Supporting Solar: The Causal Impact of Subsidies on Domestic Photovoltaic Installations

Leanne Cass[1] Misato Sato[1] Aurélien Saussay[1]

[1]The London School of Economics and Political Science, London, UK

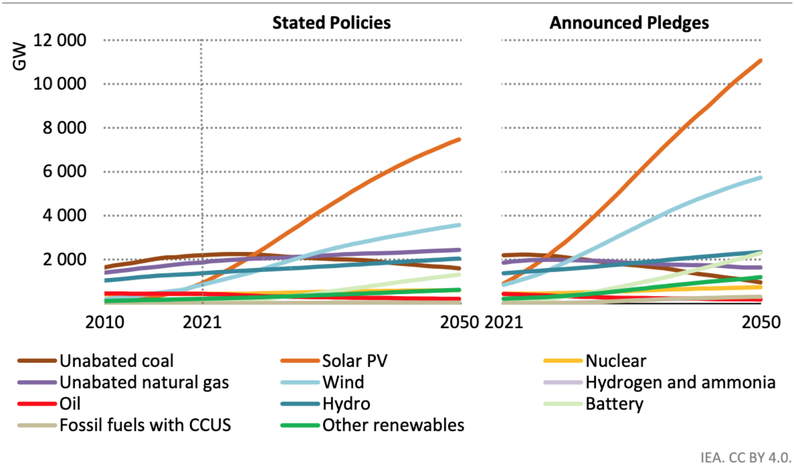
EEA-ESEM 2024
August 27th, 2024

Grantham Research Institute on Climate Change and the Environment

GEOCEP Global Excellence in Modelling Climate and Energy Policies

Solar PV will play a major role in the energy transition

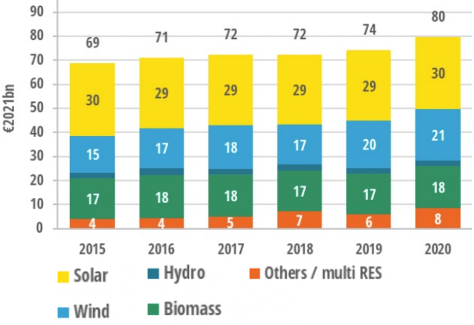
- Global installed electricity capacity by source 2010-2050

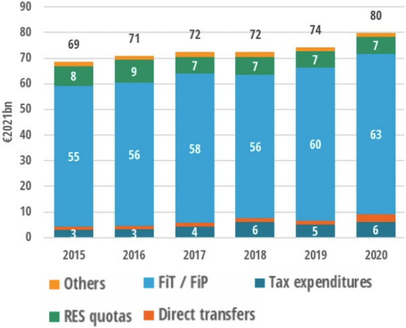


Source: IEA WEO (2022)

Solar generation has been heavily subsidised

- EU renewable energy subsidies by technology/financial instrument





Source: European Commission (2022) https://data.europa.eu/doi/10.2833/304199

Does solar PV still need to be subsidised?

- PV and wind are becoming competitive sources of electricity
- Small PV systems expected to break even with wholesale electricity by 2027 in UK (Mandys et al. 2023)

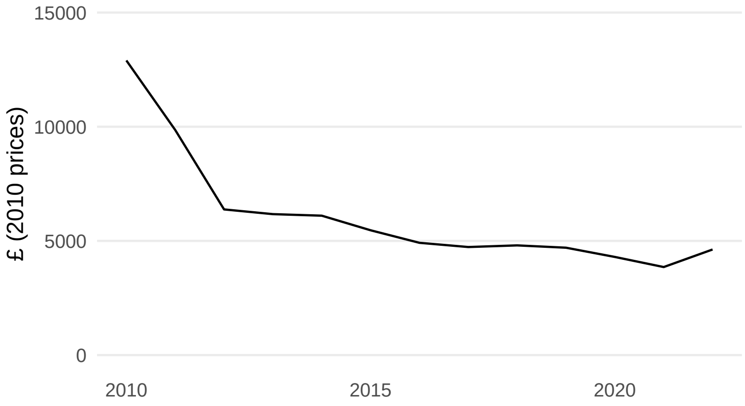


Figure 1: Mean total costs to install solar PV systems of 3 to 4 kW capacity.
Source: Authors' own calculations from MCS database.

