Household Responses to the Tax Treatment of Income from Solar PV Feed-in in Germany

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Presentation Outline

1. Introduction and Research Motivation

- Studies on **impact of compliance costs** on the adoption of residential solar PV are still scarce
- There might be **unintended (negative) impacts** of tax compliance costs regarding choice of system size and technology adoption, with repercussions on achieving energy and climate policy goals
- Specifically: How did the German 2021 tax policy instruction impact households’ decisions to adopt PV?
- Use of **discontinuity analysis** and similar other approaches from the bunching literature (1st study in context)
- EEG, first introduced in 2000, includes both feed-in tariffs (FITs) and a surcharge* to promote the use of solar PV
- Currently, only about 10% of German suitable rooftop potential have been used for solar PV

* EEG levy, abandoned 2021

Specific Research Question posed: ***Does the Treatment of Residential Prosumers as Commercial Traders Inhibit Germany’s PV Capacity Expansion?***

H1*: The BMF tax instruction from June 2021 leads to excess bunching of newly deployed residential PV systems below the 10 kWp threshold.*

H2*: The BMF tax instruction from June 2021 leads to a decrease in the average power capacity of newly deployed residential PV systems.*

Related Literature

EEG, Distribution Effects and Solar Rebound:

- Priesmann J., Spiegelburg, Madlener R., Praktiknjo A. (2022). Does Renewable Electricity Hurt the Poor? Exploring Levy Programs to Reduce Income Inequality and Energy Poverty Across German Households, *Energy Research and Social Sciences* 93: 102812
- Atasoy A.T., Schmitz H., Madlener R. (2021). Mechanisms for Rebound Effects of Solar Electricity Prosuming in Germany, *FCN Working Paper No. 10/2021*, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Effects of Attribute-Based Regulation (ABR) on Technology Adoption (various topics):

- Germeshausen (2018) – Feed-in tariffs in Germany, EEG 2012 vs. EEG 2014
  → Finds a 29% decrease in capacity expansion and additional 14% due to installation of smaller systems than w/o ABR
- Ito and Sallee (2018) – Japanese car manufacturers
  → Increase of vehicle weight by 10% in response to weight-based fuel economy regulation
- Atasoy (2020), Houde (2022) – Energy efficiency standards
  → Practice of manipulating attributes to match certain thresholds

Grid Parity and *Liebhaberei*

- Recent residential PV systems generate **none or only small taxable profits**

- German income tax law provides a special case for commercial activities causing ongoing losses: **“*Liebhaberei*”**

  → Commercial losses cannot be deducted from tax anymore

  → Businessperson is released from income tax obligation

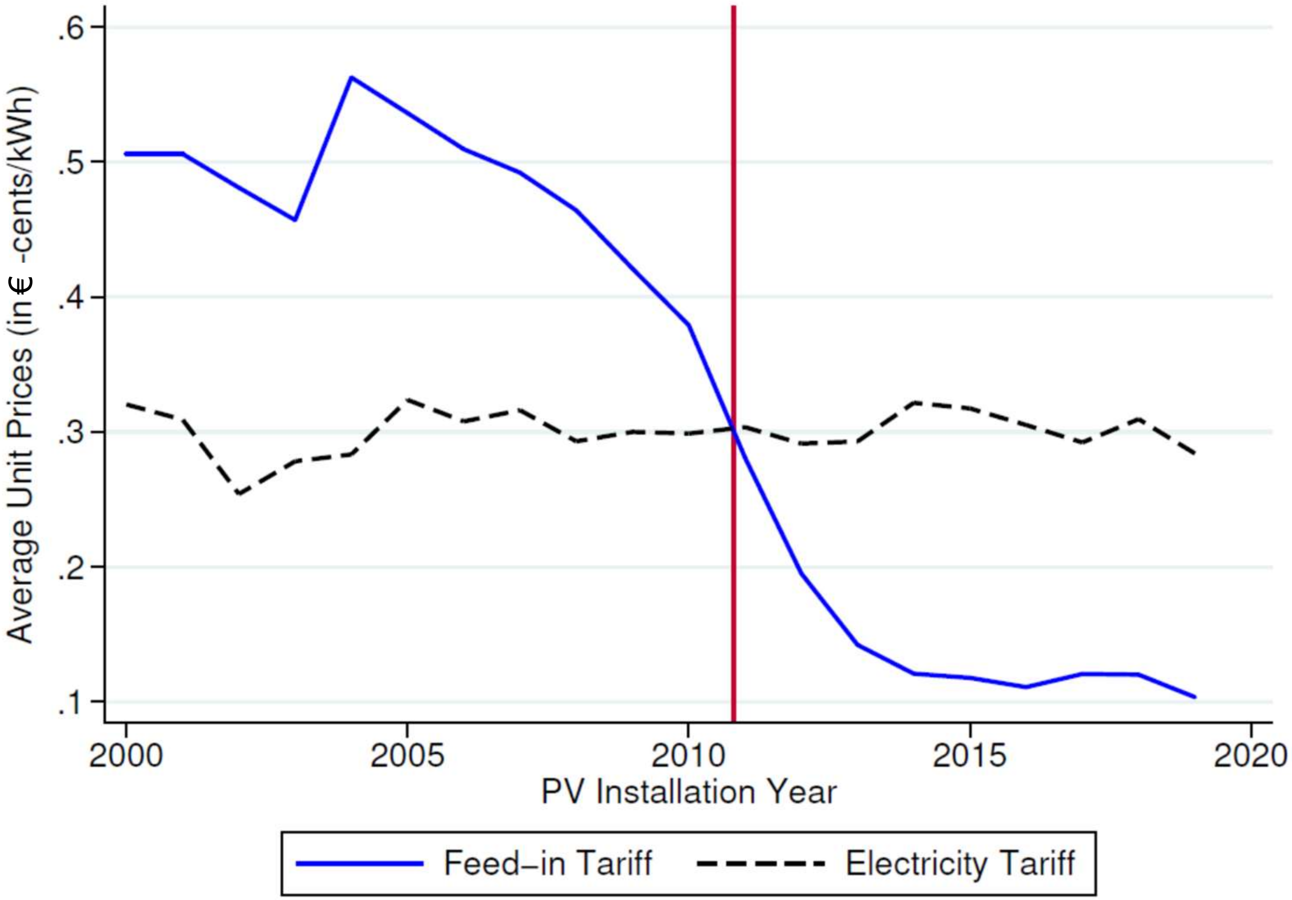
- Policy instruction by **German Federal Ministry of Finance (BMF)** as of June 2, 2021, aimed at simplifying administrative procedures for both tax offices and the PV system operators.

