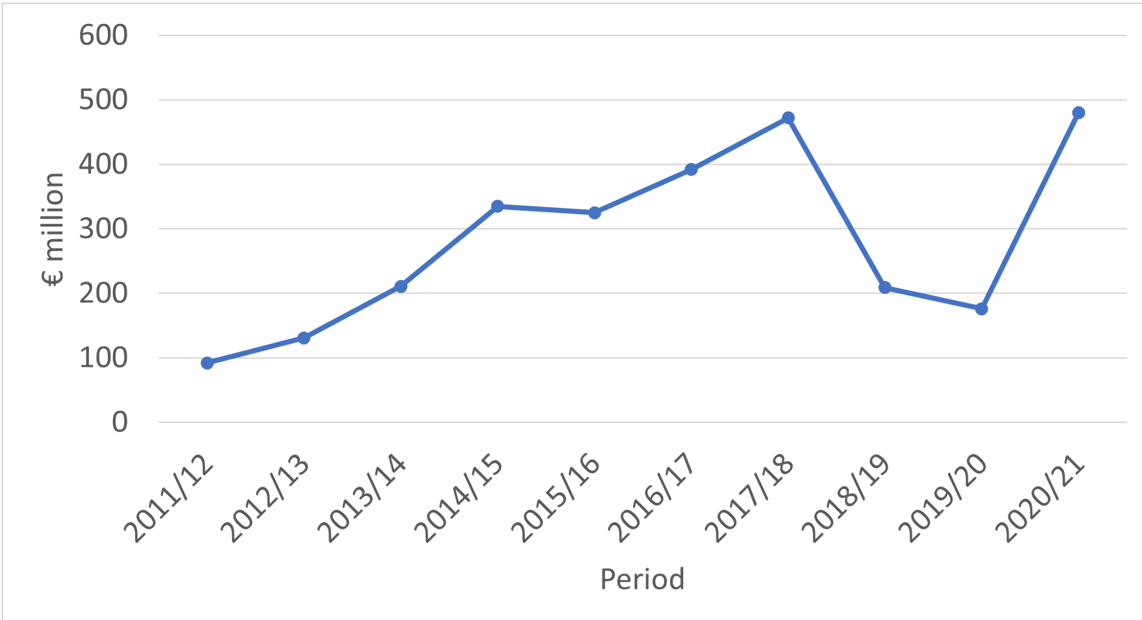
Two schemes support the majority of Irish renewable energy capacity and are funded by the PSO levy. Since 2019/2020, renewable energy capacity has been supported by the Renewable Energy Support Scheme (RESS). This is a competitive auction, where generators bid the price at which they are willing to supply electricity. If successful, they will receive a price support equivalent to the difference between the market price and the agreed strike price. Should the market price exceed the strike price, this difference is returned to the regulator. Prior to the RESS scheme, the Renewable Energy Feed-in Tariff (REFIT) scheme

[2] This has been considered in a policy setting. For instance, financial protection for vulnerable consumers is explicitly acknowledged as a policy priority by the UK regulator Ofgem [57, 58, 59].

provided a guaranteed price floor. This was a uniform price floor for all generators. Market revenues in excess of the price floor were not returned to the regulator. While the REFIT scheme is no longer open to new applicants, the costs of financing capacity introduced in previous years continues.

The PSO levy is the electricity surcharge placed on consumers to recover the funds required to finance these policies. Figure 1 shows the total funds recovered in recent years, with Table 1 showing the levies imposed at the household level. Approximately 40% of total revenues are recovered from c. 2 million Irish dwellings, with the remainder recovered from commercial and industrial consumers. Both display items show inter-annual volatility attributable to forecast errors and electricity price fluctuations. Required funds comprise the difference between the wholesale electricity price and the guaranteed strike price. As wholesale prices fluctuate, so too do required revenues. In addition, revenues in a given year are often under/over-recovered due to incorrectly predicting renewable electricity generation and/or the forecast wholesale market price. This results in a correction ('R-factor') during the following period of cost-recovery.

Figure 1: Total PSO Receipts



Note: Lower receipts required in 2018/19 and 2019/20 due to high negative R-factor. This reflects a correction due to greater than expected receipts in preceding period. Source: [21]

Currently, these costs are recovered from each consumer in Ireland by means of a uniform levy. In other markets, such as Italy [79], Germany [41] and the UK[15], a surcharge on the volumetric price has been imposed. While the distributional effects of these two choices has been the subject of debate [15, 56, 41, 34, 79], the economic rationale behind either choice has not been fully explored.

A priori, one expects that a consumption surcharge creates a distortion should all externalities be internalised.[3] Such a surcharge will also have distributional implications, affecting certain households more than others. Further, should environmental externalities not be fully internalised, and electricity prices do not reflect social marginal cost, a surcharge that is less than or equal to the marginal abatement cost may guide consumption closer to the social optimum (assuming volumetric prices reflect private marginal cost). A

[3]While [45] finds evidence to suggest consumers respond to average price when faced with complex, non-linear price schedules, [46] find evidence that consumers do respond to marginal price in the presence of a fixed charge. This is the approach taken by the literature in this area, when considering two-part tariffs [10, 67].

uniform consumer levy does not drive an additional wedge between price and marginal cost, so it does not have this distortive effect. It does, however, create an additional cost which has distributional implications. The following empirical analysis explores these equity and efficiency effects in scenarios with and without uninternalised environmental externalities.

Table 1: Irish Public Service Obligation Levy Costs per household: 2011-2021

Year	Monthly PSO levy	Annual PSO levy
2011-2012	1.61	19.33
2012-2013	2.32	27.82
2013-2014	3.57	42.87
2014-2015	5.36	64.37
2015-2016	5.01	60.09
2016-2017	5.90	70.75
2017-2018	7.69	92.28
2018-2019	3.48	41.76
2019-2020	2.84	34.08
2020-2021	6.52	78.24
2021-2022	4.30	51.60

Note: Data Source [21]

3 Empirical framework and data

In this section, we describe the methods employed in our empirical application. This paper employs a simulation-based estimation procedure, expanding on the methods of [10], [12] and [33]. The application takes the following constituent steps. A socioeconomic profile of income and electricity consumption is first constructed. Household-level micro-data provide a representative sample of electricity expenditures, income and other socioeconomic information. Combined with electricity tariff data, we calculate the amount spent on each tariff component and the quantity of electricity consumed per household. Currently, the PSO levy is recovered via a uniform consumer levy. We construct a counterfactual tariff which incorporates an electricity consumption surcharge for energy subsidy cost-recovery. Taking into acccount the consumption response, both equity and efficiency effects are quantified in total, on average and by income group. Efficiency is considered relative to the loss of consumer surplus and the deadweight loss. Finally, a social welfare function is specified to calculate the optimal tariff structure, through which losses in consumer surplus may be considered relative to a more progressive distributional cost burden. Each step will now be discussed in detail.

3.1 Step 1: Household Budget Survey Microdata Foundation

The 2015/2016 Irish Household Budget Survey (HBS) provides the microdata foundation for this analysis. This is a household-level survey which records household income and average weekly expenditure alongside a variety of other household characteristics. The HBS also contains a rich set of socioeconomic information, including appliance ownership and household characteristics. The HBS contains information on household electricity expenditure which is of particular interest for this study.

Table 2 reports the distribution of pertinent economic and social variables. These are reported in total and, to give insight into the importance of distributional factors, by equivalised disposable income quintile.[4] One can see that while electricity consumption is correlated with income, the burden is much greater for low-income households. Distributional

[4]Equivalised disposable income is disposable income (income after taxes and transfers) adjusted for household size. The OECD modified equivalence scale is used. This is the equivalence scale commonly employed by Eurostat. To calculate equivalised income using the modified OECD equivalence scale, each member of the household is first given an equivalence value: 1.0 to the first adult; 0.5 to the second and each subsequent person aged 14 and over; 0.3 to each child aged under 14. The equivalence values for each household member are summed to give a total equivalence number for the household. Household disposable income is then divided by the total equivalence number.

concerns surrounding PSO cost-recovery therefore warrant further investigation.

Table 2: Descriptive statistics by equivalised disposable income quintile

	First	Second	Third	Fourth	Fifth	Total
Disp. income	337.8	591.8	860.1	1109.0	1685.2	914.4
	(163.7)	(225.4)	(277.5)	(363.9)	(750.9)	(619.8)
Expenditure	474.6	592.9	821.6	1009.7	1343.0	846.6
	(361.9)	(368.3)	(431.7)	(510.9)	(707.7)	(581.1)
Elec. expenditure	14.75	16.58	19.27	19.32	20.35	18.04
	(11.50)	(11.60)	(11.52)	(10.99)	(11.25)	(11.56)
Elec. as prop. income	0.0517	0.0295	0.0233	0.0182	0.0132	0.0273
	(0.0544)	(0.0212)	(0.0142)	(0.0107)	(0.00777)	(0.0307)
Children	0.404	0.641	0.700	0.677	0.503	0.585
	(0.896)	(1.045)	(1.076)	(1.037)	(0.911)	(1.002)
Adults	1.829	2.127	2.359	2.224	2.112	2.130
	(1.090)	(1.056)	(1.036)	(0.983)	(0.849)	(1.021)
HRP retired	0.295	0.297	0.199	0.194	0.136	0.224
	(0.456)	(0.457)	(0.399)	(0.395)	(0.343)	(0.417)
HRP homeowner	0.560	0.647	0.759	0.826	0.859	0.730
	(0.497)	(0.478)	(0.428)	(0.379)	(0.348)	(0.444)
HRP working	0.216	0.412	0.659	0.742	0.830	0.570
	(0.412)	(0.492)	(0.474)	(0.438)	(0.376)	(0.495)

Note: Standard errors in parentheses. The data are from the 2015/2016 Household Budget Survey (HBS). All values are calculated using sample weights and distribution of electricity expenditure calculated before the simulated impact of the household benefits package. Income and expenditure data represent weekly averages per income quintile. HRP refers to 'Household Reference Person'.

3.2 Step 2: Electricity tariff data

Having established a baseline dataset of households, including electricity expenditure, the next step is to break down total expenditure to expenditure on units, standing charges and PSO payments. This facilitates the estimation of PSO payments but also electricity consumption in terms of units consumed, from which a volumetric price surcharge may be calculated.

The fist step in this process is to match each household with a representative electricity tariff. Households may be subject to either a standard tariff or a 'Nightsaver' tariff. Under a standard tariff, all units consumed have the same volumetric price. Under a 'NightSaver' tariff, day and night consumption are subject to different prices. We souce historical tariff information to identify what tariffs were available during the 2015/16 time period. Ireland's retail electricity market was dominated by four suppliers during this time: Electric Ireland, Bord Gais, SSE Airtricity and Energia. An internet archive provides a snapshot of published tariffs at a given moment. For each supplier, we collect the archived tariff snapshot that is closest to the 2015/16 HBS sample period.[5] Tariff calculation is outlined in full in Appendix A. We weigh each tariff by market share to create a composite that reflects the relative weighting of charges faced by households.[6] This process is outlined in full in Appendix A with the set of representative tariffs employed shown in Table 3. To validate our choice of tariffs, a second source is consulted. The Commission for Regulation of Utilities (CRU) has published the average electricity tariff for the 2015/16 time period. Appendix A shows that the tariffs calculated using this procedure are similar to those obtained through our preferred calculation procedure. The conclusions of this paper are insensitive to the assumptions employed in this calculation, therefore.

The final step is to assign a standard or 'Nightsaver' tariff to a household. The HBS does not provide information on whether a household is using the standard or Nightsaver tariff.

[5] For Electric Ireland, tariffs are sourced from September 2014 [Standard] and September 2015 [NightSaver]; for SSE Airtricity, rates are for April 2015; for Bord Gais, rates are for March 2015; for Energia, rates are for November 2017

[6] A sensitivity check is carried out in Appendix B and the results of this paper are insensitive to the tariff calculation assumptions.

Following [33] and [37], we use electric heating as a proxy for being on the NightSaver tariff, as the day/night meter is generally recommended for those with electric storage heaters. When calculating consumption, We assume 60% peak and 40% off-peak usage, following the assumptions of [33] and [37]. A sensitivity analysis on this assumption is also carried out in Appendix A, demonstrating that the conclusions of this paper are insensitive to variations to these assumptions. Finally, urban and rural households face different tariffs. The HBS contains an urban/rural indicator and this is used to assign the appropriate tariff to households.

3.3 Step 3: Calculate the Quantity of Electricity Consumed

The tariffs of Table 3 are used to calculate units consumed and the PSO levy faced by each household. For each household, the standing charge and appropriate PSO are subtracted from total expenditure and the remaining expenditure is divided by the appropriate volumetric tariff to identify the number of units consumed.[7]

The appropriate PSO levy is predicated on the time of being surveyed. From 1st October 2014 to the 30th of September 2015, each household in Ireland paid €1.34/week (€5.36/month). From 1st October 2015 to the 30th of September 2016, each household in Ireland paid €1.25/week (€5.01/month) [19, 20]. The HBS data contains information on the year and quarter surveyed and the relevant tariff is applied to each household.

When calculating units consumed, any social assistance must be accounted for. Certain vulnerable households are recipients of the household benefits package (HHB). HHB comprises an electricity or gas allowance, and a free television licence. To cover fuel costs, the allowance is €1.15 per day [7]. Households eligible for the HHB are therefore assumed to spend an additional €8.05 per week on electricity.

The HBS does not detail HHB eligibility and this is proxied using a number of indicators. The package is generally available to people living in the Irish state, aged 66 years or over

[7] For 'Nightsaver' customers, a weighted tariff reflecting the assumed share of consumption is used. This corresponds to: $units = \frac{expenditure}{(NightTariff \cdot 0.4) + (DayTariff \cdot 0.6)}$.

who are in receipt of a social welfare type payment or who satisfy a means test. It is a universal payment from the age of 70. Any households where all residents are between 66-70 are in receipt of the old-age pension or social transfers are eligible for the HHB. Households where a recipient is eligible but their spouse is not in receipt of a social welfare payment (proxied by being full-time in gainful employment) are not deemed eligible.

Finally, the HHB is availed of by a number of persons under 66, such as those in receipt of Disability Allowance; Invalidity Pension; Blind Pension; Incapacity Supplement (for at least 12 months) with Disablement Pension (for at least 12 months); if you are caring for and living with a person who is getting Constant Attendance Allowance; Carer's Allowance (full or half-rate payment), but you must be living with the person you are caring for; an equivalent Social Security Pension or Benefit from a country covered by EU Regulations, or from a country with which Ireland has a Bilateral Social Security Agreement. The HBS does not contain detailed information on such recipients. However, proxy indicators exist. We code households where the household reference person has a permanent incapacity to work or is assisting relatives either full or half-time as being a recipient of the HHB. It is assumed that all eligible households apply the allowance to their electricity consumption, providing a lower bound on the regressivity of any proposed PSO levy change (i.e. the estimated effect is at least as regressive as that estimated).

