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Welfare and Redistribution Effects in Energy Markets with Solar Power ¹

Abstract

Renewable energy production via photovoltaic (PV) installations has increasingly taken off during the last years. This trend is desirable from an environmental perspective, but it challenges the financing of utilities' energy infrastructure networks. This happens because buildings with PV installations still require energy from the network, leaving the fixed costs of grid maintenance unchanged, but contribute less to the grid costs, as they mostly pay volumetric charges and intermittently produce their own energy. In this paper we propose an alternative tariff scheme to both incentivize PV adoptions and guarantee the sustainability of network costs. We use detailed data on energy consumption, income, wealth, and building characteristics for around 180,000 households in the Canton of Bern (Switzerland) in the years 2008-2013 to estimate models of energy demand and PV installation. We identify energy demand elasticities using a matching boundary discontinuity design that exploits price variation at spatial discontinuities, and we model PV adoption as a dynamic single agent investment framework. Using a counterfactual exercise we find that under a uniform tariff scheme low income households would experience a very small welfare loss.

JEL-classification: D12; D31; L51; L94; L98; Q42

Keywords: energy; photovoltaics; income distribution; welfare

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1 Introduction

Photovoltaic (PV) installations have experienced a remarkable increase in the last years. For example, in the Swiss Canton of Bern there was an average yearly growth rate of 60% in the period 2008-2013. While this trend is desirable from an environmental perspective, the expansion of distributed generation constitutes a challenge for utilities worldwide (MIT, 2011). The two main issues that a growing number of PV adoptions poses regard financing network costs and the regressive redistributive effect of green energy incentives. In this paper we propose an alternative tariff scheme to both incentivize PV adoptions, guarantee the sustainability of network costs, and reduce the regressive redistributive effect. We use detailed data on energy consumption, income, wealth, and building characteristics for around 180,000 households in the Canton of Bern (Switzerland) in the years 2008-2013 to estimate models of energy demand and PV installation. We identify energy demand elasticities using a matching boundary discontinuity design that exploits price variation at spatial discontinuities, and we model PV adoption as a dynamic single agent investment framework. Using a counterfactual exercise we find that under a uniform tariff scheme low income households would experience a very small welfare loss.

Under the current renewable energy technology, almost all buildings that install solar panels are still connected to the electricity grid, but intermittently produce their own energy. This implies that energy distribution and transmission lines are still indispensable for the supply of energy. Nowadays a substantial part of transmission and distribution network costs is recovered through the so called volumetric kilowatt hour-based rates. Volumetric charges together with increased penetration of PV installations imply lower energy demand and therefore lower revenues for electricity and network providers. However, network costs are largely fixed, so it is becoming increasingly difficult for utilities to cover these costs under volumetric charges and increased PV adoptions. Furthermore, the solar PV technology creates large variations in the net energy demand, placing additional stress on distribution feeders which were initially not designed for simultaneously accommodating out-

and inflows of energy, thus potentially increasing network operation costs (Joskow, 2012).

This increasing trend in solar PV adoptions may therefore even induce a spiral of rising volumetric rates, distorting consumer incentives and inducing them to switch to alternative energy sources in an inefficient way (Borenstein, 2014), as the burden of financing the energy infrastructure is progressively shifted onto non PV owners, which are usually households with lower income. The average income of households with a PV installation in the Canton of Bern is in fact already 45% higher than the average income of households without PV. This leads us to the second issue that a growing number of PV adoptions causes, the regressive redistributive effect.

The rising popularity of distributed generation and renewable energy can be attributed to the supportive renewable policies implemented by countries worldwide. Most European Union members, the United States, and Switzerland have introduced the so called feed-in tariff programs for small scale renewable generation. These programs compensate producers for generating their own energy at a fixed electricity rate.² This rate usually exceeds wholesale energy cost and is often financed by a surcharge paid on the electricity bill.³ Under a system of net metering where end users are in addition allowed to consume their own energy production, the owners of PV installations save not only on the per kWh charges that are used to recover fixed network transmission and distribution costs, but also on the surcharge that finances the feed-in tariff.

This differential cost burden for households of different income levels raises questions about the vertical equity of the system, which may be discriminatory for low income households, representing the larger share of those customers less able to finance PV installations. To shed light on this issue we investigate in this paper whether PV installations in a regime of volumetric charges have negative distribu-

²These rates range between 6.38 to 13.88 p/kWh in the UK, 8.92-12.88 €-ct/kWh in Germany, or 0.191-0.304 CHF/kWh in Switzerland.

³In Switzerland it amounts to 0.011 CHF/kWh as of 2015.

tional consequences. We simulate the welfare implications of replacing the current volumetric charges by a uniform fixed tariff or alternative high and low tariffs for households with above or below median energy consumption.⁴ As the objective of the policymaker is not only to guarantee vertical equity, but also to encourage the diffusion of renewable energy, we analyze how the trend in PV adoptions would change under each alternative tariff scheme.

The alternative tariff regime we propose in our counterfactual scenario targets not only the vertical equity, but most importantly the infrastructure financing problem. In fact, if on one hand advocates of renewable energy generation through PV installations argue that solar panels have reduced the costs of energy transmission and distribution, since power is generated at the end-user's location, Borenstein's (2008) analysis contradicts this argument, showing that the costs of installing the PV technology exceed its market benefits. As Bushnell (2015) states, the problem with volumetric charges is that the costs of the infrastructure do not scale with the consumption of energy. The paradox is that the more efficient energy consumption becomes, the less households contribute to the infrastructure costs of national energy utility distributors. Stated differently, the lower the energy consumption bill, the higher the rates needed to recover network costs. These increasing distribution rates may provide even larger incentives to reduce energy consumption, and create incentives to shift costs to third parties (Bushnell, 2015, MIT, 2011). To counteract this phenomenon, academics and policymakers support an alternative financing scheme that provides for the separation of the cost recovery from energy consumption. This "revenue decoupling" (Bushnell, 2015; MIT, 2011) could be accomplished by a user fee that is independent of consumption. This could take for instance the form of a fixed charge faced by all customers (Bushnell, 2015, MIT, 2011) or with a demand charge based on individual consumers' peak load on the distribution system

⁴A first best solution to financing energy infrastructure networks would actually entail capacity based network charges, implying a system of peak load pricing. However, as the implementation of smart meters which would allow such a pricing system is very costly, fixed charges represent a second best alternative.

(Joskow, 2012).

Assessing the distributional impact of alternative tariff structures requires estimating households' energy demand elasticity. To recover that we employ a unique and detailed dataset for around 180,000 households in the Canton of Bern (Switzerland) during the years 2008-2013. Our data matches households' detailed energy consumption and PV installations to income and wealth information, but also to additional household and building characteristics. Differently from most of the literature, we are able to exactly match households' yearly energy consumption, income and wealth. In order to identify accurately energy demand elasticities we employ alternatively OLS, panel data models, and a bounded regression discontinuity design framework (BDD) to exploit price variation at spatial discontinuities, as in Ito (2014). In the Canton of Bern there are in fact three energy providers and households are assigned to one of them depending on their location. This design allows us to match similar households falling within different service areas. Using this approach we estimate energy demand elasticities in the range between -2.4 and -0.65. These estimates are larger than those obtained by fixed effects regressions, which range between -0.06 and -0.6.

An alternative tariff structure may also change households' incentives to install solar panels. Therefore, we also estimate a model of households' PV adoption, framed as a dynamic optimal stopping problem (Rust (1987), Burr (2014)). We develop a dynamic structural model where households choose when to install the PV, and exit the market once they install it. Using detailed data on weather, buildings' characteristics, and household energy consumptions we are able to recover for every household-year both the fixed cost of PV installation and the present discounted value of the PV's generation over a 25 years horizon. We use this model to determine how the alternative tariff scheme would impact the households' decision to install solar panels.

Our paper belongs to the more general body of literature which seeks to estimate energy demand elasticities, addressing the redistributive impact of different

energy policies and the equity efficiency trade-off in public sector pricing. It is still an open debate as to whether the government and/or public utilities should intervene in income distribution other than via income taxes. Following the Atkinson, Stiglitz (1976) argument, if the utility function is separable between leisure and consumption, there should be no commodity taxes. Hence, redistribution should be only achieved via the direct income tax and the government should not intervene in the pricing of different commodities. In practice various governments do care about the affordability and distributional effects of basic goods and services such as energy.

Our paper is structured as follows. The next section presents an overview of the literature, and Section 3 introduces the institutional details of the energy and PV market in Switzerland and in the Canton of Bern. Section 4 provides a detailed description of the data and presents various descriptive statistics. In Section 5 we describe the energy demand model, and in Section 6 we present the PV installation framework. Section 7 outlines the results and the welfare effects of the counterfactual tariff structure, and Section 8 concludes.

2 Background Literature

The literature estimating price elasticities of residential electricity demand mostly focuses on the United States and mainly employs aggregate data, typically at the state level. Significant contributions of this kind are Herriges and King (1994), Maddock, Castano and Vella (1992), Kamershen and Porter (2004), Alberini, Gans, and Velez-Lopez (2011), Alberini and Filippini (2011) or Bernstein and Griffin (2006). Reiss and White (2005) use instead household level energy consumption data, but have information from a survey on a sample of only 1,300 households. They evaluate the effects of different tariff structures on energy demand, finding a highly asymmetric shape of the distribution of energy price elasticities. They show that only a small share of the population accounts for the largest part in aggregate demand response, and that the mean estimated price elasticity is -0.39.

A recent paper closely related to our work is Ito (2014), which uses household-level energy demand data. Similarly to other papers in the literature (Borenstein (2012)), the author can only imperfectly match households' energy consumption with income census data. Our data instead allows us to have a perfect match of household-year level energy consumption, income and wealth. Ito's (2014) panel data spans over the years 1999-2007 and includes energy consumption data provided by two major Californian utility providers, namely Southern California Edison and San Diego Gas & Electric. He exploits price variations at spatial discontinuities between these operators to identify the price coefficients in his model. Despite the non linear price schedule faced by customers, Ito (2014) finds evidence that consumers do not respond to marginal but to average prices. Thus, nonlinear pricing schemes appear to be unsuccessful in achieving energy conservation. Other relevant papers on European energy markets are Filippini, Blazquez, and Boogen (2012) (using Spanish data), Mohler and Müller (2012), and Boogen, Datta and Filippini (2014) (both focusing on Switzerland).

One takeaway from this literature is that an accurate estimation of energy price elasticities requires a highly disaggregate dataset, as it allows to capture the heterogeneity in consumption patterns. Another takeaway is that spatial discontinuities between energy providers provide a good source of exogenous variation in prices to identify price coefficients. We have access to a large household-year level dataset that combines both a high level of disaggregation and spatial discontinuities between three energy suppliers. Differently from most of the papers in the literature, our dataset covers almost the whole population of the area we consider (Canton of Bern), and has an exact match between energy consumption and income and wealth data. This allows us to estimate different price elasticities for different income groups. Ignoring heterogeneity in price elasticities may dramatically underestimate the variance of the impact of energy price changes across consumers. Welfare measures that don't consider this dimension of heterogeneity may lead to substantially biased estimates of the effects of different policy reforms by failing to correctly account for the distributional implications.