  Prerequisites:

  1. PV system installed on residential building (or other on same site) and owned by applicant
  2. Total power capacity (of all PV systems operated by the applicant) no more than 10 kW_p
  3. Produced energy must in parts be self-consumed by the applicant (or co-operator)
  4. Produced energy is only used for self-consumption (by applicant or a co-operator) and for grid feed-in
  5. The PV system was commissioned after Dec 31, 2003

  → Excludes numerous residential rooftop solar PV systems (operators still obliged to prove *Liebhaberei*, or to fill in revenue surplus reports)

FiT, Electricity Tariffs and Grid Parity in Germany



- **“Grid parity”** refers to the situation where electricity from the grid costs as much as self-generated electricity (LCOE)
- Similar, **parity between FiT and electricity tariffs** implies that it has become cheaper to self-consume instead of feed-in
- In Germany, on average, residential electricity prices have been ~**30 €-ct/kWh**
- Feed-in tariffs declined sharply throughout the 2000s (at ~8-9 €-ct/kWh for small-scale PV systems; cf. Table 1 on next slide)

Source: Atasoy et al. (2021), based on data from self-conducted representative survey among ~1600 residential households

EEG Surcharges (System Sizes 10 kW$_p$ vs. 13 kW$_p$ and 2020 vs. 2021)

Table 1: Exemplary EEG Surcharges on Self-Consumption and Decreased FiT for Solar PV Systems ≥ 10 kWp

	Date of Commissioning / System Capacity [kWp]			
	June 1, 2020		June 1, 2021	
	9.9	13.0	9.9	13.0
	Feed-In Remuneration [€-ct/kWh]			
Feed-In Tariff for < 10 kWp	9.17	9.17	7.58	7.58
Reduced Feed-In Tariff for ≥ 10 kWp	-	8.91	-	7.36
Effective Feed-In Tariff	9.17	9.11	7.58	7.53
	EEG Surcharge on On-Site Consumption			
EEG Surcharge [€-ct/kWh]	6.76	6.76	6.50	6.50
EEG Surcharge on On-Site Consumption [%]	0	40	0	0
Effective EEG Surcharge on On-Site Consumption [€-ct/kWh]	0.00	2.70	0.00	0.00

Notes:

- Difference in effective remuneration is negligible for system sizes close to the 10 kW$_p$ threshold
- Still, FiT differentiation influences the distribution of actual system sizes towards bunching slightly below 10 kW$_p$ (Germeshausen 2018)
- Difference regarding the EEG levy on self-consumption is much more striking (discontinuous profitability at 10 kW$_p$ cut-off before EEG 2021 amendment)

Income Tax Law Perspective

Table *2*: Exemplary Numbers for the Profit Calculation from Private and Income Tax Law Perspective

Exemplary System Specification			
System Capacity [kWp]	13.0	Yield Factor [kWh/kWp]	922
Commissioning Date	06-01-2022	Depreciation Period [a]	20
Investment Cost [€/kWp]	1,400	Self-Consumption Rate [%]	10.4
Feed-In Tariff [€-ct/kWh]	7.53	Electricity Price [€-ct/kWh]	29.93
Resulting Values			
Total Investment [€]	18,200.00	Annual Depreciation [€]	910.00
Total Annual Production [kWh]	11,986	Production Cost per Unit [€-ct/kWh]	7.59
Self-Consumption per Year [kWh]	1,246.5	Feed-In per Year [kWh]	10,739.5
		Tax Law Perspective	Private (Prosumer) Perspective
Income from Feed-In [€]		808.68	808.68
Income from Self-Consumption [€]		94.61	373.08
Annual Depreciation [€]		- 910.00	- 910.00
Annual Taxable Profit / Annual Profit [€]		- 6.71	271.76

Notes:

- Simplistic calculation, ignoring some costs (e.g. insurance, maintenance)
- Opportunity costs and inflation also ignored
- Realistic exemplary solar PV specifications, based on LIE (2014), Fraunhofer ISE (2021), Verivox (2022), and HTW (2022)

2. The Data

- We use data from a public energy producer's registry (***Marktstammdatenregister***, *MaStR*), 2.3 million PV systems commissioned since 2000 (incl. zip code, capacity, type of operator)
- Deleted systems commissioned before 2017, with installed capacities etc.), and such owned by juristic persons
- In the end, we made use of **704,551 observations** (PV systems)

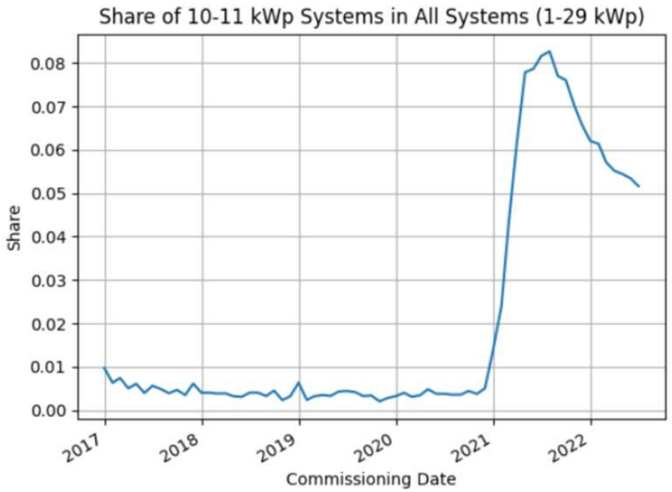


Figure 3: Share of 10–11 kWp Systems in All Residential Systems between 1-29 kWp

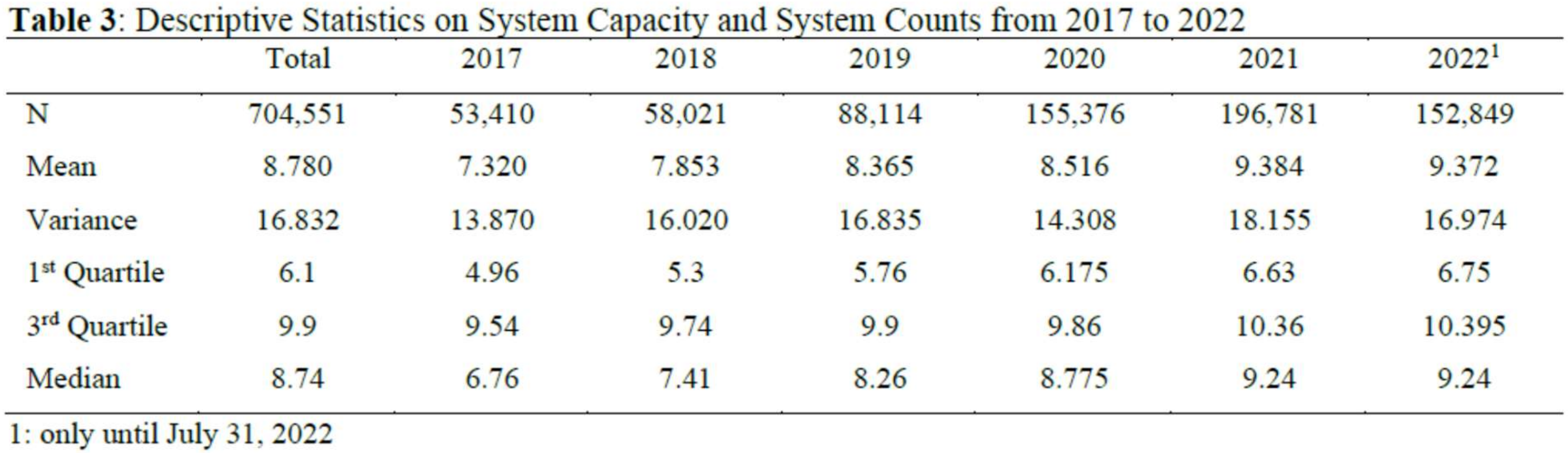


Table 3: Descriptive Statistics on System Capacity and System Counts from 2017 to 2022