Solar subsidies: effective but often expensive and regressive

- PV subsidies **increase household adoptions** Bollinger & Gillingham, 2012; Hughes & Podolefsky, 2015; Rogers & Sexton, 2014; Germeshausen, 2018; Gillingham & Tsvetanov, 2019
- However, their **cost effectiveness** may be undermined by:
  - **Poor targeting** of marginal adopters and locations with high solar potential or CO_2 mitigation potential Snashall-Woodhams, 2019; Rogers & Sexton 2014; Callaway et al., 2018; Fowlie & Muller 2019; Sexton et al., 2021
  - Households' **high discount rates** and **low price sensitivity** De Groote & Verboven, 2019; Gillingham & Tsvetanov, 2019; Rogers & Sexton, 2014; Talevi, 2019
- PV adoptions, subsidy benefits, and their environmental benefits may be **regressively distributed** Grover & Daniels, 2017; Borenstein 2017; Degroote et al., 2016; Barbose et al., 2020; Lukanov & Krieger, 2019; O'Shaughnessy, et al. 2021; Dauwalter & Harris, 2023
- Assessing the impact of decarbonization policies requires **navigating complex trade-offs among diverse socioeconomic and technical outcomes and objectives** Peñasco et al., 2021; Deng et al., 2017

This paper

- Evaluate the zero-interest **Home Energy Scotland (HES) Loan**, 2017 - 2021:
  - Does it boost PV adoption?
  - Who benefits?
  - Is it cost effective?

- Better understand socioeconomic trade-offs, and links to policy design

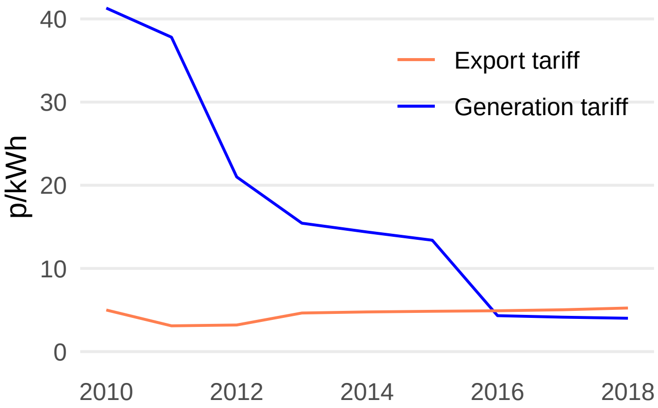
- **Quasi-experimental research design** identifying causal effects
  - Exploit the devolved nature of renewable support policies in the UK
  - DiD with cardinality matching at the local authority level

- **Rich administrative data**
  - Universe of domestic PV installations from the UK's Microgeneration Certification Scheme (MCS)

Outline

The UK-wide Feed-in-Tariff (FiT) subsidy initially provided a high level of support but declined with technology costs

- 04/2010 to 03/2019
- Subsidy payment made quarterly, guaranteed for 20-25 years



Solar PV still needed support in 2010s despite fall in cost

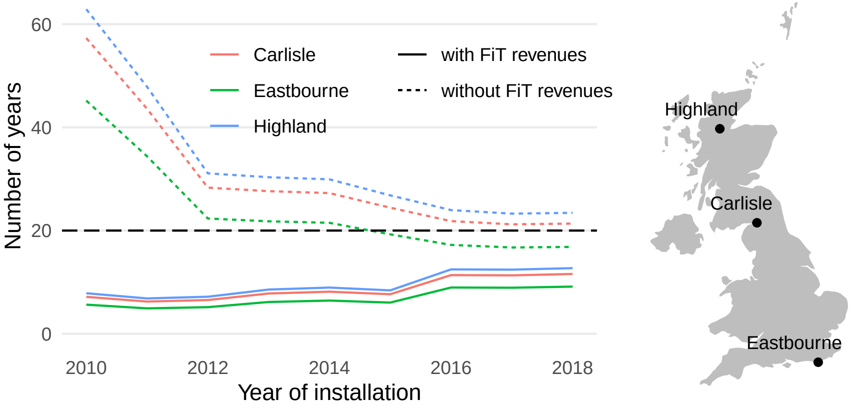


Figure 2: Expected payback period for a 3 to 4 kW PV system

History of non-FiT support Details

The 2017 Home Energy Scotland (HES) Loan

- **Interest-free loan** for energy efficiency upgrades or installing microgeneration including solar PV panels
- Maximum loan amount increased: **£2,500** in 2017; **£5,000** in 2018; **£6,000** in 2022.
- Expanded eligibility: **all homeowners** and private landlords
- Previously, capital cost support was more targeted:
    - live in an energy-inefficient home that they own or privately rent and
    - either receive a means-tested benefit or are 75+ years of age and have no working heating system.

