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Redistribution through Income Taxation and Public Utility Pricing in the Presence of Energy Efficiency Considerations

Abstract

Many OECD countries such as the USA, the UK or Switzerland are concerned with the affordability of utility services and the distributional consequences inherent in the pricing strategy of basic goods and services, such as electricity. However, the effectiveness of the electricity tariff as a redistribution device is questionable in the presence of a progressive income tax schedule. To shed light on this controversy, we structurally estimate a model that combines public utility pricing and income taxation. We employ a large panel data set on about 105,000 households in the Swiss Canton of Bern from 2008 to 2013, including detailed energy consumption and household income and tax payment characteristics. While the theoretical model predicts that electricity prices should be subsidised in the presence of purely income redistribution concerns, we find a positive mark-up of 49%, in our data. This suggests that, in practice, the government is concerned with energy conservation as well as income redistribution.

JEL-Codes: D120, D310, H210, H230, H240, L940, L980.

Keywords: redistribution, public utility pricing, energy, asymmetric information.

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1 Introduction

Governments worldwide have income redistribution and energy efficiency on their policy agendas. However, the optimal strategy for achieving these goals is subject to considerable debate. As such, whether or not public utilities should play a role in income redistribution remains an open issue. At the same time, the adequacy of different instruments for achieving energy efficiency, such as CO_2 taxes, subsidies for renewable energy, and so on, are also controversial.

The affordability and distributional effects of basic goods and services such as energy represents a salient issue in practice. For instance, most energy providers deviate from marginal cost pricing, relating to the regulator's role in redistributing income. For example, in the case of the CARE program in California, the program directly offers reduced energy rates for low income households (Borenstein, 2012). Similar concerns about the affordability of utility services, or the distributional effects of energy taxes are present in other OECD countries (Deller and Waddams, 2015; Flues and Thomas, 2015). In the United Kingdom, for instance, expenditures on energy represent the second largest expenditure item after food for the poorest 10% of households whereas it is negligible for the richest households (Advani, Johnson, Leicester and Stoye, 2013). Hence, it is not surprising that preceding the May 2017 elections, the representatives of both the Tories and the Labour party supported the introduction of energy price caps if markets "were thought to be failing ordinary families" (The Guardian, May 9^{th}, 2017). In Switzerland, voters also expressed similar concerns regarding the distributional consequences of energy tariffs, especially in light of the 2050 Energy Strategy and its implications, which the population voted on in 2017 (Meister, 2012; Boos, 2017). The above mentioned issues are even more pertinent in times of rising inequality, which cause economic, social and even political challenges.

Residential electricity markets also display particular characteristics given that the government heavily regulates electricity prices and that (partial) state monopolies provide the corresponding infrastructure. In practice, most countries finance the cost of energy transport and distribution infrastructure through energy price mark-ups.[4] In fact, energy providers commonly employ so-called two-part tariffs which include a fixed fee in addition to the variable charge. From a theoretical perspective, the mark-up is equivalent to a linear commodity tax and the fixed fee is equivalent to a head tax. We can draw an analogy

[4]In Europe, almost all energy providers use mark-ups to finance the energy infrastructure. The percentage of the grid charge ranges from 25% to 60% of total variable electricity costs (Eurostat, 2017).

to a consumption tax since we can compare the difference between the marginal cost and the price to the wedge introduced by a consumption tax between the consumer and the producer price. This constellation is thus similar to the theoretical debate concerning the economic justification of two tax instruments rather than one for income redistribution purposes (Atkinson and Stiglitz, 1976; Saez, 2002).

In this paper, we examine the extent to which the structure of public utility pricing influences income redistribution in the presence of energy efficiency considerations and a progressive income tax schedule. Given the ambiguous nature of the results of the theoretical literature on this topic, more extensive empirical research is necessary. Our paper aims to fill the gap produced by the very scant empirical evidence on this issue. We employ an extensive household level panel data set for the Swiss Canton of Bern and the years 2008-2013. In contrast to previous empirical studies that lack access to such detailed and granular household level information, and which disregard the existence of an income tax schedule, we structurally estimate a model that combines both taxation and public utility pricing. Our model addresses the equity efficiency trade-off in public utility pricing and incorporates the government's energy efficiency goals. We account for labour supply responses to taxation, allow for energy consumption-based welfare weights and for an asymmetric information setting between the regulator and the utility. Our theoretical model suggests that if the government exclusively considers income redistribution concerns, it should subsidise electricity prices. However, instead, our data reveals a positive price mark-up of 49%. This divergence between the theoretical predictions and the actual practice of Swiss utilities has different explanations. For instance, labour supply distortions induced by income taxation shift the optimal mark-up upwards. In addition, a positive mark-up also emerges if the government seeks to promote energy efficiency.

The paper adopts the following structure. The next Section presents an overview of the literature, Section three introduces the theoretical model and Section four outlines our structural estimation approach. Section five describes the data we employ and Section six presents the estimation results for the structural parameters and the simulation of optimal prices. In Section seven, we extend the model to allow for asymmetric information between the regulator and the utility, as well as for two part tariffs. Section eight provides a conclusion.

2 Literature

Our work contributes to the literature on the joint determination of optimal electricity prices and income taxation. Feldstein (1972a and b) was the first to consider the equity efficiency trade-off in public utility pricing. His contributions show that as long as the publicly produced commodity is not inferior, optimal prices will exceed marginal costs. Such a tariff structure provides gains in distributional equity because high-income individuals implicitly bear a larger fraction of fixed costs.[5] The resulting mark-up is a function of price and the income elasticity of electricity demand, and the mean and variance of the income distribution in the population, as well as a distributional parameter. He demonstrates that the optimal price is i.a. higher, the higher the income demand elasticity or the relative variance of income. Munk (1977) extends Feldstein's framework to a general equilibrium model and to a case where the alternative revenue source is an income tax. He shows that it is more likely that public utility costs are below marginal costs than assumed in Feldstein's model. Furthermore, when prices are below marginal costs, and the commodity must be subsidised accordingly, the redistributional costs are lower when the government can resort to a progressive income, as opposed to a head tax. In such a case, optimal prices depend on the distributional characteristics of the income tax. Munk's analysis reveals that, as long as the income elasticity of a tax increase is higher than the income elasticity of the demand for the commodity, the optimal price will be below the marginal cost. However, the above mentioned papers do not consider labour supply distortions due to income taxation, which we explicitly analyse in the model developed in the present paper. [6]

More recent papers, like that of Cremer and Gahvari (2002), also ascribe a redistributive role to nonlinear utility pricing in the presence of an optimal nonlinear income tax. When individuals differ in both earning ability and tastes, the marginal price a person

[5] An optimal two part tariff with a fixed fee and marginal prices equal to marginal costs is regressive due to the fixed component, which resembles a head tax. Feldstein (1972a) implicitly assumes that the alternative source of revenue is a head tax, since consumers cannot reduce the consumption of the publicly produced commodity to zero. In this two part tariff approach, consumers are charged a constant marginal price per unit purchased as well as a fixed fee.

[6] Jacobs and van der Ploeg (2017) address the more general question of if, from a theoretical point of view, corrective pollution taxes should also take distributional concerns into account. They show that, assuming Gorman polar preferences, such as quasi-linear preferences, pollution taxes should not deviate from the Pigouvian level, despite possible regressive effects. However, under more general utility functions, they can be set below the Pigouvian level if low income households spend a higher fraction of their income on polluting goods.

with a low valuation of public sector output encounters, must exceed the marginal cost. If however, earning ability and tastes are perfectly correlated, the marginal cost of the commodity should be strictly below its price - and this should hold for the entire population. This latter result is sometimes employed in the public debate as an argument for subsidising the electricity consumption of low income customers.

We make a number of contributions to this literature. First, we augment these models to account for energy consumption-based welfare weights. Second, we allow for non-zero labour supply responses. Third, we introduce asymmetric information between the regulator and the public utility, because in general, the two institutions may represent distinct entities with diverging interests. Fourth, we structurally estimate our model by drawing on extensive household level electricity consumption and expenditures information, as well as data on income and other sociodemographic attributes.

