Residential Solar Panel Adoptions, Electricity Tariffs and Income Redistribution

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AlpEnForCe, Energieforschungsgespräche Disentis

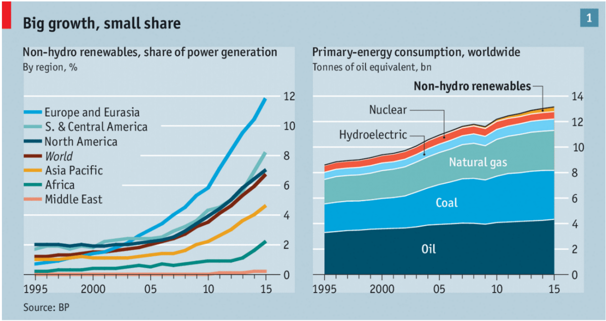
Outline

- Tariff Design and Welfare in Residential Solar Markets
- Income Redistribution vs. Environmental Concerns

Tariff Design and Welfare in Residential Solar Markets

Motivation - Reducing Emissions

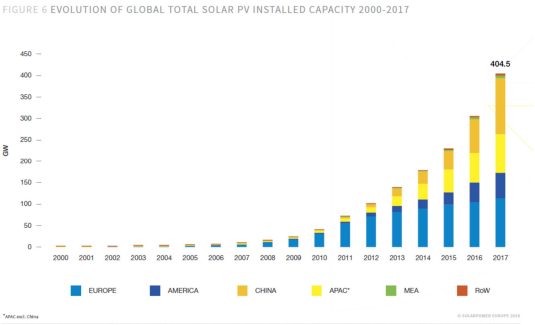
- Governments worldwide aim at cutting fossil fuel emissions, keep global worming below 2°C (now 1.5°C) (In 2015 195 countries have signed the Paris Agreement)
- Solar PhotoVoltaic (PV) is one of the main renewables
  - Between 2010-2019, USD 1,349 bn investments in solar capacities worldwide



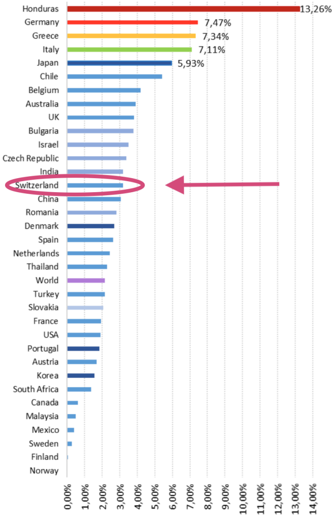
Economist.com

Motivation - Development of Installed Capacity

- Global capacity increased from ∼5 GW in 2005 to ∼404 GW in 2017
- Solar PhotoVoltaic (PV) is one of the main renewables
  - Since 2017 contributes to more than 2% of global demand



Motivation - PV Installed Capacity



Switzerland successful example (2017)

- 2.9GW installed PV capacity
- Over 3% of PV contribution to electricity demand
- 950 kWh/kWp average irradiation (same as Germany, Belgium,..)
- Capacity of ∼200W per inhabitant
  - 40% wrt Germany
  - 60% wrt Italy
  - 170% wrt Spain
  - 185% wrt France

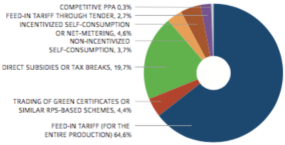
Motivation - Growth Drivers

Growth in solar PV installations mostly driven by

1. Government incentives
    - Direct: Feed-in tariffs, installation cost subsidy
    - Indirect: Two-parts tariff for electricity bill
        - Consumption-based tariffs (cent per kWh) to finance energy costs, network costs

2. Declining PV systems' prices
    - From $\sim$ 7 USD/W in 2001 to $\sim$ 0.3 USD/W in 2017

FIGURE 11: HISTORICAL MARKET INCENTIVES AND ENABLERS



SOURCE IEA PVPS.