There are only a small number of papers investigating the rise of renewable and distributed generation, in connection with the recovery of fixed network costs by volumetric charges. Using data on residential PV installations provided by Pacific Gas & Electric, a major Californian utility, Borenstein (2015) shows that income distribution of PV adopters is skewed towards wealthier households, but the skew has lessened during the last years. Furthermore, his findings show that, due to the increasing-block pricing (IBP) scheme applied in the US, the probability of adopting a PV installation is higher for households with higher energy consumption. Borenstein and Davis (2012) consider the distributional consequences of volumetric charges for the US natural gas market. They find that high volume consumers pay a large fraction of the fixed infrastructure costs. However, they also emphasize that the correlation between high gas consumption and high income is weak, such that the prevailing volumetric charges approach does not favor low income households.

Borenstein (2012) uses household level billing data from three major utilities in California and census income data to show that the IBP structure applied in California redistributes income from the richer to the poorer households, but only to a modest extent. This result is ascribed to the existence of the CARE program, which offers lower electricity tariffs to low income households. His findings imply that the efficiency effect of the policies depends on the relationship between the marginal and the average electricity cost. On the one hand, if the marginal cost exceeds the average costs, an IBP tariff which applies marginal cost pricing may reduce the deadweight loss and benefit low-income households. On the other hand, if average costs exceed marginal cost, a mean-tested tariff for low income households may be the right approach. Picciariello, Ramirez, Guillén, Marin and Söder (2014) and Eid, Guillén, Marin and Hakvoort (2014) use simulations to evaluate how different tariff structures affect different consumer types. They show that cross subsidization from customers without self generation to those with self generation is likely to arise in case volumetric tariffs and net metering is adopted. This problem has also been acknowledged in further studies, such as Pérez-Arriaga, Rueter, S., I.J. Schwenen, S., Battle, C. and J.M. Glachant (2013). Both studies express concerns about the

fact that non-distributed energy customers absorb the lost revenues induced by the policy of net metering accompanied by volumetric charges.

3 The Electricity and PV Market in Switzerland

Switzerland is an exemplary federal state. The Swiss federation comprises 26 cantons and is divided into roughly 3,000 municipalities of varying size and population. The supply of energy is decentralized and is organized by each canton. Within each canton one or more utilities have a local monopoly when it comes to households' energy provision. Large scale consumers with an annual energy consumption exceeding 100 MWh can choose their provider since 2009. Households will only be able to do so from 2018. This means that even within the borders of a canton residential customers can be assigned different energy providers, depending on their location. Utility providers can have the legal form of purely private companies, but in most cases they are still at least partially public monopolies. In the Canton of Bern for example, 52% of the main utility (BKW Energie AG) is owned by the Canton of Bern. This implies that these utilities cannot set their prices independently, but have to follow the requirements of the regulatory agency ELCom.

Figure 1 depicts the evolution of PV electricity generation in Switzerland between 1990 and 2013.

– Figure 1 here –

In 2005, PV production in Switzerland added up to 21 GWh. Seven years later, in 2012, PV electricity generation amounted to 319 GWh. Even though this number may seem rather negligible at this stage, the trend is increasing exponentially. In 2013 photovoltaic electricity generation amounted to 543 GWh, equivalent to an increase of around 70% in only one year. Hence, solar energy production has increased by 25 times in only 8 years.⁵

⁵In 2014, the energy produced by PV installations in the EU amounted to 6,953 in 1,000 tons

In 2008 Switzerland introduced the feed-in tariff remuneration system to encourage the development of PV installations. The incentive scheme was designed to last for 25 years, with tariffs varying depending on the type of PV installed (ground-mounted, rooftop or building integrated), and its size, ranging between 10 kW and 10,000 kW. In the years after 2008 the compensation was markedly reduced⁶ both because the pre-determined budget couldn't match the large number of incentive requests, and because of the sharp decline in PV installation costs. The overall amount of feed in remuneration paid by the government amounted to around CHF 23 million in 2011, CHF 45 million in 2012, and CHF 66 million in 2013. Of these amounts, CHF 8 million, CHF 14 million, and CHF 17 million were allocated to households in the respective years. These tariffs were financed by an energy consumption surcharge. Between 2009 and 2013 the surcharge amounted to around 0,0045 CHF/kWh and it has been steadily increased since then. Nowadays it amounts to 0,11 CHF/kWh. In 2013 almost 6,000 installations received feed in tariffs and their overall production amounted to 141 GWh (Swiss Federal Office of Energy, 2015).

The electricity price Swiss consumers pay consists of four major components. First, the basic supply tariff defined by the individual supplier, reflecting the costs of internal production and of procurement on the market. Second, a uniform surcharge levied by the federal state used to promote renewable energy. Third, a surcharge for grid usage which covers the energy distribution network costs and varies between suppliers. The fourth component represents taxes levied by the communal, cantonal or federal authorities. As opposed to Californian utilities which usually resort to IBP schemes, Swiss utilities apply a constant price per kWh irrespective of the amount of electricity consumed. Residential customers of two of the three operators (BKW and EWB) can only choose between a uniform tariff and a day-night tariff, with

of oil equivalent and in the United States to 6,201 MW.

⁶In 2014 tariffs ranged between 0.172 CHF/kWh for ground-mounted installations larger than 1,000 kW to 0.304 CHF/kWh for building integrated PV installations between 10 and 30 kW of size.

higher rates during the day. All households in the jurisdiction of Energie Thun, the third operator in the canton, are subject to a two part tariff (see Tables 3-5 for details of the tariff structures of these energy providers).

4 The Data

We constructed a unique dataset for the Canton of Bern (Switzerland) that combines yearly household level energy consumption, income, wealth, and buildings' characteristics. With an area of 5,959 km² and 1,001,281 inhabitants the Canton of Bern is the second largest Swiss canton in terms of population. The three main energy providers in the canton are BKW Energie AG (BKW), Energie Wasser Bern (EWB) and Energie Thun (ET). The major provider is by far BKW, supplying more than 7,500 GWh of energy to around 200,000 households in 400 municipalities in the canton. EWB supplies energy to around 70,000 households and is mainly responsible for the city of Bern, whereas Thun serves only 20,000 households. Thun supplied around 200 GWh to its customers in 2013. The following maps show the distribution of households and the coverage of the respective energy providers in the Canton of Bern.

– Figure 2 - 4 here –

The first map refers to the overall canton of Bern, whereas Figure 3 and Figure 4 represent respectively the city of Bern and the city of Thun and their surroundings. In Figure 2 we show the distribution of households according to their assignment to one of the three providers, where the dark blue area represents the city of Thun, the blue area the city of Bern and the larger light blue area the remaining canton of Bern where households fall under the jurisdiction of BKW. The following two maps are just enlargements of particular regions of Figure 2, which highlight the border areas of the two cities.⁷

⁷This map will be useful later on for the regression discontinuity desing.

Of the 141 GWh of energy produced by PV installations subject to feed in remuneration in Switzerland in 2013, those in the area supplied by BKW produced 46 GWh, so around one third. Data on household energy consumption and data on PV installations and infrastructure network costs and tariffs are provided by the three main energy providers in the canton of Bern (BKW, EWB and ET). Detailed individual income and wealth data were provided by the Tax Office of the Canton of Bern and data on building characteristics are drawn from the Swiss Federal Statistical Office.

We obtained a list of grid connections (i.e. energy meters) with their respective energy usage, energy infusion, customer information and some other household specific variables from all three energy providers. These datasets contain both households and businesses. We collapse the data by customer as some households may have more than one meter. The customer information (name and address) is used to merge the energy customer information with the tax data and the building characteristics data. This ultimately allows us to create the final data set, which combines energy, income, wealth data and building information for each household. The data provided by the tax administration also offers information on additional household level information, such as household size, number of children, marital status, and on owner occupied housing.

The original list provided by BKW contains data on about 300,000 grid connections from 2008 to 2013. We first use the imperfect sector identifier of BKW⁸ and drop customers denominated as firms which reduces our sample to about 250,000 grid connections. Collapsing by customer we end up with a sample of about 210,000 households by year. Of these customers we manage to match around 110,000 households with tax information (in 2013). The mismatches are mainly due to data imprecision, different ways to write names and addresses, and the fact that the BKW sample may still include a number of businesses. As we only have the current address for BKW customers but historical personal information in the tax data, the

⁸Imperfect as some small businesses are wrongly labelled as households.

matches steadily decline in the earlier years down to around 85,000 in 2008, as some households relocated during this time period.

For the city of Bern we use a list of about 110,000 grid connections per year from 2008 to 2015. This data is collapsed to a sample of 85,000 business partners, including both households and firms. Matching the energy data with the tax data leads to about 40,000 matched households per year. Beside losses due to data imprecision, all firms drop out in the merging process⁹. As we have historical information on names and addresses in the energy data of the EWB the successful matches only decline slightly to about 36,000 in the earlier years. As of the city of Thun, we start with a list of about 28,000 grid connections per year between 2009 and 2014¹⁰. This is equivalent to about 24,000 Energie Thun customers between households and firms. During the merging process this number is reduced to approximately 15,000 households with both energy and tax data. Again, as we have historical personal information on the energy customers this number is fairly steady during the relevant period. In the aggregated sample of around 174,000 households per year we undertake further adjustments. First, we exclude all grid connections with annual energy consumption below 500 kWh. This number is chosen arbitrarily to exclude abnormal energy meters and false data. For comparison, a single person household usually with only one grid connection has a minimum energy usage of over 2,550 kWh per year¹¹. Second, we drop all households reporting negative income.

Table 1 provides summary statistics for different measures of income and household tax payments. Mean annual gross total income (*TotalIncome*) amounts to CHF 99,061 with a maximum of up to CHF 59 million. Taxable income (*TaxableIncome*)¹² is about one third lower and reaches on average CHF 76,000. Total wealth (*TotalWealth*) averages at CHF 542,563. Both income and wealth exhibit a large variation between

⁹Although there may still be some self-employed people in the data.

¹⁰Unfortunately the data prior to 2009 is not available due to a system change.

¹¹See <http://www.ewb.ch>

¹²Taxable income is defined as total income (in the form of labor income or income from self-employment) plus rental value of owner occupied housing less mortgage interest payments and commuting and living expenses.

households as shown by the large values of the standard deviation. Finally, the last three variables in Table 1 *CantonalTax*, *MunicipalTax*, and *FederalTax* show the tax payments for the three different types of income taxes. Given the federal structure of Switzerland, households are subject to three different income taxes levied by the three different levels of government. Accordingly, the mean municipal tax payment (*MunicipalTax*) in our sample is approximately CHF 3,869 per year, which is paid in addition to the federal (*FederalTax*) and the cantonal tax (*CantonalTax*), with an average of CHF 1,788 and CHF 7,507 per year respectively.