The aforementioned papers illustrate particular cases that are available in the generic literature that determines optimal commodity taxes jointly with optimal income taxes. The presence of a second instrument (mainly in the form of indirect taxation) for redistribution purposes, in addition to the nonlinear income tax, has a long tradition of being contentious in public economics since the seminal contribution of the Atkinson-Stiglitz (1976) theorem. This influential work demonstrates that, assuming weak separability between leisure and consumption goods, as well as homogeneous sub-utility of consumption across individuals, differential commodity taxation is redundant in the presence of optimal non-linear income taxation. This result can also be extended to apply to the pricing strategies of public utilities. In our context, an analogy can be drawn between the difference between the price and the cost set by a public utility and the wedge between the producer and the consumer price, introduced by a consumption tax (Bös, 1984). The Atkinson-Stiglitz result suggests that, under consumption-leisure separability, differential taxation cannot relax the incentive compatibility constraint that is inherent in the optimal tax problem and hence cannot reduce the underlying distortion of the labour leisure choice, instead, it adds further distortions to the choices between consumption goods (Kaplow, 2006).[7] In contrast, Saez (2002) shows that a differential commodity tax can be adequate

[7]The Atkinson-Stiglitz result applies when, conditional on income, the government sets the same social weights on similar individuals in terms of income. Saez (2002) shows that the crucial assumption relates to the conjecture of taste homogeneity - in other words, the fact that the entire population has the same subutility of consumption. Over the course of time, scholars have challenged the Atkinson-Stiglitz result, i.a.Stiglitz (1982), Naito (1999; 2007) or Christiansen (1984). Further contributions that ascribe a that ascribe a redistribution role to commodity taxation relax the underlying assumptions of the Atkinson-Stiglitz theorem. Hence, with different underlying production technologies (Naito, 2007), heterogeneity

if consumption patterns are related to leisure choices or earning power. In such circumstances, there may be a case for differential commodity taxes if high income individuals have a relative preference for a specific commodity, or if leisure and consumption of this commodity are positively correlated.

Our work also contributes to the body of literature that analyses the potential regressive or progressive effects of different environmental policies and energy prices. For instance, Burtraw, Sweeney, and Walls (2009), Hassett, Mathur, and Metcalf (2009) or Fullerton, Heutel, and Metcalf (2012) provide evidence for the regressive nature of US climate policy. Conversely, Chancel and Piketty (2015) find that the bottom 50% of carbon emitters only cause 13% of global emissions, whereas the top 10% are responsible for 45% of emissions, making the case for a global progressive carbon tax, which would be borne by the rich. With respect to energy prices, Borenstein (2012) shows that utilities charge non-marginal increasing block prices and inefficiently low access fees to protect low-income customers. Levinson and Silva (2018) find that energy utilities concerned about inequality charge lower than efficient fixed costs and higher than efficient volumetric charges. However, in contrast to our paper, these studies do not employ a framework that combines both personal income taxes and environmental policies. Instead, they solely address the redistributive effects of environmental policies, without accounting for the existence of an income tax.

This paper also relates to the literature on the inverse optimal tax-method, pioneered by Bourgignon and Spadaro (2000, 2012), and used to derive social welfare weights. A number of studies derive these weights for different countries and different types of individuals or households (see for instance Blundell, Brewer, Haan and Shephard, 2009; Bargain and Keane (2010); Lockwood and Weinzierl (2016) or Jacobs, Jongen and Zoutman (2017) for political welfare weights). We add to this line of research by adjusting welfare weights to include household energy consumption which reflects the government's desire to promote energy conservation.

between agents besides their ability (Cremer, Pestieau, and Rochet, 2001), different evasion characteristics of income vs. consumption taxes (Boadway and Richter, 2005) or wage uncertainty (Cremer and Gahvari, 1995), there is a scope for redistributive policy via a second instrument.

3 Theoretical model

Our theoretical model draws on Munk (1977) which is a generalization of Feldstein's (1972a) model. We study an economy with N households, a private good produced by a public utility and a private outside good produced by competitive firms. A benevolent regulator decides on two instruments. First, she sets the price of the good provided by the public utility (p_y). Second, she chooses the income taxation parameter (τ) in order to steer the revenue generated by income taxation. However, τ controls the total sum of tax revenue, while a predefined taxation scheme allocates the total sum to individual households. [8]

Household i's utility is a function of electricity consumption (y_i), private good consumption (x_i), labour (l_i) and a taste parameter (θ_i). Thus, a household's decision is characterised by the following constrained maximisation:

$$\begin{aligned} &\max_{x_i, y_i, l_i} u = u(y_i, \theta_i, x_i, l_i) \\ &s.t. \quad p_x x_i + p_y y_i \leq z(l_i) - t(z(l_i), \tau) + g, \end{aligned} \tag{1}$$

where $z(\cdot)$ is labour income, $t(\cdot)$ is the amount of taxes paid as a function of household income and the income tax parameter τ, and g is a lump sum transfer from the government. We assume that $u'(\cdot) > 0$ and $u''(\cdot) < 0$. By plugging the solution of the maximisation problem into the utility function we can express indirect household utility as:

$$v_i(p_y, p_x, \tau) = u(y_i(p_y, p_x, \tau), x_i(p_y, p_x, \tau), l_i(p_y, p_x, \tau), \theta_i) \tag{2}$$

The regulator maximises the weighted sum of the agents' utilities subject to the governmental budget constraint:

$$\max_{p_y, \tau} W = \sum_i w_i \cdot v_i(p_y, p_x, \tau) \tag{3}$$

$$s.t. \quad \sum_i \left[p_y y_i(p_y) + t(z_i, \tau)\right] \geq C\left(\sum_i y_i\right) + gN, \tag{4}$$

where w_i is the welfare weight assigned to each household and $C(\sum_i y_i)$ represents the public utility's total costs of providing the good (i.e. electricity generation and energy

[8] This assumption mimics political constraints or prohibitive costs to redesigning the structure of the overall tax system. Furthermore, it simplifies the regulator's decision while still allowing for non-linearity in income taxation.

infrastructure cost). We further assume that $\sum_i t(z_i, \tau) \geq gN$ such that we do not allow the public utility's revenue to cross-subsidise government lump sum transfers.[9]

Solving the regulator's maximisation problem yields the first order conditions[10] :

$$\frac{\partial W}{\partial p_y} = \sum_i w_i \frac{\partial v_i}{\partial p_y} - \varphi \left[\sum_i y_i + \sum_i p_y \frac{\partial y_i}{\partial p_y} - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i} \frac{\partial \sum_i y_i}{\partial p_y} \right] \tag{5}$$

$$\frac{\partial W}{\partial \tau} = \sum_i w_i \frac{\partial v_i}{\partial \tau} - \varphi \left[\sum_i \frac{\partial t_i}{\partial \tau} + \sum_i \frac{\partial t_i}{\partial z_i} \frac{\partial z_i}{\partial \tau} \right] \tag{6}$$

where φ is the Lagrange multiplier of the constraint and we replace $t(z_i, \tau)$ by t_i to simplify notation.

Combining both FOCs and expressing marginal utility in terms of the marginal utility of income λ_i, that is $\frac{\partial v_i}{\partial p_y} = -\lambda_i y_i$ and $\frac{\partial v_i}{\partial \tau} = -\lambda_i \frac{\partial t_i}{\partial \tau}$, yields:

$$-\sum_i w_i \lambda_i y_i + \sum_i w_i \lambda_i \left(\frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum_i t_i}{\partial \tau} + \sum_i \frac{\partial t_i}{\partial z_i} \frac{\partial z_i}{\partial \tau}} \right) \left[(p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}) \frac{\partial \sum_i y_i}{\partial p_y} + \sum_i y_i \right] = 0. \tag{7}$$

By rearranging terms we derive the following equation that determines the optimal mark-up:

$$\frac{p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}}{p_y} = \left(1 - \frac{R_y}{R_\tau} \right) \frac{1}{-\beta}, \tag{8}$$

As in Munk (1977), we define $R_y = \sum_i w_i \lambda_i \frac{y_i}{\sum_i y_i}$ as the distribution parameter of the good provided by the public utility, $R_\tau = \sum w_i \lambda_i \left(\frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum t_i}{\partial \tau} + \sum_i \frac{\partial t_i}{\partial z_i} \frac{\partial z_i}{\partial \tau}} \right)$ as the distribution parameter of income taxation and $\beta = \frac{\partial \sum_i y_i}{\partial p_y} \frac{p_y}{\sum_i y_i}$ as the price elasticity of commodity y. In the remainder of the paper, we will refer to the left hand side of the equation (8) as the (price) mark-up. The sign of the optimal mark-up is determined by the relative size of R_y and R_τ. R_y is high if households with high welfare weights consume a large share of good y.[11] R_τ is high if individuals with a high welfare weight bear most of an increase in income taxation. Thus, the mark-up depends on whether households with a high welfare weight are better off with a price increase or with a corresponding increase in income taxes.