Motivation - Swiss Policy Initiatives

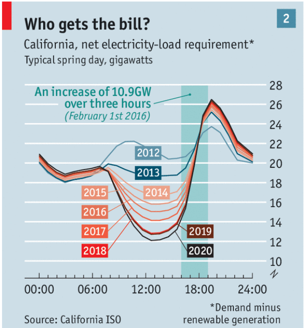
Neue Zürcher Zeitung

Wie die Zürcher Klimaallianz mit einem radikalen Vorstoss die Solarwende erzwingen will
Die Stadt Zürich hinkt beim Solarstrom hinterher. Nun fordert die links-grüne Klimaallianz einen fundamentalen Wandel. Das wird Hunderte Millionen Franken kosten – und das Gesicht der Stadt verändern.
13.06.2019

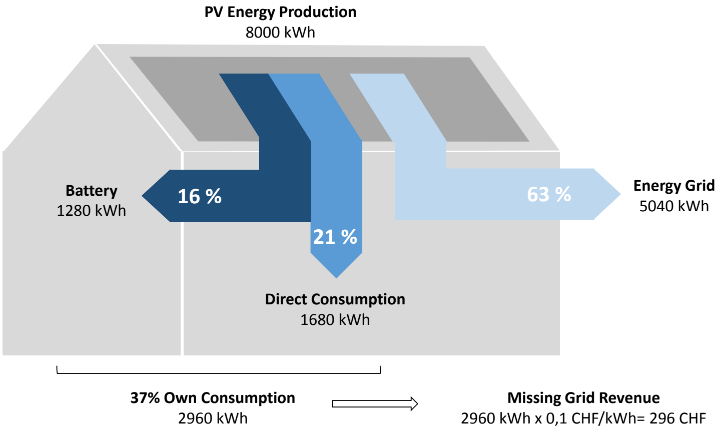
Bundesrat umgarnt Strombranche
Die Schweiz habe 30 Jahre, um klimaneutral zu werden. Diese Zeit reiche für grosse Veränderungen, wenn man nicht zögere, sondern jetzt entschlossen handle. Die Branche müsse die **Stromproduktion aus einheimischen und erneuerbaren Quellen forcieren**, damit die Dekarbonisierung vorankomme und die Versorgungssicherheit gewährleistet bleibe.[…] **«Vehement investieren»** müsse die Branche in die Photovoltaik, deren Chancen enorm seien.
17.01.2020

Motivation - Challenges from Growth in Solar PV

1. **Network Financing**: Households with PV need grid access
   - But contribute less to largely fixed network costs, increasing due to intermittency (doubled in South Australia since 2008)
   - Swiss regulator forecasts 6 bn CHF additional grid costs from decentralized production until 2035.
   - Paradox: The more efficient energy consumption becomes, the less households contribute to grid financing.



Motivation - Example



Motivation - Challenges from Growth in Solar PV

2. **Equity**: Richer households more likely to install PV, shifting the burden of network costs onto poorer households
   - More likely to own single house and afford installation costs
   - In our Swiss data the average income of households with a PV is 45% higher than the average income of those without

Motivation - Challenges from Growth in Solar PV

3. **Cannibalization**: Solar PVs produce at zero marginal costs, driving down energy prices
    - Reduces incentive to adopt solar panels

Key Questions

- Are there undesirable income redistribution aspects in a system of PV installations and volumetric charges?
- How should optimal tariffs look like that
  - Guarantee network financing
  - Do not redistribute income
  - Incentivize PV adoptions

Contribution

Address the challenges of **network financing** and **equity** using

- 2008-2014 yearly panel for 165k households in Bern (CH)
  - Data on electricity consumption, prices, income, wealth, demographics, PV adoption, building characteristics
- Estimate a dynamic structural model of households' electricity consumption and PV adoption

Literature

- **Electricity demand**: Reiss, White (2005), Ito (2014)
  - ⇒ Exact match of household income & wealth data
- **PV adoption**: Borenstein (2015), Burr (2014), De Groote, Verboven (2019)
  - ⇒ First paper to combine energy consumption & PV adoption data, show how tariffs affect adoption
- **Network financing**: Borenstein (2008), Bushnell (2015)