Outline

The domestic energy certification authority: MCS

- The **Microgeneration Certification Scheme** (MCS) sets and maintains standards for renewable technology installations, products, and installers in the UK
- To be eligible for support (e.g. FiT scheme or HES Loan), installations **must be certified by MCS**
- **MCS Installations Database**
  - Comprehensive coverage
  - **1.52 million** installations since 2008
  - **83.5%** are domestic solar PV installations
- Contains rich information on each installation e.g.:
  - **Total capacity** of installation and estimated annual generation
  - **Product installed** (name, manufacturer, MCS product number)
  - **Postcode**
  - **Total cost** of installation (48% coverage)

Descriptive statistics

Other data on key drivers of PV adoption

- Local **solar generation potential**
  - Local Authority District (LAD) level
  - Source: World Bank Global Solar Atlas
- Local **housing stock characteristics**
  - Energy Performance Certificates Register
- Postcode-level **electricity consumption**
- **Home ownership** rates
- **Population density**
  - Source: Office for National Statistics (ONS)
- Localised **house price** data
  - Proxy for localized household income
  - Source: HM Land Registry and Registries of Scotland

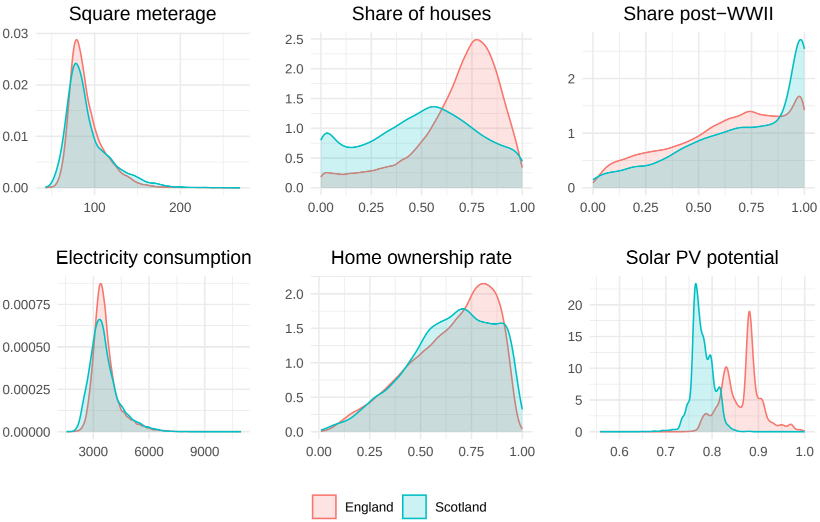
Outline

1. **Motivation**
2. **Policy Background - PV support in Scotland and the UK**
3. **Data and descriptives**
   - The MCS dataset
   - Other data
4. **Empirical Strategy**
5. **Results**
   - Results on PV adoption
   - Distributional analysis
   - Cost effectiveness
6. **Conclusions**

Matching with Difference-in-Differences

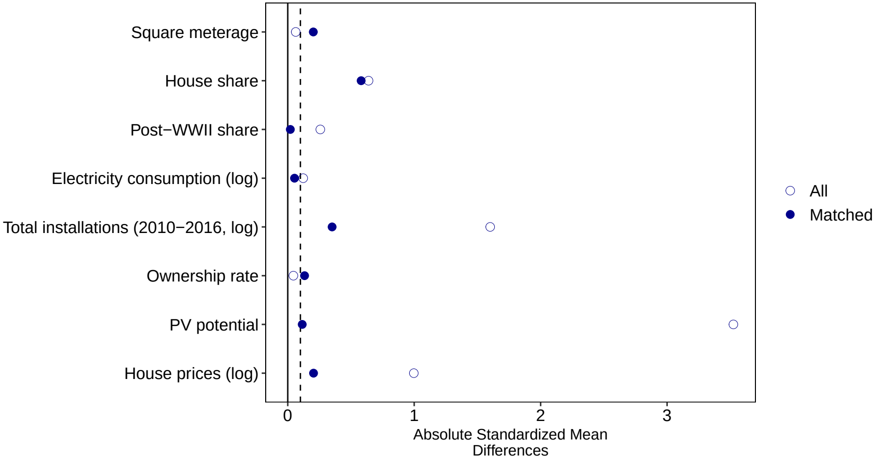
- Take advantage of the **devolved** nature of support policies to causally assess the impact of the HES Loan
- Match at the **Lower Layer Super Output Area (LSOA)** level
  - **42,622 LSOAs** across the whole UK, 6,976 in Scotland
- Match on observable key characteristics:
  - **Housing stock**: square meterage, house share, post-WWII share
  - **Electricity consumption**
  - **Home ownership** (2011)
  - **House prices** (2012-2016)
  - **PV production potential**
- Coarsened Exact Matching (Iacus et al., 2012)