[9] However, we do allow the social planner to use tax revenues to finance the energy infrastructure.

[10] We note that we assume the price effect on taxes and the tax effect on consumption to be of second order: $\frac{\partial t_i}{\partial p_y} \approx 0$, $\frac{\partial y_i}{\partial \tau} \approx 0$

[11] Hence, R_y is high for basic and low for luxury goods.

There are two main reasons why the regulator may wish to deviate from marginal cost pricing in the present model. First, correlation between the welfare weight and household's consumption of the good provided by the public utility allows the regulator to shift the tax burden to low welfare weight households through public utility pricing. Second, the pricing of y represents a second decision variable for the regulator, in addition to the income tax parameter τ. The following examples illustrate the intuition behind this result. The optimal mark-up is zero if all households receive an equal welfare weight (hence $R_y = R_\tau = 1$) and the effect of taxes on labour income is approximately zero ($\sum_i \frac{\partial t_i}{\partial z_i} \frac{\partial z_i}{\partial \tau} \approx 0$). Since electricity consumption is not correlated with the welfare weight, the price setting strategy of the utility does not provide any redistributive gains. The mark-up should also be zero if the redistributive impact of a price change is identical to the redistributive impact of a corresponding tax change ($R_y/R_\tau = 1$). In this case as well, the price setting of energy utilities does not offer any additional advantage over income taxes in terms of redistribution.

While public utility pricing may help to redistribute income, it also distorts households' consumption. With a non-zero mark-up, marginal utility does not equal the marginal production cost. This efficiency loss increases with the price elasticity of energy demand, as shown in equation (8). The higher the absolute value of the price elasticity β, the lower the absolute value of any mark-up.

We can compare the implications of equation (8) to the Atkinson and Stiglitz (1976) result of no-commodity taxation. As shown by subsequent proofs (cf. Laroque, 2005; Kaplow, 2006; Piketty and Saez, 2012), the Atkinson-Stiglitz result assumes that the non-linear income tax can mimic any commodity tax. In this case, commodity taxes distort optimal consumption without any redistributive benefit. Two main assumptions drive this result. First, the regulator can choose any non-linear income tax. Second, preferences are homogeneous such that consumption is identical across households conditional on income. In the model presented here, both assumptions are violated. The regulator can only adjust τ instead of setting optimal non-linear income taxes and the consumption of the good provided by the public utility might differ among households with the same income level. In our framework, people differ in two dimensions: their income (earning ability) and their preference for electricity. Hence, the distributional incidence of any electricity price cannot be perfectly off-set by the income tax. This would be the case if labour earnings were the only reason for which people differ. Consequently, under certain circumstances, public utility pricing that deviates from marginal costs generates redistributive gains.

4 Structural model of electricity grid pricing

Households

We assume the following quasi linear utility function and linear energy pricing[12] and separability between the leisure consumption choice. This functional form is appropriate when the good under consideration, in this case electricity, constitutes a small part of an agent's income. Furthermore, such a non-homothetic function implies that consumption of the good is independent of an agent's income, which confirms what we find in the data since electricity consumption does not vary with income conditional on other household characteristics. y_i denotes electricity consumption, x_i consumption of the outside private good, l_i household labour supply, θ_i a taste parameter for electricity consumption specific to customer i and ϵ the elasticity of taxable income [13]:

$$u(y_i, l_i, x_i, \theta_i) = x_i + \frac{\beta}{1+\beta} y_i^{\frac{1+\beta}{\beta}} \theta_i^{\frac{1}{-\beta}} - \frac{\epsilon}{1+\epsilon} l_i^{\frac{1+\epsilon}{\epsilon}} \tag{9}$$

$$s.t. \quad x_i + p_y y_i \leq z(l_i) - t(z(l_i), \tau) + g. \tag{10}$$

Setting the private good x_i as nummeraire, household utility maximization yields the following demand function:

$$y_i = p_y^{\beta} \theta_i \tag{11}$$

We define $z(l_i) = w_i l_i$, where w_i is wage per unit of labor. The following condition defines optimal working hours as a function of the taxation parameter τ:

$$l_i = \left[w_i (1 - t'(\tau, z(l_i)) \right]^{\epsilon} \tag{12}$$

[12] We do not consider non-linear energy pricing, such as increasing block pricing. While block pricing is a common practice in the USA, Switzerland and many EU countries use linear pricing. The fixed cost F of the energy infrastructure indirectly induces a nonlinearity for the average cost but not for the marginal costs, which is of main interest in the present model.

[13] In a framework with corrective pollution taxes instead of energy pricing, quasi-linear utility functions would suggest that the optimal pollution tax should not deviate from the Pigouvian level, according to Jacobs and van der Ploeg (2017). However, they do not allow for heterogeneous taste as we do in the present framework. In our model, people differ in their income (earning ability) and their preference for electricity. Hence, the distributional incidence of any electricity price cannot be perfectly off-set by the income tax. Furthermore, even assuming homogeneous tastes, the government may resort to indirect taxation as a practical third-best instrument in order to redistribute income and collect revenues if it is not able to collect and administer labour income effectively, as is the case in developing countries (see Deaton, 1977).

Cost of electricity production and transmission

The total costs of the energy utility $C(\sum y_i)$ include two components: The variable cost of energy production and the fixed cost of the transmission and distribution infrastructure. We specify the following cost function of the energy utility:

$$C(\sum y_i) = \sum y_i c + F \tag{13}$$

where c represents the generation cost of one unit of electricity and F denotes fixed infrastructure costs.

Tax function

Following Heathcote, Storesletten, and Violante (2016), we define the functional form of the individual tax burden as follows:

$$t_i = z_i - (1-\tau)z_i^{1-\omega}, \tag{14}$$

Thus, individual tax payments t_i are a function of labour income and two additional parameters. Parameter ω captures the degree of tax progressivity. When $\omega > 0$ the tax system is progressive, when $\omega < 0$ it is regressive and when $\omega = 0$ it is linear. [14] Parameter τ determines the average level of taxation in the economy. Specifically, increasing τ raises additional revenue from households. τ and the total revenue generated by income taxation are mutually dependent. That is, the total tax revenue required by the government $\sum \bar{t}_i$ implicitly defines τ for a given sum of total labour income: $\tau = \frac{\sum \bar{t}_i - \sum z_i}{\sum z_i^{1-\omega}} + 1$.

Welfare weight

We specify an income-based welfare weight where the welfare weight of household i is defined as $w_i^z = \left(\frac{z^1}{z_i}\right)^e$. e captures inequality aversion and z^1 is the income of the poorest household (Madden and Savage, 2014). In our preferred specification, we set $e = 1$[15] such that:

$$w_i^z = \frac{z^1}{z_i}.$$

[14] $1 - \omega = \frac{1-\frac{\partial t_i}{\partial z_i}}{1-\frac{t_i}{z_i}} = \frac{ATR}{MTR}$ (Heathcode, Storesletten and Violante, 2016).

[15] See also H.M. Treaury (2011), Appraisal and Evaluation in Central Government. Technical report.

In addition, a regulator concerned with energy efficiency assigns households a welfare weight based on their respective electricity consumption. This is also in line with more recent contributions (Saez, 2002 or Saez and Stantcheva, 2016) that posit that welfare weights may even differ between individuals with the same income if the government favours some types of individuals over others. Saez and Stantcheva (2016) also advance the concept of so called generalised social welfare weights, which can be defined very generally and thus capture a broader set of justice concepts. The characteristics that are thus part of these welfare weights reflect the dimensions along which society considers redistribution to be fair. In the present framework, this suggests that society considers low electricity consumption households to be more deserving and, accordingly, the government assigns higher welfare weights to these households. Hence, the electricity consumption-based weight reads:

$$w_i^y = \frac{y^1}{y_i},$$

The total welfare weight of each household is the weighted sum of the income based weight and the electricity consumption based weight:

$$w_i = (1-\pi)w_i^z + \pi w_i^y = (1-\pi)\left(\frac{z^1}{z_i}\right) + \pi\left(\frac{y^1}{y_i}\right),$$

where π is the relative weight the regulator assigns to income and efficiency considerations, respectively. [16]

Optimal price markup

In this last step, we insert the elements defined above into equation (8) in order to derive the price mark-up as a function of the parameters that we can estimate from the data[17]:

$$\frac{p_y - c}{p_y} = \left(1 - \frac{\sum_i \left((1-\pi)\frac{z^1}{z_i} + \pi\frac{y^1}{y_i}\right)\frac{y_i}{\sum_i y_i}}{\sum_i \left((1-\pi)\frac{z^1}{z_i} + \pi\frac{y^1}{y_i}\right)\left(\frac{z_i^{1-\omega}}{\sum_i z_i^{1-\omega} - \epsilon\sum_i [\frac{z_i}{1-\tau} - (1-\omega)z_i^{1-\omega}]}\right)}\right)\frac{1}{-\beta}. \tag{15}$$

[16]The literature on the optimal direct-indirect tax structure also considers the implications of externalities. Accordingly, Sandmo (1975) or Pirtilla and Tuomala (1997) study the issue of second-best commodity taxation in the presence of externalities. In this case, differential commodity taxation may be appropriate and taxing a polluting good plays the role of a Pigouvian corrective tax as well as of a revenue raising instrument.