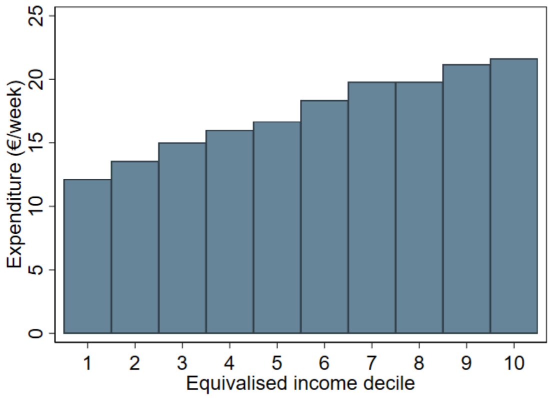
In calculating electricity consumption, a small number of households are coded as having negative electricity expenditures and these are recoded as having zero expenditure.

Table 3: Representative Tariffs

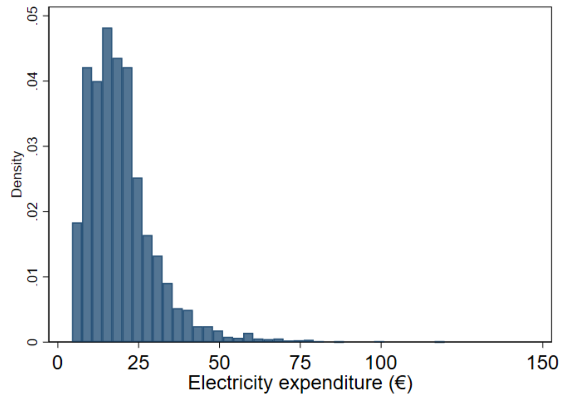
	Vol. Charge (€/kWh)		Standing Charge
Tariff	Day	Night	(€/hh/week)
Urban Standard	0.1907	0.1907	2.80
Rural Standard	0.1914	0.1914	3.65
Urban Nightsaver	0.2016	0.0996	3.76
Rural Nightsaver	0.2022	0.0998	4.71

Figure 2: Relationship between income and electricity expenditure in Ireland

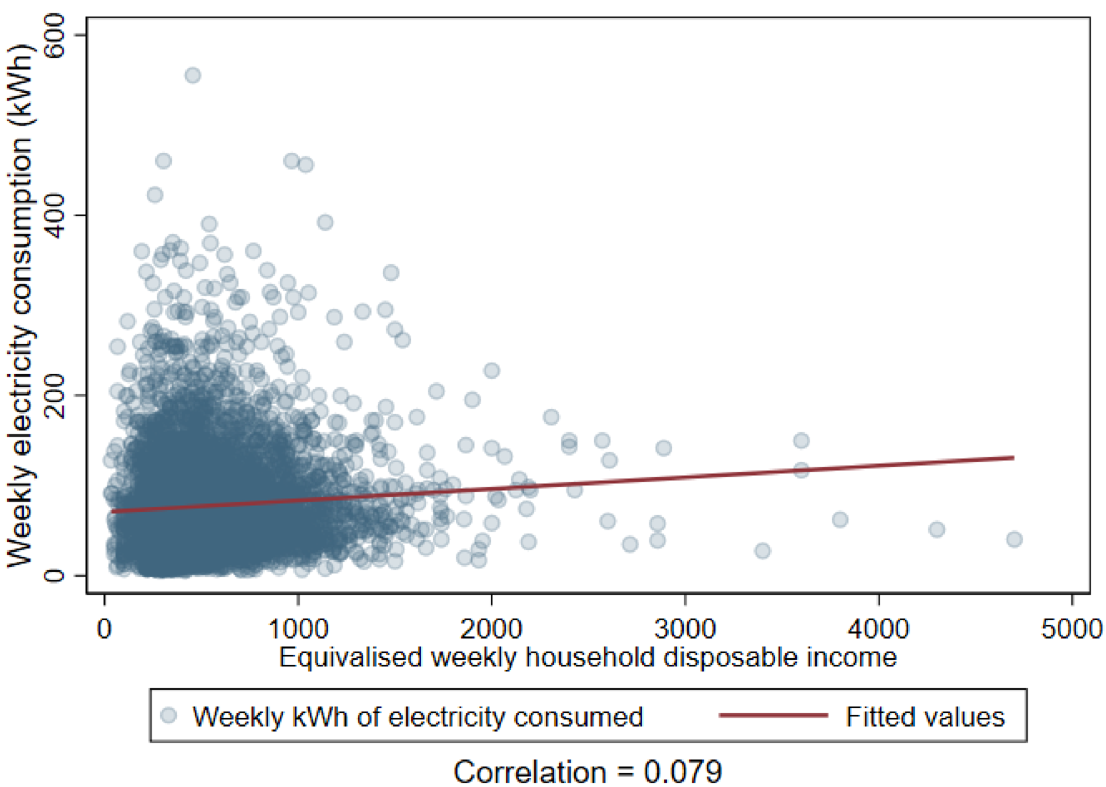
(a) Average Income



(b) Average Expenditure



(c) Distribution (Income)



Data Source: 2015/2016 Household Budget Survey (HBS)

3.4 Step 4: Simulate counterfactual consumption

Should volumetric prices change, economic theory suggests that the quantity demanded should change [10, 46]. Following [10], [22] and [33], we assume that Demand by consumer k (D_k) follows an isoelastic demand function:

$$D_k(p) = A_k p^e \tag{1}$$

Where p is the volumetric price of electricity faced by household k. The parameter e denotes the price elasticity of demand for electricity and A_k is a constant. Each household has an individual A_k parameter calibrated according to $A_k = \frac{D_k}{p}$. While results for a range of assumed elasticities are presented, the true long run price elasticity is expected to be between -0.3 and -0.8.[8]

3.5 Step 5: Calculate subsidy cost-recovery

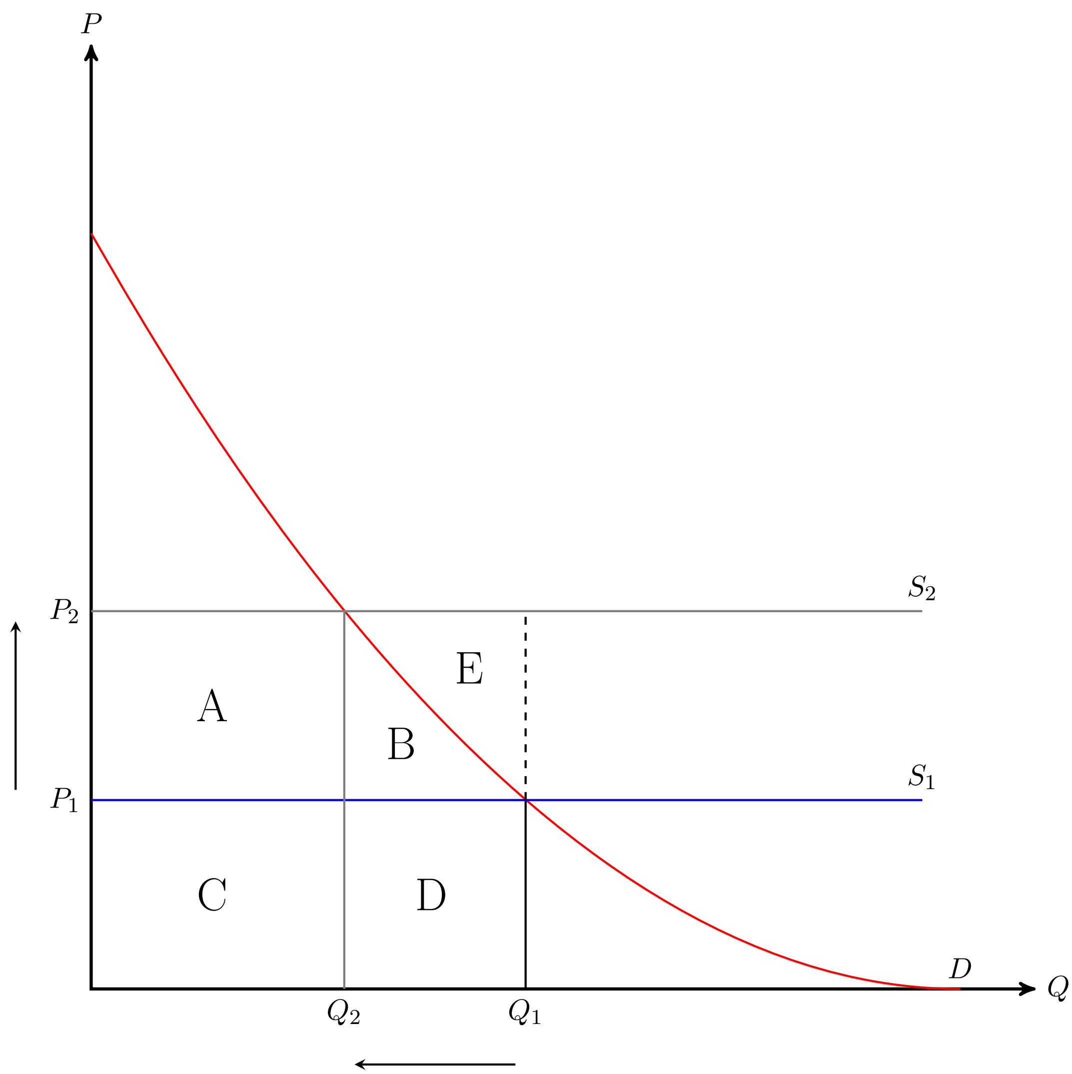
We analyse the uniform consumer levies imposed at the time the survey took place (see Section 3.3 for futher discussion). An electricity price surcharge is designed according to a revenue-neutral reform whereby we divide the sum of all PSO revenues paid by households under a uniform consumer levy by the sum of all electricity consumed by households in the Household Budget Survey. One must account for a demand response to ensure a revenue-neutral reform; as the price surcharge increases, demand falls (and revenue falls) if the price elasticity of demand is non-zero. To account for this, an iterative procedure is employed; the levied surcharge increases incrementally from the revenue-neutral surcharge imposed when no demand response is in place. This continues until the total revenue recovered is equal to that of the uniform consumer levy. This procedure is repeated under each assumed price elasticity of demand.

[8] In a meta-analysis of international research, [49] find a global long-run average of -0.365. Historically, national studies have reported estimates for residential use in the range of -0.21 to -0.7 [31, 36, 8]. For the UK, [4] find an own-price elasticity of demand of -0.75 for residential consumers. In a global meta-analysis, [29] find a long-run elasticity estimates of -0.8. This value is used by recent UK policy analyses, such as that of [1]. [71] find a long-run price elasticity of electricity demand of -0.4 for residences, whilst [13] find much higher values, in the region of -1.

3.6 Step 6: Quantify welfare change

3.6.1 Calculating consumer surplus and deadweight loss

Figure 3: Changes in social surplus associated with electricity price surcharge



The final step of this analysis is to aggregate societal welfare. This is considered in a number of aspects in this analysis. First, we calculate changes in consumer welfare. Figure 3 illustrates the components that make up changes in social surplus due to a change in price from P_1 to P_2. The loss of consumer welfare, or consumer surplus, is equivalent to sections

A and B. Assuming linear marginal costs[9], the total loss of welfare, or deadweight loss, is equivalent to section B. To calculate deadweight loss, we subtract portion A ($(P_2 - P_1) \cdot Q_2$) from the change in consumer surplus.

3.6.2 Equity vs efficiency

Second, we wish to consider the optimal policy choice, accounting for both conflicting policy priorities to maximise total consumer surplus while also ensuring an equitable distribution of costs. This is carried out in the following way. Net household income (y_i) may be calculated as disposable income ($y_{i,disp}$), net of energy subsidy costs incurred (s_i):

$$y_i = y_{i,disp} - (s_i) \tag{2}$$

Societal welfare may be considered as an aggregation of individual welfare (Equation (2)). Equation (3) shows a general welfare function where household income y_i is aggregated according to a utility function u, where the functional form of u reflects societal preferences for inequality, transforming individual incomes to account for each household's place on the income distribution. An additive social welfare function calculates societal welfare (W) as the sum of individual utilities:

$$W = \frac{1}{N} \cdot \sum_{i=1}^{n} U(y_i) \tag{3}$$

There are many functional forms for U. We choose the following functional form as adopted for use in the Atkinson index:[10]

$$U(y_i) = \frac{1}{1-\epsilon} \cdot y_i^{1-\epsilon} \qquad \text{if } \epsilon \neq 1 \tag{4}$$

$$U(y_i) = \log\, y_i \qquad \text{if } \epsilon = 1 \tag{5}$$

[9]For marginal changes associated with changes in the energy price surcharge, the assumption of constant marginal cost is reasonable and any error is likely to be negligible

[10]Sensitivty analysis finds that the results are insensitive to the choice of index of inequality

3.6.3 Accounting for uninternalised environmental externalities

When emissions are priced at a rate that is equal to the social cost of carbon, the relative merits of a cost-recovery mechanism are determined by societal preferences for total household welfare relative to the equitable distribution of subsidy costs.

There may be uninternalised greenhouse gas emissions where emissions are priced at a rate that is less than the social cost of carbon. An electricity price surcharge can act to (partially) internalise these costs. We compare the deadweight loss (section B of Figure 3) to the avoided uninternalised environmental externalities. The welfare effect is therefore the loss of social surplus ('deadweight loss' - B of Figure 3), less the social cost of avoided environmental emissions. We calculate deadweight loss as the loss in consumer surplus less portion A of Figure 3 ($[P_2 - P_1] * Q_2$). The loss in consumer surplus may be calculated as:

$$\sum_{i=1}^{n} U(y_i, s) - \sum_{i=1}^{n} U(y_i, f), \tag{6}$$

where $U(y_i, s)$ is utility for household i under an electricity price surcharge and $U(y_i, f)$ is utility for household i under a uniform consumer ('flat-rate') levy. The cost of environmental emissions may be calculated as difference in the quantity of electricity generated $(Q_1 - Q_2)$, scaled according to the emissions intensity of electricity (ρ), times the social cost of carbon (τ). Net Welfare Change (NWC) may therefore be characterised as

$$NWC = \left[\sum_{i=1}^{n} \left(U(y_i, s) - U(y_i, f) - \left(P_2 - P_1 \right) * Q_2 \right) - (Q_1 - Q_2) \cdot \tau \cdot \rho \right] \tag{7}$$

τ and ρ parameters are chosen to correspond to the Irish 2015/16 case study, with these data presented in Table 4. During this period, Ireland's electricity had an emissions intensity of 468gCO_2/kWh [73]. Ireland's electricity generation was subject to the EU Emissions Trading System (ETS) carbon price. In 2015/16, the EU ETS price was between c.€$7.00 - 8.50/tCO_2$ [72]. The High-Level Commission on Carbon Prices, a group of leading economists working with the Carbon Pricing Leadership Coalition, concluded that the 2017 carbon-price consistent with achieving the Paris temperature target is at least USD40–80/tCO2 by 2020 and USD 50–100/tCO2 by 2030 [76]. Assuming USD 1 = c. €0.91, as was the case in 2015/2016, then the midpoint USD 60 corresponds to a social cost of carbon of c. €54.60. Relative to this benchmark, the EU ETS underpriced emissions by €46.10/tCO_2 during this period.