Overlap in the distribution of covariates



▸ PV vs density ▸ PV vs solar potential

Match quality assessment (2,918 LSOAs matched)



Map of matched LSOAs

Nonlinear Difference-in-Differences Specification

For each LSOA i and year t, we estimate using PPML:

$$y_{it} = exp(\beta_t^{HESL} \mathbb{1}_{it}^{HESL} + \mu_i + \gamma_t) \times \epsilon_{it},$$

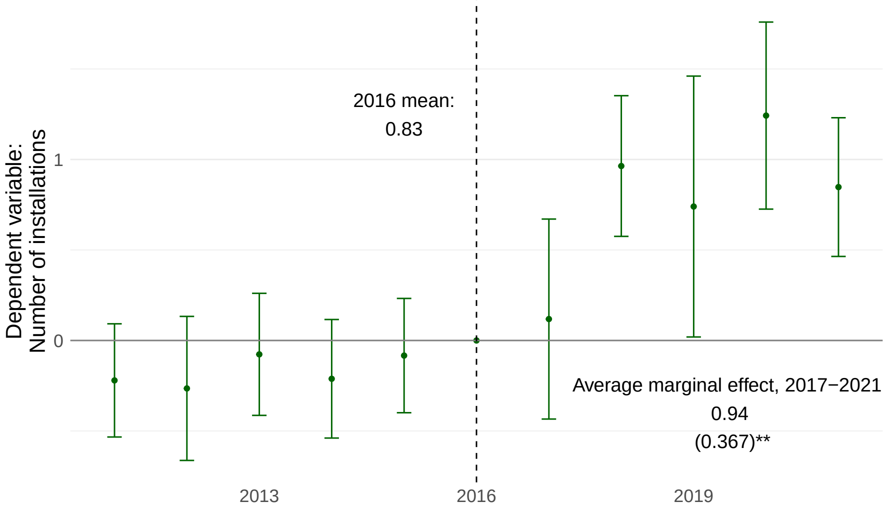
where

- $\mathbb{1}_{it}^{HESL}$ is the treatment indicator for the HES Loan, $= 1$ from 2017 onward in Scotland
- Dependent variables y_{it} studied are:
  - Number of installations
  - Average estimated annual generation of new installations
- Standard errors are clustered at the matching subclass level