[17]See Appendix B for details on the derivation.

Based on the optimality condition above, the regulator essentially decides how to finance the utility's fixed cost F: either by setting energy prices above marginal costs or by increasing income taxation. In practice, most regulated energy providers levy a grid charge on top of the market price of electricity, such that $p_y - c > 0$.

5 Data

We base our empirical analysis on Swiss data. While Switzerland is one of the richer OECD countries, energy consumption is an important part of household expenditure. In fact, in 2013, Swiss households' spending on energy related to housing amounted to roughly 3% of their total final good consumption (Bundesamt für Statistik, 2018), a share that is in line with that of many other OECD countries.[18] Examining the underlying research question using Swiss data offers several advantages for our analysis. First, the electricity market for private customers is not yet liberalised. Second, electricity tariffs are subject to rate-of-return regulation and must be approved by the federal agency, Elcom. Third, Swiss law demands that energy providers incorporate energy efficiency considerations into their tariff design.

Our unique household level data includes the Canton of Bern, the second largest Swiss canton in terms of population, inhabited by 1,001,281 individuals and covering an area of 5,959 km^2. We combine data from three different sources. First, we use detailed income, wealth and tax data from Bern's tax administration. This data allows us to infer various household characteristics. Second, BKW, the Canton of Bern's main energy utility, supplied us with energy consumption and expenditure data. Third, we draw on building characteristics information supplied by the Swiss Federal Statistical Office. Our ultimate data set spans the years 2008 to 2013. For more information on the data and its merging process we refer the reader to Feger, Pavanini, and Radulescu (2017).

In Switzerland, customers face a two-part electricity tariff, that is, utilities apply a volumetric charge (i.e. a price per kWh of electricity consumption) and a fixed fee. The volumetric charge is a linear price and combines three elements: the price of electricity generation, a grid charge to finance part of the infrastructure and several taxes on electricity consumption[19]. In the context of this paper, the grid charge and taxes represent a positive mark-up on marginal electricity costs. Table 1 illustrates the relative impor-

[18]In the same year USA/UK households spent 2.2% / 3.2% of total final good expenditure on energy. The average for European Union countries in that year was 4.7% (OECD Statistics, 2018)

[19]A municipal tax and a tax to finance subsidies on renewable energy.

tance of the tariff elements for BKW. The combined volumetric charge amounts to 23-25 Rp/kWh during the 2008-2013 period. The mark-up on the electricity cost is mainly used to finance grid investments. The mark-up shows a slight downwards trend induced by a reduction in grid charges. Lastly, the annual fixed fee is 100-140 CHF, which corresponds to roughly a tenth of the total electricity bill for an average household in 2013.

Table 1: Prices and mark-up between 2008-2013 - BKW

Variables	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Fixed fee						
Basic grid fee (CHF)	142.03	142.03	142.03	122.66	103.68	103.68
Volumetric charge elements						
Energy price (Rp/kWh)	11.03	11.03	11.3	11.78	11.83	11.77
Grid price (Rp/kWh)	10.49	11.3	11.3	10.6	8.91	8.91
Swissgrid tax(Rp/kWh)	0	0	0	0	.43	.33
KEV tax (Rp/kWh)	.16	.48	.48	.48	.49	.49
Municipal tax (Rp/kWh)	1.59	1.59	1.59	1.59	1.6	1.6
Total volumetric charge (Rp/kWh)	23.3	24.4	24.7	24.5	22.8	22.6
Markup (%)	52.6	54.8	54.2	51.8	49.1	49

Notes: The table presents the prices for BKW's uniform tariff. We omit BKW's prices for the double tariff scheme (separate prices for peak and off-peak consumption) for illustrative purposes. Swiss Grid is the national monopoly that owns the high voltage grid. KEV is a federal subsidy scheme that finances feed-in remuneration for renewable energy.

Table 2 provides summary statistics for our sample. We have information on 502,141 pooled observations, including approximately 105,000 households over 5 years. As Table 2 shows, mean taxable income[20] amounts to CHF 75,053 with a taxable wealth average of CHF 578,577. Switzerland is a federal state so taxes are levied on three different levels. The cantonal tax constitutes the largest part of average tax payments and is approximately twice and four times as high as the municipal tax and federal tax, respectively. Table 2 also illustrates that annual mean household electricity consumption reaches 4,926 kWh with a corresponding electricity bill of 1,066 CHF. Lastly, the table reports different household and apartment characteristics, which are available in our data.

[20]Taxable income is defined as total income (in the form of labour income or income from self-employment) plus the rental value of owner occupied housing less mortgage interest payments and commuting and living expenses.

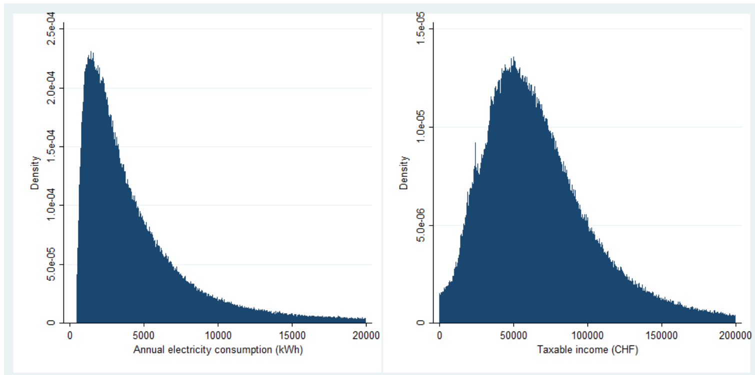
Table 2: Overview main variables

	N Obs	Mean	Std Dev	5th Perc	Median	95th Perc
Tax Data						
Taxable income (CHF)	502,141	75,053	128,033	10,615	63,764	161,949
Taxable wealth (CHF)	502,141	578,577	2223694	0	325,365	1717864
Cantonal tax (CHF)	502,141	7,502	15,307	69	5,535	19,175
Municipal tax (CHF)	502,141	3,849	7,192	37	2,907	9,715
Federal tax (CHF)	502,141	1,814	10,205	0	493	6,582
Electricity Data						
Consumption (kWh)	502,141	5,649	5,565	1,015	3,939	16,874
Electricity bill (CHF)	502,141	1,226	970	358	941	3,224
Characteristics						
Homeownership (%)	502,141	52.9	49.9	0	100	100
One apartment house (%)	502,141	34.4	47.5	0	0	100
Apartment area (sqmt)	502,141	107	44	57	97	190
Married (%)	502,141	56.9	49.5	0	100	100
Household size	502,141	2.1	1.1	1	2	4
Age household head	502,141	54.7	16	29	54	82
Retired (%)	502,141	31.7	46.5	0	0	100

Notes: The descriptive statistic is pooled over all companies and years. The sample contains 104826 unique households.

Figure 1 depicts income distribution, as well as the distribution of energy consumption, which are important for our subsequent analysis. The distribution of energy consumption is heavily skewed to the right, whereas the skewness is less pronounced in the case of the income distribution. While not presented here, the distribution of wealth looks fairly similar to income distribution.