Table 4: Parameters for social welfare calculation

Parameter	A	B	Unit
Social Cost of Carbon (τ)	54.60	54.60	€/tCO_2
EU ETS price	8.50	8.50	€/tCO_2
Uninternalised environmental externality		46.10	€/tCO_2
Emissions intensity of electricity (ρ)	468	468	gCO_2/kWh

Note: Scenario A corresponds to the situation where all externalities are assumed internalised by the EU ETS price, while Scenario B assumes there are residual uninternalised externalities. The average EU ETS price during 2015-2016 was c.€8.50, and this is therefore chosen as the benchmark price. the Carbon Pricing Leadership Coalition, concluded that the explicit carbon-price level consistent with achieving the Paris temperature target is at least USD 40–80/tCO2 by 2020 and USD 50–100/tCO2 by 2030 [76]. Assuming USD 1 = €0.91, as was the case during 2015-2016, then the midpoint USD 60 corresponds to a social cost of carbon of c. €54.60. Relative to this benchmark, the EU ETS underpriced emissions by c. €46.10/tCO_2 during this period. Emissions intensity of Irish electricity generation corresponds to the value quoted by [73].

4 Results

We present the results according to two distinct scenarios: an energy subsidy as first-best policy (e.g. to correct for market failures with respect to innovation or household-level under-investment in sustainable technology) and energy subsidy as second-best policy (i.e. to internalise carbon emissions).

4.1 Energy subsidy as first-best policy (emissions fully internalised)

To compare welfare effects when emissions are fully internalised, Table 5 presents the welfare loss associated with a uniform consumer levy and an electricity price surcharge for a range of assumed price elasticities of demand. As Section 3.4 has outlined, long-run price elasticities are expected to be in the range of −0.3 to −0.8, with many studies converging on the upper end of this spectrum.

First, we consider the aggregate welfare loss. The welfare loss associated with the flat-rate consumer levy is calculated as the sum of the concurrent 2015/16 PSO levy (either €1.25 or €1.34 per household, depending on time period of analysis), across 1.7 million households. An electricity consumption surcharge further reduces consumer welfare by distorting prices. Table 5 shows that the magnitude of this additional effect is in the order of 1-3%.

Table 5: Change in consumer surplus by tariff type

Scenario	per week	per annum	additional impact
Uniform consumer levy	€2,164,791	€112,569,132	-
Consumption surcharge			
$\epsilon = -0.2$	€2,181,532	€113,439,664	0.8%
$\epsilon = -0.4$	€2,199,004	€114,348,208	1.6%
$\epsilon = -0.6$	€2,217,220	€115,295,440	2.4%
$\epsilon = -0.8$	€2,236,182	€116,281,464	3.3%

Note: The change in consumer surplus associated with the flat-rate consumer levy is calculated as the sum of 2015/16 PSO levy payments (€1.25 or €1.31/week, depending on time of survey), across 1.7 million households.

Table 6 isolates the difference in consumer surplus losses, calculated as the cost under a uniform consumer levy less the additional loss under an electricity price surcharge. Welfare losses increase with price elasticity of demand, varying from €2.72m when the price elasticity of demand is −0.6 to €3.71m when elasticity is −0.8.

The mechanism of action warrants further discussion. If the price elasticity of demand is more elastic, the demand curve is flatter and therefore the area under the demand curve bounded by the two price points is smaller. This suggests that consumers incur a lesser welfare loss with an increase in price elasticity, holding price change constant. However, there is a counteracting surcharge effect. A revenue-neutral reform when elasticity is greater requires that costs be recovered through a surcharge on fewer units. This requires a greater surcharge per unit and this effect outweighs the diminishing loss in consumer surplus. The net effect is for an increasing loss in consumer surplus is shown by Table 6. As predicted by Table 5, the welfare loss created by the price distortion is relatively small.

Table 6: Switching from a consumer levy to a consumption surcharge: change in consumer surplus

Elasticity	Change (€m/annum)
e= -0.1	-0.430
	(.062)
e= -0.2	-0.869
	(.060)
e= -0.3	-1.318
	(.061)
e= -0.4	-1.778
	(.063)
e= -0.5	-2.246
	(.062)
e= -0.6	-2.72
	(.065)
e= -0.7	-3.212
	(.063)
e= -0.8	-3.71
	(.062)

Note: Change in consumer surplus is calculated as difference between costs levied when flat-rate consumer levy is in place, less the loss in consumer surplus when a volumetric surcharge is in place, relative to no cost-recovery. Mean and standard errors calculated from 1,000 bootstrap replications

To further understand this welfare loss, Table 7 shows the distributional impact by equivalised income quintile[11] when the price elasticity of demand is equal to -0.6[12]. The average effect is constant among income groups for the consumer levy (varying only according to bootstrap sampling variance), however the average cost rises by income group under the electricity price surcharge. In particular, households in income quintiles 1 and 2 incur

[11] Equivalised income is calculated by dividing gross disposable household income by the sum of each household member's equivalence value. We adopt the equivalence values used in the OECD-modified equivalence scale, with the first adult in each household being assigned an equivalence value of 1, subsequent adults taking a value of 0.5, and children taking a value of 0.3. These equivalence values capture the fact that having additional adults in the households allows for economies of scale in consumption

[12] This is chosen as it corresponds to the midpoint between the expected -0.4 to -0.8 range

a lesser cost while households in income quintiles 3 to 5 incur a greater cost. An electricity price surcharge is more progressive than a uniform consumer levy, therefore.

The full distribution of welfare change is presented in Figure 4. A number of insights may be observed. First, it can be seen that the distribution of impact is negatively skewed: while the majority of households incur a change in welfare of between +/- €10, there is a not insignificant number of households who incur a change in welfare many times that amount. Indeed, there are many households who incur a loss in the region of €100- 200 per annum.

Second, there are a greater number of 'losers' than 'winners' as a result of this policy change. This is due to a number of reasons. The extent with which a household may 'win' has an inherent upper limit. Those who consume less electricity are net 'winners', with a cap on how little you can consume (zero). However, is no upper limit on how much you can consume. Households who consume electricity in excess of c.81 units (c. 20 units per week) incur a loss. Assuming a price elasticity of -0.6, 1% of households incur a loss greater than or equal to €172 per annum, 10% incur a loss of €57 per annum or greater, whereas 25% incur a loss of €22 per annum or greater. These relatively large losses in consumer surplus are among large users and correspond to the value of the electricity consumption foregone.

Table 7: Average household loss in consumer surplus imposed by each cost-recovery method ($\epsilon = -0.6$)

	Equvalised income quintile				
	1	2	3	4	5
Consumer levy	66.14	66.10	66.08	66.20	66.18
	(0.001)	(0.002)	(0.002)	(0.003)	(0.001)
Volumetric surcharge	57.49	64.66	72.74	70.65	73.25
	(0.040)	(0.158)	(0.111)	(0.006)	(0.005)
Difference	8.65	1.44	-6.66	-4.46	-7.07
	(0.0417)	(0.160)	(0.113)	(0.003)	(0.004)

Note: Loss in consumer surplus calculated as cost incurred when uniform consumer levy is in place, less the loss in consumer surplus when an electricity price surcharge is in place. Mean and standard errors calculated from 1,000 bootstrap replications

Figure 4: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = -0.6$)

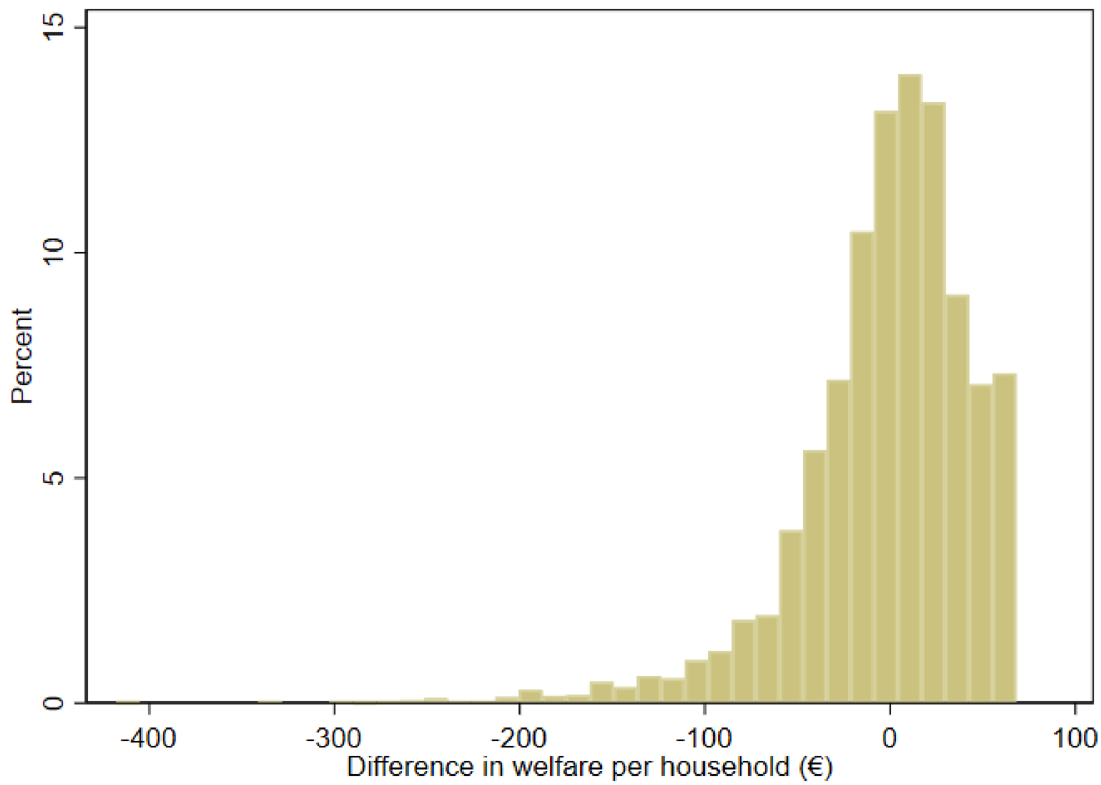
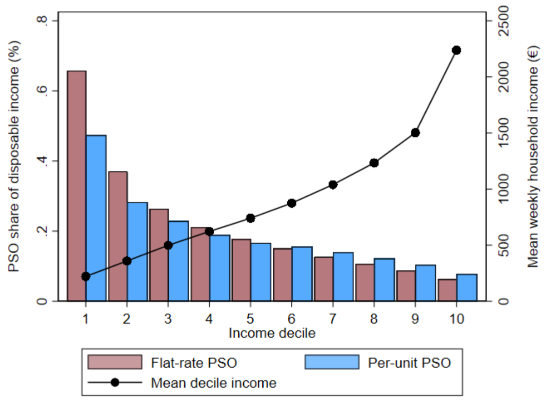


Figure 5 provides further insight into the distributional impact of each cost-recovery mechanism. We find a strong distributional argument in favour of a consumption surcharge. Figure 5 shows that there is a regressive distribution of policy costs; the uniform levy comprises a greater share of household resources for those households in lower income or expenditure deciles. Figures 5a and 5b show that a switch to a consumption levy increases the cost as a proportion of income for those in higher income groups, whilst the burden of cost is reduced, on average, for those on the lower end of the income distribution.

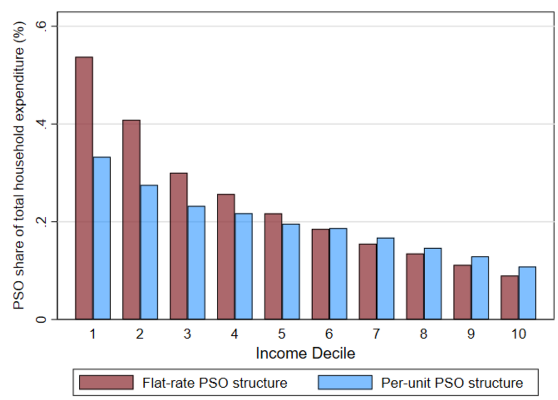
Figure 5c shows that while a uniform consumer levy represents a greater burden on households in lower income groups, on average, the electricity consumption surcharge incurs a wider distribution of burden within each income group. This is because of the variance in electricity consumption between households. Tables 8 and 9 give further distributional insight. Switching from a per-unit to a consumption surcharge has a greater impact on households with more children and on larger dwellings as, on average, these homes consume more electricity.

Figure 5: Distributional impact of energy subsidy cost ($\epsilon = -0.6$)

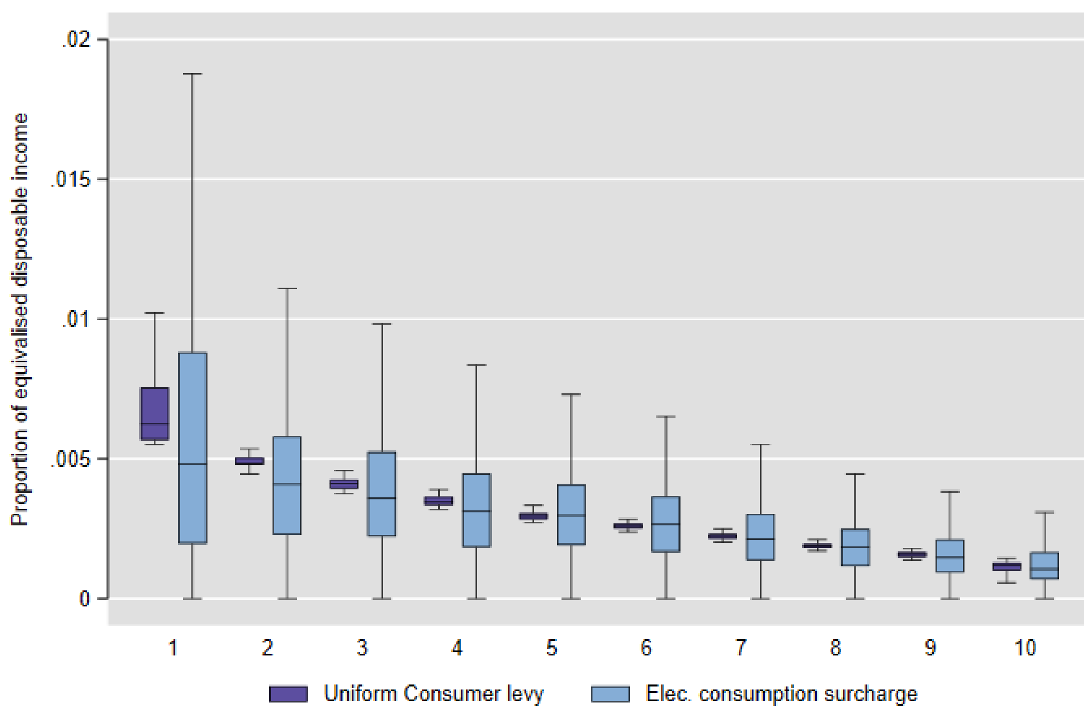
(a) Average Income



(b) Average Expenditure



(c) Distribution (Income)



Note: Distribution calculated based on weighted HBS 2015/2016 sample. Boxplot in Figure 5c excludes outliers.