– Table 1 here –

Table 2 presents descriptive statistics of the energy consumption profiles and annual expenditures on the different components of the electricity bill. As displayed in the first row of Table 2, the annual household energy consumption (*EnergyCons*) is on average 4,942 kWh and varies between 500 kWh and 49,991 kWh. As explained in Section 3 above, households which are assigned to BKW or EWB can choose between two different types of tariff: the uniform tariff, independent of usage time,¹³ and the two part tariff.¹⁴ As shown in Table 2, mean annual household energy consumption under the uniform tariff scheme (*ConsUniTariff*) amounts to 2,352 kWh, whereas the numbers are higher for consumption for the high and low tariffs (*ConsHighTariff* and *ConsLowTariff*) with 2,820 kWh and 3,588 kWh respectively. Rows 5-12 in Table 2 display summary statistics for the different expenditure components of the electricity bill. The average annual household expenditure (*EnergyExpend*) reaches CHF 1,043 varying from a minimum of CHF 168 to as much as CHF 20,527. As explained in Section 3, the electricity bill consists of several parts. First, households pay for the amount of energy consumed according to the chosen tariff. This component (*EnergyPriceExpend*) is on average CHF

¹³This amounts to CHF 0.118 per kWh in 2012 for BKW and CHF 0,096 for EWB.

¹⁴For BKW (EWB) customers this tariff distinguishes between a higher charge of CHF 0.112 (0,1075) for daytime and a lower charge of CHF 0.0778 (0,067) for night time.

476 per year. In addition, households pay a network charge used to finance the infrastructure. These charges include both a fixed fee¹⁵ and a volumetric charge.¹⁶ Overall, the average annual expenditure on financing the network (*GridExpend*) reaches CHF 475. Finally, households' energy consumption is subject to cantonal and municipality level charges of around CHF 70 per year and the contribution to promote renewable energy of CHF 0.005 per kWh, which translates into annual mean household charges of CHF 21. Tables 3-5 report the detailed price components for BKW, EWB, and ET respectively for the years 2008-2013.

– Tables 2-5 here –

In Table 6 we show various moments of the distribution of data on PV installations. In total 1,080 households in our dataset own PV installations. 986 of them are BKW customers, 19 EWB, and the rest Energie Thun.

– Table 6 here –

These installations produce on average 6,304 kWh energy per year, with a maximum of 94,100 kWh. Given that the production of this type of renewable energy is also remunerated via the feed-in-tariffs, the numbers in Table 6 display the average income of CHF 2,481 per year with a maximum of CHF 27,327 per annum. As mentioned above, ET only offers its customers the double tariff consisting of a high (daytime) and a low (nighttime) rate. The yearly grid basic fee levied by ET (CHF 84) and EWB (CHF 63) are markedly lower than those charged by BKW (CHF 123 or CHF 103).

Table 7 reports the average energy consumption (*EnergyCons*), expenditure on energy (*EnergyExpend*), the share of taxable income spent on energy (*IncomeShareEnergy*)

¹⁵This amounted to more than CHF 100 per year for BKW and to around CHF 60 for EWB in 2012 (see also Tables 3-5).

¹⁶These vary between 0.02 CHF/kWh and 0.11 CHF/kWh depending on the tariff structure households are subject to.

by income decile or by different income classes. Furthermore, the table displays the proportion of owner occupied housing (*Homeowner*), the average household size (*Householdsize*) in each decile, the fraction of retired households (*Retired*) per decile as well as the share of households who own a PV installation in each decile or income class (*PVinstall*). The last four rows report building or apartment characteristics such as the number of rooms (*NbRooms*), the apartment surface (*AppSurface*) and whether electricity is used for heating or hot water (*ElectheatWater*). Each decile counts around 80,000 observations. The first decile pertains to income less than CHF 27,000, whereas the last one includes annual incomes exceeding CHF 130,000. The unconditional means in Table 7 suggest that the annual average electricity consumption rises steadily with income. For instance, households in the lowest income decile consume on average 3,443 kWh per year, whereas those in the 10th decile display a more than double annual energy consumption of 7,817 kWh per year. This trend is visible also from Figure 5, which depicts the correlation between average income by percentile and average annual energy consumption of the households belonging to the respective income percentile in our dataset. Each dot in Figure 5 represents the correlation between average income in the respective percentile and mean annual energy consumption for all households in the respective percentile.

From Table 7 we can also see a slight increase in household size ranging between 1.34 and 2.7 for the lowest and highest income decile, respectively. The fraction of retired households is constant at around 20%. We can notice however a sharp increase in the proportion of owner occupied housing from as low as 23% for low income households to as much as 58%, 65% and 76% for households in the last three income deciles respectively. The sharp rise in energy consumption in terms of kWh is also reflected in the annual expenditures on electricity consumption. We can notice an increase between 764 CHF/year for households with annual income of less than CHF 27,000 to 1,557 CHF/year for households in the 10th income decile. Both expenditures on main energy consumption (*EnergyPriceExpend*) as well as the payments for the network charge (*GridPriceExpend*) contribute in almost equal

parts to the overall expenditures. The numbers in Table 7 indicate a sharp decline in the share of taxable income spent on energy consumption, from 11% for households in the first income decile to 3%-1% for households from the second income decile onwards. Finally, the average number of rooms and the apartment surface also increase steadily between deciles. The share of the different components of the electricity bill is depicted in Figure 6. As the Figure shows, for very low annual energy consumption levels, the largest part is represented by the fixed grid charge *GridFixExpend*, with almost 60%. This fraction however declines as energy consumption increases, and the largest amounts are then those spent on variable network charges (*GridVarExpend*) and main energy consumption (*EnergyPriceExpend*). The parts spent on cantonal and municipal taxes and on the contribution to financing renewable energy are relatively constant shares of the electricity bill and almost independent of the amount of energy consumed.

– Table 7 here –

– Figures 5 and 6 here –

Figures 7 and 8 depict respectively the distribution of taxable income and of annual energy consumption in our dataset. Median energy consumption amounts to approximately 5000 kWh/year and the median annual taxable income is CHF 64,000. The distribution of energy consumption is skewed to the right, whereas for the income distribution the skewness is less sharp.

– Figures 7 and 8 here –

In Table 8 we report mean annual energy consumption and household income according to different household characteristics. We observe that both income and energy consumption increase with the size of the household. Households using electricity for heating or hot water have a 50% higher energy consumption than those that don't. Finally, the last two rows of Table 8 report the average values for owners

of PV installations (*PVInstall*) versus the rest (*NonPVInstall*). Owners of PV installations seem to consume around 70% more energy and have on average a 45% higher income than their counterparts.

– Table 8 here –

Figure 9 depicts the distribution of the PV installations in the BKW dataset by income decile. We notice an almost monotone increase in the frequency of PV installed over the income distribution. The density almost quadruples between the second and 10th income deciles, where the frequency of PVs installed for households earning more than CHF 130,000 is 24%.

– Figure 9 here –

5 A Model of Household Energy Demand

In this Section we present the econometric model used to estimate energy demand elasticities across the income distribution. As a benchmark we start by performing OLS and fixed effects regressions for the overall sample and per income decile. The latter allows us to compute the income elasticity for each decile separately. We consider $i = 1, \dots, N$ households $i = 1, \dots, N$ across $t = 2008, \dots, 2013$ years. Our main regression specification is the following:

$$\ln(y_{it}) = \alpha + \eta_i + \lambda_t + \beta \ln Price_{ut-1} + \mathbf{X}'_{it} \boldsymbol{\delta} + \epsilon_{it}, \quad (1)$$

where $\ln(y_{it})$ is the log of the annual energy consumption of household i in year t , η_i are household fixed effects, λ_t are year dummies, $\ln Price_{ut-1}$ is the log of the marginal electricity price in the previous year¹⁷, and ϵ_{it} are residuals. The vector \mathbf{X} includes various other controls, such as household size, whether the household

¹⁷We follow Ito (2014) considering the price in the previous year.

owns the house or the apartment, whether the households has a PV installation, the household's annual taxable income.

We report the results of the most basic OLS regression in column (1) in Table 9. In columns (2) to (3) we gradually include year fixed effects and household fixed effects. As opposed to the first three specifications which also include an interaction term between price and income, $Price * Income$, in column (4) of Table 9 we account instead for the interaction between price and income by income decile. We also control for building characteristics, which explain a large part of the variation in electricity consumption. We construct a dummy variable which equals one if the household's dwelling draws on electricity for its heating system or for hot water heating (*Electheatwater*), and zero otherwise. *NbRooms* and *AppSurface* denote respectively the number of rooms and the apartment's surface. *Constr.period* represents the time period during which the building was constructed. We rationalize the impact of these controls as follows: *Income*, *Homeowner*, *Householdsize*, *Electheatwater*, *Nb.rooms* and *AppSurface* should all have a positive effect on energy consumption as we expect a household's energy demand to increase with its income, number of individuals living in the household, the size or surface of the dwelling, whether electricity is used for heating or hot water, or whether we have owner occupied housing. Finally, the more recent the building is, the better its isolation and hence *Constr.period* should display a negative effect on our main variable of interest. In all specifications standard errors are clustered at the household level. Table 10 presents an alternative of specification (3) in Table 9 as we report the same regression but this time by income decile to compute price elasticities by income decile.

One of the key challenges for this model is the identification of the price coefficient β . Even though we control for time-invariant household fixed effects, we cannot rule out the possibility that household-year specific unobservables affecting energy consumption may be correlated with prices. To address this potential endogeneity bias we employ a geographical boundary-based regression discontinuity

design (RDD) combined with a matching framework in the spirit of Fack and Grenet (2010), Gibbons, Machin and Silva (2013) or Basten, Ehrlich, and Lassmann (2015). Ito (2014) also uses a geographical regression discontinuity design to estimate energy price elasticities, but we differ from his approach as we combine the RDD with a matching framework that pairs neighbouring households, similar in terms of observables. Most of the existing studies estimating energy price elasticities (Alberini, Gans, and Velez-Lopez (2011), Alberini, Filippini (2011), Reiss, White (2005)) may suffer from omitted variable bias since all salient household characteristics are usually not observed. We address this problem using similar neighboring households facing different energy prices, as households on different sides of some geographic boundaries (discontinuities) fall within the area of different service providers. Using boundary fixed effects or taking the difference between energy consumption and prices of matched households on each side of the border and differentiating the data can then overcome this bias.

We are able to exploit time-series and especially cross-sectional variation at the spatial discontinuity of the three different electricity service regions within the same canton. Issues such as omitted variable bias or potential sorting at the border which may be problematic with a RDD (Lee and Lemieux, 2010) are unlikely to affect our design for two reasons. First, households in the canton of Bern are not allowed to choose their energy provider, and it is highly improbable that they will sort based on their energy bill. Our estimation strategy will account for boundary fixed effects to correct for between service area unobserved heterogeneity. Second, we inverse-weight our observations such that households that are close neighbors receive a larger weight (see also Gibbons, Machin, and Silva (2013)). We observe the annual energy consumption of household i in year t falling within the service area of utility $u \in \{BKW, EWB, ET\}$. Each household is uniquely assigned to the service area of one of the three energy providers. Using geographical information in terms of latitude and longitude we determine for each household its spatial location, defined as border point b . Based on this design the new specification will be:

$$\ln(y_{ibut}) = \alpha + \beta \ln Price_{uit-1} + \delta_{bt} + \epsilon_{ibut}, \quad (2)$$

where δ_{bt} absorbs all time varying unobservable determinants of energy consumption specific to the neighborhood of the border point. β is the energy price elasticity and ϵ_{ibut} is an error term.