	Total	2017	2018	2019	2020	2021	2022[1]
N	704,551	53,410	58,021	88,114	155,376	196,781	152,849
Mean	8.780	7.320	7.853	8.365	8.516	9.384	9.372
Variance	16.832	13.870	16.020	16.835	14.308	18.155	16.974
1st Quartile	6.1	4.96	5.3	5.76	6.175	6.63	6.75
3rd Quartile	9.9	9.54	9.74	9.9	9.86	10.36	10.395
Median	8.74	6.76	7.41	8.26	8.775	9.24	9.24

1: only until July 31, 2022

Compliance Costs and Impact of Tax Authority Treatment on Profits

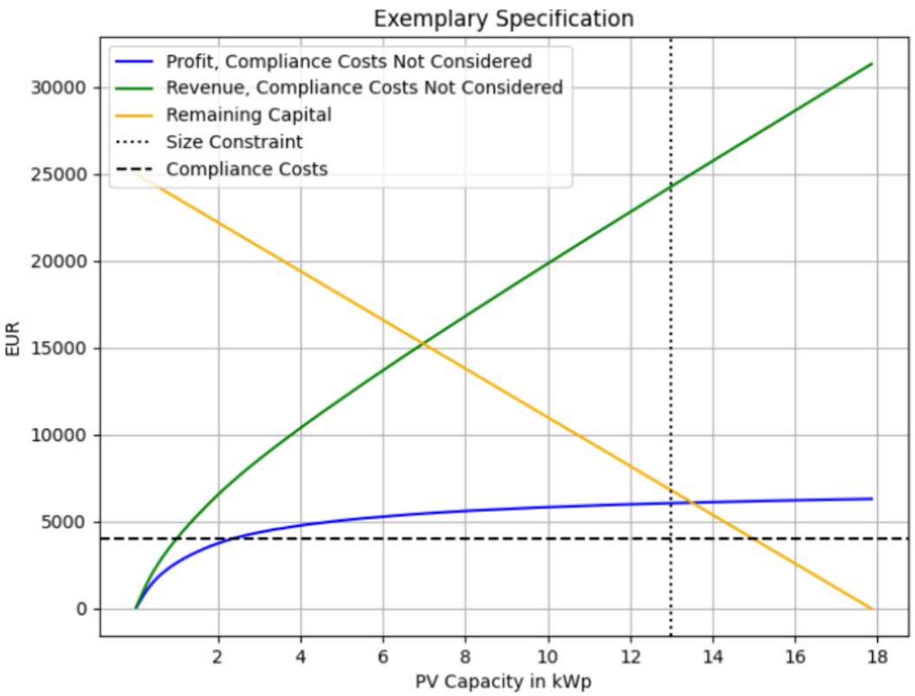


Figure 1: Output of an Exemplary Residential Solar PV System with Constraints

Tax instruction effective only up to 10 kW_p

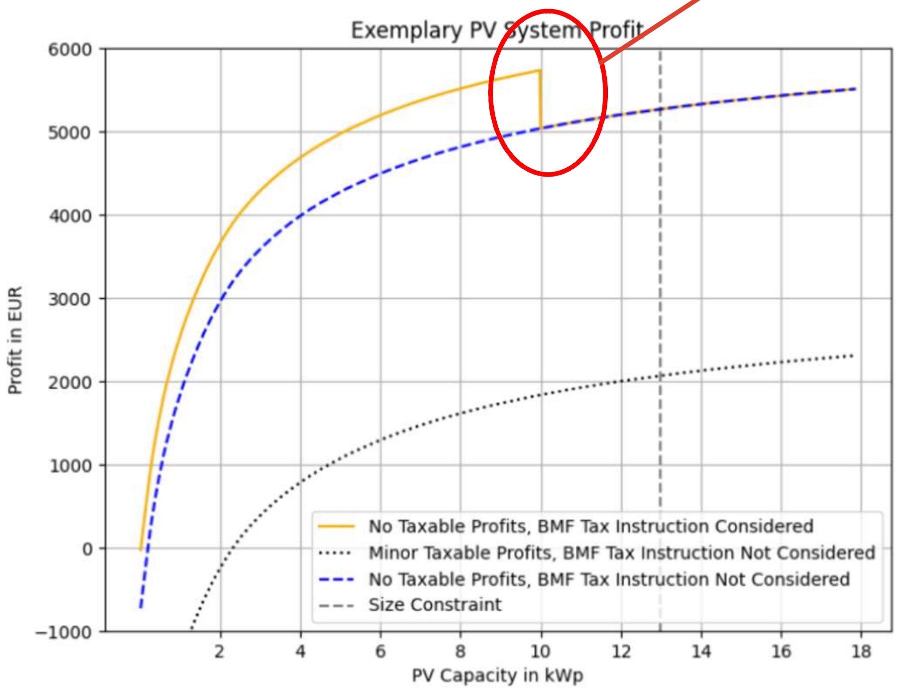


Figure 2: PV System Output and Profit of an Exemplary System under Different Tax Treatments

- Output choice decision model based on Eichfelder (2011), adapted to our needs
- PV output and self-consumption calculations based on a webtool of HTW Berlin
- Budget constraint set to € 25,000, O&M costs to €200 p.a.

3. Bunching Model Specification (Chetty et al. 2011)

$$N_{j,d} = \sum_{i=0}^{q} \beta^{0}_{i,d} \times (C_j)^i + \sum_{i=t-r_l}^{t+r_{u,d}} \gamma^{0}_{i,d} \times 1[C_j = i] + \varepsilon_{j,d} \tag{7}$$

$$N^{counterfactual}_{j,d} = \alpha_d \times N^{extrapolated}_{j,d} = \alpha_d \times \sum_{i}^{q} \beta^{OLS}_{i,d} \times (C_j)^i \tag{8}$$

where $\alpha_d = \frac{1}{\sum N^{extrapolated}_{j,d}}$

$$\hat{b}_d = \sum_{j=t-r}^{t} \frac{N_{j,d} - N^{counterfactual}_{j,d}}{N_{j,d}} \tag{9}$$

Bunching estimator

β … leading coefficient
γ … excess (or lacking) system count for each capacity bin
q … highest-order polynomial
C … capacity value of bin j
$N_{j,d}$ … share of systems in capacity bin j and month d

* Sum of all estimated system count shares equals unity

- The **affected range**, where distortions of the distribution are expected, are **narrow and symmetrical** (standard assumption, based on findings in Chetty et al. 2011)
- For discrete changes in the treatment **("notches")**, as found here, the missing mass is expected to be much broader, so that **exception range** needs to be asymmetrical around the threshold (cf. Kleven 2016)
- We **visually determine the lower limit** and determine the upper range limit s.t. relevant constraint* is fulfilled
- Determination of **upper limit of the exception range**: total system count of estimated counterfactual distribution equals actual system count