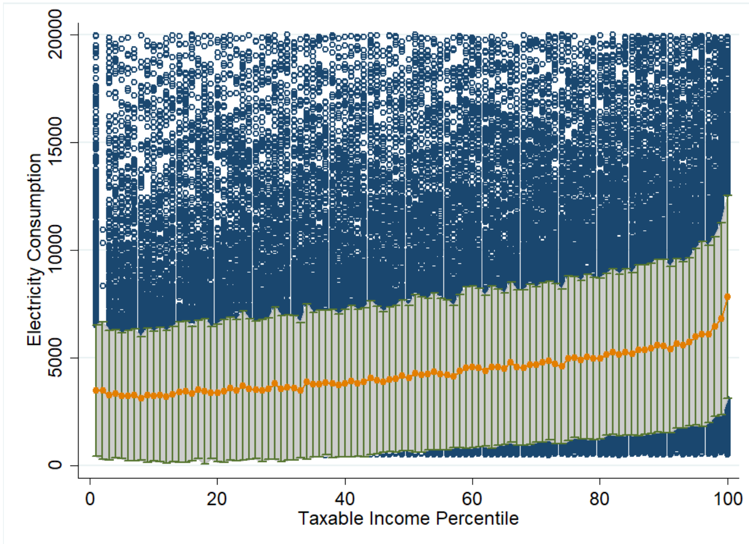
Figure 1: Distribution of electricity consumption and taxable income



Notes: The figure shows the distribution of energy consumption (left panel) and taxable income (right panel) in the sample. All observations with a taxable income below zero or with consumption less than 500 kWh are excluded from the sample. In both graphs, the maximum level of taxable income and energy is chosen for illustrative purposes.

Figure 2 correlates electricity consumption to income. It shows that mean electricity consumption slightly increases at higher income percentiles. In line with the structural model, household characteristics drive the correlation between consumption and income. Nevertheless, we should note that there is a significant amount of variation in electricity consumption present in the sample. For instance, many low income households consume electricity at levels well above the mean.

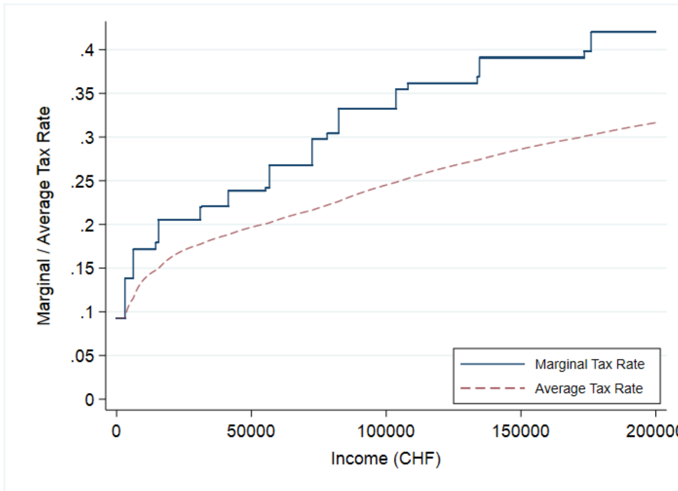
Figure 2: Electricity consumption by income percentile



Notes: The figure shows the distribution of electricity consumption by income percentile. The shaded area depicts consumption covered by one standard error while the middle line depicts the mean for each decile. The outliers of this bandwidth are illustrated as dark circles.

Income taxes in Switzerland are progressive, with marginal tax rates that increase stepwise by income level. Figure 3 illustrates marginal and average tax rates for an unmarried individual living in the Canton of Bern in the year 2013. The depicted tax rates are the sum of federal, cantonal, and municipal taxes.

Figure 3: Individual tax burden



Notes: The graph shows tax rates for an unmarried individual living in the Canton of Bern in 2013. The tax rates combine federal, cantonal, and municipal taxes. Municipal tax rates are based on the median municipal tax multiplier.

6 Calibration and results

Equation (15) requires the calibration of the price elasticity of electricity demand β, tax progressivity parameter ω, and the elasticity of taxable income with respect to the marginal tax rate ϵ.

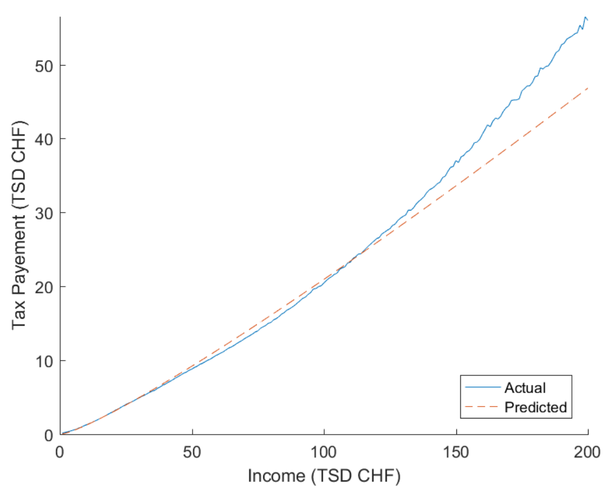
We draw on earlier work by Feger, Pavanini, and Radulescu (2017) to calibrate the price elasticity of electricity demand β. In that paper, they employ the same dataset to study the network financing implications and redistributive impact of distributed generation via the increased penetration of solar panels. They derive an optimal tariff design for when the regulator seeks to achieve solar energy targets while guaranteeing the sustainability and equitable distribution of network costs. Within that framework, the authors estimate the price elasticity of electricity demand using a geographic boundary regression discontinuity design. That is, they compare neighbouring households in the Canton of Bern located in the service area of one of the three main service providers BKW, Energie Thun or Energie Wasser Bern, in order to exploit these spatial discontinuities and the fact that Swiss households cannot choose their energy provider since energy markets are not yet completely liberalised. Based on this specification, we calibrate β to -0.16. Furthermore, this estimate allows us to derive the taste parameter $\theta_i = \frac{y_i}{p_y^{\beta}}$, as implied by equation (11).

To estimate the tax progressivity parameter ω, we first define $z_i^T = (1-\tau)z_i^{1-\omega}$. Log linearisation of this expression yields:

$$\ln(z_i^T) = \ln(1-\tau) + (1-\omega)\ln(z_i) \tag{16}$$

Thus, we can obtain estimates for both τ and ω by regressing net-of-tax income on gross income and a constant. The resulting coefficients amount to $\hat{\omega} = 0.046$ ($s.e. = 0.000$) and $\hat{\tau} = -0.34$ ($s.e. = 0.003$), respectively. Figure 4 compares the actual tax payments of the households in our sample and tax payments as approximated by the estimated tax function. Due to the high density of households, the best fit is obtained for income values below 100,000 CHF.

Figure 4: Fit of Tax Function



Notes: Actual tax payments correspond to the average tax payments of households in 1000 CHF bins. Estimated tax payments are calculated for the upper bound of each bin based on the tax function of equation (14) with $\hat{\omega} = 0.046$ and $\hat{\tau} = -0.34$.

Given that we do not observe enough variation in tax rates across time, the available dataset does not allow us to accurately estimate the elasticity of taxable income. This is why we opt to resort to widely acknowledged estimates from the literature. We set the elasticity of taxable income ϵ to 0.25, which represents, according to Saez, Slemrod, and Giertz (2012), a consensus estimate. Additionally, we perform a sensitivity analysis for inelastic labour supply ($\epsilon = 0$) and a higher value of $\epsilon = 0.5$.

When using estimated price elasticity β, estimated progressivity ω, household income z_i and electricity consumption y_i as inputs for equation (15), the optimal markup $\frac{p_y - c}{p_y}$ is a function of the government's preference for energy conservation, solely represented by π.