When we extend the geographical regression discontinuity design by matching households with similar characteristics on opposite sides of the borders, we assume that households that are sufficiently close share the same time-varying vicinity effect in energy consumption, so the new specification becomes:

$$\ln(y_{ibut}) - \ln(y_{i'bu't}) = \beta(\ln Price_{uit-1} - \ln Price_{u'it-1}) + (\epsilon_{ibut} - \epsilon_{i'bu't}), \quad (3)$$

where β is estimated running an OLS regression of the difference in energy consumption between matched households on opposite sides of the border. Each pair receives a weight $\sum_{j=1}^J \frac{1}{d_{ij}}$ such that greater weight applies to observations that are close neighbors, where d_{ij} is the distance between households. In this specification we compute standard errors clustered at the boundary year level. Differently from (2), (3) eliminates common area specific trends by spatial differencing and accounts for the distance between households on opposite sides of the border. We match a distance-weighted counterfactual of a BKW customer to the border observations falling within the service area of EWB or ET respectively. We use a subsample of all observations within 1 km of the predefined border points. Each observation is assigned a unique nearest border point for the matching procedure. The counterfactual is defined as a distance-weighted average of the 50 nearest BKW observations to each ET/EWB observation. The dependent variable $\ln(y_{ibut})$ is constructed as the predicted residual from a regression of energy consumption on the full set of control variables. In a first step we control for different household observable characteristics, and in a second step we regress the difference of the unexplained variation in energy consumption on the price difference.

Assuming that all other unobservable factors vary continuously at the boundary, the coefficient β can be interpreted as the unbiased price elasticity of energy demand. If other determinants were to also vary discontinuously at the border, we would not be able to isolate the energy price effects. For this reason we eliminate boundaries that coincide with significant geographical barriers.

6 A Model of PV Adoption (Preliminary)

The effects of an alternative tariff structure on households' energy consumption is not the only relevant dimension that a policymaker should consider. Another crucial feature of the regulation of energy markets entails in fact promoting the diffusion of renewable energy sources, like residential solar panels, and each tariff regime generates different incentives for households' PV installation decisions. Therefore, to better understand the consequences of an alternative tariff structure, we develop a model of households' PV adoption.

We are in the process of obtaining the relevant data we need to estimate this model. Given the information about households and buildings that we already have, we are collecting detailed information about weather in each community, slope and area of the roof of each building, and estimates of the installation costs that local companies charge households. In cooperation with a software developer, this information will allow us to recover two household-year specific key variables for the structural model: fixed installation costs and present discounted value of 25-year production revenues from the PV's electricity generation. These estimates are typically presented by PV installation companies to households when requesting a price quote for a PV installation.

Let there be $i = 1, \dots, I$ households over $t = 1, \dots, T$ periods. Every period households make two choices: their optimal level of energy consumption y_{it} , and whether to install a PV system on their rooftop $PV_{it} = \{0, 1\}$. Given the feed-in system in place and the solar panel's energy production, the choice to install a PV affects

the price of energy that households pay P_{it} . Following Rust (1987), Burr (2014) and Reddix (2014), we model households' PV adoption PV_{it} as a dynamic optimal stopping problem. The state variables of this program are the household's yearly cost of energy $C_{it} = y_{it}P_{it}$, the fixed costs of installing a PV F_{it} , and net present value of 25-year production revenues from solar electricity generation R_{it} . Note that installing a PV changes the marginal price for energy, as a fraction of electricity is now produced by the solar panel, and might be even be sold back to the grid. We define these state variables as $S = \{C, R, F\}$, whereas we allow ε to be a state variable unobserved by the econometrician, distributed as Type 1 extreme value. The current period households' utilities from adopting or not adopting a PV will be:

$$u_{it}(\cdot) = \begin{cases} -\theta_1 C_{it} + \theta_2 R_{it} - \theta_3 F_{it} + \varepsilon_{1it} & \text{if } PV_{it} = 1 \\ -\theta_1 C_{it} + \varepsilon_{0it} & \text{if } PV_{it} = 0, \end{cases}$$

where θ_1 represents the disutility from current period energy cost, θ_2 the utility from future solar energy generation, and θ_3 the disutility from the fixed installation cost. Based on these utilities, the alternative specific value functions will be:

$$V_{it}(\cdot) = \begin{cases} u_{it}(\cdot | PV_{it} = 1) & \text{if } PV_{it} = 1 \\ u_{it}(\cdot | PV_{it} = 0) + \rho EV_{it+1} & \text{if } PV_{it} = 0, \end{cases}$$

where ρ represents the discount factor. In a counterfactual exercise we want to simulate a different price-subsidy structure and analyze how this would affect not only energy consumption, but also PV adoption decisions across the income distribution.

7 Empirical results and simulations

7.1 Energy demand elasticities

Our baseline regression results are presented in Tables 9 and 10. First of all, we can see in Table 9 that household fixed effects explain a large part of the variation in energy consumption, as the R^2 increases from 0.45 to 0.96 once we include them. All the coefficient display the expected sign and the coefficients of the main explanatory variables *Price*, *Income*, *Homeowner*, *Householdsize*, *Electheatwater*, *Nb.rooms* and *AppSurface* are highly significant at the one per cent level. The price elasticity of demand is as expected negative, and it declines significantly from -0.63 to -0.12 when we control for household fixed effects (see Table 9). To see how this price elasticity varies with income, in column (4) we also include the interaction of price and income for each income decile. We find that households in higher income deciles seem to be more price elastic. This is confirmed also by the results presented in Table 10. The coefficients for the price elasticity of energy demand vary between -0.051 and -0.123 for the first and the tenth income decile respectively. Given that energy can be seen as a basic necessity, it is not surprising that especially lower income deciles react almost inelastically to a change in the energy price. Since we include households fixed effects in these regressions and we perform the estimation per income decile, it is not surprising that the coefficients of the remaining control variables apart from *Householdsize* and *Constr.period* are not significant as the effects are already captured by the time invariant household effects.

In Table 11 we report the results of the RDD and MBDD estimation strategies. Columns (1) and (2) report the results for Equation (2), whereas columns (3) to (6) refer to Equation (3). In the first two columns we include year and border fixed effects. In the second column we adopt a conservative strategy and include only households residing within 500m to each side of the border, which explains the drastically smaller sample counting only around 50,000 observations, compared to the overall sample of 574,037 observations. In columns (3) and (4) we report the

results for the matched boundary discontinuity design for households falling within the service area of BKW and EWB. Columns (5) and (6) report the results when focusing only on customers of BKW and ET. In all four regressions we use only households living within 1km on the opposite sides of the respective border. Finally in columns (4) and (6) we also include pair fixed effects. The results reported in the first two columns of Table 11 are quite similar in terms of magnitude to the respective coefficients in Table 9. The reported energy demand elasticities are in the range of -0.65 to -0.84. The results are larger for the MBDD estimation strategy where we obtain elasticities ranging between -0.54 and -2.4. We should also note here that using this latter estimation strategy shrinks our sample considerably, as the number of observations decreased to 5,873 in columns (3) and (4) and to only 1,609 in the last two columns.

– Tables 9-11 here –

7.2 Simulation results

In this subsection we turn to the computation of the welfare changes implied by a switch in the financing structure of the energy transportation and distribution network. As explained in the Introduction, the increasing installation of rooftop solar panels, together with the current financing of the energy infrastructure via volumetric charges, may lead to an increase in tariffs. As of 2013 the number of installed rooftop solar panels in the Canton of Bern is still low, and there has not been any increase in charges yet, but as Figure 1 shows the number of installations has increased exponentially since 2008, and if this growth rate continues the financing issue will become relevant in the near future. To address this concern we propose a system of alternative fixed tariff. A solution can be a uniform tariff structure, or alternatively a high and low fixed tariff that applies to households above and below the median energy consumption.

To evaluate the welfare changes for each household decile and for the overall

group of households we consider different scenarios. First, we assume as a benchmark a zero energy demand elasticity, such that the overall welfare effect is equivalent to the income effect as the quantity of energy demanded does not change following the change in the tariff structure. In subsequent scenarios we employ the estimated values of the elasticities by income decile computed in Tables 9 and 10. For all simulations performed, we assume profits of the utility are not affected, such that a change in consumer surplus corresponds to the overall change in welfare. We use 2013 as our base year for the simulations in Figures 10 and 11, and in Tables 12 and 13. We compute for each household the change in consumer surplus as the difference between the annual expenditure on electricity under the current pricing scheme (volumetric charges) and a counterfactual scenario with a fixed tariff.

Figure 10 reports welfare changes for each income decile assuming an electricity demand elasticity of zero. To obtain the alternative fixed network charge we sum up all current volumetric expenditures on network financing of all households in our sample. This overall cost is then divided by the number of households to obtain the uniform per household fee of around CHF 450 per year. While customers in the first five income deciles with annual incomes up to CHF 75,000 face a decrease in welfare, households in the last four top income deciles experience an increase in surplus. However, this welfare change is extremely small, as welfare losses are at most around 0.7% of household income, whereas welfare increases are only up to 0.1% of household income. The lower panel of Figure xx depicts the resulting welfare change if we replace the uniform tariff with a high and low fixed tariff that applies to households above and below the median energy consumption. Under this scenario welfare losses are only around 0.3% of household income for the first income decile. The remaining households except those in the last decile experience almost negligible welfare losses, below 0.1% of their income.

– Figures 10 and 11 here –

Given that energy consumption largely varies with household size, the numbers in Table 12 show welfare changes as a function of household size. We note that under

the uniform tariff only single households would experience a welfare loss. Furthermore, homeowners face on average a decline in their annual energy consumption bill, and tenants experience an increase in the expenditures for network financing. This difference is explained by the fact that homeowners consume on average more energy.

– Table 12 here –

Figure 11 reports the simulations with the estimated elasticity for each income decile, as reported in Table 10. The graphs are quite similar to those ones in Figure 10 and the welfare losses (gains) are only slightly lower (higher). This result is explained by the fact that estimated elasticities are in general quite low. The switch from volumetric charges to fixed fees generates a reduction in marginal prices per kWh, causing households to increase their energy consumption. This might be considered as an undesirable consequence of a fixed fee, from an environmental perspective, but it's outside the scope of this paper.

We now consider the implications of the increased penetration of distributed energy on infrastructure financing and income distribution. Starting with the 1st of January 2015 Swiss households are not required anymore to feed the overall amount of distributed energy produced by their PV installations into the network, but are now allowed to consume the energy they produce. This implies that with a system of volumetric charges tariffs per kWh need to be increased to finance fixed network costs. In Table 13 we present the results of two simulations. In the first one households consumer only 30% of the PV production, whereas in the second scenario PV owners consume tall the energy they produce¹⁸. If on the one hand home owners with a PV installation experience a welfare gain, on the other hand the remaining residential customers suffer a decline in consumer surplus. We find that households in the 1st, 7th, 9th and 10th decile experience welfare gains, while the others' consumer surplus reduces. The welfare increase for the lowest

¹⁸In these simulations we still assume a zero energy demand elasticity.

decile, representing households with an annual income below CHF 27,000, can be explained by looking at Figure 9, as solar panels are as frequently installed by 1st as by 5th income decile households. Hence, the relationship between frequency of PV installations and welfare change is slightly U shaped between the 1st and the 5th income decile and positive and linear from the 6th decile onwards. Moreover, households with yearly income up to CHF 27,000 display a low energy consumption, which means that they obtain a large part of their energy demand from self produced energy and save on grid costs. In the presence of net metering the savings on energy expenditures exceed the higher costs due to increased volumetric charges for these consumer types.