Table 8: Average welfare change per household by household size ($\epsilon = -0.6$)

Inhabitants	Avg. welfare change (€/hh/annum)
1-2	6.944
	(0.045)
3-4	-7.537
	(0.0645)
5+	-20.570
	(0.117)

Note: Standard errors in parentheses calculated from 1,000 bootstrap replications

Table 9: Average welfare change per household by number of children ($\epsilon = -0.6$)

Inhabitants	Avg. welfare change (€/hh/annum)
1 child	-3.509
	(0.104)
2 children	-7.094
	(0.115)
3+ children	-15.110
	(0.164)

Note: Standard errors in parentheses calculated from 1,000 bootstrap replications

The final analysis of this section is to consider the losses in surplus due to the adoption of an electricity price surcharge (See Tabes 5 and 6) relative to the progressive distributional counter-effects (see Figure 5).

Figure 5 shows the welfare-maximising policy option considering the trade-off between equity and efficiency. A matrix of scenarios comparing assumed price elasticity of demand and inequality aversion are presented, with the darker shade indicating a societal preference for a uniform consumer levy and a lighter shade indicating a preference for an electricity price surcharge.

When interpreting the inequality aversion parameter (ϵ), one must consult the empirical literature which has identified the degree of inequality aversion implicit in many public expenditure decisions. [50] provide a review. [38] find implied values between 1.72 and 1.94

in relation to US income tax policy between 1979 and 1989. In a similar study of US income tax policy, values of 1.61 were found for 1957, 1.52 for 1967 and 1.72 for 1977 by [81]. [81] found inequality aversion values of 1.63 for the West German nominal tax schedule in 1984; 1.40 for the Italian tax schedule in 1987; and 1.59 for the Japanese tax schedule in 1987. [74] found inequality aversion parameters of 1.97 for the UK income tax code in fiscal year 1973/4.

Stern's (1977) paper also contains a comprehensive survey of many other approaches to evaluating the elasticities of both private and social marginal utilities of income, reporting values found by a range of authors for different countries using various methodologies as high as 10 and as low as 0.4. From this review, it is clear that inequality aversion parameters lower than 0.4 rarely correspond to the degree of inequality aversion inherent in public policy. Indeed, the median value is greater than 1 and often greater than 1.5.

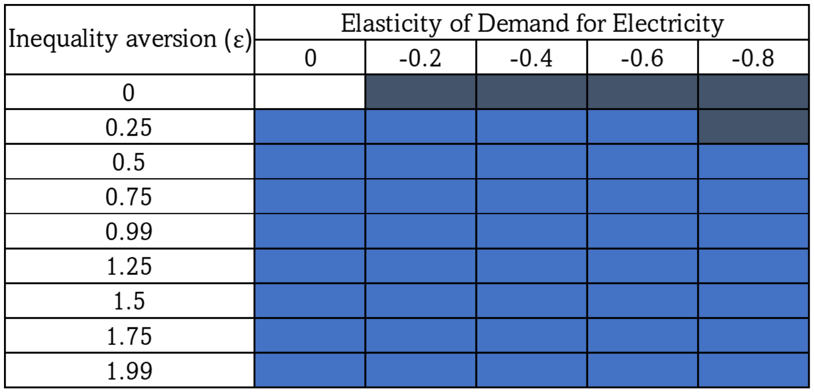
Figure 6 shows the policy option that yields the greatest social welfare, conditional on total subsidy cost to be recovered, the degree of price elasticity and societal aversion to inequality. One can see that under the majority of scenarios, equity takes precedence over efficiency and an electricity price surcharge emerges as the preferred policy.

Figure 6a shows the relative ranking of cost-recovery options under the 2015/16 PSO levy in Ireland. One can see that a uniform consumer levy is preferred only if inequality aversion is much lower than values identified in the empirical literature, in the order of magnitude of 0.25 or less. Should the subsidy cost burden increase, efficiency begins to take precedence in a greater number of circumstances. This is shown in Figures 6b - 6d. These are generally limited to scenarios where price elasticity of demand is high. Should the Irish subsidy burden increase threefold, for instance (Figure 6c), then a uniform consumer levy may be preferable should price elasticity of demand be high (c. -0.8). Inequality aversion must be in the region of 1, a value which remains on the low end of values identified in the empirical literature.

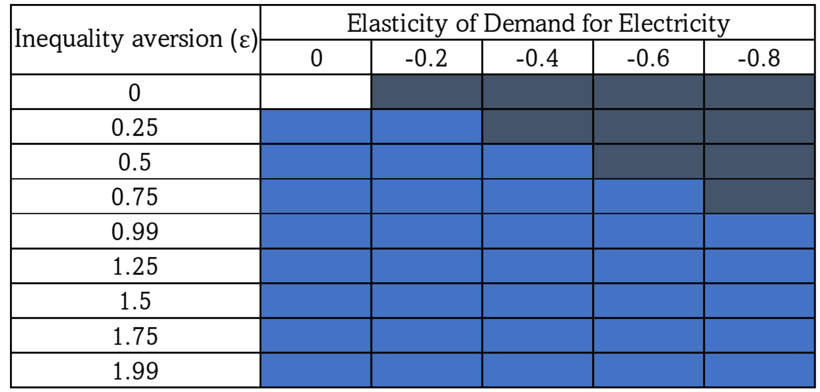
Once costs increase by about 4.5 times, efficiency becomes a greater concern. Figure 6d shows that the uniform consumer levy becomes the optimal choice for a wider range of scenarios, including those where price elasticities and assumed societal aversion to inequality converge on the range expected by the literature. However, these remain at the lower end of the expected range and therefore one may conclude that a uniform consumer levy may be considered in an Irish context as subsidy costs become a much greater proportion of household expenditure. Holding everything else constant, this occurs when costs are about 4.5 times the rates of the Irish PSO levy in 2015/16.

Figure 6: Equity vs. Loss in consumer surplus: uniform consumer levy or electricity price surcharge

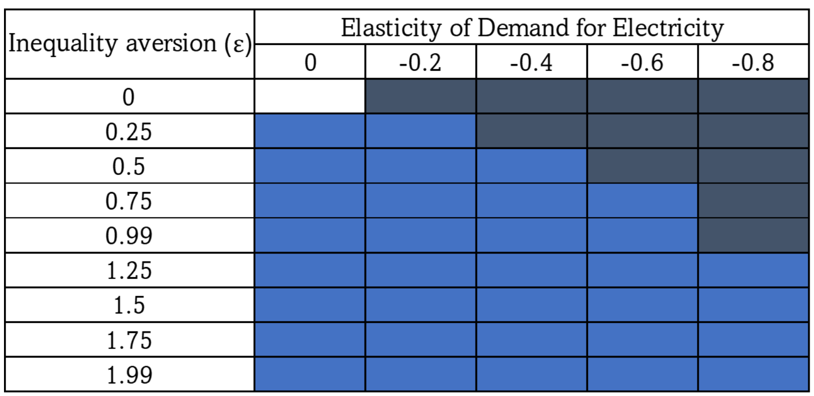
(a) Subsidy cost: 2015/16 levels



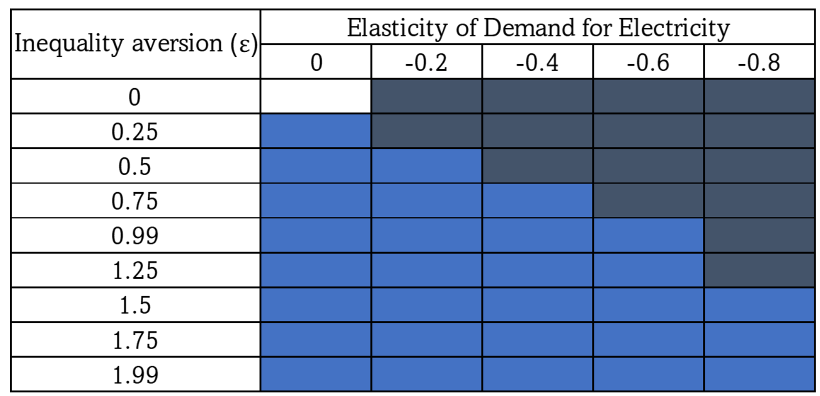
(b) Subsidy cost 2015/16 x2



(c) Subsidy cost: 2015/16 x3.5



(d) Subsidy cost: 2015/16 x4.5



Note: Figure shows welfare-maximising policy option considering relative preferences for equity and efficiency. Light blue indicates that an electricity surcharge is optimal, dark blue indicates that a uniform consumer levy is optimal. A white square indicates parity between policy options. Data Source: 2015/2016 Household Budget Survey (HBS)

4.2 Uninternalised emissions exist

When uninternalised emissions are present, there are two sources of welfare loss. First, an electricity price surcharge distorts prices, creating a loss in consumer surplus, a subset of which is a deadweight loss (See Figure 3). Second, should there be uninternalised environmental externalities, an electricity price surcharge mitigates against these effects. While it does not price emissions at the efficient rate, it prices them at a rate closer to the efficient rate. The net welfare effect when there are uninternalised emissions is therefore the value of the deadweight loss less the uninternalised environmental externalities.

In our considered 2015/16 scenario, the price of carbon emissions was c. €8.50 per annum. This is less than the expected social cost of carbon of €54.60. We calculate these effects under the counterfactual where there is (1) a carbon price surcharge of 46.10, such that the total cost of carbon corresponds to the expected social cost of carbon of €54.60 (US$ 60) and (2) an electricity price surcharge for 2015/16 energy subsidy cost recovery. Average effects per household are shown in Table 10, while total effects are shown in Table 11.

One can see that societal welfare net of both deadweight loss and avoided carbon emissions, is greatest should carbon be priced at a rate equal to the social cost of carbon. The deadweight loss in welfare is less than the avoided negative welfare effects of carbon emissions. When carbon is not priced at a rate equal to the social cost of carbon, Tables 10 and 11 show that an electricity price surcharge also yields a positive change in welfare; the positive effects due to avoided emissions outweigh the negative effects due to a deadweight loss. This is a second-best outcome relative to an efficient carbon price. As such, in the absence of a fully-internalised social cost of carbon, an electricity price surcharge may have a positive effect on societal welfare, should the additional price effect be less than or equal to that expected under an appropriately priced social cost of carbon.

Table 10: Average change in social surplus: carbon price and electricity price surcharge

	$\epsilon = 0$	$\epsilon = -0.2$	$\epsilon = -0.4$	$\epsilon = -0.6$	$\epsilon = -0.8$
	€	€	€	€	€
Target-consistent carbon price supplement (€46.10/tCO2)					
Change DWL	0	-0.996	-1.963	-2.902	-3.814
	-	(0.0005)	(0.001)	(0.0016)	(0.002)
Change Ext	0	2.035	4.027	5.977	7.884
	-	(0.001)	(0.002)	(0.003)	(0.004)
Net	0	1.040	2.065	3.075	4.070
	-	(0.001)	(0.001)	(0.002)	(0.002)
Electricity price surcharge					
Change DWL	0	-0.513	-1.047	-1.604	-2.186
	-	(0.000)	(0.001)	(0.001)	(0.001)
Change Ext	0	1.042	2.133	3.278	4.482
	-	(0.001)	(0.001)	(0.002)	(0.002)
Net	0	0.529	1.086	1.674	2.296
	-	(0.000)	(0.001)	(0.001)	(0.001)

Note: Change calculated as difference between welfare before any additional price surcharge and the specified scenario. Standard errors in parentheses calculated from weighted HBS sample using 1,000 bootstrap replications. All calculations rounded to three decimal places.

Table 11: Total annual change in social surplus: carbon price and electricity price surcharge

	$\epsilon = 0$	$\epsilon = -0.2$	$\epsilon = -0.4$	$\epsilon = -0.6$	$\epsilon = -0.8$
	€	€	€	€	€
Target-consistent carbon price supplement (€46.10/tCO2)					
Change DWL	0	-1,695,219	- 3,341,079	- 4,939,282	-6,491,531
Change Ext	0	3,463,625	6,854,063	10,173,015	13,418,781
Net	0	1,770,108	3,514,686	5,233,733	6,927,250
Electricity price surcharge					
Change DWL	0	- 873,140	-1,782,022	- 2,730,051	- 3,720,631
Change Ext	0	1,773,512	3,630,424	5,579,245	7,628,485
Net	0	900,372	1,848,401	2,849,193	3,907,854

Note: Change calculated as difference between welfare before any additional price surcharge and the specified scenario. Total calculated as average (Table 10) multiplied by HBS population.

5 Conclusion

The specification of efficient electricity tariffs requires the consideration of efficiency, equity, and environmental concerns. Well-established economic principles exist to guide efficiency; price should equal marginal cost and a carbon price equal to the social cost of carbon should be employed to internalise emissions externalities. Should innovation or capital investment not be served adequately by the market, a subsidy may be efficient. Should an efficient carbon price be infeasible due to institutional or political economy constraints, then a subsidy may also be considered as a second-best option. In both circumstances, costs must be recovered, with many markets choosing to do so through electricity consumer-levied surcharges.

This paper focusses on the welfare impacts of the two most common cost-recovery methods; a uniform consumer levy and an electricity price surcharge. We show that the method of cost-recovery is important, for equity, efficiency and environmental impacts. Taking an Irish case study, we show that an electricity price surcharge leads to an additional loss of consumer welfare of up to 3.3% per annum. However, an electricity price surcharge has a less progressive distribution of incidence; households in the lower end of the income distribution would benefit, on average, with the subsidy burden concentrated to a greater extent among wealthier households.

Comparing equity and efficiency effects, we show that the distributional and environmental benefits outweigh impacts on consumer welfare and efficiency. This pattern holds unless policy costs grow considerably and, even at this point, a uniform consumer levy is only cost-effective under scenarios of high price elasticity of demand and low levels of inequality aversion.

The final contribution of this paper is to compare welfare losses due to an electricity price surcharge, relative to the avoided carbon emissions from electricity consumption foregone. As expected, a carbon price equal to the social cost of carbon maximises societal welfare. However, we illustrate that, when carbon pricing is constrained to a value that is less than the social cost of carbon, and subsidies are used for second-best climate policy, an electricity price surcharge can lead to the welfare-maximising outcome should the surcharge be less than or equal to price of the uninternalised externality.

This research has a number of important policy implications. This is the first to demonstrate that the method of cost-recovery is important for equity, efficiency and environmental purposes. Second, we show that a tariff structure that is prima facie inefficient is potentially optimal, conditional on the magnitude of the cost and societal preferences for equity relative to efficiency. Finally, we show that the choice of energy subsidy cost-recovery can be used as a tool in a second-best world where carbon pricing is constrained to a level below social cost.

References

[1] Arun Advani, Paul Johnson, Andrew Leicester, and George Stoye. *Household energy use in Britain: A Distributional Analysis*. Number No. R85 in IFS Reports. 2013.