6.1 Mark-up without redistribution considerations

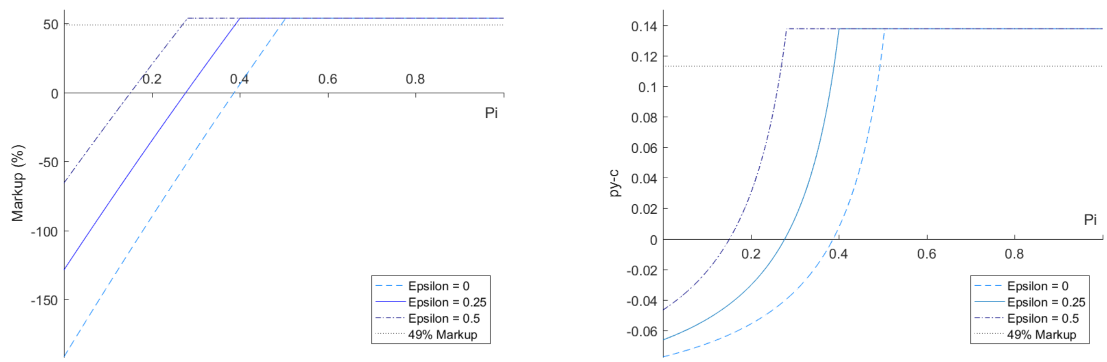
If the government is not concerned with redistribution, the markup that maximises aggregate welfare assumes an identical welfare weight for all households. Hence, efficiency considerations prevail. The resulting mark-up is positive, amounts to 48.2% and deviates from marginal cost pricing. The regulator essentially trades off the electricity consumption distortion and the distortion that originates from a lower labour supply, due to increased income taxation. The efficient mark-up is slightly lower than BKW's current mark-up of 49% and must be accompanied by higher revenues generated through tax payments. In monetary, terms this means that of the CHF 67.3mn total grid costs, CHF 20.6mn are not raised through electricity pricing but via increased income taxation.

As a robustness check, we calculate the efficient mark-up for alternative values of ϵ. When $\epsilon = 0$, the efficient mark-up is 0, such that the government completely generates the required revenue for covering grid costs through income taxation. When $\epsilon = 0.5$, the regulator sets the mark-up to 53.9 %, so that the public utility recovers the overall grid costs through variable tariffs, given that the high elasticity of taxable income exacerbates the distortion of income taxation.

6.2 Optimal mark-up with redistribution considerations

When taking into account redistributional considerations, the optimal mark-up depends on parameter π, the relative importance of energy efficiency in the welfare weight. Figure 5 illustrates the simulated mark-ups for a range of different values for π. When $\pi = 0$, i.e. a welfare weight that linearly decreases in income, the optimal mark-up is negative, meaning that the regulator should subsidise electricity consumption using an increase in income taxation. Our data shows that a negative mark-up is optimal because in such a case low income households only bear a small share of income taxation, while the difference in electricity consumption is less nuanced. When $\pi > 0$, the optimal mark-up rises monotonically. The stronger the emphasis on energy conservation, the larger the mark-up. This result is also in line with the theoretical literature on second best commodity taxation in the presence of externalities. This literature demonstrates that, in the case of external diseconomies, it is appropriate to apply non-uniform taxation, i.e., a higher tax on the polluting good that reflects social damages (Sandmo, 1975). The right hand panel of Figure 5 illustrates the size of the subsidy for ease of interpretation. When π is close to 0, the subsidy amounts to approximately 6 Rp./kWh which is substantial, relative to the marginal costs of 11.7 Rp/kWh.

Figure 5: Optimal mark-up for different welfare weights



Notes: The left panel shows the optimal mark-up according to the optimality condition (15) and a specified π. The right hand panel illustrates the absolute difference between price and marginal costs in CHF/kWh. The value of parameter π corresponds to the extent to which the regulator emphasises energy conservation goals.

We can also perform the reverse exercise and retrieve the underlying welfare weight associated with the mark-up observed in our data. In 2013, BKW levied a mark-up of approximately 49% on the energy price. According to our simulation, this is equivalent to $\pi = 0.39$. Thus, in this benchmark scenario, the present policy indicates that the government not only stresses income redistribution but also energy conservation.

These results depend on the assumed value for the elasticity of taxable income. Figure 5 also depicts the evolution of the mark-up for an inelastic labour supply or for a high elasticity of taxable income ($\epsilon = 0.5$). Without labour supply responses the curve shifts to the right so that $\pi = 0.49$ for a mark-up of 49%. In contrast, for very elastic labour supply responses, the regulator increasingly resorts to public utility pricing above marginal costs as a redistribution tool. Furthermore, for $\epsilon = 0.5$, the mark-up of 49% implies $\pi = 0.27$.

The observed positive mark-up is also consistent with an energy efficiency target, that is, if the regulator were to limit total energy consumption to a specific level. A lower (more lax) target has the same qualitative effect as increasing the welfare weight on high electricity consumption households. However, with an energy efficiency target the optimal markup is potentially extremely high. Based on the Swiss regulator's official target for the year 2020, a demand reduction of 16% compared to the year 2000 [21], demands a much higher electricity price of 0.72 CHF/kWh, and thus a mark-up of 83%.

7 Extensions

7.1 Asymmetric information

Following Baron and Myerson (1982) we relax the complete information setting and consider a case where the regulator and monopoly provider are two separate agents. The regulator sets an upper price limit for electricity but compensates potential losses through tax payments. The new budget constraint now includes a transfer S to the monopolist and reads:

$$\sum_i [p_y y_i + t(z_i, \tau)] \geq S + gN, \tag{17}$$

The public utility maximises profits:

$$\max_p \pi = (p - c) \sum_i y_i(p) - F + S \tag{18}$$

$$s.t. \quad p \leq p_y \tag{19}$$

where p_y is the price limit set by the regulator. The following only considers cases where the upper price limit is binding, that is, $p = p_y$.

We assume that the regulator assigns a welfare weight of zero to the profits of the public utility. [22]

Demand $y(p)$ and fixed costs F are known to both agents whereas marginal costs c are the private information of the public utility. The regulator offers a menu of contracts to the public utility, each including a price and a corresponding government transfer. The public utility then chooses a contract by revealing their marginal costs.

[21] See Energie Strategie 2050 (Bundesamt für Energie, 2018).

[22] With full information about the monopolist's cost, the regulator chooses to transfer S in order to make the public utility break even $S = F - (p_y - c) \sum y_i(p_y)$, which is identical to the benchmark scenario where the regulator and the utility are one and the same entity.

As a simplification, we assume that the public utility is either a high cost type H or a low cost type L, with probabilities of μ_L and μ_H respectively. The participation constraint of the high cost type H is binding, that is, the regulator chooses a combination of the transfer S_H and price limit p_y^H, resulting in zero profits. Consequently, $S_H = F - (p_y^H - c_H)\sum_i y_i(p_y^H)$. For the low cost type, L, the incentive compatibility constraint is binding:

$$\pi_L(p_y^L, S_L) \geq \pi_L(p_y^H, S_H) \tag{20}$$

$$(p_y^L - c_L)\sum_i y_i(p_y^L) + S_L \geq \sum_i y_i(p_y^H)(c_H - c_L) \tag{21}$$

The condition indicates that the regulator allows for a positive profit for the low cost type in order to reveal her true marginal costs c_L.

With asymmetric information, welfare maximisation is subject to two additional constraints:

$$\max_{p_H, p_L, \tau} W = E\left[\sum_i w_i \cdot v_i\left(\tau, p_y^L, p_y^H\right)\right] \tag{22}$$

$$s.t. \quad \sum_i t(z_i, \tau) \geq E[S] + gN, \tag{23}$$

$$s.t. \quad S_H \geq F - (p_y^H - c_L)\sum y_i(p_y^H) \tag{24}$$

$$s.t. \quad (p_L - c_L)\sum_i y_i(p_y^L) + S_L \geq \sum_i y_i(p_y^H)(c_H - c_L) \tag{25}$$

where p_y^H and p_y^L are the price limits of the high and low type respectively.

Solving the maximisation problem yields the following pricing rule:[23]

$$\frac{p_y^H - c_H - \frac{\mu_L}{\mu_H}(c_H - c_L)}{p_y^H} = \left[1 - \frac{R_y}{R_\tau}\right]\frac{1}{-\beta} \tag{26}$$

Without a low cost type ($\mu_L = 0$), the expression is identical to the pricing rule under full information. However, when $\mu_L > 0$, the optimal price is higher. Intuitively, increasing the price for the high cost type relaxes the incentive compatibility constraint of the low cost type. This effect is stronger, the higher the share of low cost types relative to the high cost types ($\frac{\mu_L}{\mu_H}$), and the higher the cost difference between both types ($c_H - c_L$). This finding dates back to the Baron and Myerson (1982) result where prices under asymmetric information are higher than in the First Best case for all but the lowest cost type.

Table 3 presents simulations of the optimal price of the high cost type under different assumptions on the share of high types and the cost difference. We set $\pi = 0$ (no energy

[23]The derivation is shown in Appendix C.

conservation considerations) and $\epsilon = 0$ (no tax induced labour supply distortions) to simplify the analysis. The last column refers to the case of known marginal costs. Optimal mark-ups increase under asymmetric information and $\mu_H < 1$. The increase is more pronounced with higher cost differences. For instance, with a cost difference of 0.05 CHF and $\mu_H = 0.2$, p_y^H should be more than double the price under full information.