– Table 13 here –

8 Conclusion

In this paper we analyzed the redistributive impact of a change in the financing structure of energy distribution and transmission lines. We considered a system switch from volumetric charges to fixed fees, because the increasing penetration of PV installations combined with a system of net metering and kWh based rates may not guarantee the financing of the energy infrastructure network in the long run. Therefore a different financing scheme which doesn't depend on the volume of consumption may be more appropriate. We show the welfare effects of this transition for each households' income decile and for different household categories. To calculate these welfare changes we estimate energy demand elasticities using a detailed dataset with 180,000 Swiss households in the Canton of Bern for the years 2008-2013. We rely on a RDD and a matching boundary discontinuity design, and find elasticities in the range of -0.63 to -0.06. Households in income classes with greater levels of elasticity experience lower welfare losses (or larger welfare gains). However, even though a fixed fee policy may make the financing of the energy infrastructure more sustainable, it may work against energy efficiency by encouraging more energy

consumption.

We also consider the implications of the increased penetration of PV installations under a regime of net metering. As the number of PV installations is still very low in 2013, the required increase in volumetric charges to finance the fixed network costs does not turn out to be very significant. If the 1,000 PV owners in 2013 were consuming 100% of the energy they produced, they would gain on average approximately CHF 600 each. Households without a PV installation would instead lose on average CHF 4 each, as the great majority of customers still don't have a PV. It is important however to predict how these number would change in the coming years, given the exponential increase in PV adoptions. We recognize that instead of a fixed fee a first best solution would entail capacity based charges, which reflect the individual customer's peak load on the distribution system. This kind of pricing strategy is however difficult and costly to implement, as it requires the widespread adoption of smart meters. Until the adoption of smart meters will become less costly and more accessible, fixed charges can represent an improvement with respect to volumetric charges, as the latter may not allow to recover network costs and may induce households to switch to alternative energy sources in an inefficient way.

Figures

Figure 1: PV Electricity Generation in Switzerland (in GWh)

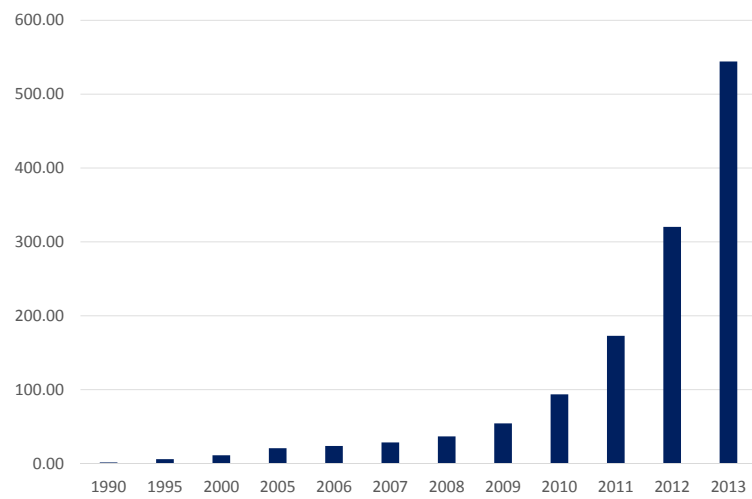


Figure 2: MAP CANTON BERN (HOUSEHOLDS)

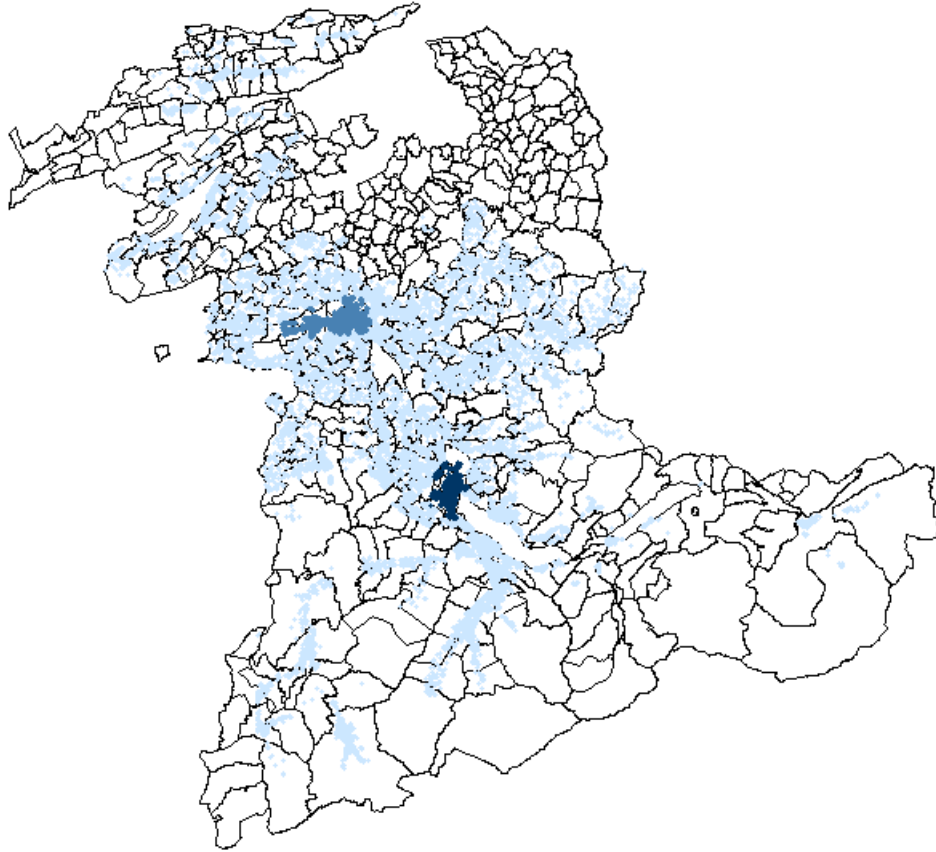


Figure 3: MAP CITY BERN (HOUSEHOLDS)

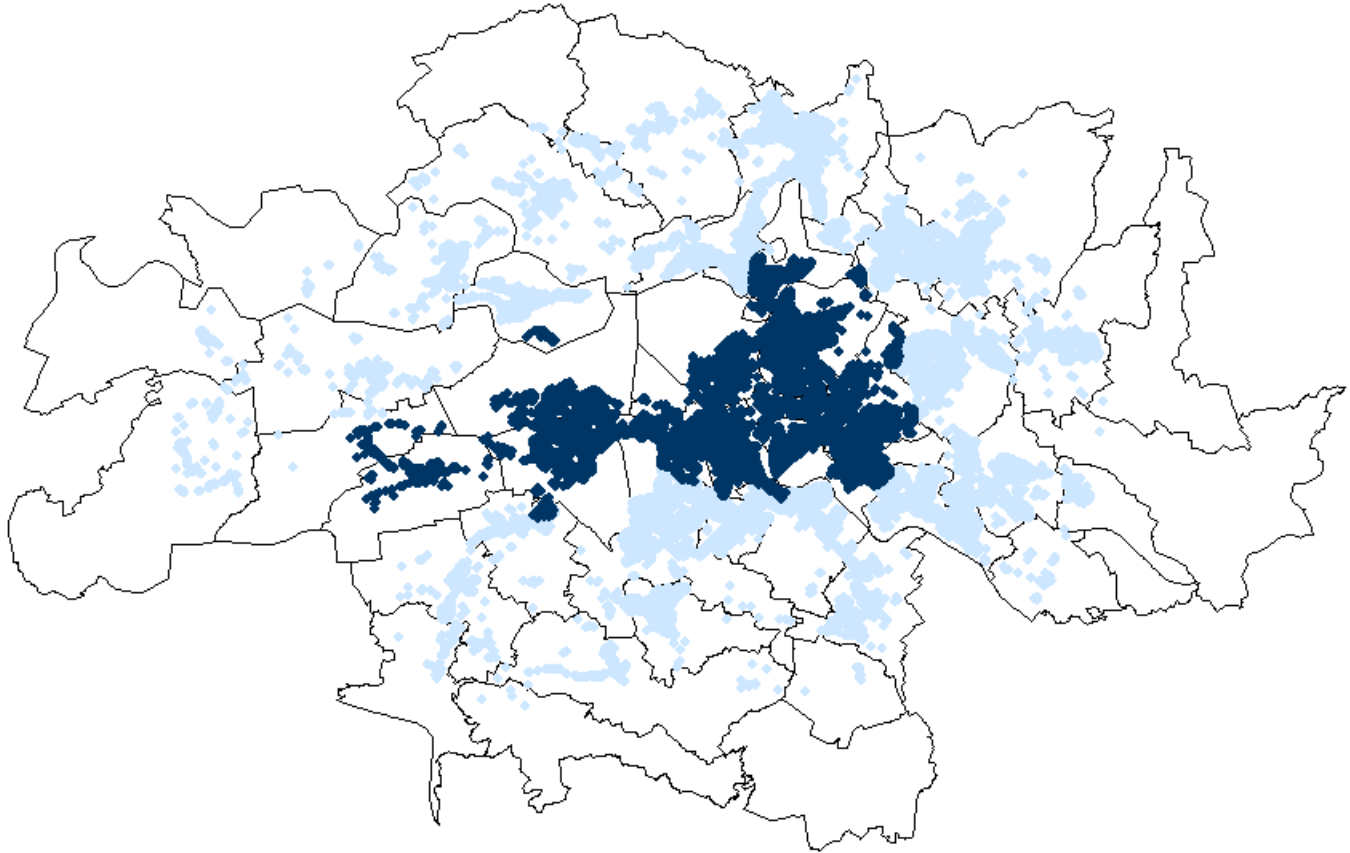


Figure 4: MAP CITY THUN (HOUSEHOLDS)