[2] International Energy Agency. Net zero by 2050. 2021.

[3] Kenneth Arrow. Economic welfare and the allocation of resources for invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, pages 609–626. Princeton University Press, 1962.

[4] Paul Baker, Richard Blundell, and John Micklewright. Modelling household energy expenditures using micro-data. *The Economic Journal*, 99(397):720–738, 1989.

[5] Salvador Barrios, Jonathan Pycroft, and Bert Saveyn. The marginal cost of public funds in the eu: the case of labour versus green taxes. Taxation Papers 35, Directorate General Taxation and Customs Union, European Commission, 2013.

[6] Lori Snyder Bennear and Robert N Stavins. Second-best theory and the use of multiple policy instruments. *Environmental and Resource economics*, 37(1):111–129, 2007.

[7] Citizen's Information Board. Citizen's information: Household benefits package. *citizensinformation.ie*, 2021.

[8] D R Bohi and M B Zimmerman. An update on econometric studies of energy demand behavior. *Annual Review of Energy*, 9(1):105–154, 1984.

[9] M. Boiteux. Sur la gestion des Monopoles Publics astreints a l'equilibre budgetaire. *Econometrica*, 24(1):22–40, 1956.

[10] Severin Borenstein. The Redistributional Impact of Nonlinear Electricity Pricing. *American Economic Journal: Economic Policy*, 4(3):56–90, August 2012.

[11] Severin Borenstein. The Economics of Fixed Cost Recovery by Utilities. *The Electricity Journal*, 29(7):5–12, 2016.

[12] Severin Borenstein and Lucas Davis. The Equity and Efficiency of Two-Part Tariffs in US Natural Gas Markets. *The Journal of Law and Economics*, 55(1):75–128, 2012.

[13] Ashani Burke, Paul J. & Abayasekara. The Price Elasticity of Electricity Demand in the United States: A Three-dimensional Analysis. *The Energy Journal*, 2017.

[14] CER. Review of competition in the electricity and gas retail markets: A consumer focussed assessment. *CER17019*.

[15] Mallika Chawla and Michael G. Pollitt. Energy-efficiency and environmental policies and income supplements in the uk: Evolution and distributional impacts on domestic energy bills. *Economics of Energy and Environmental Policy*, 2(1):21–40, 2013.

[16] Ronald Harry Coase. Monopoly Pricing with Interrelated Costs and Demands. *Economica*, 13(52):278–294, 1946.

[17] John F. Cogan. Fixed costs and labor supply. *Econometrica*, 49(4):945–963, 1981.

[18] Michael A. Crew and Paul R. Kleindorfer. Peak load pricing with a diverse technology. *The Bell Journal of Economics*, 7(1):207–231, 1976.

[19] CRU. Public service obligation levy 2014/15. Proposed Decision Paper CER/14/125, Commission for Regulation of Utilities, 2014.

[20] CRU. Public service obligation levy 2014/15. Proposed Decision Paper CER/15/142, Commission for Regulation of Utilities, 2015.

[21] CRU. Public service obligation levy 2020/21. Proposed Decision Paper CRU/20/061, Commission for Regulation of Utilities, 2020.

[22] Lucas W. Davis. The Economic Cost of Global Fuel Subsidies. *American Economic Review*, 104(5):581–585, 2014.

[23] Lucas W Davis and Erich Muehlegger. Do Americans consume too little Natural Gas? An Empirical Test of Marginal Cost Pricing. *The RAND Journal of Economics*, 41(4):791–810, 2010.

[24] Angus Deaton and Nicholas Stern. Optimally uniform commodity taxes, taste differences and lump-sum grants. *Economics Letters*, 20(3):263–266, 1986.

[25] DECC. Final stage impact assessment for the green deal and energy company obligation. Secondary Legislation IA No: DECC0072, DECC, 2012.

[26] Peter A Diamond and James A Mirrlees. Optimal taxation and public production i: Production efficiency. *The American economic review*, 61(1):8–27, 1971.

[27] Peter A Diamond and James A Mirrlees. Optimal taxation and public production ii: Tax rules. *The American Economic Review*, 61(3):261–278, 1971.

[28] Nada Eissa and Jeffrey B. Liebman. Labor supply response to the earned income tax credit. *The Quarterly Journal of Economics*, 111(2):605–637, 1996.

[29] James A. Espey and Molly Espey. Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities. *Journal of Agricultural and Applied Economics*, 36(1):65–81, 2004.

[30] Eurostat. Gini coefficient of equivalised disposable income (2020) - eu-silc survey. *https : //ec.europa.eu/eurostat/databrowser/view/tessi190/default/table?lang = en*, 2020.

[31] Shu Fan and Rob J Hyndman. The price elasticity of electricity demand in South Australia. *Energy Policy*, 39(6):3709–3719, 2011.

[32] Niall Farrell. *Wind Energy in Ireland*. Teagasc, Oak Park, 2013.

[33] Niall Farrell. The increasing cost of ignoring coase: Inefficient electricity tariffs, welfare loss and welfare-reducing technological change. *Energy Economics*, 97:104848, 2021.

[34] Niall Farrell and Sean Lyons. Who should pay for renewable energy? comparing the household impacts of different policy mechanisms in ireland. *Energy Research and Social Science*, 7:31–42, 2015.

[35] Martin S Feldstein. Equity and efficiency in public sector pricing: the optimal two-part tariff. *The Quarterly Journal of Economics*, pages 176–187, 1972.

[36] Massimo Filippini. Swiss Residential Demand for Electricity. *Applied Economics Letters*, 6(8):533–538, 1999.

[37] Centre for Sustainable Energy. Guidance document on cse dimpsa data. 2016.

[38] Miguel Gouveia and Robert P Strauss. Effective federal individual income tax functions: An exploratory empirical analysis. *National Tax Journal*, 47(2):317–339, 1994.

[39] Bruce C Greenwald and Joseph E Stiglitz. Externalities in economies with imperfect information and incomplete markets. *The quarterly journal of economics*, 101(2):229–264, 1986.

[40] André Grimaud, Gilles Lafforgue, and Bertrand Magné. Climate change mitigation options and directed technical change: A decentralized equilibrium analysis. *Resource and Energy Economics*, 33(4):938–962, 2011.

[41] Peter Grosche and Carsten Schroder. On the redistributive effects of germany's feed-in tariff. *Empirical Economics*, 46(4):1339–1383, 2014.

[42] Jerry A. Hausman. Chapter 4 taxes and labor supply. volume 1 of *Handbook of Public Economics*, pages 213–263. Elsevier, 1985.

[43] Cameron Hepburn, Jacquelyn Pless, and David Popp. Policy brief—encouraging innovation that protects environmental systems: Five policy proposals. *Review of Environmental Economics and Policy*, 12(1):154–169, 2018.

[44] Harold Hotelling. The Relation of Prices to Marginal Costs in an Optimum System. *Econometrica*, pages 151–155, 1939.

[45] Koichiro Ito. Do consumers respond to marginal or average price? evidence from nonlinear electricity pricing. *American Economic Review*, 104(2):537–63, 2014.

[46] Koichiro Ito and Shuang Zhang. Willingness to pay for clean air: Evidence from air purifier markets in china. *Journal of Political Economy*, 128(5):1627–1672, 2020.

[47] Jesse D Jenkins. Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? *Energy Policy*, 69:467–477, 2014.

[48] Matthias Kalkuhl, Ottmar Edenhofer, and Kai Lessmann. Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? *Resource and Energy Economics*, 35(3):217–234, 2013.

[49] Xavier Labandeira, José M. Labeaga, and Xiral López-Otero. A Meta-Analysis on the Price Elasticity of Energy Demand. *Energy Policy*, 102:549 – 568, 2017.

[50] Peter J Lambert, Daniel L Millimet, and Daniel Slottje. Inequality aversion and the natural rate of subjective inequality. *Journal of Public Economics*, 87(5-6):1061–1090, 2003.

[51] Paul Lehmann. Justifying a policy mix for pollution control: a review of economic literature. *Journal of Economic Surveys*, 26(1):71–97, 2012.

[52] Abba P Lerner. *Economics of control: Principles of welfare economics.* Macmillan and Company Limited, New York, 1944.

[53] Richard G Lipsey and Kelvin Lancaster. The general theory of second best. *The review of economic studies*, 24(1):11–32, 1956.

[54] Richard R. Nelson. The simple economics of basic scientific research. *Journal of Political Economy*, 67(3):297–306, 1959.

[55] Tim Nelson, Paul Simshauser, and Simon Kelley. Australian residential solar feed-in tariffs: Industry stimulus or regressive form of taxation? *Economic Analysis and Policy*, 41(2):113–129, 2011.

[56] Karsten Neuhoff, Stefan Bach, Jochen Diekmann, Martin Beznoska, and Tarik El-Laboudy. Distributional effects of energy transition: impacts of renewable electricity support in germany. *Economics of Energy & Environmental Policy*, 2(1):41–54, 2013.

[57] Ofgem. Targeted charging review: A consultation. *Report, Ofgem Energy Systems Integration Team*, 2017.

[58] Ofgem. Current network price controls (riio-1). 2018.

[59] Ofgem. Default tariff cap: Decision. 2018.

[60] Ofgem. Working paper 4: Treatment of environmental and social obligation costs under the default tariff cap. Technical Report Working paper number 4, DECC, 2018.

[61] Arthur M Okun. *Equality and efficiency: The big tradeoff.* Brookings Institution Press, 2015.

[62] Ian WH Parry. A second-best analysis of environmental subsidies. *International Tax and Public Finance*, 5(2):153–170, 1998.

[63] David Pearce. The Role of Carbon Taxes in Adjusting to Global Warming. *The Economic Journal*, 101(407):938–948, 07 1991.

[64] Joseph A. Pechman. Tax reform: Theory and practice. *Journal of Economic Perspectives*, 1(1):11–28, September 1987.

[65] Arthur Cecil Pigou. *The Economics of Welfare*. Macmillan, 1924.

[66] Simon Porcher. Efficiency and equity in two-part tariffs: the case of residential water rates. *Applied Economics*, 46(5):539–555, 2014.

[67] Simon Porcher. Efficiency and equity in two-part tariffs: the case of residential water rates. *Applied Economics*, 46(5):539–555, 2014.

[68] Frank P Ramsey. A contribution to the theory of taxation. *The Economic Journal*, 37(145):47–61, 1927.

[69] Steven Renzetti. Evaluating the welfare effects of reforming municipal water prices. *Journal of Environmental Economics and Management*, 22(2):147–163, 1992.

[70] Armon Rezai and Frederick Ploeg. Second-Best Renewable Subsidies to De-carbonize the Economy: Commitment and the Green Paradox. *Environmental & Resource Economics*, 66(3):409–434, March 2017.

[71] A.J. Ros. An econometric assessment of electricity demand in the united states using utility -specific panel data. *The Energy Journal*, 38(4):73–99, 2017.

[72] Sandbag. Carbon price viewer. Report, 2021.

[73] SEAI. Energy-related emissions in ireland: co_2 emissions from fuel consumption. Report, 2016.

[74] Nicholas Stern. The marginal valuation of income. In M.J. Artis and A.R. Nobay, editors, *Essays in Economic Analysis*. Cambridge University Press, Cambridge, 1977.

[75] Nicholas Stern and Joseph E Stiglitz. The social cost of carbon, risk, distribution, market failures: An alternative approach. Working Paper 28472, National Bureau of Economic Research, February 2021.

[76] Joseph E Stiglitz, Nicholas Stern, Maosheng Duan, Ottmar Edenhofer, Gaël Giraud, Geoffrey M Heal, Emilio Lèbre La Rovere, Adele Morris, Elisabeth Moyer, Mari Pangestu, et al. Report of the high-level commission on carbon prices. 2017.

[77] Stephen K Swallow and Carlos M Marin. Long run price inflexibility and efficiency loss for municipal water supply. *Journal of Environmental Economics and Management*, 15(2):233–247, 1988.

[78] UNFCCC. Paris agreement. *UN Treaty No. XXVII-7-d*, 2015.

[79] Stefano F. Verde and Maria Grazia Pazienza. Energy and climate hand-in-hand: Financing res-e support with carbon revenues. *Energy Policy*, 88:234–244, 2016.

[80] Frank A Wolak. The benefits of purely financial participants for wholesale and retail market performance: lessons for long-term resource adequacy mechanism design. *Oxford Review of Economic Policy*, 35(2):260–290, 04 2019.

[81] H Peyton Young. Progressive taxation and equal sacrifice. *The American Economic Review*, 80(1):253–266, 1990.

Appendix A Tariff Calculation

Each household must be matched with a electricity tariff representative of that which they faced in 2015/16. This allows us to elicit household-level PSO payments and quantity of electricity consumed. This is required as the HBS does not contain consumption volume or tariff data. The representative tariff is constructed in the following way. Ireland's retail electricity market was dominated by four suppliers in 2015/2016: Electric Ireland, Bord Gais, SSE Airtricity and Energia. Electricity tariffs change through time and, unfortunately, an archive of tariffs is unavailable. Two methods were taken to specify a set of representative tariffs. First, each supplier publishes their current tariffs online. While a supplier archive does not exist, an internet archive provides a snapshot of published tariffs at a given moment. This archive was consulted to identify a representative tariff from each supplier. The internet archive contains intermittent snapshots and the available snapshot that is closest to the HBS sample period is chosen.

The tariffs available on the internet archive are as follows. For Electric Ireland, September 2014 [Standard] and September 2015 [NightSaver] tariffs are available, For SSE Airtricity, tariffs for April 2015 are available. For Bord Gais, tariffs for March 2015 are available. For Energia, tariffs for November 2017 are available. For the standard tariffs, Tables 12- 15 lists each tariff (including VAT) and weighs the tariff according to market share (excluding minor participants such as PrePayPower, Pinergy and 'others' who collectively serve c.5% of the market). These data are obtained from [14]. Tables 16- 21 carry out this process for the nightrate tariff.

Under a standard tariff, all units consumed have the same volumetric price. Under a 'NightSaver' tariff, day and night consumption are subject to different prices. The HBS does not provide information on tariff type. Following [33] and [37], we use electric heating as a proxy for being on the NightSaver tariff, as the day/night meter is generally recommended for those with electric storage heaters. When calculating consumption, We assume 60% peak and 40% off-peak usage, following the assumptions of [33] and [37]. The resulting a weighted average volumetric tariff for urban and rural customers is outlined in Tables 22 and 23.

To validate our choice of tariffs, a second source is consulted. The Commission for Regulation of Utilities (CRU) has published the average electricity tariff for the 2015/16 time period. This tariff is shown in Table 28, yielding a very a similar tariff calculation.