Table 3: Optimal p_y^H (in CHF) with unknown marginal costs

	$\mu_H = 0.2$	$\mu_H = 0.4$	$\mu_H = 0.6$	$\mu_H = 0.8$	$\mu_H = 1$
$c_H - c_L = 0.01$	0.057	0.049	0.046	0.045	0.044
$c_H - c_L = 0.02$	0.075	0.057	0.052	0.049	0.047
$c_H - c_L = 0.03$	0.092	0.066	0.057	0.053	0.051
$c_H - c_L = 0.04$	0.109	0.075	0.063	0.057	0.054
$c_H - c_L = 0.05$	0.126	0.083	0.069	0.062	0.057

Notes: The table shows optimal prices for the high cost type with unknown marginal costs. The price of the low cost type is set to 0.117 in line with the data. All other parameters are chosen as in the baseline case.

Therefore, the presence of asymmetric information provides a different explanation for the positive mark-up encountered in our data.

7.2 Fixed fee financing

As described in the Introduction, energy providers commonly rely on two-part tariffs. That is, in addition to the consumption-based charge, consumers pay a fixed (access) fee. We now add the option of fixed fee financing to the baseline model. The new government budget constraint reads:

$$\sum_i p_y y_i + \sum_i f_i + \sum_i t(z_i, \tau) \geq C\left(\sum_i y_i\right) + gN \tag{27}$$

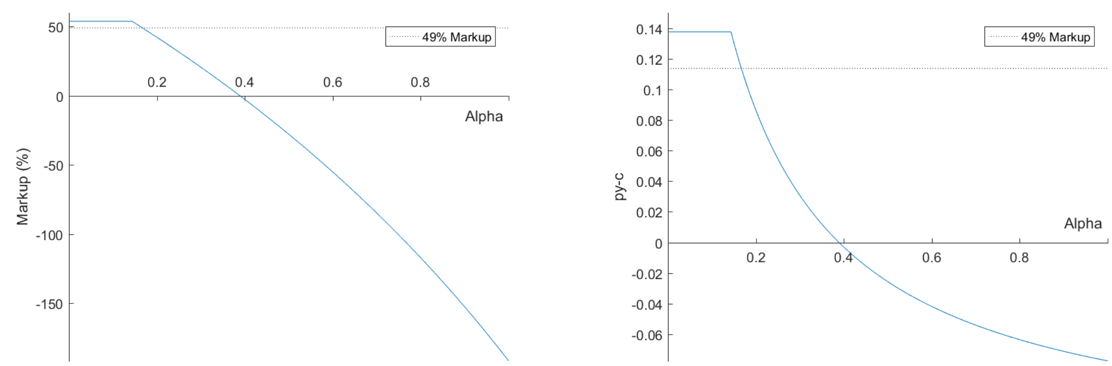
where f_i is the fixed fee and $t(z_i, \tau)$ is the progressive income tax already introduced. The regulator generates a share α of total revenues by means of fixed fees f_i and $(1 - \alpha)$ through the progressive income tax.

Including the fixed fee as a financing instrument alters the optimality condition as follows:[24]

$$\frac{p_y - c}{p_y} = \left(1 - \frac{\sum_i \frac{z^1}{z_i}\frac{y_i}{\sum_i y_i}}{\sum_i \frac{z^1}{z_i}\left[\frac{(1-\alpha)}{N} + \alpha\frac{z_i^{1-\omega}}{\sum_i z_i^{1-\omega}}\right]}\right)\frac{1}{-\beta} \tag{28}$$

where we assume $\epsilon = 0$ and $\pi = 0$ to simplify the analysis. When $\alpha = 0$, the government distributes the additional tax burden uniformly among households, which is equivalent to a head tax. $\alpha = 1$ corresponds to the baseline case.

Figure 6: Optimal mark-up for different income tax schemes



Notes: The left hand side shows the optimal mark-up according to the optimality condition (28) with $w_i = \frac{z^1}{z_i}$ as a function of α. The right hand side illustrates the difference between price and marginal costs ($p_y - c$) in CHF/kWh.

Figure 6 presents the optimal mark-up for different values of α, assuming $\pi = 0$ (that is energy conservation is irrelevant). The graph only shows a positive mark-up for low values of α. In comparison to the progressive income tax system, if the government resorts to a fixed fee, the burden of taxation shifts to lower income households. Thus, with a low α a positive mark-up on the energy price is desirable from an income redistribution perspective. A high α, however, is closer to the baseline case where low income households bear a minor share of additional tax revenue. The mark-up based on BKW's pricing strategy amounts to 49% and suggests that $\alpha = 0.17$.

[24] See the Appendix D for the derivation.

8 Conclusion

With rising concerns regarding the affordability of electricity and the redistributive impact of the rate structure of electricity pricing, additional research is required in order to gain a deeper understanding of these topics. Our paper addresses these issues within a framework that combines public utility pricing and income taxation using an extensive household-level data set for the Swiss Canton of Bern. Our structural model focuses on the residential electricity market. The regulator simultaneously decides on the price set by electricity providers and the tax revenue generated through income taxation, maximising the weighted sum of household utilities. The resulting sign of the optimal electricity price mark-up depends on the electricity consumption share of different household types, as well as the distribution of the income tax burden. The calculations show that if theincome redistribution concerns predominate, electricity price mark-ups should be negative. In contrast, the mark-up levied by the Swiss energy utility, BKW, is positive and amounts to 49% in the year 2013. We find several possible explanations for this discrepancy. First, an elastic labour supply induces efficiency costs for income taxation, shifting the optimal mark-up upwards. Second, a larger emphasis on energy conservation goals expressed in terms of the welfare weight also increases the mark-up.[25] Last, asymmetric information between the regulator and the public utility may lead to an increase in the mark-up for high marginal cost firms.

[25]Swiss law requires energy providers to offer tariffs that stimulate energy efficiency.

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Appendix

A Derivation of optimal markup

$$-\sum w_i\lambda_i y_i + \sum_i w_i\lambda_i \left(\frac{\frac{\partial t_i}{\partial \tau_i}}{\frac{\partial \sum_i t_i}{\partial \tau_i}}\right)\left[\left(p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}\right)\frac{\partial \sum_i y_i}{\partial p_y} + \sum_i y_i\right] = 0$$

$$\sum_i w_i\lambda_i \left(\frac{\frac{\partial t_i}{\partial \tau_i}}{\frac{\partial \sum_i t_i}{\partial \tau_i}}\right)\left[(p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i})\frac{\partial \sum_i y_i}{\partial p_y} + \sum_i y_i\right] = \sum_i w_i\lambda_i y_i$$

$$(p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i})\frac{\partial \sum y_i}{\partial p_y} = \frac{\sum w_i\lambda_i y_i}{\sum w_i\lambda_i\left(\frac{\frac{\partial t_i}{\partial \tau_i}}{\frac{\partial \sum t_i}{\partial \tau}}\right)} - \sum_i y_i$$

$$\frac{p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}}{\sum_i y_i}\frac{\partial \sum_i y_i}{\partial p_y} = \frac{\sum_i w_i\lambda_i \frac{y_i}{\sum_i y_i}}{\sum w_i\lambda_i\left(\frac{\frac{\partial t_i}{\partial \tau_i}}{\frac{\partial \sum_i t_i}{\partial \tau}}\right)} - 1$$

$$\frac{p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}}{p_y} = -\left(1 - \frac{R_y}{R_\tau}\right)\frac{1}{\frac{p_y}{\sum_i y_i}\frac{\partial \sum_i y_i}{\partial p_y}}$$

$$\frac{p_y - \frac{\partial C(\sum_i y_i)}{\partial \sum_i y_i}}{p_y} = \left(1 - \frac{R_y}{R_\tau}\right)\frac{1}{-\beta}, \qquad (29)$$

where β is the price elasticity of electricity demand.