Data Evaluation: Actual and Counterfactual Distribution of PV Capacities, 2021 and 2022

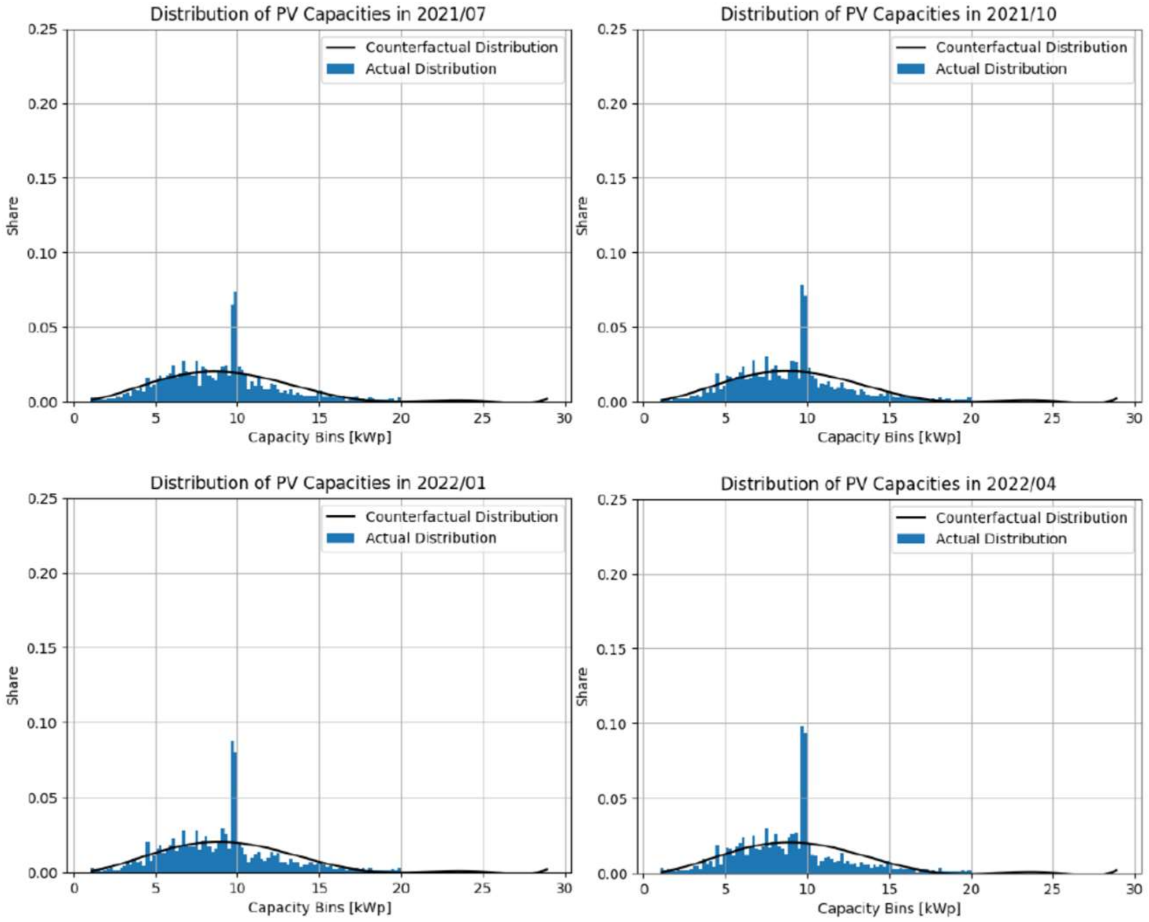


Figure 4: Actual and Estimated Counterfactual Distribution by Month (Jan 2022 vs. Apr 2022)

- Bunching approach by Chetty et al. (2011), originally used for estimating bunching at income thresholds when marginal tax rates change

Procedure:

- Monthly histograms of present data with binned capacities
- Fitting a polynomial to the actual distribution (OLS regression)
- Extrapolation of resulting polynomial is used as an estimate for counterfactual distribution
- Total system count of each month is normalized to unity
- Fig. 4 shows substantial bunching just below 10 kW_p

Data Evaluation: Residuals

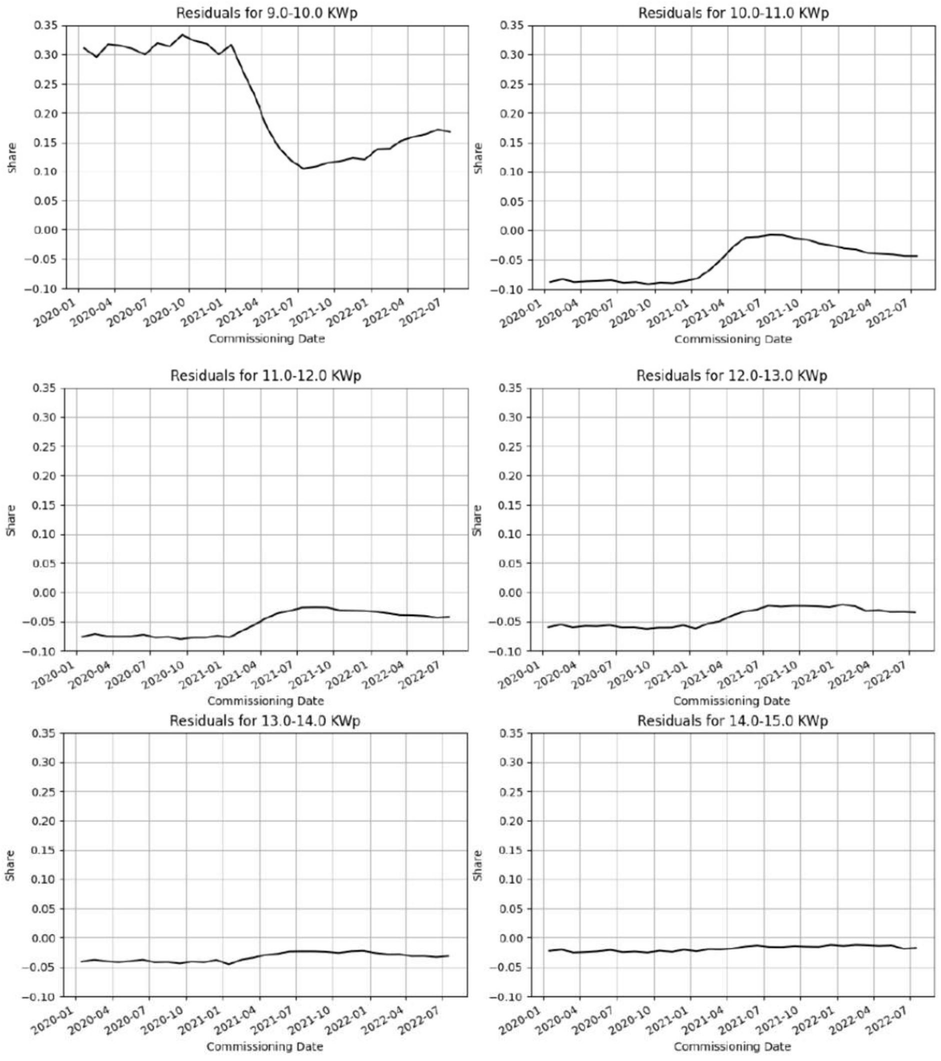


Figure 5: Residuals Over Time in 1 kWp Bins, by system size (Jan 2020 – Jul 2022)