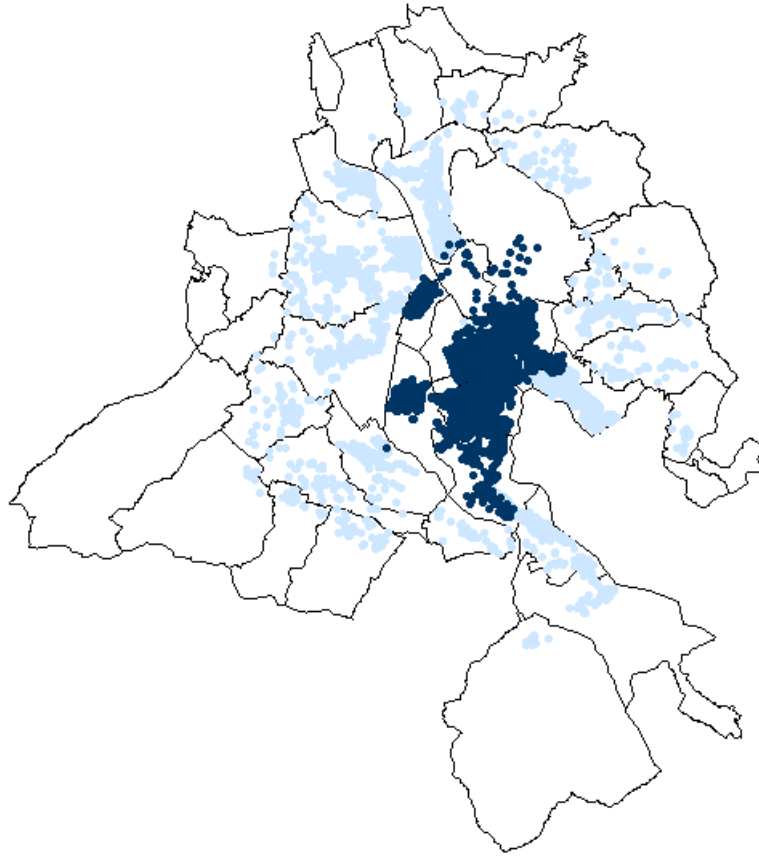


Figure 5: Annual Electricity Consumption by Income

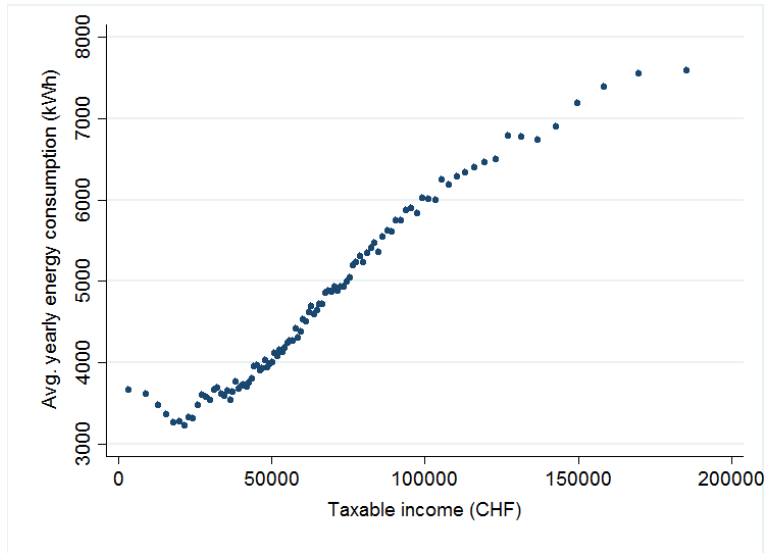


Figure 6: Expenditure Share of Tariff Elements by Consumption

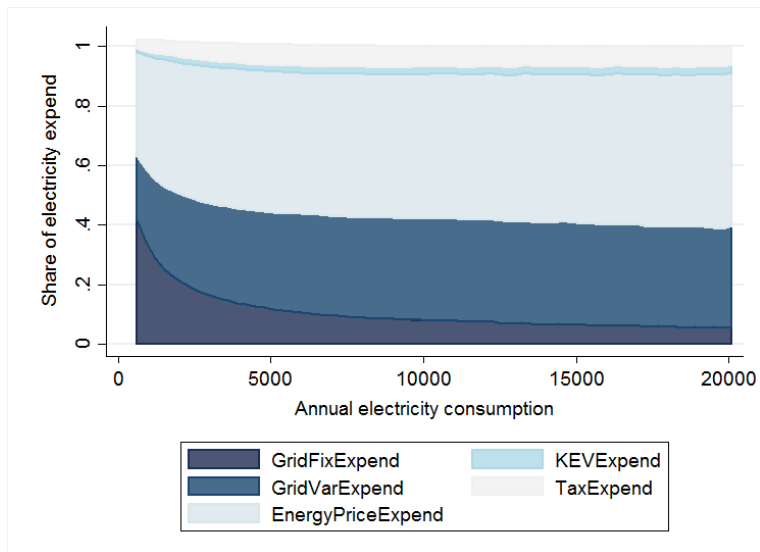


Figure 7: Distribution of Taxable Income

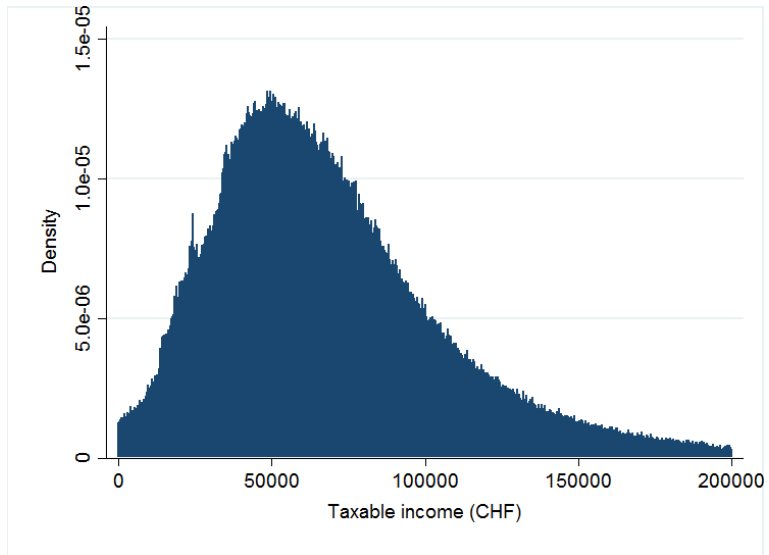


Figure 8: Distribution of Annual Electricity Consumption

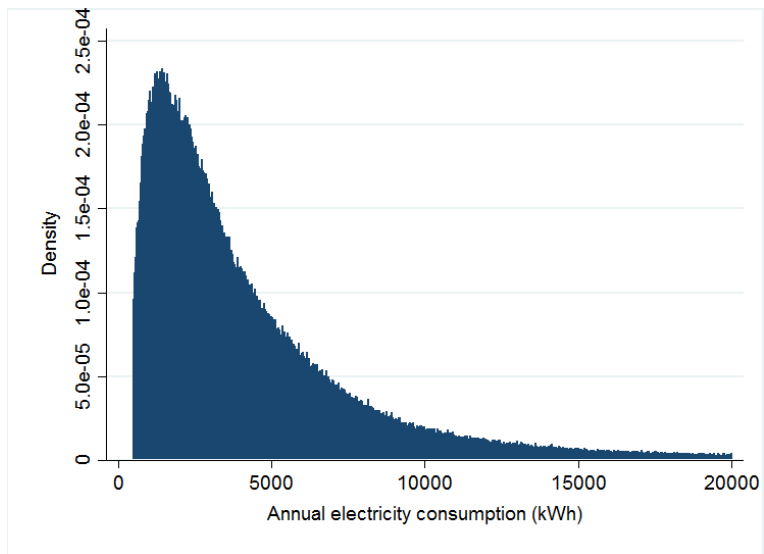


Figure 9: Distribution of PV Installations by Income

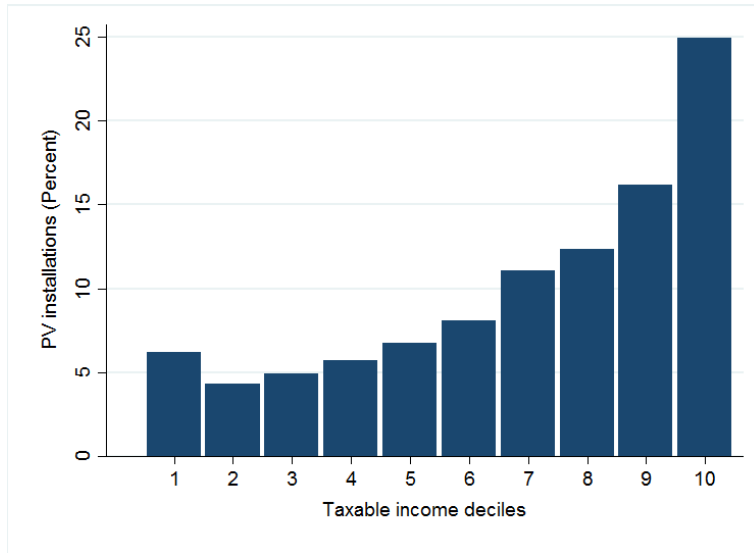


Figure 10: WELFARE CHANGE AS % OF TAXABLE INCOME ($\epsilon = 0$)