Literature

Redistribution via one or two instruments

- Atkinson and Stiglitz (1976); Saez (2002); Kaplow (2006)
- Feldstein (1972a and b); Munk (1977); Cremer and Gahvari (2002)
- Sandmo (1975); Pirtilla and Tuomala (1997); Sjögren and Aronsson (2017)

Regressive/progressive effects of environmental levies and energy prices

- Hassett, Mathur and Metcalf (2009); Burtraw, Sweeney and Walls (2009); Chancel and Piketty (2015)
- Borenstein (2012); Levinson and Silva (2018)

The Dataset

Unique 2008-2014 yearly panel dataset for 165k households in the Canton of Bern, merging data from

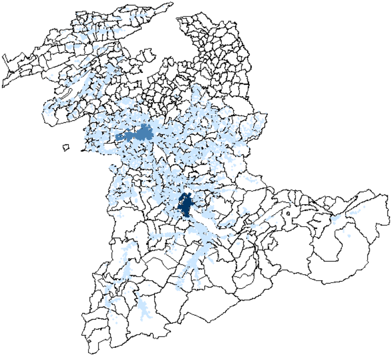
1. Energy companies (BKW, EWB, ET)
   - Energy consumption and expenditure, PV installations, prices
2. Tax office of Bern
   - Income, wealth, and tax payments
3. Swiss Federal Statistical Office
   - Buildings' characteristics
4. Eturnity AG
   - Simulated PV production, installation costs, consumption profiles for all households

PV Investment Model

- Estimate energy price elasticities
- Household PV investment decision depends on
  - energy costs wit/without a solar panel
  - investment costs
  - future remuneration of PV produced energy
- We can compute for each household the probability to install a PV
- Simulate how tariff changes influence the investment decision

Energy Demand - Identification

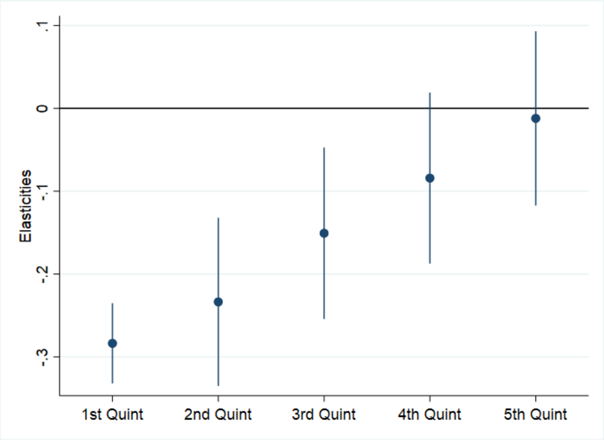
⇒ Assign households to common border points (1km distance) and include border point fixed effects



Results Energy Demand

Elasticities across the income distribution

⇒ High income quintiles less elastic



Results PV Adoption

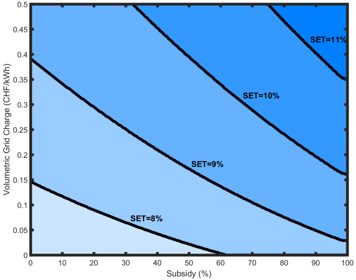
- 1 CHF reduction in installation costs weighs twice as much as 1 CHF increase in PV revenue.

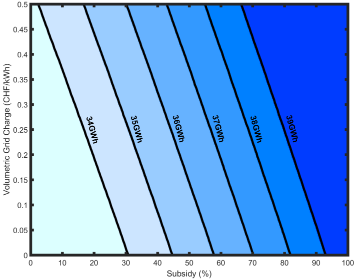
Instruments of the Regulator

- **Volumetric charges** P_G : Stimulate investments in PV contribute to financing the network infrastructure, are progressive.
- **Subsidy of PV installations cost** s : Stimulates investment, requires additional financing.
- **Fixed fees** f : Contribute to network financing, no incentives to install a PV, are regressive.