Notes:

- Fig. 5 shows the **residuals by commissioning date** (Jan 2020 – Jul 2022)
- Given the rather **small bin size of 0.2 kW$_p$**, cumulative residuals for five consecutive bins (1 kW$_p$ bins) are shown
- Residuals are reported for the 9-10 kW$_p$ bin and up to the 14-15 kW$_p$ bin
- One can see a strong decline in bunching in H1/2021, confirming the strong impact of the 2021 EEG amendment
- There is clear evidence for a significant response lag as well as increasing bunching from 8/2021 onwards
- In 7/2022, ~40% of the EEG 2021 effect vanishes
- Effect and countereffect are similar for all bin sizes

4. Main Results: PV Capacity Distribution in Areas with Different Population Densities

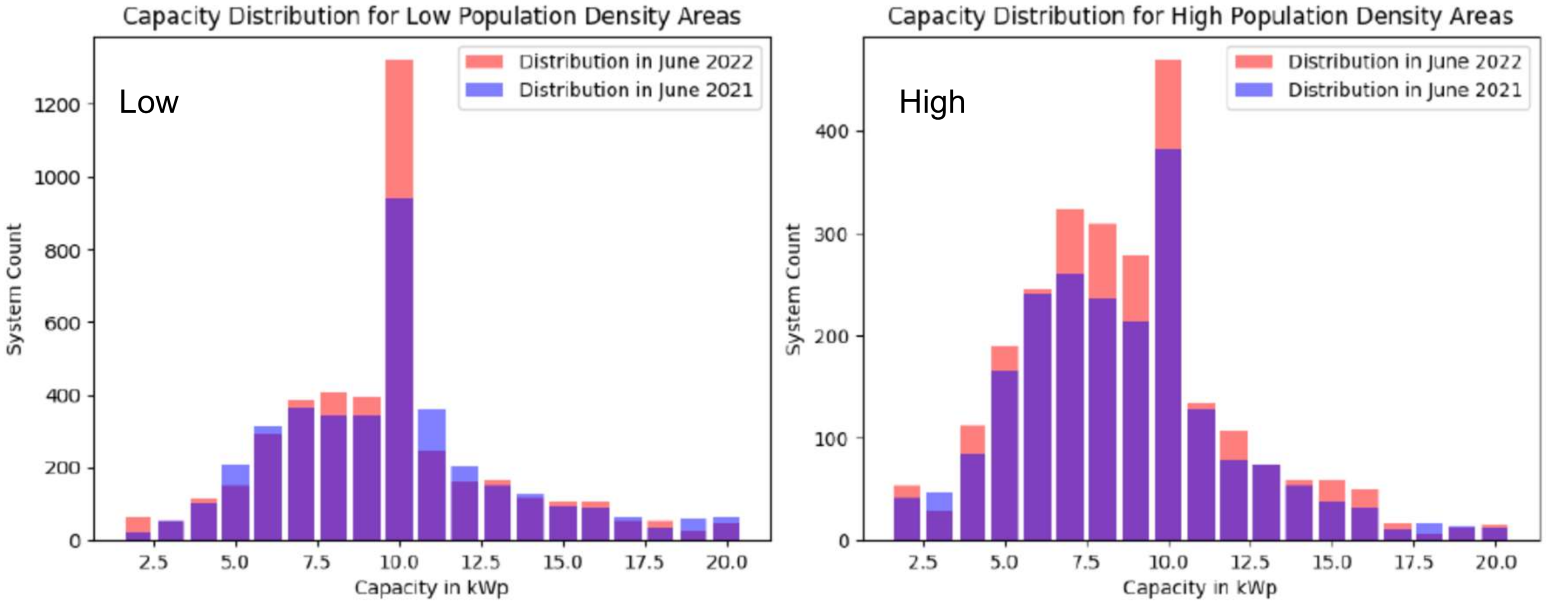


Figure 6: Comparison of the PV Capacity Distribution in June 2021/ and June 2022 for Areas with Different Population Densities

- Assume that **population density** can be **used as a proxy** for average rooftop size
- We find marked differences in the initial capacity distribution in June 2021, and changes from 2021 to 2022

3. Model Specification: Regression Discontinuity in Time (RDiT)

$$\begin{aligned} capacity_i = {} & \alpha + \beta_1 \times treatment_{t_i} + \beta_2 \times EEG\ change_{t_i} + \beta_3 \times t_i \\ & + \beta_4 \times \log(PV\ price_{t_i}) + \beta_5 \times \log(electricity\ price_{t_i}) \\ & + \beta_6 \times \log(FiT_{t_i}) + \sum_{j=7}^{17} \beta_j \times month_{t_i} + \sum_{j=18}^{18+c-2} \beta_j \times county_i \\ & + \varepsilon_i \end{aligned} \tag{10}$$

We aim at discriminating the effects of the EEG amendment from tax exemption rule:

$$\begin{aligned} capacity_i = {} & \alpha + \beta_1 \times treatment_{t_i} \boxed{\times CDF^{treatment}(t_i)} \\ & + \beta_2 \times EEG\ change_{t_i} \boxed{\times CDF^{EEG\ change}(t_i)} + \beta_3 \times t_i \\ & + \beta_4 \times \log(PV\ price_{t_i}) + \beta_5 \times \log(electricity\ price_{t_i}) \\ & + \beta_6 \times \log(FiT_{t_i}) + \sum_{j=7}^{17} \beta_j \times month_{t_i} + \sum_{j=18}^{18+c-1} \beta_j \times county_i \\ & + \varepsilon_i \end{aligned} \tag{11}$$

Nomenclature:

t … no. of days between commissioning and start of observation period

PV price … average PV module wholesale price

electricity price, *FiT* … aver. end-user electricity price and feed-in tariff for first 10 kW_p of capacity (both in €-ct/kWh)

month, *country* … categorical variables

treatment = 0 (PV system built before) or = 1 (built after tax instruction)

EEG change (2^{nd} intervention dummy)

4. Main Results: Interaction Effects (Fitting Cum. Density Function to Actual (Detrended) Shares)

Alternative approach to detect differences in the impact between the two interaction terms used
→ Comparison shows that the BMF tax instruction was not foreseen as well as the EEG amendment