The process of calculating the average tariff of Table 28 is outlined in Tables 24 - 27, weighted according to the market share data of [14]. Table 24 calculates the average expenditure per supplier. Table 25 subtracts the PSO levy. Table Table 26 calculates the

Table 12: Representative Standard Volumetric Tariff (€/ kWh): Urban Households

Firm	**Market share**	**€/kWh Urban**	**Weighted Average Price**
Electric Ireland	0.629	€0.1931	€0.1215
SSE Airtricity	0.163	€0.1908	€0.0311
Bord Gáis	0.163	€0.1831	€0.0298
Energia	0.044	€0.1890	€0.0083
		TOTAL:	**€0.1907**

Table 13: Representative Standard Tariff Standing charge: Urban Households

Firm	**Market share**	**Standing Charge**	**Weighted Average Price**
Electric Ireland	0.629	€139.61	€87.81
SSE Airtricity	0.163	€162.53	€26.49
Bord Gáis	0.163	€149.41	€24.35
Energia	0.044	€158.05	€6.95
		TOTAL/annum:	**€145.62**
		TOTAL/week:	**€2.80**

average standing charge. This is subtracted from the expenditure, along with the PSO, in Table 27. Finally, a weighted price is calculated in Table 28

Appendix B Sensitivity to tariff calculation

To further ensure the robustness of the tariff specification, a sensitivity analysis is carried out. Lower and upper bound tariffs are assumed to show that the results of this paper are insensitive to the chosen tariff calculation methodology presented above. We specify tariffs that are upper and lower bounds of the calculated tariffs, +/i 10%. Figure * shows that resulting distributional analysis is insensitive to this choice of tariff.

To ensure that our results are not sensitive to the assumed rate of disaggregation between day and nighttime usage for households on the 'Nightsaver' tariff, a sensitivity analysis is carried out. We vary the assumed 60% day/40% night split to 75% day/25% night and 40%

Table 14: Representative Standard Volumetric Tariff (€/ kWh): Rural Households

Firm	Market share	€/kWh Rural	Weighted Average Price
Electric Ireland	0.629	€0.1931	€0.1215
SSE Airtricity	0.163	€0.1947	€0.0317
Bord Gáis	0.163	€0.1835	€0.0299
Energia	0.044	€0.1890	€0.0083
		TOTAL:	**€0.1914**

Table 15: Representative Standard Tariff Standing charge: Rural Households

Firm	Market share	Standing Charge	Weighted Average Price
Electric Ireland	0.629	€186.13	€117.08
SSE Airtricity	0.163	€204.03	€33.26
Bord Gáis	0.163	€187.56	€30.57
Energia	0.044	€201.00	€8.84
		TOTAL/annum:	**€189.75**
		TOTAL/week:	**€3.65**

day and 60% night. 25% is a lower bound for off-peak consumption as below this figure it is more costly to be on a NightSaver meter than a standard 24hr meter.

Finally, Figure **??** shows that the inclusion of the household benefits package reduces the magnitude of the regressive burden but the pattern remains the same.

Appendix C Distribution of energy subsidy cost per unit

Table 16: Urban Nightsaver: €/kWh (day)

Firm	**Market share**	**€/kWh**	**Weighted Average Price**
Electric Ireland	0.629	€0.2011	€0.13
SSE Airtricity	0.163	€0.2079	€0.03
Bord Gáis	0.163	€0.1969	€0.03
Energia	0.044	€0.2073	€0.01
		TOTAL:	**€0.2016**

Table 17: Urban Nightsaver: €/kWh (night)

Firm	**Market share**	**€/kWh**	**Weighted Average Price**
Electric Ireland	0.629	€0.0994	€0.06
SSE Airtricity	0.163	€0.1029	€0.02
Bord Gáis	0.163	€0.0975	€0.02
Energia	0.044	€0.0993	€0.00
		TOTAL:	**€0.0996**

Table 18: Urban Nightsaver: standing charge

Firm	**Market share**	**Standing Charge**	**Weighted Average Price**
Electric Ireland	0.629	€191.64	€120.54
SSE Airtricity	0.163	€208.92	€34.05
Bord Gáis	0.163	€196.47	€32.02
Energia	0.044	€197.99	€8.71
		TOTAL/annum:	**€195.33**
		TOTAL/week:	**€3.76**

Table 19: Rural Nightsaver: €/kWh (day)

Firm	Market share	€/kWh	Weighted Average Price
Electric Ireland	0.629	€0.2011	€0.1265
SSE Airtricity	0.163	€0.2079	€0.0339
Bord Gáis	0.163	€0.2006	€0.0327
Energia	0.044	€0.2073	€0.0091
		TOTAL:	**€0.2022**

Table 20: Rural Nightsaver: €/kWh (night)

Firm	Market share	€/kWh	Weighted Average Price
Electric Ireland	0.629	€0.0994	€0.06
SSE Airtricity	0.163	€0.1029	€0.02
Bord Gáis	0.163	€0.0992	€0.02
Energia	0.044	€0.0993	€0.00
		TOTAL:	**€0.0998**

Table 21: Representative Rural Nightsaver Tariff: Standing Charge

Firm	Market share	Standing Charge	Weighted Average Price
Electric Ireland	0.629	€242.64	€152.62
SSE Airtricity	0.163	€254.40	€41.47
Bord Gáis	0.163	€243.40	€39.67
Energia	0.044	€251.88	€11.08
		TOTAL/annum:	**€244.84**
		TOTAL/week:	**€4.71**

Table 22: Representative Urban Nightsaver €/kWh Tariff

Period	Tariff	Proportion of use	Weighted tariff
Day	€0.2016	0.6	€0.1210
Night	€0.0996	0.4	€0.0398
	Weighted average		€0.1608

Table 23: Representative Rural Nightsaver €/kWh Tariff

Period	Tariff	Proportion of use	Weighted tariff
Day	€0.2022	0.6	€0.1213
Night	€0.0998	0.4	€0.0399
	Weighted average		€0.1613

Table 24: Annual average household expenditure incl. SC, PSO & VAT

Supplier	Jan-15 Exp.	Jan-16 Exp.	Average Exp.	Price (€/kWh)
Electric Ireland	1211	1182	1196.5	0.226
Energia	1253	1228	1240.5	0.234
Bord Gáis	1218	1169	1193.5	0.225
SSE Airtricity	1271	1218	1244.5	0.235

Note: Data pertain to average household expenditure for 5300kWh annual consumption. Calculation includes standing charge, PSO & VAT. 'Jan-15 Exp.' pertains to the average expenditure for January 2015, 'Jan-16 Exp.' pertains to the average expenditure for January 2016. 'Average Exp.' refers to the average of these two numbers.

Table 25: Annual average household expenditure incl. SC & VAT

Supplier	Average Exp.	Exp. less PSO	Price (€/kWh)
Electric Ireland	1196.5	1128.26	0.213
Energia	1240.5	1172.26	0.221
Bord Gáis	1193.5	1125.26	0.212
SSE Airtricity	1244.5	1176.26	0.222

Note: Data pertain to average household expenditure for 5300kWh annual consumption. Average Exp. pertains to average expenditure including standing charge, PSO & VAT (See table 24. 'Exp. less PSO' refers to average expenditure less a PSO of €68.24. This is the average PSO for 2015/16 as calculated by [14]. Price (€/kWh), refers to the average price inclusive of the standing charge and VAT alone.

Table 26: Annual Average Standing Charge

Supplier	**Jan-15 S.C.**	**Jan-16 S.C.**	**Average S.C**
Electric Ireland	122	127	124.5
Energia	140	139	139.5
Bord Gáis	131	130	130.5
SSE Airtricity	144	138	141

Note: Data pertain to average household expenditure for 5300kWh annual consumption. Calculation includes VAT. 'Jan-15 S.C.' pertains to the average standing charge for January 2015, 'Jan-16 S.C.' pertains to the average standing charge for January 2016. 'Average S.C' refers to the average of these two numbers.

Table 27: Annual average household expenditure incl. VAT

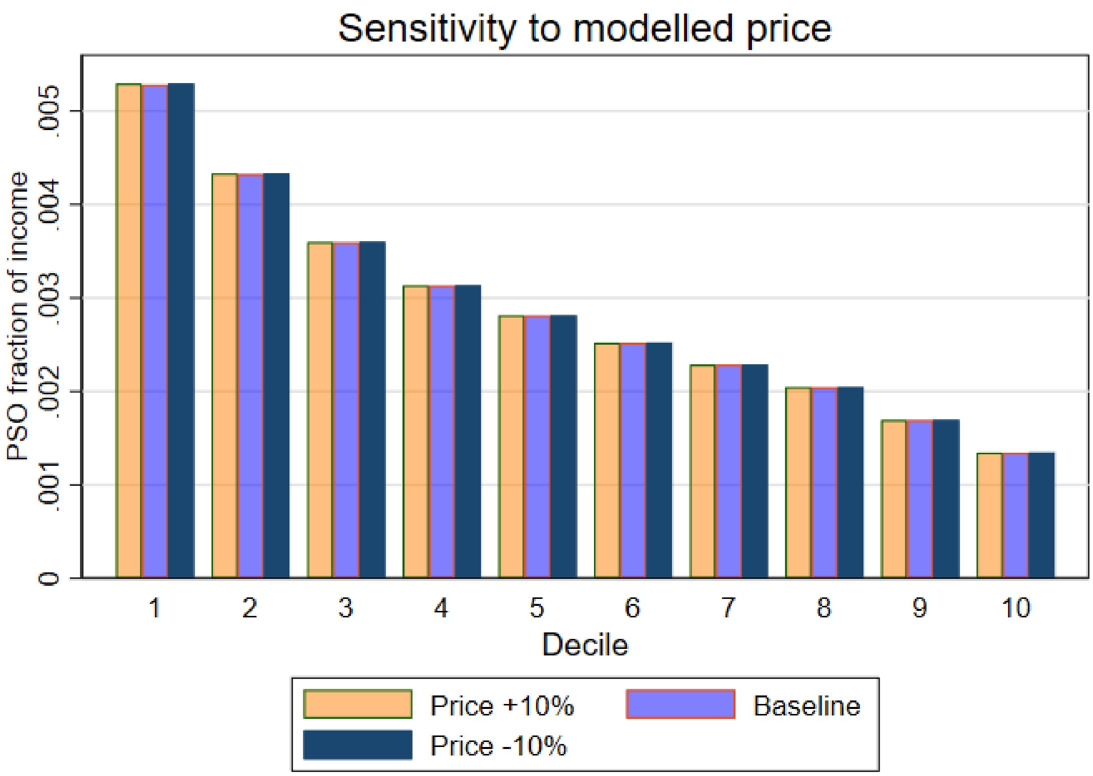
Supplier	**Average Exp.**	**Less PSO**	**Less S.C.**	**Price (€/kWh) incl. VAT**
Electric Ireland	1196.5	1128.26	1003.76	0.189
Energia	1240.5	1172.26	1032.76	0.195
Bord Gáis	1193.5	1125.26	994.76	0.188
SSE Airtricity	1244.5	1176.26	1035.26	0.195

Table 28: Weighted Average Tariff (Alternative Calculation)

Supplier	**Price (€/kWh)**	**Market Share**	**Weighted Price (€/kWh)**
Electric Ireland	0.1894	0.6290	0.1191
Energia	0.1949	0.1630	0.0318
Bord Gáis	0.1877	0.1630	0.0306
SSE Airtricity	0.1953	0.0440	0.0086
		Average:	0.1901

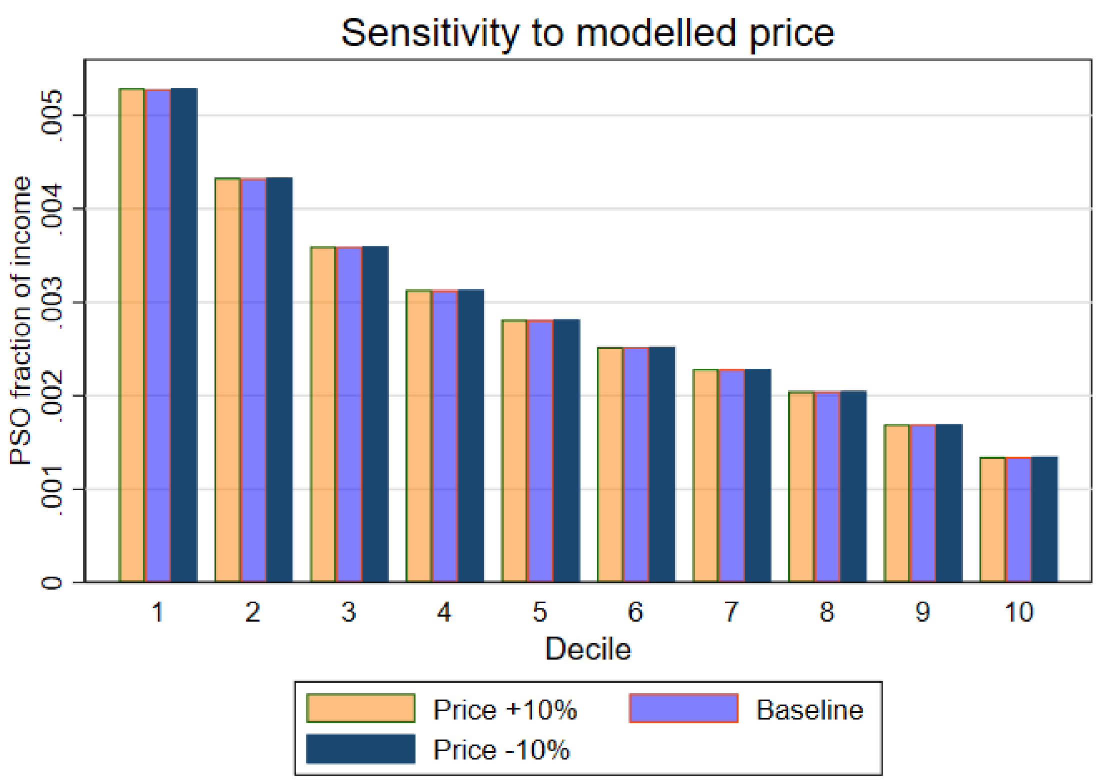
Note: Data pertain to average volumetric tariff as calculated by Tables 24 - 27, weighted according to the market share data of [14].