Outline

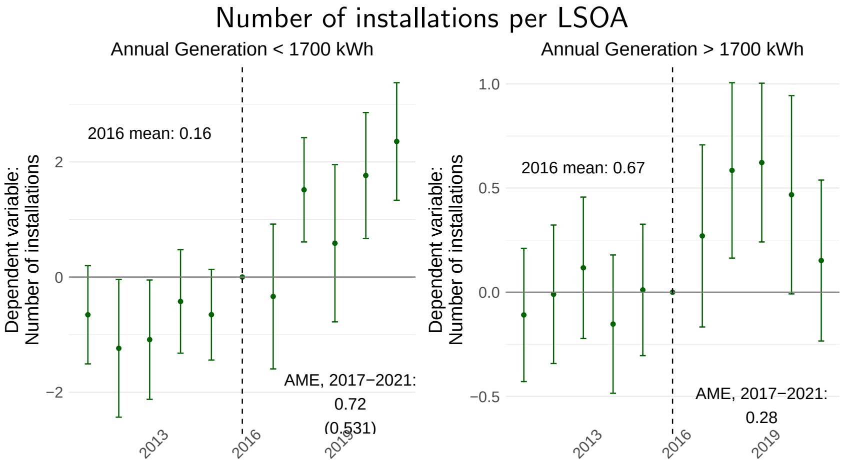
Main results

HES Loan increased the number of solar PV installations



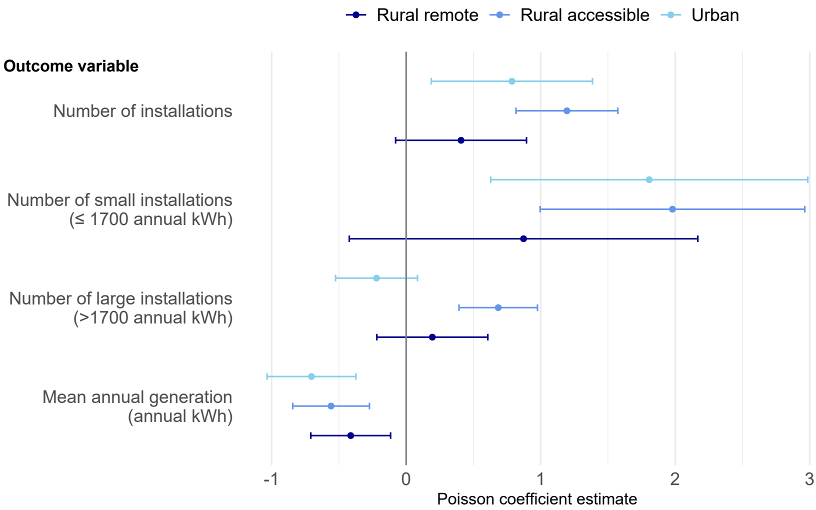
Average Marginal Effects RDD OLS

Increased installations concentrated on small installations



Average Partial Effects | OLS

Policy impact was strongest in less remote LSOAs



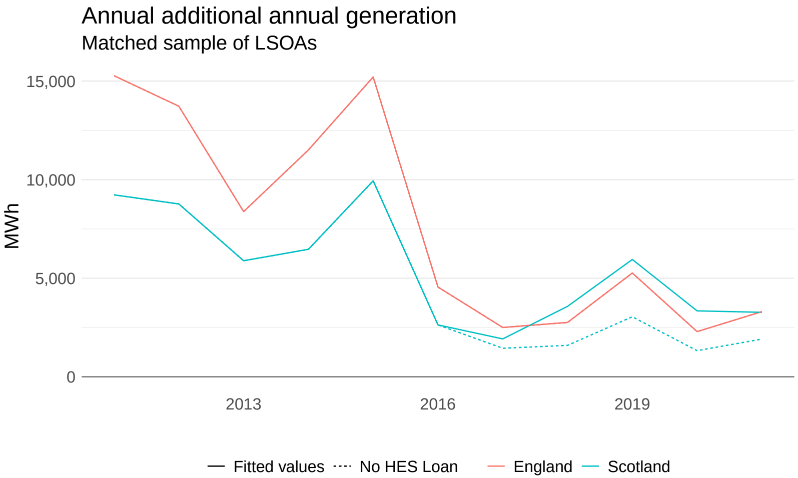
Output Area results

Why did installation size decrease?

Potential hypotheses:

- Cost differentials between small and medium-size systems have dwindled
  ▸ Details
- The HES Loan + end of FiT scheme further improved relative profitability of small PV systems
  ▸ Details
- Impact concentrated on urban households with limited rooftop space? Or on low-income households that are credit constrained?
- Supply-side installer push for smaller systems?

Additional solar PV generation due to the HES Loan



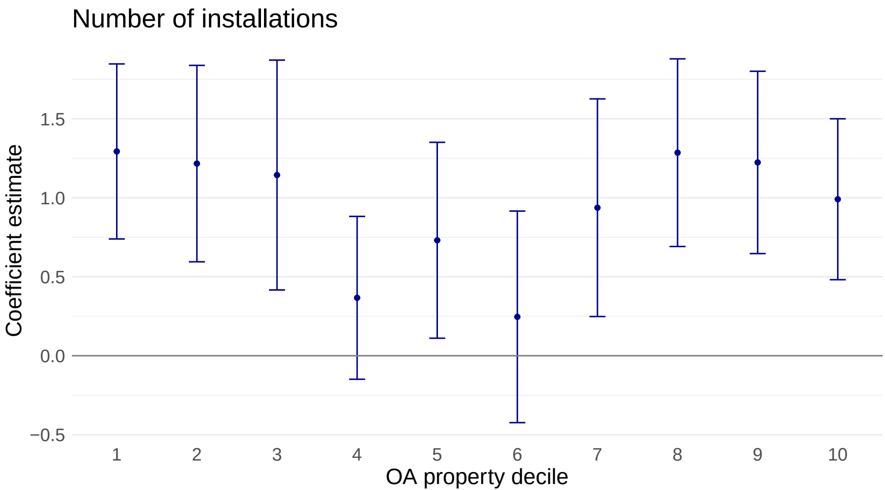
→ The HES Loan led to 8,739 MWh of additional annual generation capacity in matched Scottish LSOAs (48% of added capacity in these LSOAs in 2017-2021)

Distributional analysis: Who benefited?