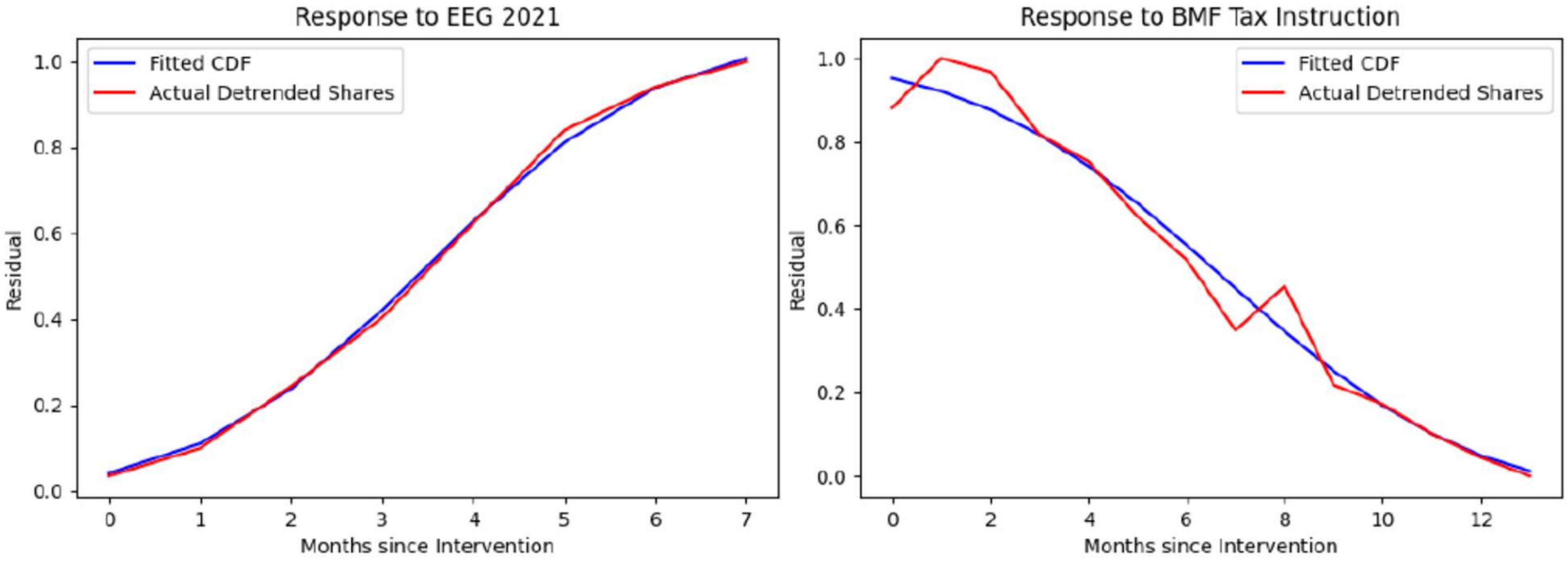


Figure 7: Normalized Detrended Shares of ≥ 10 kWp Systems in all Systems between 9.5-10.5 kWp

- **Blue** lines: values of the interaction terms used to simulate the lag in the regression model
- Interaction terms, reflecting increasing probability of affection, both converge over time towards unity

4. Main Results: Bunching Estimates by Population Density Subgroups

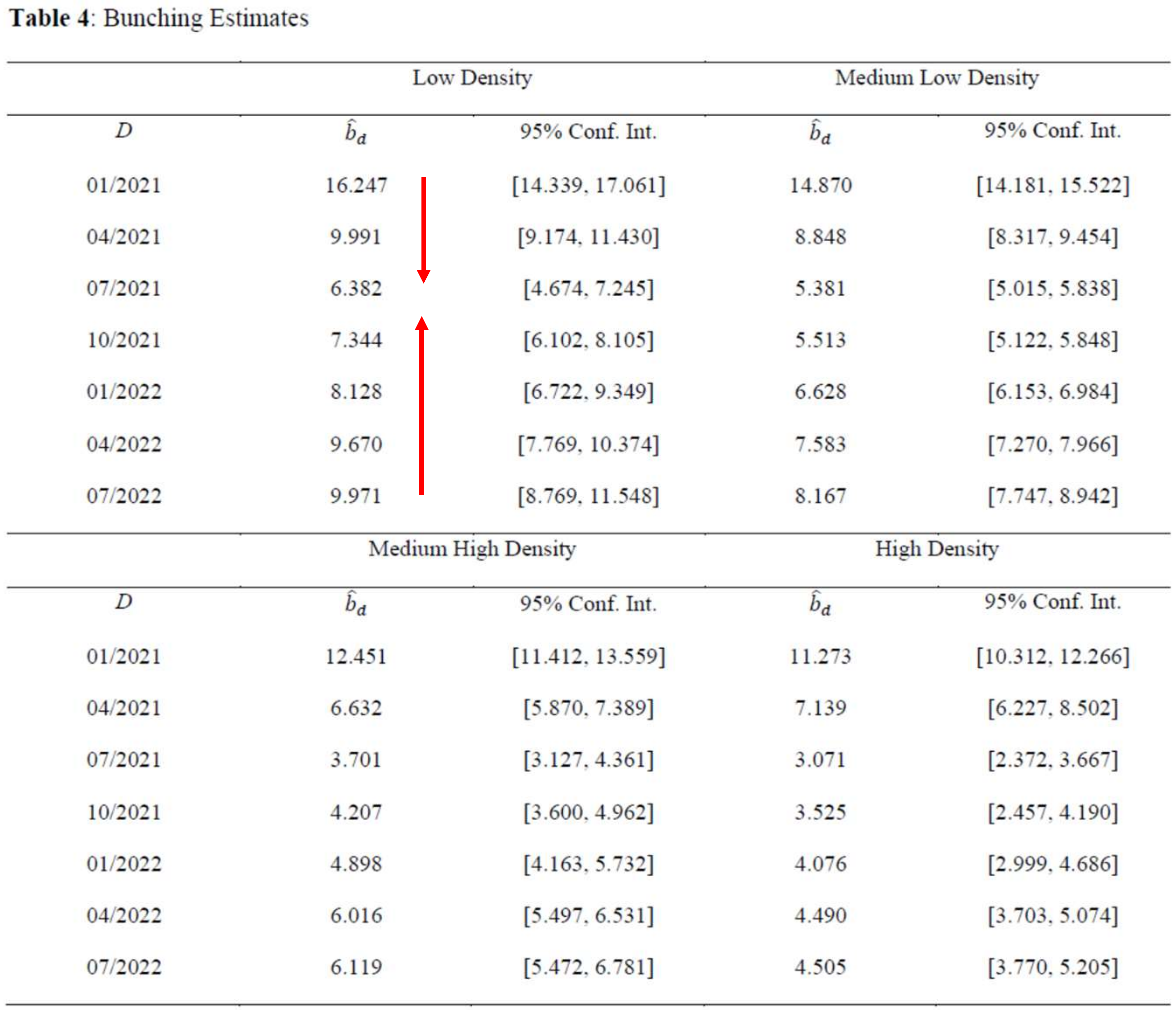


Table 4: Bunching Estimates

	Low Density		Medium Low Density	
D	$\hat{b}_d$	95% Conf. Int.	$\hat{b}_d$	95% Conf. Int.
01/2021	16.247	[14.339, 17.061]	14.870	[14.181, 15.522]
04/2021	9.991	[9.174, 11.430]	8.848	[8.317, 9.454]
07/2021	6.382	[4.674, 7.245]	5.381	[5.015, 5.838]
10/2021	7.344	[6.102, 8.105]	5.513	[5.122, 5.848]
01/2022	8.128	[6.722, 9.349]	6.628	[6.153, 6.984]
04/2022	9.670	[7.769, 10.374]	7.583	[7.270, 7.966]
07/2022	9.971	[8.769, 11.548]	8.167	[7.747, 8.942]