Figure 7: PSO burden as a proportion of income for alternative tariff calculations



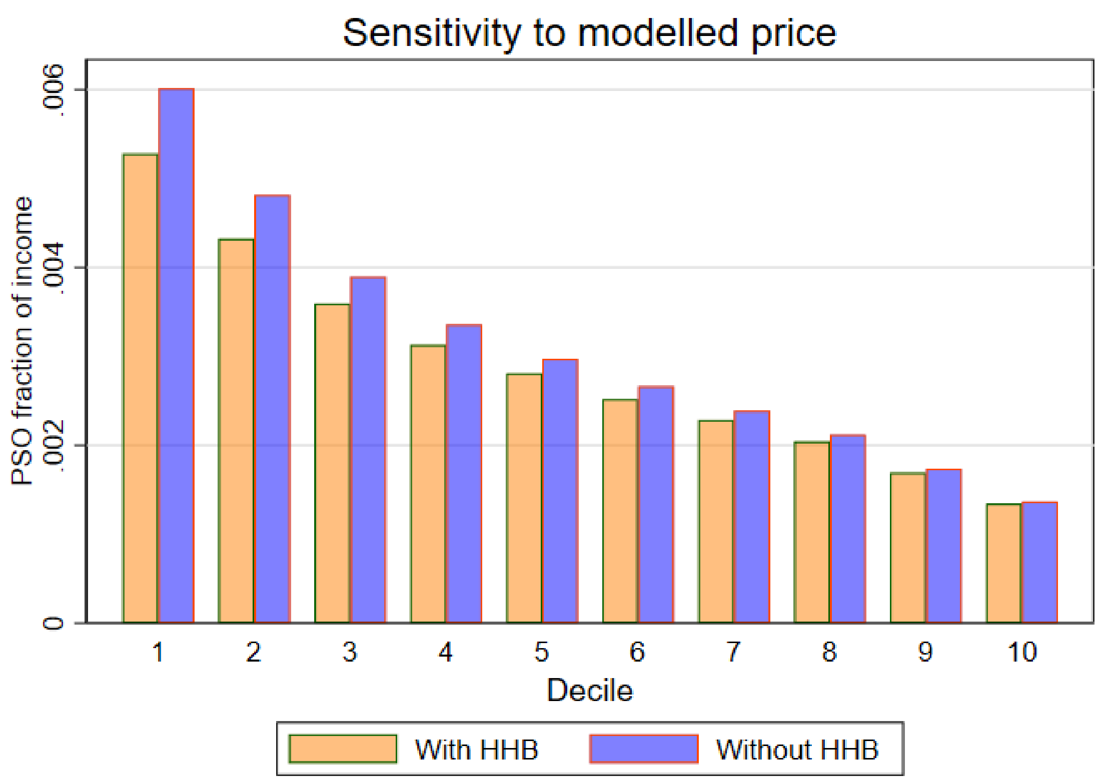
Note: Bars calculate PSO costs as a proportion of household equivalised disposable income. Price + 10% represents a scenario where the assumed baseline volumetric prices and standing charges are increased by 10%. Price - 10% represents a scenario where the assumed baseline volumetric prices and standing charges are reduced by 10%

Figure 8: PSO burden as a proportion of income for alternative day/night consumption disaggregations



Note: We vary the assumed 60% day/40% night split to 75% day/25% night and 40% day and 60% night. 25% is a lower bound for off-peak consumption as below this figure it is more costly to be on a NightSaver meter than a standard 24hr meter.

Figure 9: PSO burden as a proportion of equivalised disposable income: before and after accounting for the household benefits package



Note: We vary the assumed 60% day/40% night split to 75% day/25% night and 40% day and 60% night. 25% is a lower bound for off-peak consumption as below this figure it is more costly to be on a NightSaver meter than a standard 24hr meter.

Figure 10: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = 0$)

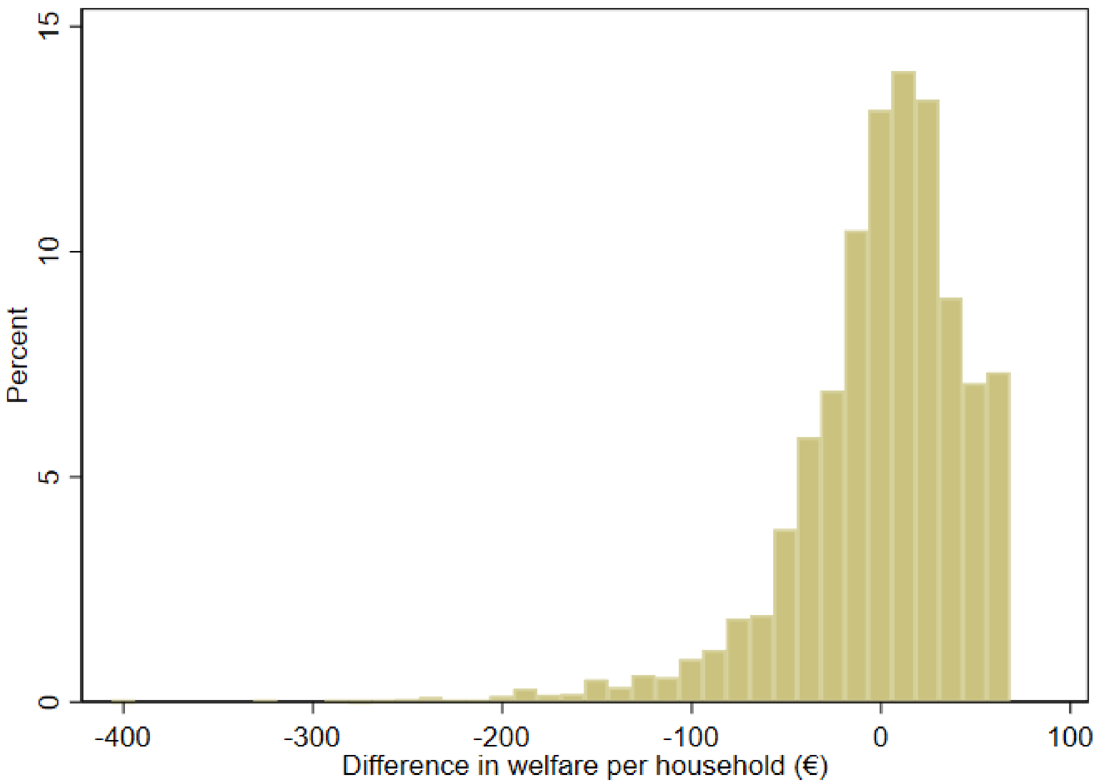


Figure 11: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = -0.2$)

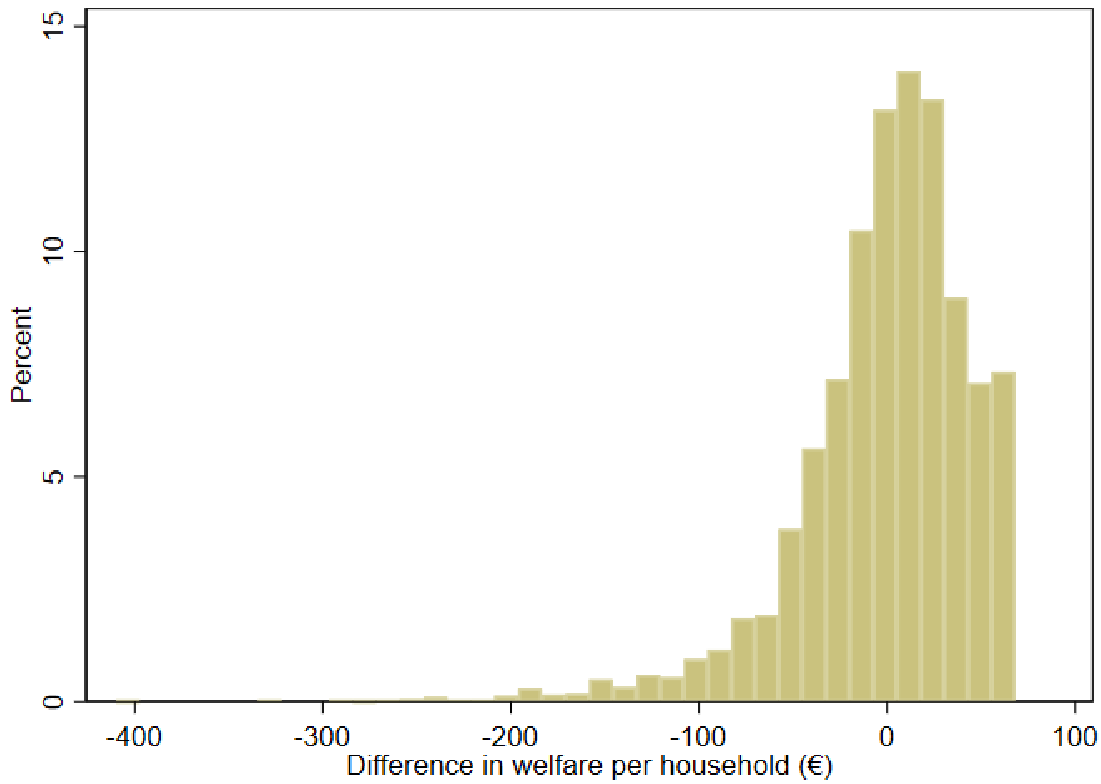


Figure 12: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = -0.4$)

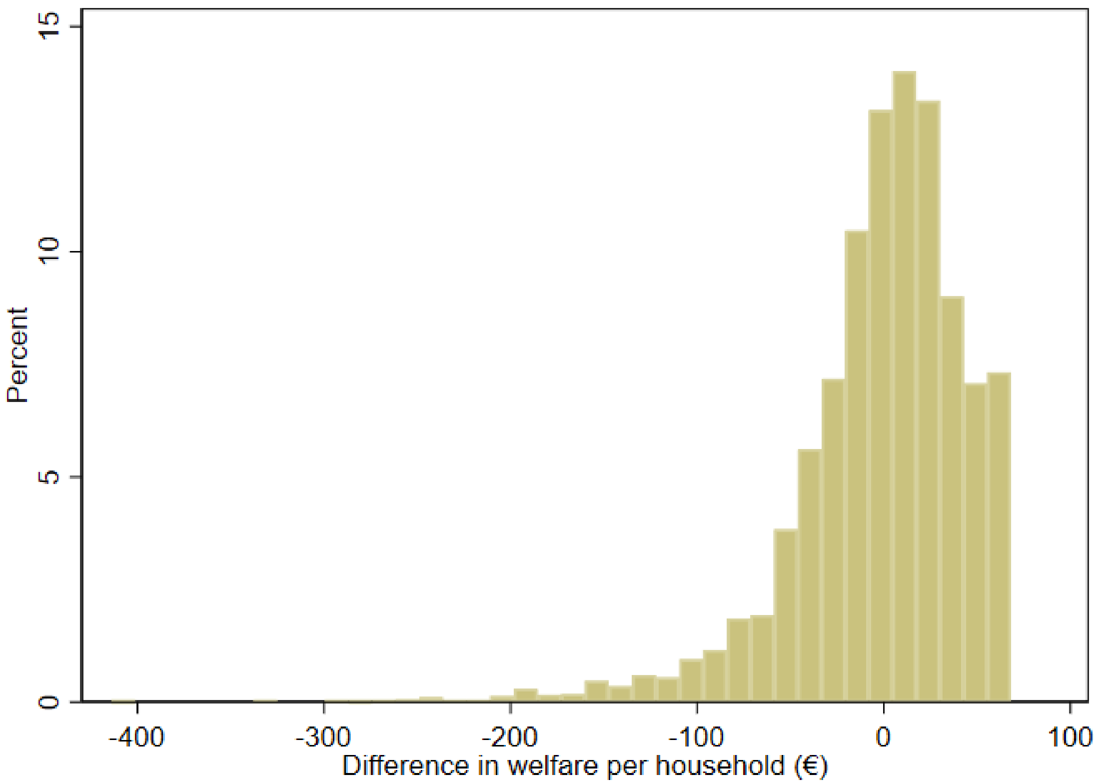


Figure 13: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = -0.6$)

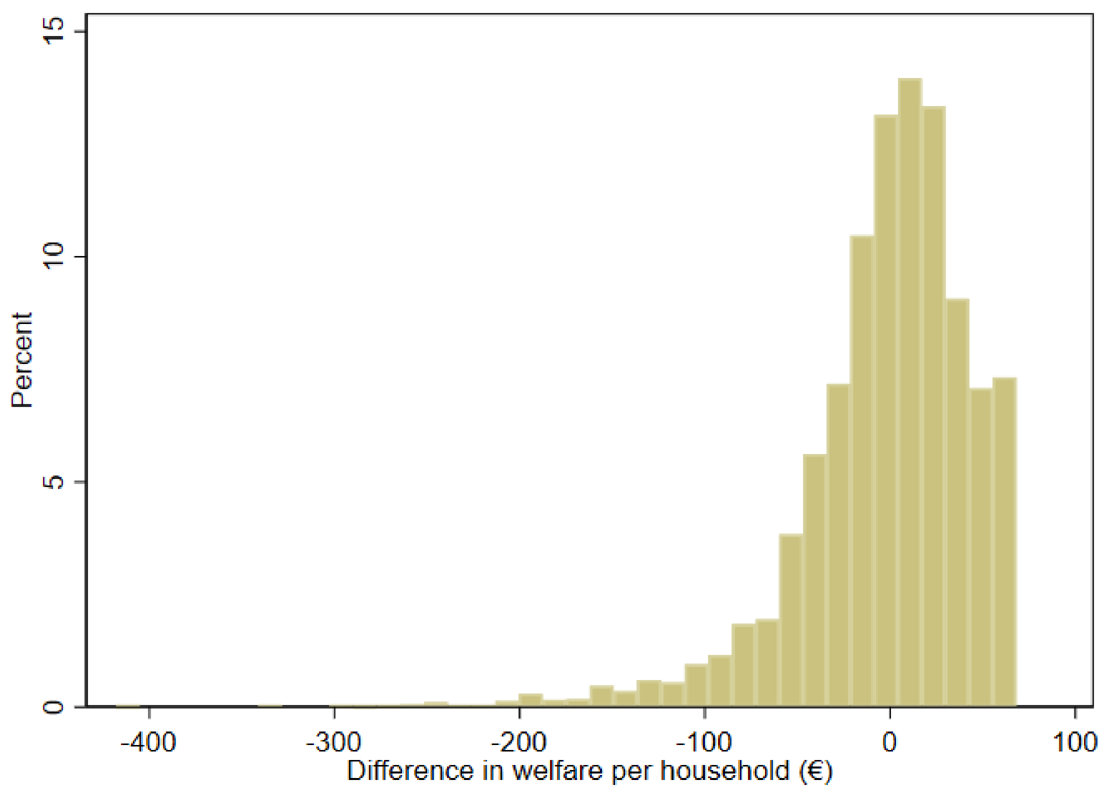


Figure 14: Annual household-level welfare losses due to switch from flat-rate levy to consumption surcharge ($\epsilon = -0.8$)