$\Rightarrow$ Different solar energy and income redistribution targets require different combinations of tariffs.

Solar Energy Induced by Variable Price (P_G) and Subsidy (s)



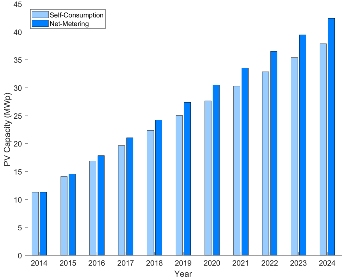


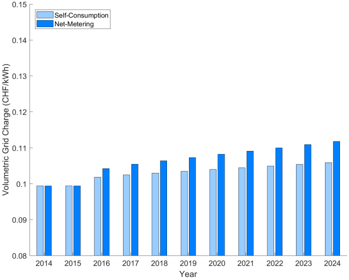
Counterfactual Simulations

Death spiral:

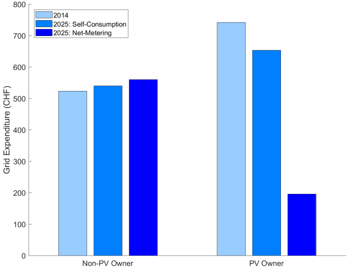
- (a)14.7% self-consumption
- (b) net metering (100% deduction of solar energy from electricity bill)
- Increase in grid tariff (P_G) to recover grid costs
- Change in energy bill across income quintiles

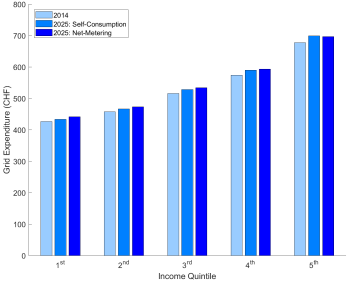
Future Adoption and Increase in Volumetric Charges (1)





Future Adoption and Increase in Volumetric Charges (2)





Counterfactual 2 - Optimal Tariff Design

Change in P_G, f, s to achieve 9% solar energy target, recover grid cost, minimize equity distortions. Account for grid integration costs of CHF 0.055/kWh

- Four different objective functions
  - Minimize grid expenditures (*Cost*)
  - Minimize grid costs and equitable grid cost distribution (*Cost/Equity*)
  - Maximize welfare (*Welfare*)
  - Maximize welfare and equitable grid cost distribution (*Welfare/Equity*)

Table: % Change in Variable Price, Fixed Fee, Subsidy, Grid Expenditure, Welfare

	Solar Energy Target (9.0%)			
	Cost	Cost Equity	Welf	Welf Equity
Instruments				
% Price (P_G) Change	30.8	-1.9	-42.2	-9.5
% Fixed Fee (f) Change	-95.3	22.3	173.5	50.1
% Subsidy (s) as % F_i	62.0	72.5	86.5	75.0
Percentage Change GE_i by Inc. Quintile				
1^{st} Quintile	-12.1	9.9	38.3	15.1
2^{nd} Quintile	-8.5	9.4	32.5	13.6
3^{rd} Quintile	-3.4	8.6	24.1	11.4
4^{th} Quintile	0.9	7.9	17.0	9.5
5^{th} Quintile	5.7	7.0	9.0	7.4
Percentage Change GE_i by PV				
Non-PV HH	6.4	7.4	8.8	7.6
PV HH	-16.2	-9.6	-1.2	-8.1
Grid Integr. Cost (M CHF)	3.17	3.30	3.51	3.34
Subsidy Cost (CHF per kWh)	0.31	0.37	0.45	0.39

Income Redistribution vs. Environmental Concerns

Affordability of Energy

Minister for the environment Altmaier: „Strom darf kein Luxusgut werden" (2013)

FT

Conservatives promise to cap prices in UK energy market (2017)

Theresa May promised to intervene in electricity markets if they
"are thought to be failing ordinary families." (The Guardian, 8.5.2017)

Energy Poverty vs. Environmental Concerns

Affordability of public utility services such as electricity is a salient issue in European and OECD countries.