	Medium High Density		High Density	
D	$\hat{b}_d$	95% Conf. Int.	$\hat{b}_d$	95% Conf. Int.
01/2021	12.451	[11.412, 13.559]	11.273	[10.312, 12.266]
04/2021	6.632	[5.870, 7.389]	7.139	[6.227, 8.502]
07/2021	3.701	[3.127, 4.361]	3.071	[2.372, 3.667]
10/2021	4.207	[3.600, 4.962]	3.525	[2.457, 4.190]
01/2022	4.898	[4.163, 5.732]	4.076	[2.999, 4.686]
04/2022	6.016	[5.497, 6.531]	4.490	[3.703, 5.074]
07/2022	6.119	[5.472, 6.781]	4.505	[3.770, 5.205]

Notes:

- Table 4 shows selected bunching estimators for the four population area subgroups considered
- Significant bunching is found in all months observed and across all population density subsets
- Bunching declines markedly in H1/2021
- Between July and Sep. 2021, the dynamic reverses (excess mass rises by 50-65%)
- Behavior is consistent across all subgroups

4. Main Results: Regression Analysis by Population Group Density (w/o Categorical Variables)

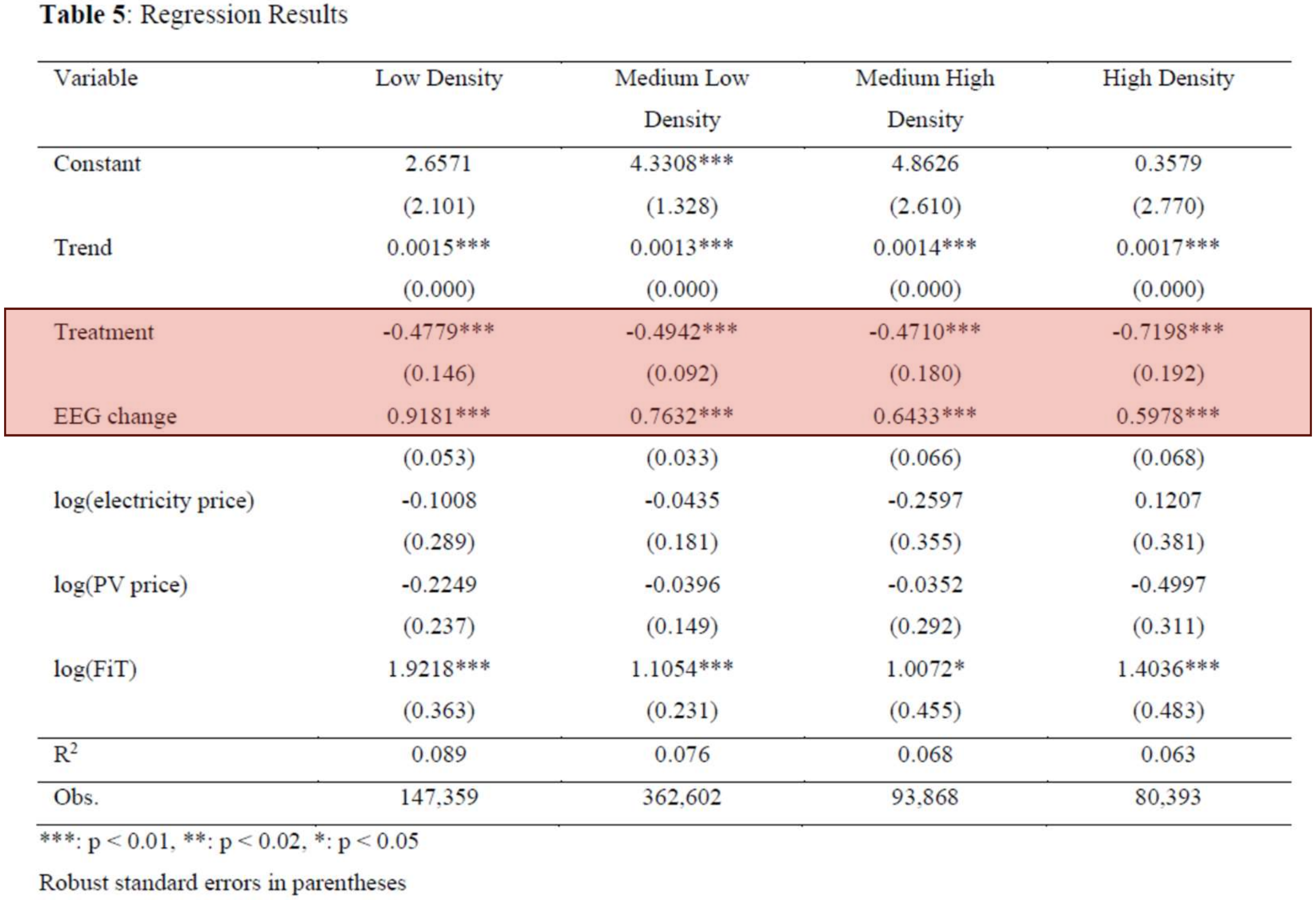


Table 5: Regression Results

Variable	Low Density	Medium Low Density	Medium High Density	High Density
Constant	2.6571	4.3308***	4.8626	0.3579
	(2.101)	(1.328)	(2.610)	(2.770)
Trend	0.0015***	0.0013***	0.0014***	0.0017***
	(0.000)	(0.000)	(0.000)	(0.000)
Treatment	-0.4779***	-0.4942***	-0.4710***	-0.7198***
	(0.146)	(0.092)	(0.180)	(0.192)
EEG change	0.9181***	0.7632***	0.6433***	0.5978***
	(0.053)	(0.033)	(0.066)	(0.068)
log(electricity price)	-0.1008	-0.0435	-0.2597	0.1207
	(0.289)	(0.181)	(0.355)	(0.381)
log(PV price)	-0.2249	-0.0396	-0.0352	-0.4997
	(0.237)	(0.149)	(0.292)	(0.311)
log(FiT)	1.9218***	1.1054***	1.0072*	1.4036***
	(0.363)	(0.231)	(0.455)	(0.483)
R^2	0.089	0.076	0.068	0.063
Obs.	147,359	362,602	93,868	80,393

***: $p < 0.01$, **: $p < 0.02$, *: $p < 0.05$

Robust standard errors in parentheses

- "Low Density": pop. density < 100 pop / km^2
- "Medium Low Density": 100–500
- "Medium High Density": 500–1000
- "High Density": ≥ 1000

- Results are consistently significant for the time trend and both intervention variables
- Estimated coefficients of *EEG change* are smaller in the more densely populated areas
- Coefficient estimate for *Treatment* is similar for the three less densely pop. areas, and larger in high density areas