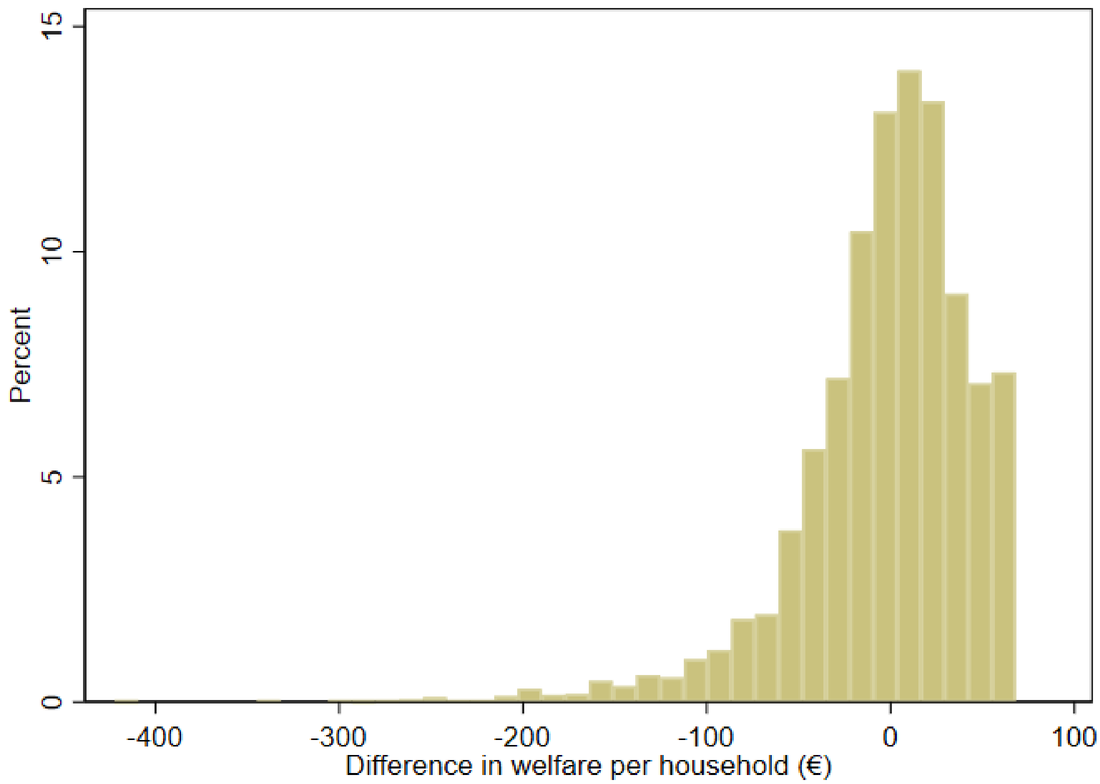
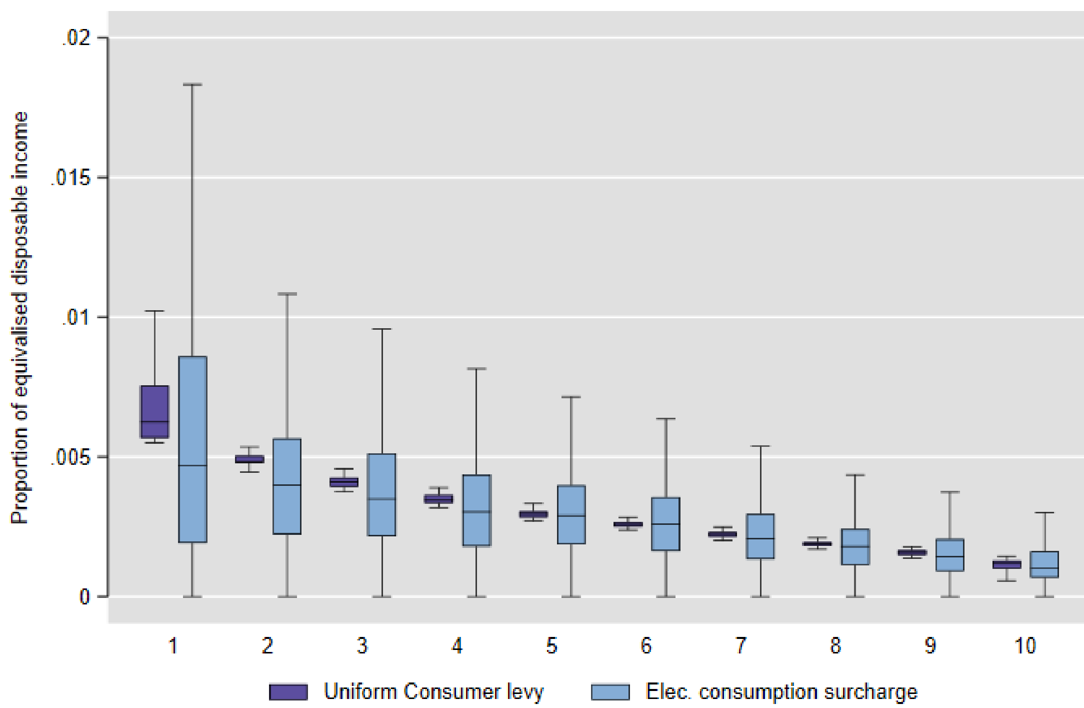
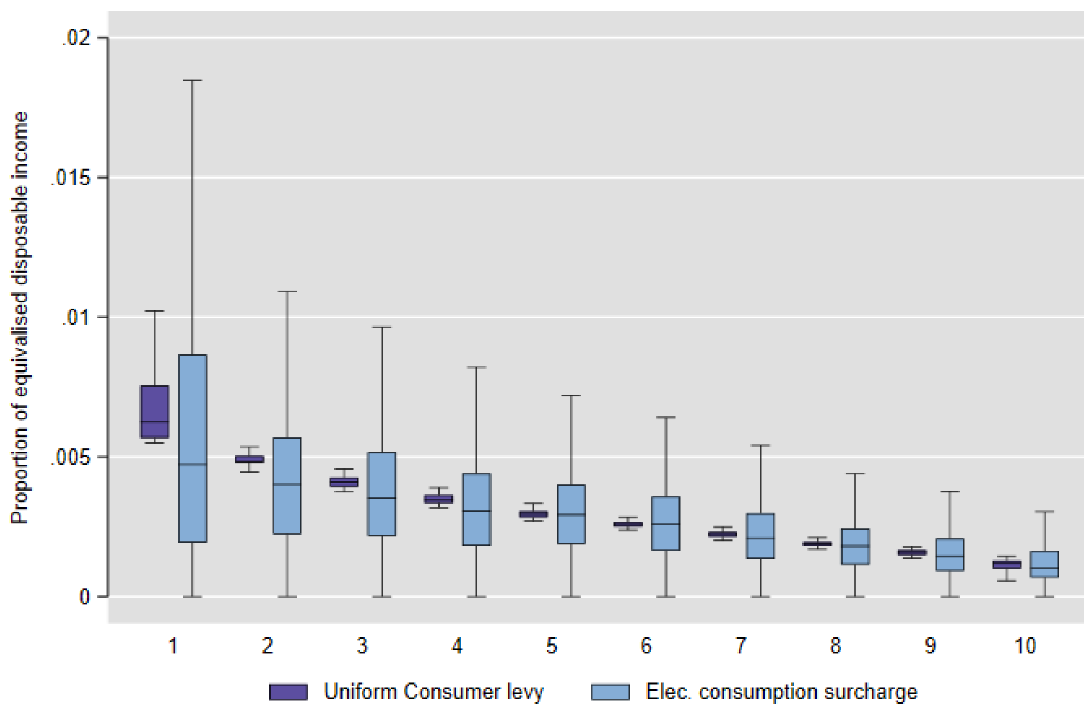


Figure 15: Energy subsidy cost as a proportion of equivalised disposable income ($\epsilon = 0$)



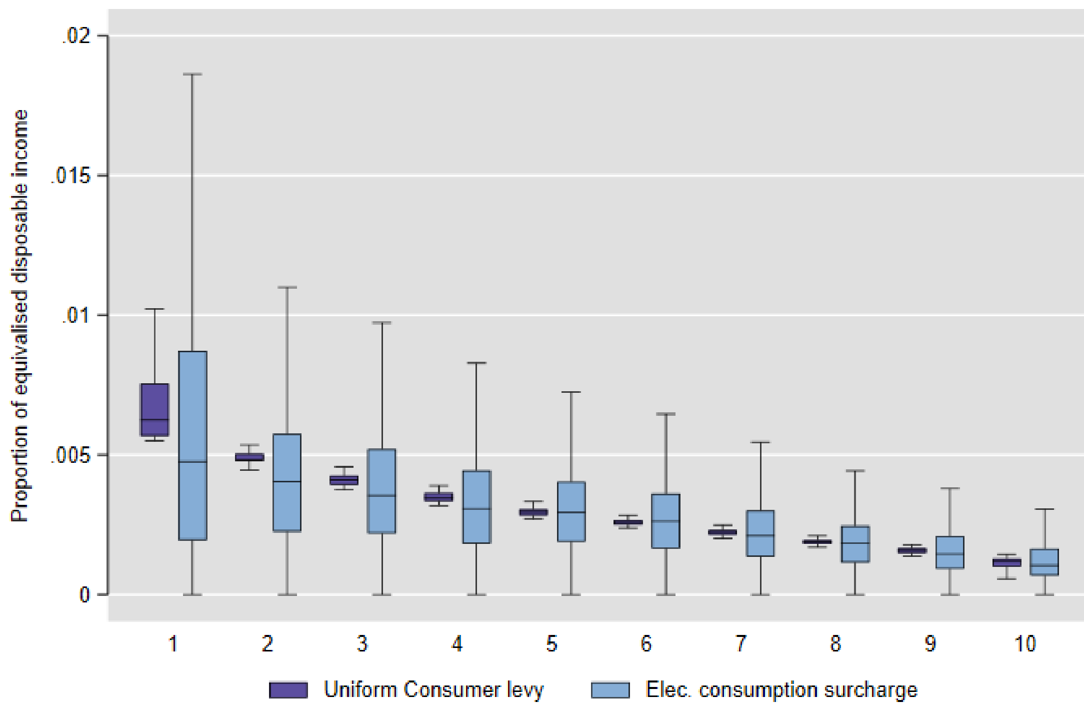
Note: Distribution calculated based on weighted HBS 2015/2016 sample. Figure excludes outliers

Figure 16: Energy subsidy cost as a proportion of equivalised disposable income ($\epsilon = -0.2$)



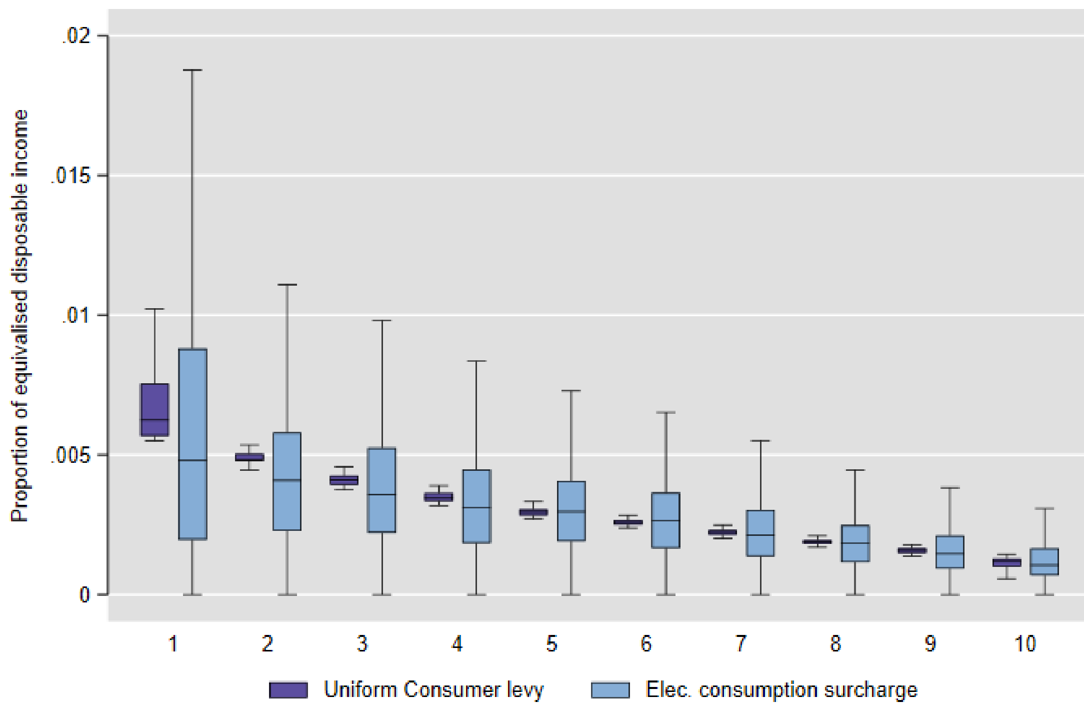
Note: Distribution calculated based on weighted HBS 2015/2016 sample. Figure excludes outliers

Figure 17: Energy subsidy cost as a proportion of equivalised disposable income ($\epsilon = -0.4$)



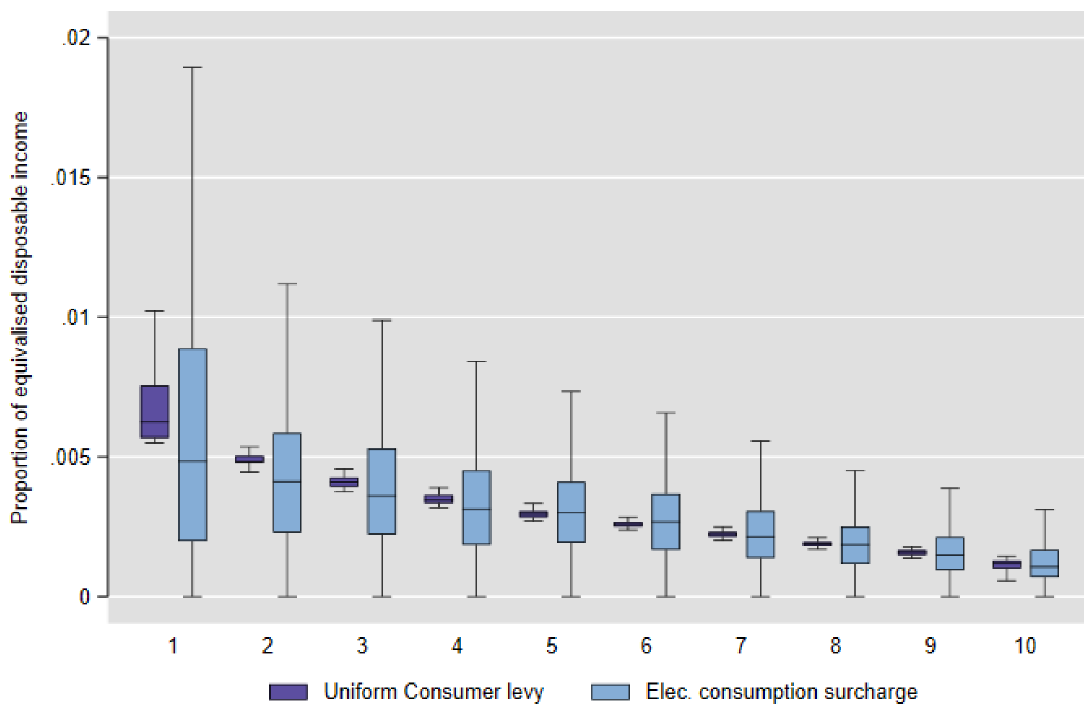
Note: Distribution calculated based on weighted HBS 2015/2016 sample. Figure excludes outliers

Figure 18: Energy subsidy cost as a proportion of equivalised disposable income ($\epsilon = -0.6$)



Note: Distribution calculated based on weighted HBS 2015/2016 sample. Figure excludes outliers

Figure 19: Energy subsidy cost as a proportion of equivalised disposable income ($\epsilon = -0.8$)



Note: Distribution calculated based on weighted HBS 2015/2016 sample. Figure excludes outliers