- Conducting a distributional analysis requires **localized household income** data
- Three levels provided by the UK ONS:
  - OA (Output area) $\approx$ 150 households
  - LSOA (Lower Layer Super Output Area) $\approx$ 650 households
  - MSOA (Middle Layer Super Output Area) $\approx$ 3,000 households
- **Only MSOA available in England**
- Instead construct a **localized indicator of property value**
  - **Universe** of **housing transactions** from HM Land Registry and Registries of Scotland
  - At the **OA level**, calculate average inflation-adjusted value of all transactions over **2010-2016**

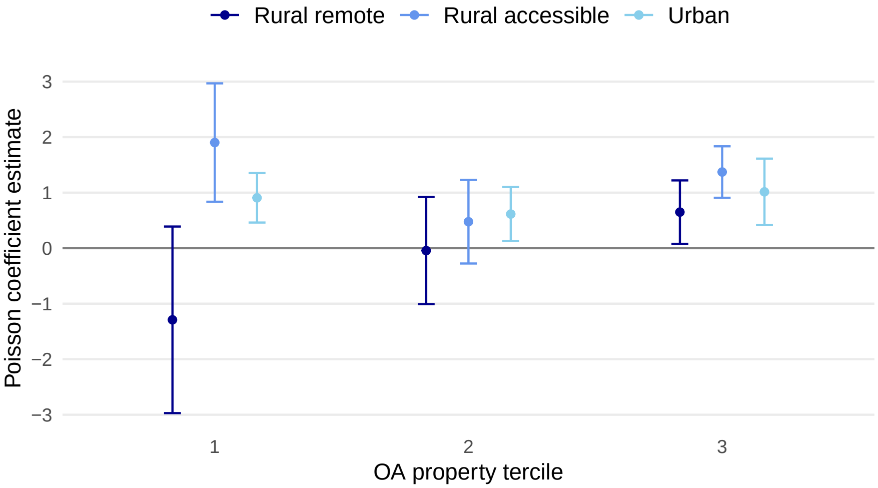
▸ Details

Strongest impact in poorest and wealthiest OAs

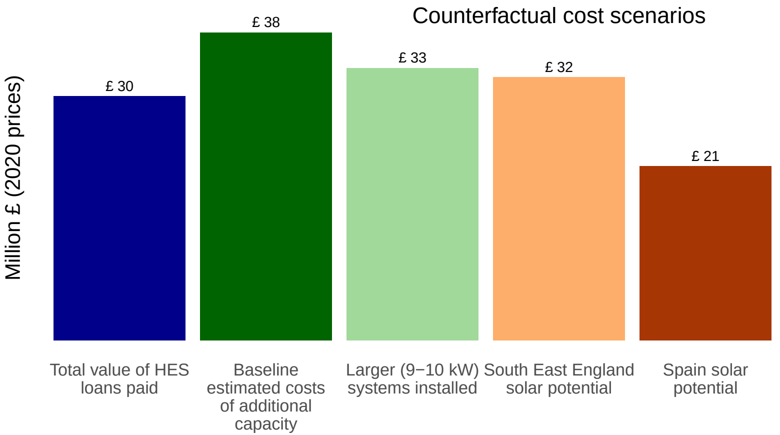


▸ Specification ▸ Joint distributions ▸ Installation size

Distributional impacts differ by urban versus rural

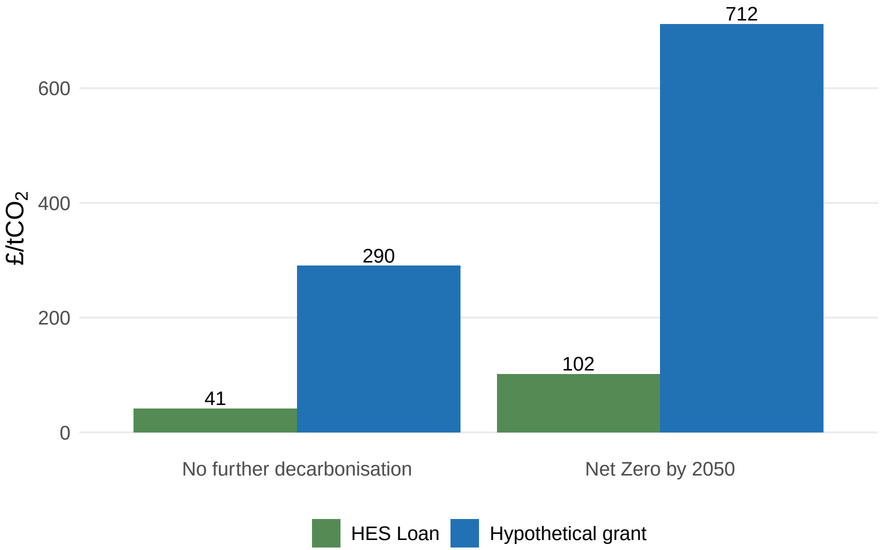


Cost effective? Estimated total installation costs of additional generation



Notes: Total costs of additional annual generation estimated based on median cost per kW in MCS database. Baseline total cost estimate assumes small (1-2 kW) systems installed.

Cost effective? Estimated cost per tCO_2 abated



Assumptions: 25 year PV lifetime and government discount rate on loans of 3%. Details

Comparison with other PV support scheme's abatement costs

- Hughes and Podolefsky (2015): CA Solar Initiative's rebate programme cost **\$130 to 196/ tCO_2** abated
- Rogers and Sexton (2014): The CA Solar Initiative's rebate programme cost **\$270-\$328/tCO_2** abated.
- Gillingham and Tsvetanov (2019): The Connecticut up-front subsidy programme cost **\$364/tCO_2** abated
- Talevi (2019): The UK FiT scheme cost **£179 /tCO_2** abated. (Assumes carbon intensity of electricity grid remains at 2010 levels).
- Srivastav (2023): The UK FiT scheme impact on utility-scale solar cost **£100 /tCO_2** abated

$\Rightarrow$ *A loan scheme can be a relatively cost effective policy design to induce household PV adoptions and achieve some abatement even when solar potential is relatively low*