5. Discussion and Conclusions

- We find that **excess bunching increased by 50-65%** from 7/2021 to 7/2022
- Given that rooftop size changes slowly, an increase in excess bunching can best be explained by an increase in **PV adopters not fully exploiting the** available roof size **potential**
- **Tax compliance costs** are **decisive** for PV system capacity choice of private households (in Germany, PV system capacity decreased as a consequence of the BMF tax instruction)
- BMF tax instruction is linked to a **445-500 W_p decrease in average system capacity** in areas with < 1000 pop/km^2 (in line with our findings from the bunching analysis, and in part also the theoretical decision model introduced)
- **Effect size estimate is significantly larger at 755 W_p** for the highest population density group (but statistically indifferent at the 5% level from that of the other subgroups studied)
- **Treatment effect** is not decreasing in more densely populated areas, whereas the **effect size** (2021 EEG revision) is, with **910 W_p larger average system size** (in less densely populated areas) and only **591 W_p larger average system size** in areas with > 1000 pop/km^2
  → Is in line with the bunching estimates, indicating less pronounced bunching in densely populated areas
- Taken together, these results provide evidence that the tax exemption causes distortions in PV adoption and system sizing (→ bunching effect); → **population density** is **a useful proxy for rooftop size**

Thank you for your kind attention.
Any questions?

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Paper on which this presentation is based upon:
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Backup Slide #1

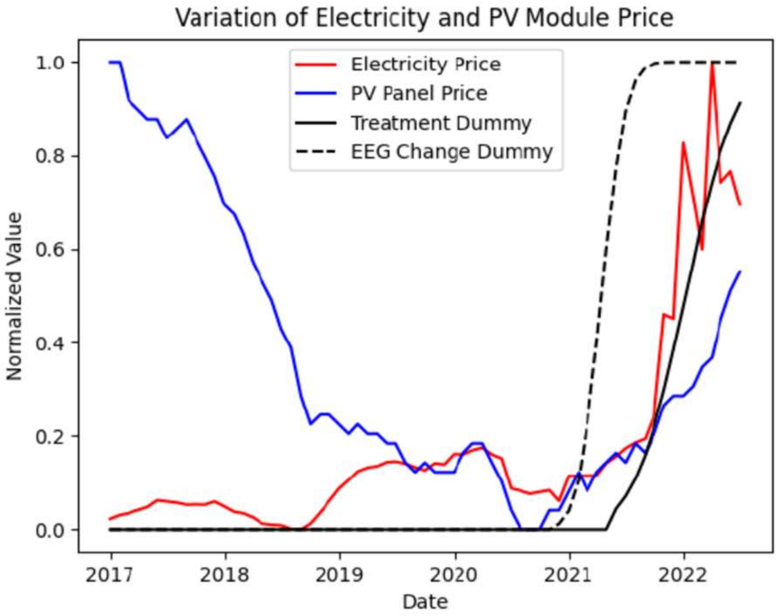


Figure 8: Development of Electricity Price and PV Panel Price versus Treatment Variable, 2017-2022

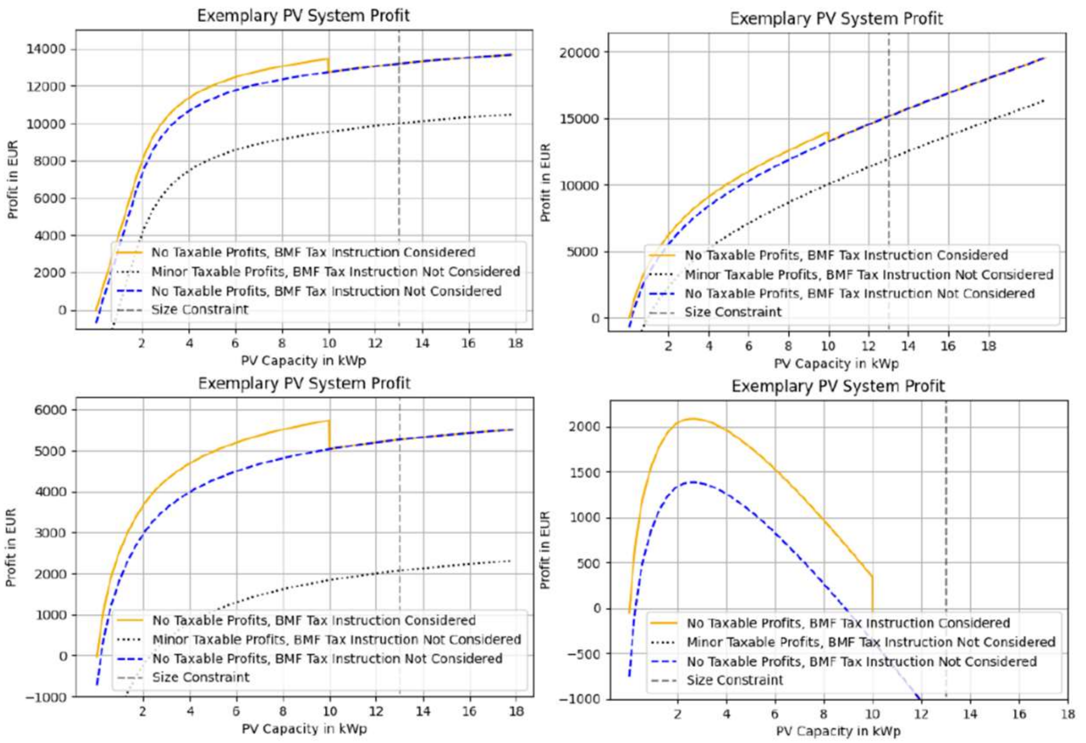
- **Visualization** of covariates and intervention dummies:
- Electricity price strongly correlates with the treatment dummy (when accounting for the distributed time lag)
- PV module prices started rising end of 2020, accelerating in H2/2021 → PV system price correlates with both the electricity price and the treatment variable
- Before 2021: rather stable electricity price

→ Findings are **sensitive to model misspecification** (minor changes in the modeling might lead to ambiguous results)

→ **Lag of treatment response** is widespread and very long, negative in discontinuity approaches

Backup Slide #2

Appendix 2: Output Curves for Alternative System Specification



Upper left-hand corner: Same specification as in Figure 2 (Section 3.1) but with 7 kWh battery storage

Upper righthand corner: High household electricity consumption (6000 kWh/a), high specific yield (1100 kWh/(kWp*a), low specific investment cost (1200 €/kWp)

Lower lefthand corner: Figure 2 (Section 3.1) for comparison

Lower righthand corner: Low household electricity consumption (2500 kWh/a), low specific yield (800 kWh/(kWp*a), high specific investment cost (1600 €/kWp)

Notes:

- **Different system specifications** can lead to very different results (our model is simplified in many ways)

- With **sufficient productivity, budget and roof size**, and only **moderate compliance costs**, a household may decide against utilization of the BMF tax instruction and employ a larger system instead

- Alternatively, under different conditions, the **optimal system size** may lie between 0-10 kW_p such that capacity choice would be unaffected by the 10 kW_p threshold value