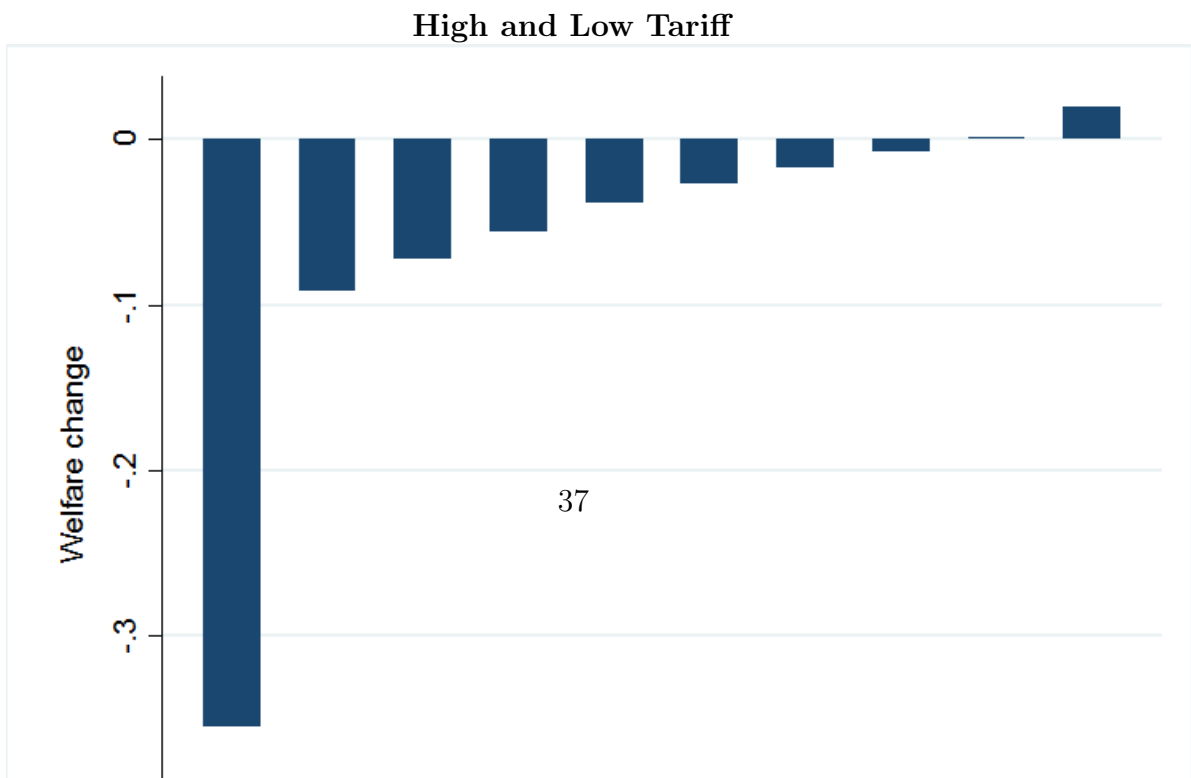
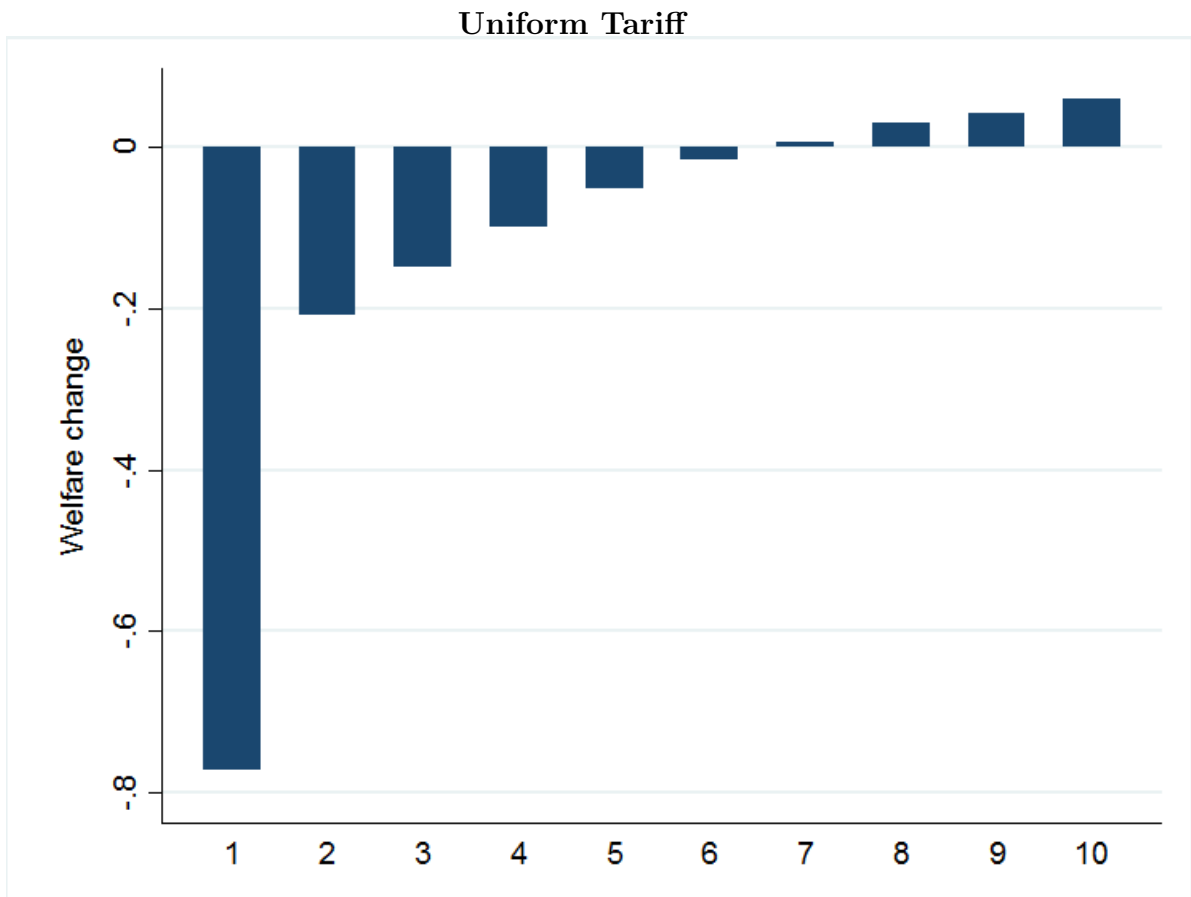
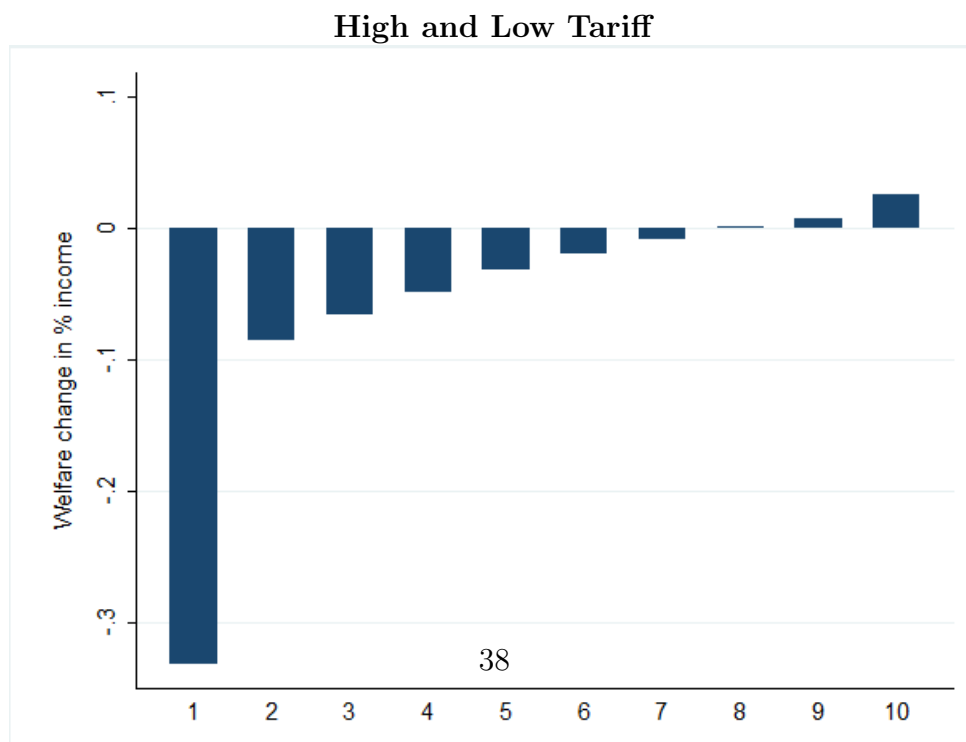
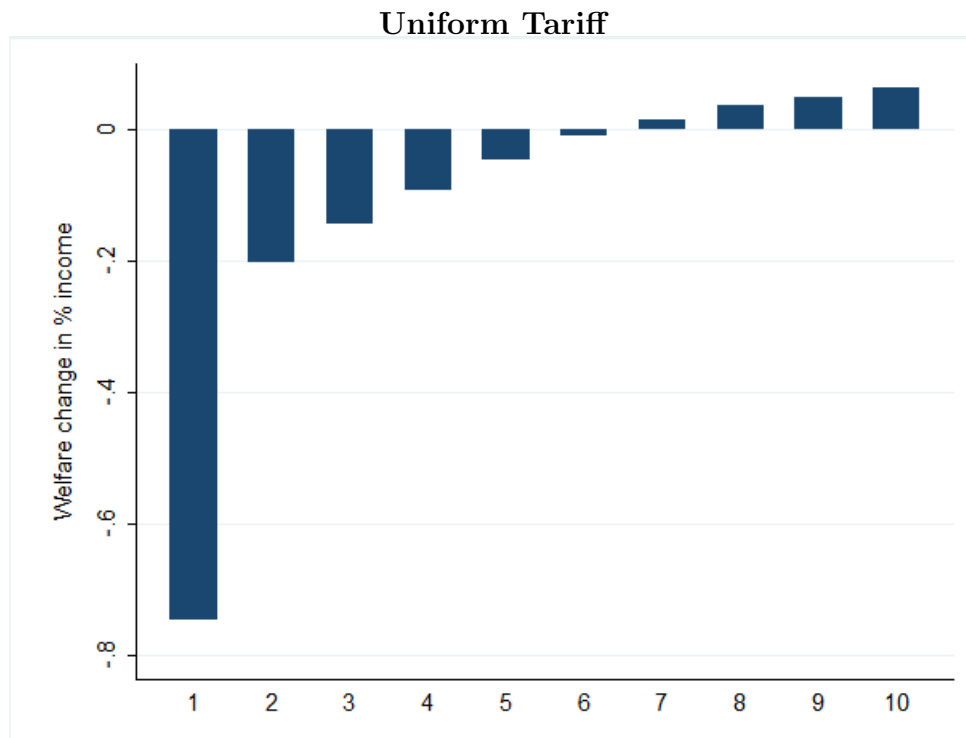


Figure 11: WELFARE CHANGE AS % OF TAXABLE INCOME ($\epsilon \neq 0$)



Tables

Table 1: Income, Wealth and Tax Payments (in CHF)

	Mean	Stddev	Median	Min	Max	NumbObs
TotalIncome	99,061	125,027	82,428	5	5.91e+07	789,098
TaxableIncome	76,100	114,195	63,556	1	5.91e+07	789,098
TotalWealth	542,563	2531557	259,016	-6454216	8.40e+08	789,098
CantonalTax	7,507	13,989	5,559	0	6031271	789,098
MunicipalTax	3,869	6,769	2,915	0	2857955	789,098
FederalTax	1,788	9,206	499	0	4142024	789,098

Table 2: Energy Consumption and Expenditure

	Mean	Stddev	Median	Min	Max	NumbObs
EnergyCons(kWh)	4,942	5,289.5	3,261	500	49,991	789,098
ConsHighTariff	2,820.7	2,432.9	2,161	.8	41,166	495,915
ConsLowTariff	3,588.2	4,352.6	2,436	1	47,634.8	496,000
ConsUniTariff	2,352	1,721.5	1,931	4	45,478	306,654
EnergyExpend(CHF)	1,043.4	872.2	775.4	-68.4	10,527.1	789,098
EnergyPriceExpend	476.1	458.4	335.7	-352.5	16,869.7	789,098
PriceExpendHT	324	267.5	253	.1	5,760.8	495,916
PriceExpendLT	263.3	317.1	178.7	.1	3,952.3	496,001
PriceExpendUT	258.8	190.5	211.2	-352.5	4,547.8	306,656
GridExpend	475.4	347.3	376.5	0	4,509.4	789,098
TaxExpend	69.2	70.9	50.9	0	1,547.2	789,098
KEVExpend	21.2	24.3	13.5	0	244.9	789,098

Table 3: Energy Prices, Network Tariffs and Taxes - BKW

	2009	2010	2011	2012	2013
<i>Double tariff</i>					
EnergyPriceHT(Rp/kWh)	11.57	11.57	12.16	12.20	11.88
EnergiePriceLT(Rp/kWh)	7.21	7.21	7.21	7.24	7.78
GridBasicFeeHT(CHF)	180.77	180.77	142.03	123.12	123.12
GridPriceHT(Rp/kWh)	11.30	11.30	11.14	9.18	9.18
GridPriceLT(Rp/kWh)	4.20	4.20	5.54	4.59	4.59
<i>Uniform tariff</i>					
EnergyPriceET(Rp/kWh)	11.03	11.30	11.78	11.83	11.77
GridBasicFeeET(CHF)	142.03	142.03	122.66	103.68	103.68
GridPriceET(Rp/kWh)	11.30	11.30	10.60	8.91	8.91
<i>Both tariffs</i>					
Swissgrid(Rp/kWh)	-	-	-	0.43	0.33
KEV(Rp/kWh)	0.48	0.48	0.48	0.49	0.49
MunicipalTax(Rp/kWh)	1.61	1.61	1.61	1.62	1.62

Note: Prices include value-added tax.

Table 4: Energy Prices, Network Tariffs and Taxes - Energie Thun

	2009	2010	2011	2012
<i>Double tariff</i>				
EnergyPriceHT(Rp/kWh)	11.23	11.21	11.60	11.61
EnergiePriceLT(Rp/kWh)	8.73	8.71	9.10	9.10
GridBasicFee(CHF)	84.00	84.00	84.00	84.00
GridPriceHT(Rp/kWh)	8.00	8.00	8.50	8.40
GridPriceLT(Rp/kWh)	2.00	2.00	2.30	2.30
Swissgrid(Rp/kWh)	0.40	0.40	0.77	0.46
KEV(Rp/kWh)	0.45	0.45	0.45	0.45
MunicipalTax(Rp/kWh)	4.28	4.28	4.31	3.10

Note: Prices include value-added tax.