Outline

Conclusions

- Domestic solar **PV adoption can be increased** even:
  - with a loan rather than a grant
  - in northern latitudes with low solar potential
- Interest free loans **need not be regressive**
- **Costs were reasonable**
  - a loan was a good instrument choice
  - increased domestic PV in Scotland

$\Rightarrow$ *Boosting domestic solar PV may not be the most cost effective way to achieve CO_2 abatement, but the cost difference relative to other technologies and abatement strategies is perhaps acceptable, particularly if pursuing other goals alongside abatement*

Appendix

A short history of non-FiT support to solar PV in the UK

- Non-FiT policies to support solar PV are not UK-wide, and tend to be **devolved** to the nations within the UK
- Before 2017, these non-FiT policies **targeted households that are both low-income and energy-poor**, for example:
  - Nest Scheme in Wales since 2011
  - Energy Company Obligation since 2013 in England, Scotland, and Wales
  - Warmer Homes Scotland since 2015
- Although solar PV is available under these schemes, the vast majority of the funding seems to have been directed towards **energy efficiency improvements**

Back

Calculating expected payback time

Expected payback time, P_{lt}, for a 4 kW solar PV system installed in LAD l in year t:

$$P_{lt} = TC_t \div AR_{lt}$$

Where:

- TC_t is total installation costs. We use average costs in year t for 3 to 4 kW systems in the MCS data.
- AR_{lt} is **expected annual net revenue**:

$$AR_{lt} = (G_l \times T_t) + (\alpha G_l \times S_t) + ((1 - \alpha) G_l \times p_t)$$

- Annual electricity generation $(G_l) = 4$ kW $\times$ solar potential in LAD l (kWh/kWp)
- T_t is the generation subsidy and S_t is the export subsidy
- $\alpha =$ share of generation exported back to the National Grid. We assume 50%.
- p_t is the electricity price in the year of installation. Data on average UK electricity price from BEIS.