- Expenditures on electricity represent 5% of annual annual income for the lowest income decile and 1% for the 10th decile in the Canton of Bern (Switzerland).
- In 2015, the poorest households in the EU spent on average 870€on energy products (excl. transport)= 10% of total consumption expenditure.
- Poorest households spent only 3% of total expenditures on energy in Sweden, but up to 23% in Slovakia.

However

- The residential sector also contributes to around 17% of CO_2 emissions from fuel combustion with electricity and heat (IEA, 2018).

Protecting the Environment - Fighting Inequality

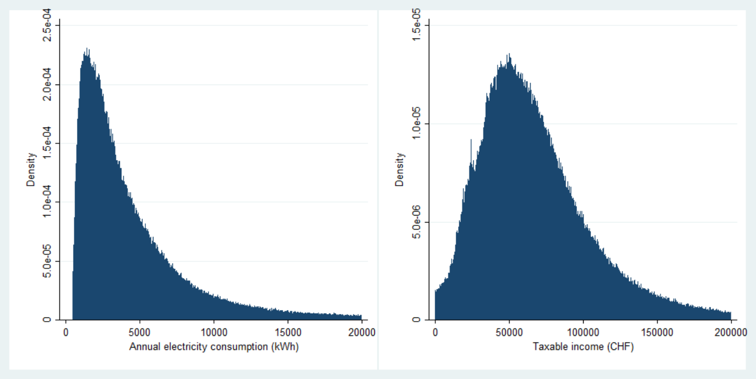
What We Do

- Analyse redistributional effects of electricity prices in the presence of income taxation and environmental externalities.
- Controversies in the theoretical literature on the optimal direct-indirect tax mix (in economies with environmental externalities) call for more empirical work.

Findings

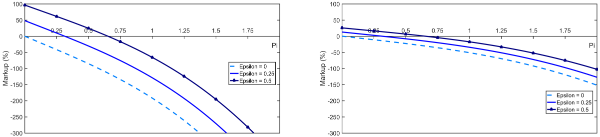
- **No externalities**: Redistribution concerns mostly require subsidisation of electricity prices in addition to progressive income tax.
- **Low inequality aversion and non zero externality costs**: Upward deviation from marginal cost. Pigouvian tax
- **Asymmetric information between regulator and utility**: Positive price mark-up.

Distribution of Electricity Consumption and Taxable Income

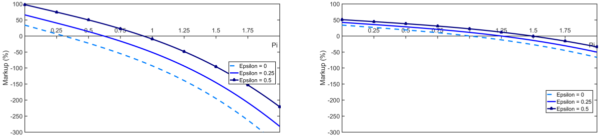


Optimal Markup for Different Degrees of Inequality Aversion and $\beta = -0.16$ or $\beta = -0.6$

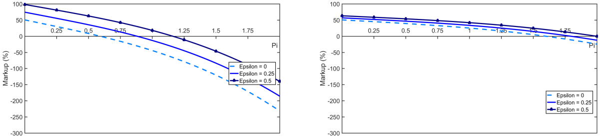
Panel (I): $e = 0$



Panel (II): $e = 0.06$



Panel (III): $e = 0.12$



Conclusion

- We address two issues posed by the growing number of PV installations: network financing and equity.
- We recover optimal tariffs through a regulator's optimization problem, based on models of energy demand and PV adoption.
- Our model can be applied to different types of networks infrastructures (i.e highways, postal network) and be generalized to several household's technology adoption decisions.
- The trade-off between equity and environmental concerns has implications for the design of electricity tariffs.