Table 5: Energy Prices, Network Tariffs and Taxes - Energie Bern

	2009	2010	2011	2012	2013
<i>Double tariff</i>					
EnergyPriceHT(Rp/kWh)	11.85	11.82	11.93	11.44	10.75
EnergiePriceLT(Rp/kWh)	7.33	7.32	7.25	7.03	6.73
GridBasicFeeHT(CHF)	131.95	121.13	120.35	112.41	63.07
GridPriceHT(Rp/kWh)	7.94	7.46	6.53	5.92	6.58
GridPriceLT(Rp/kWh)	1.96	1.80	1.73	1.68	2.89
<i>Uniform tariff</i>					
EnergiePriceUT(Rp/kWh)	10.70	10.66	10.64	10.25	9.61
GridBasicFeeUT(CHF)	96.64	85.41	84.48	78.99	43.37
GridPriceUT(Rp/kWh)	7.39	7.25	6.31	5.45	6.08
<i>Both tariffs</i>					
Swissgrid(Rp/kWh)	.00	.00	.07	.40	.37
KEV(Rp/kWh)	.42	.45	.45	.45	.47
MunicipalTax(Rp/kWh)	.25	.27	.27	.61	2.35

Note: Prices include value-added tax.

Table 6: PV Production and Remuneration

	Mean	Stddev	Median	Min	Max	NumbObs
PvProduction(kWh)	6,304	6,537	4,800	0	94,100	2,785
PvIncome(CHF)	2,481	2,308	2,064	0	27,327	2,785
PvOwner	.593	.491	1	0	1	2,568

Table 7: Energy and Household Characteristics

	1st Dec	2nd Dec	3rd Dec	4th Dec	5th Dec	6th Dec	7th Dec	8th Dec	9th Dec	10th Dec
TCHF	<27	27-38	39-47	48-55	56-64	65-73	74-85	86-101	102-130	>130
EnergyCons(kWh)	3,443	3,641	3,830	4,098	4,458	4,839	5,261	5,776	6,371	7,817
EnergyExpend(CHF)	764	808	843	893	960	1,030	1,105	1,194	1,299	1,557
EnergyPriceExpend	334	353	370	396	431	467	506	553	611	752
GridPriceExpend	362	381	396	416	443	472	501	536	578	677
IncomeShareEnergy	.11	.025	.02	.018	.016	.015	.014	.013	.012	.009
Homeowner	.231	.298	.318	.34	.397	.452	.513	.576	.651	.759
Householdsize	1.34	1.46	1.58	1.77	1.98	2.16	2.28	2.39	2.53	2.7
PVInstall	.0022	.0015	.0017	.002	.0024	.0028	.004	.0043	.0059	.0088
Retired	.144	.21	.202	.19	.213	.248	.245	.237	.221	.21
Electheatwater	.37	.37	.38	.38	.39	.4	.41	.43	.44	.45
NbRooms	3.26	3.39	3.44	3.53	3.63	3.75	3.88	4.05	4.26	4.69
AppSurface ^{m²}	82	86	87	91	94	98	103	110	119	137
OneAppartBuild	.15	.18	.18	.2	.23	.27	.31	.36	.42	.51
NumbObs	79,292	79,369	79,291	79,335	79,348	79,348	79,111	78,830	78,388	76,786

Table 8: Energy Consumption and Income by Household Characteristics

	EnergyConskWh	IncomeCHF
Householdsize (Numb. of people)		
1	3,162	53,053
2	5,651	87,006
3	6,250	93,859
4	7,107	101,446
5	7,880	104,775
> 5	8,604	106,034
Electheatwat	7,093	78,906
NonElectheatwat	3,498	74,217
PVInstall	8,533	110,160
NoPVInstall	4,929	75,980

Table 9: ENERGY PRICE ELASTICITIES

	OLS	Year fixed effects	Year and hh. fixed eff.	Elast-inc
	(1)	(2)	(3)	(4)
Price	-.628 (.008)***	-.630 (.009)***	-.116 (.010)***	-.115 (.010)***
Income	.021 (.003)***	.021 (.003)***	.009 (.002)***	.008 (.002)***
Price*Income	-.004 (.002)*	-.004 (.002)*	-.00003 (.0002)	
Homeowner	.287 (.004)***	.286 (.004)***	.022 (.006)***	.022 (.006)***
Householdsize	.192 (.001)***	.192 (.001)***	.054 (.002)***	.054 (.002)***
PV-install	-.018 (.027)	-.012 (.027)	-.080 (.017)***	-.080 (.017)***
Electheatwater	.369 (.003)***	.369 (.003)***	.286 (.069)***	.286 (.069)***
Constr. period	-.008 (.0006)***	-.008 (.0006)***	-.030 (.010)***	-.030 (.010)***
NbRooms	.118 (.002)***	.118 (.002)***	.045 (.040)	.045 (.040)
AppSurface	.002 (.00007)***	.002 (.00007)***	.002 (.001)*	.002 (.001)*
Price*Income 2. Dec.				.008 (.006)
Price*Income 3. Dec				.011 (.005)**
Price*Income 4. Dec				.003 (.005)
Price*Income 5. Dec				.0004 (.004)
Price*Income 6. Dec				-.005 (.004)
Price*Income 7. Dec				-.005 (.003)*
Price*Income 8. Dec				-.005 (.003)*
Price*Income 9. Dec				-.005 (.002)**
Price*Income 10. Dec				-.00006 (.0002)
Year FE	No	Yes	Yes	Yes
Household FE	No	No	Yes	Yes
Nb. obs.	544315	544315	544315	544315
R ²	.451	.452	.963	.963

Table 10: ENERGY PRICE ELASTICITIES BY INCOME DECILE

	1. Dec	2. Dec	3. Dec	4. Dec	5. Dec	6. Dec	7. Dec	8. Dec	9. Dec	10. Dec
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Price	-.051 (.036)	-.031 (.040)	-.071 (.043)*	-.084 (.046)*	-.061 (.037)*	-.146 (.046)***	-.128 (.061)**	-.132 (.042)***	-.136 (.039)***	-.123 (.044)***
Income	-.0008 (.004)	.026 (.025)	.001 (.037)	.068 (.043)	.014 (.044)	.048 (.045)	.068 (.040)*	.024 (.032)	.038 (.021)*	.014 (.011)
Wealth	.0008 (.002)	-.002 (.003)	.002 (.003)	-.003 (.004)	.0002 (.004)	.004 (.004)	-.0004 (.005)	-.002 (.005)	-.006 (.007)	.014 (.008)*
Homeowner	.021 (.023)	-.004 (.026)	-.005 (.025)	.017 (.027)	.027 (.033)	.028 (.028)	.025 (.028)	.003 (.025)	.038 (.022)*	.016 (.027)
Householdsize	.043 (.009)***	.040 (.008)***	.056 (.009)***	.039 (.008)***	.045 (.007)***	.038 (.007)***	.039 (.007)***	.044 (.006)***	.042 (.005)***	.042 (.006)***
PV-install	-.163 (.109)	.063 (.107)	.030 (.096)	-.050 (.038)	.060 (.084)	.064 (.108)	-.079 (.077)	-.078 (.084)	-.131 (.053)**	-.076 (.067)
Electheatwater	.219 (.241)	-.256 (.241)	.064 (.315)	.124 (.333)	.245 (.575)	.063 (.276)	.375 (.295)	.521 (.330)	.214 (.206)	.308 (.282)
Constr. period	-.101 (.044)**	-.088 (.030)***	-.051 (.054)	-.044 (.059)	-.013 (.069)	-.026 (.032)	-.034 (.026)	-.091 (.053)*	.013 (.024)	-.056 (.041)
NbRooms	-.073 (.176)	-.148 (.126)	.044 (.221)	.327 (.285)	.667 (.343)*	.015 (.078)	.006 (.140)	.161 (.233)	.020 (.191)	.079 (.170)
AppSurface	.004 (.007)	.009 (.007)	.0005 (.010)	-.003 (.009)	-.009 (.010)	.008 (.004)**	.001 (.004)	-.003 (.006)	.0001 (.004)	.010 (.007)
Nb. obs.	48055	51817	52290	53132	53927	54219	54221	54076	52541	39112
R^2	.968	.974	.976	.979	.981	.981	.98	.98	.978	.98

Table 11: RDD AND MBDD: ENERGY PRICE ELASTICITIES

	OLS		MBDD			
	Full Sample	500m border	BKW-EWB	BKW-EWB	BKW Thun	BKW Thun
	(1)	(2)	(3)	(4)	(5)	(6)
Price	-.839 (.005)***	-.653 (.014)***				
Price			-1.589 (.180)***	-.537 (.074)***	-2.228 (.016)***	-2.352 (.484)***
SingleFamHouse	.253 (.002)***	.206 (.009)***				
Electheat	.677 (.004)***	.723 (.020)***				
Heatpumheat	.187 (.004)***	.143 (.020)***				
Electwater	.250 (.002)***	.256 (.006)***				
Heatpumpwater	.098 (.006)***	.075 (.023)***				
NbRooms	.056 (.001)***	.083 (.004)***				
AppSurface	.001 (.00003)***	.002 (.0001)***				
Homeowner	.251 (.002)***	.203 (.007)***				
Householdsize	.179 (.0007)***	.198 (.003)***				
Income	.069 (.001)***	.058 (.005)***				
Year FE	yes	yes	yes	yes	yes	yes
Border FE	yes	yes	no	no	no	no
Pair FE	no	no	no	yes	no	yes
Nb. obs.	574037	48679	5873	5873	1609	1609
R^2	.557	.534	.762	.987	.969	.988

Table 12: Welfare Change by Household Characteristics with Fixed Grid Charge, $\epsilon = 0$ (Base year 2013)

	CurrentCost	FixedCharge	AvgWelfCh	TotWelfCh	NumbHH
Householdsize (Numb. of people)					
1	299	360	-83	-5386152	65,194
2	479	390	31	1692749	54,186
3	514	390	68	932,654	13,727
4	595	402	118	1833916	15,517
5	653	404	164	696,438	4,240
> 5	721	409	219	230,398	1,054
NonHomeowner	302	359	-67	-5926588	88,521
Homeowner	588	407	91	5926591	65,397

Table 13: Welfare Change with Own Consumption (Base year 2013)

	dwelf03	dwelf10
<i>Panel A: By PV install</i>		
NoPVInstall	-242,332	-606,637
PVInstall	241,641	602,283
<i>Panel B: By income decile</i>		
1 decile	-1,727	-8,575
2 decile	-6,756	-18,836
3 decile	-6,291	-18,969
4 decile	-4,928	-15,581
5 decile	-6,192	-13,283
6 decile	-4,608	-15,081
7 decile	4,746	7,893
8 decile	1,020	6,089
9 decile	1,873	6,298
10 decile	22,173	65,691
<i>Panel C: By house ownership</i>		
NonOwner	-50,416	-146,195
Owner	49,725	141,841

Note: Estimated elasticities used. Almost identical to results with $\epsilon = 0$.

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