B Derivations related to the structural model

Household Optimization

$$\max_{y_i,l_i,x_i} \mathcal{L}(y_i,l_i,x_i,\theta_i) = x_i + \frac{\beta}{1+\beta}y_i^{\frac{1+\beta}{\beta}}\theta_i^{\frac{1}{-\beta}} - \frac{\epsilon}{1+\epsilon}l_i^{\frac{1+\epsilon}{\epsilon}} - \varphi^h\left[x_i + p_y y_i - z(l_i) + t(z(l_i),\tau) - g\right]$$

First order conditions:

$$\frac{\partial \mathcal{L}}{\partial x_i} = 1 - \varphi^h = 0$$

$$\frac{\partial \mathcal{L}}{\partial y_i} = y_i^{\frac{1}{\beta}}\theta_i^{\frac{1}{-\beta}} - \varphi^h p_y = 0$$

$$\frac{\partial \mathcal{L}}{\partial l_i} = l_i^{\frac{1}{\epsilon}} - (1 - t'(z_i,\tau))w_i\varphi^h = 0$$

$$\Rightarrow \quad y_i = p_y^{\beta}\theta_i$$

$$\Rightarrow \quad l_i = [(1 - t'(z_i,\tau))w_i]^{\epsilon}$$

Price elasticity of electricity demand:

$$\frac{p_y}{\sum y_i}\frac{\partial \sum y_i}{\partial p_y}m = \frac{p_y}{p_y^{\beta}\sum \theta_i}\beta p_y^{\beta-1}\sum \theta_i = \beta.$$

Distribution parameter of income taxation

The first derivatives of t_i and $\sum_i t_i$ with respect to τ act as input for the optimality condition presented in equation (8):

$$\frac{\partial t_i}{\partial \tau} = z_i^{1-\omega}$$
$$\frac{\partial \sum t_i}{\partial \tau} = \sum_i \left(z_i^{1-\omega}\right)$$

The marginal tax rate $\frac{\partial t_i}{\partial z_i}$ can be computed by taking the derivative of the tax function:

$$t_i' = \frac{\partial t_i}{\partial z_i} = 1 - (1-\omega)(1-\tau)z_i^{-\omega} \tag{30}$$

such that

$$\frac{\partial(1-t_i')}{\partial \tau} = -(1-\omega)z_i^{-w} \tag{31}$$

To structurally estimate our model, we approximate the effect of a change in τ on total tax revenue as follows:

$$\sum_i \frac{\partial t_i}{\partial z_i}\frac{\partial z_i}{\partial \tau} \approx \sum_i \frac{\partial t_i}{\partial z_i}\frac{\partial z_i}{\partial(1-t_i')}\frac{\partial(1-t_i')}{\partial \tau},$$

that is, labor supply reacts to changes in marginal tax at the status quo income level[26]. The change in labour income following a change in the marginal net-of-tax rate can be expressed in term of the tax elasticity of taxable income $\epsilon = \frac{\partial z_i}{\partial(1-t_i')}\frac{(1-t_i')}{z_i}$:

$$\frac{\partial z_i}{\partial(1-t_i')} = \epsilon\frac{z_i}{(1-t_i')} = \epsilon\frac{z_i}{(1-\omega)(1-\tau)z_i^{-\omega}} \tag{32}$$

Thus,

$$R_\tau = \lambda \sum w_i \left(\frac{z_i^{1-\omega}}{\sum z_i^{1-\omega} - \epsilon\sum_i[\frac{z_i}{1-\tau} - (1-\omega)z_i^{1-\omega}]}\right) \tag{33}$$

[26]Thus, the second order effect of the income change on the marginal tax rate is omitted.

C Derivation of optimal pricing with asymmetric information

Under asymmetric information, the regulator maximizes expected welfare and faces two additional constraints:

$$\max_{p_H, p_L, \tau} W = E\left[\sum_i w_i \cdot v_i\left(\tau, p_y^L, p_y^H\right)\right] \tag{34}$$

$$s.t. \quad \sum_i t(z_i, \tau) \geq E[S] + gN, \tag{35}$$

$$s.t. \quad S_H \geq F - (p_y^H - c_L)\sum_i y_i(p_y^H) \tag{36}$$

$$s.t. \quad (p_L - c_L)\sum_i y_i(p_y^L) + S_L \geq (c_H - c_L)\sum_i y_i(p_y^H) \tag{37}$$

where p_y^H and p_y^L are price limits of the high and low type respectively.

The corresponding first order conditions are:

$$p_L: \quad \sum_i w_i E\left[\frac{\partial v_i}{\partial p_y^L}\right] = \varphi E\left[\frac{\partial S_L}{\partial p_y^L}\right] \tag{38}$$

$$p_H: \quad \sum_i w_i E\left[\frac{\partial v_i}{\partial p_y^H}\right] = \varphi E\left[\frac{\partial S_H}{\partial p_y^H} + \frac{\partial S_L}{\partial p_y^H}\right] \tag{39}$$

$$\tau: \quad \sum_i w_i \frac{\partial v_i}{\partial t_i}\frac{\partial t_i}{\partial \tau} = -\varphi \frac{\partial \sum_i t_i}{\partial \tau} \tag{40}$$

where we define $\frac{\partial v_i}{\partial t_i} = \lambda$ as in the baseline model. Condition 1 and 3 together imply that for the low cost type pricing is identical to the case with full information, i.e. there is no distortion at the top.

For the high cost type note that:

$$\frac{\partial S_H}{\partial p_y^H} = -\left[(p_y^H - c_H)\frac{\partial \sum_i y_i(p_y^H)}{\partial p_y^H} + \sum_i y_i(p_y^H)\right]$$

$$\frac{\partial S_L}{\partial p_y^H} = (c_H - c_L)\frac{\partial \sum_i y_i(p_y^H)}{\partial p_y^H}$$

Thus

$$\mu_H \sum_i w_i \lambda_i y_i = -\sum_i \frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum_i t_i}{\partial \tau}} \lambda E \left[\frac{\partial S_L}{\partial p_y^H} + \frac{\partial S_L}{\partial p_y^H} \right]$$

$$\mu_H \left[(p_y^H - c_H) \frac{\partial \sum_i y_i(p_y^H)}{\partial p_y^H} + \sum_i y_i(p_y^H) \right] - \mu_L \left[(c_H - c_L) \frac{\partial \sum_i y_i(p_y^H)}{\partial p_y^H} \right] = \mu_H \frac{\sum_i w_i \lambda_i y_i}{\sum_i w_i \lambda_i \frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum_i t_i}{\partial \tau}}}$$

$$\left[\left(p_y^H - c_H - \frac{\mu_L}{\mu_H}(c_H - c_L) \right) \frac{\partial \sum_i y_i(p_y^H)}{\partial p_y^H} + \sum_i y_i(p_y^H) \right] = \frac{\sum_i w_i \lambda_i y_i}{\sum_i w_i \lambda_i \frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum_i t_i}{\partial \tau}}}$$

$$\frac{p_y^H - c_H - \frac{\mu_L}{\mu_H}(c_H - c_L)}{p_y^H} = \left[1 - \frac{R_y}{R_\tau} \right] \frac{1}{-\beta}$$

D Derivation of R_τ with fixed fee

Share α determines the relation between total fixed fees and the progressive income tax revenue:

$$\alpha \sum_i f_i = (1 - \alpha) \sum_i t_i^p \tag{41}$$

Aggregate tax burden:

$$\sum_i t_i = \sum_i f_i + \sum_i t_i^p \tag{42}$$

$$= \frac{1-\alpha}{\alpha} \sum_i t_i^p + \sum_i t_i^p \tag{43}$$

$$= \frac{\sum_i t_i^p}{\alpha} \tag{44}$$

Individual tax burden if f_i is spread equally across households:

$$t_i = f_i + t_i^p \tag{45}$$

$$= \frac{1}{N} \frac{(1-\alpha)}{\alpha} \sum_i t_i^p + t_i^p \tag{46}$$

Derivatives of aggregate and individual tax burden w.r.t. τ:

$$\frac{\partial \sum_i t_i}{\partial \tau} = \frac{\sum_i z_i^{1-\omega}}{\alpha} \tag{47}$$

$$\frac{\partial t_i}{\partial \tau} = \frac{(1-\alpha)}{N\alpha} \sum_i z_i^{1-\omega} + z_i^{1-\omega} \tag{48}$$

Thus:

$$R_\tau = \sum_i w_i \lambda_i \left(\frac{\frac{\partial t_i}{\partial \tau}}{\frac{\partial \sum t_i}{\partial \tau}} \right) \tag{49}$$

$$= \sum_i w_i \lambda_i \left(\frac{(1-\alpha)}{N} + \alpha \frac{z_i^{1-\omega}}{\sum_i z_i^{1-\omega}} \right) \tag{50}$$