Table: % Energy Prices, Network Tariffs and Taxes

	BKW		EWB		ET	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Fixed Fee Double Tariff (CHF/year)	153	27	121	22	111	19
Price High Tariff (Rp./kWh)	24.4	.8	19.7	1	25.6	.6
Energy Price	11.8	.3	11.6	.4	12.4	.2
Grid Price	10.4	1	7.3	.8	10.9	1.7
Municipality Tax	1.8	.2	.4	.2	1.8	1.5
KEV Tariff	.4	.1	.4	.2	.5	0
Price Low Tariff (Rp./kWh)	14	.8	10.3	.4	14.9	1.4
Energy Price	7.3	.2	7.4	.3	9.7	.2
Grid Price	4.5	.5	2	.4	2.9	.4
Municipality Tax	1.8	.2	.4	.2	1.8	1.5
KEV Tariff	.4	.1	.4	.2	.5	0
Fixed Fee Uniform Tariff (CHF/year)	125	17	90	23		
Price Uniform Tariff (Rp./kWh)	23.8	.6	18.2	1		
Energy Price	11.4	.4	10.5	.4		
Grid Price	10.2	1	6.8	.9		
Municipality Tax	1.8	.2	.5	.2		
KEV Tariff	.4	.1	.4	.2		

Table: % Energy Consumption and Expenditure

	N Obs	Mean	Std Dev	5th Perc	Median	95th Perc
Energy Consumption (kWh)	872,715	4,139	3,805	812	3,022	11,045
Consumption High Tariff	538,232	2,439	1,940	544	1,977	5,978
Consumption Low Tariff	538,232	2,788	2,874	278	2,143	7,389
Consumption Uniform Tariff	334,483	2,303	1,622	662	1,919	5,161
Energy Expenditure (CHF)	872,715	928	702	267	738	2,226
Energy Price Expenditure (CHF)	872,715	409	350	88	313	1,053
Price Expenditure High Tariff	538,232	291	231	65	236	713
Price Expenditure Low Tariff	538,232	212	219	24	162	559
Price Expenditure Uniform Tariff	334,483	258	184	73	214	584
Grid Expenditure (CHF)	872,715	441	282	157	370	960
Tax Expenditure (CHF)	872,715	59	67	2	40	178
KEV Expenditure (CHF)	872,715	19	19	3	14	53

Table: % Income, Wealth and Tax Payments

	N Obs	Mean	Std Dev	5th Perc	Median	95th Perc
Total Income (CHF)	872,715	92,485	124,687	13,239	78,256	201,248
Taxable Income (CHF)	872,715	71,156	114,552	4,866	60,663	156,036
Total Wealth (CHF)	872,715	493,641	2029507	0	195,239	1571257
Cantonal Tax (CHF)	872,715	7,158	13,992	0	5,358	18,366
Municipal Tax (CHF)	872,715	3,682	6,840	0	2,807	9,350
Federal Tax (CHF)	872,715	1,654	9,141	0	454	5,845

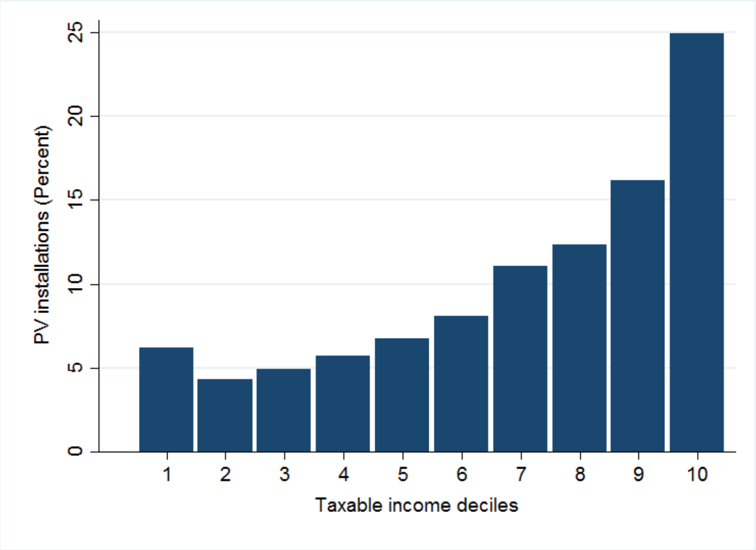
Table: % Simulated Capacity and Energy Production

	N Obs	Mean	Std Dev	5th Perc	Median	95th Perc
PV Production Capacity (kWp)	40,414	9.6	4.8	4.7	8.4	18.9
PV Energy Production (kWh)	40,414	9,697	5,604	4,708	8,354	19,133
Self-Consumption						
% of Production	40,414	14.7	9.6	5.1	12.3	33.4
% of Consumption	40,414	20.2	8.1	11.7	18.6	33
in kWh	40,414	1,213	861	592	982	2,616

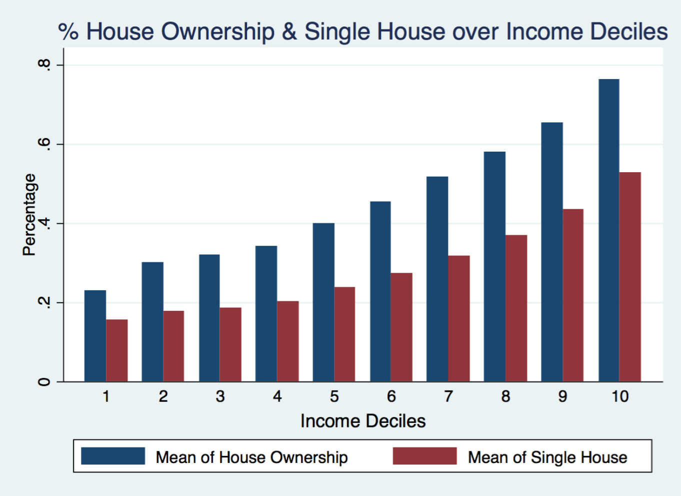
Table: % PV Energy Production and Remuneration

Variables	N Obs	Mean	Std Dev	5th Perc	Median	95th Perc
PV Inverter Capacity (kVA)	4,401	8.1	8.6	2.2	6.2	20.7
PV Energy Production (kWh)	4,401	7,675	8,357	2,000	6,000	19,500
PV Remuneration (CHF)	4,401	3,368	2,189	1,338	2,722	7,667
Energy Consumption (kWh)	4,401	8,671	6,751	1,820	7,265	20,831

Figure: Distribution of PV installations by income



Richer Households More Likely to Adopt PV



Estimating the Model

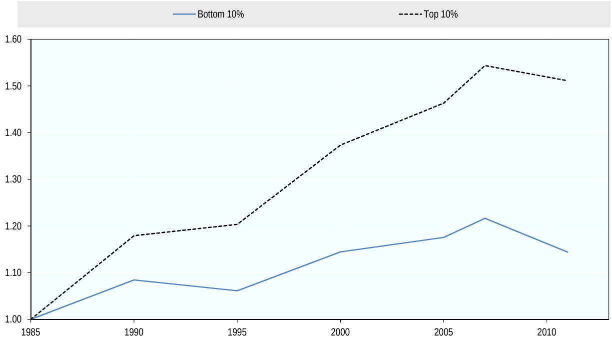
Estimate household's model in 3 steps

1. Static utility maximization to choose optimal electricity consumption, conditional on PV
   - ⇒ Parameters of electricity demand with geographic RDD
2. Expectation over evolution of state variables that determine dynamic PV adoption decision
   - ⇒ Parameters of transition probabilities
3. Dynamic utility maximization to adopt PV
   - ⇒ Parameter of installation cost function and future revenues

Inequality and Redistribution

- Inequality is a key challenge for decades to come.

Trends in real household incomes at the bottom and the top, OECD average, 1985 = 1



Note: Income refers to disposable household income, corrected for household size.
OECD is the unweighted average of 17 countries

Source: OECD Income Distribution Database (2015)

- Optimal policies to achieve redistribution still subject to considerable debate.

Individual Tax Burden Bern