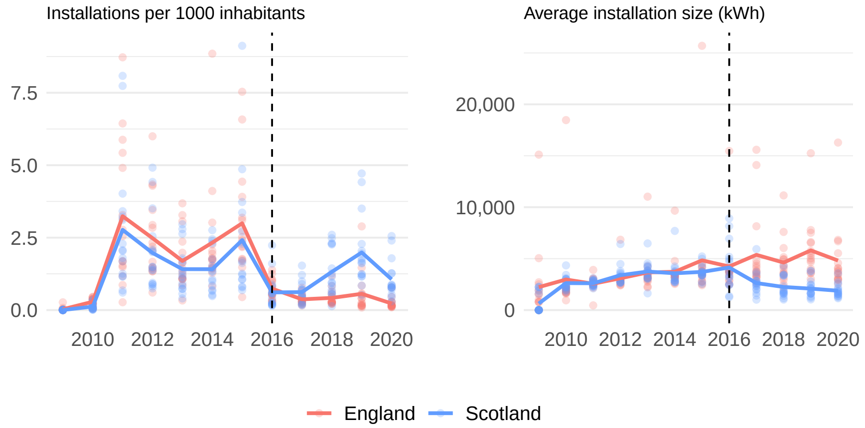
Back

Assumptions underlying Net Present Value calculations

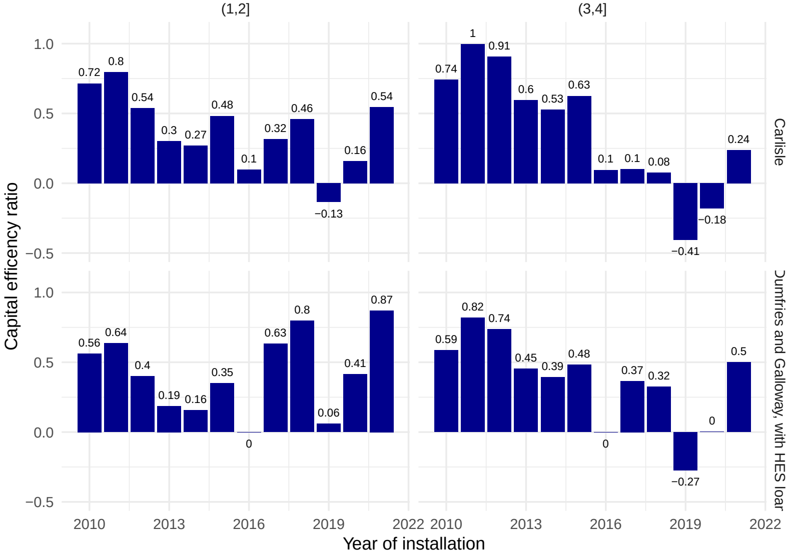
- Benefits include subsidy payments and electricity savings
- Real price of electricity is constant over system lifetime
- 50% of generation is exported back to the grid
- Zero annual operating expenses
- 20 year lifetime
- 5% discount rate
- HES Loan repaid in 10 equal annual payments

Back

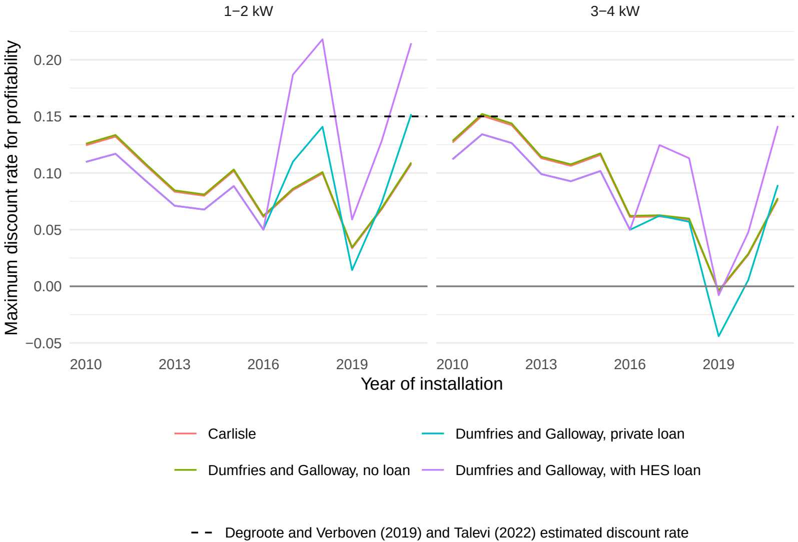
Unconditional mean outcomes: Matched LADs



Capital efficiency ratios: PV of net benefits / PV Costs



Profitability is sensitive to high discount rates



Solar PV installations, 2010-2021

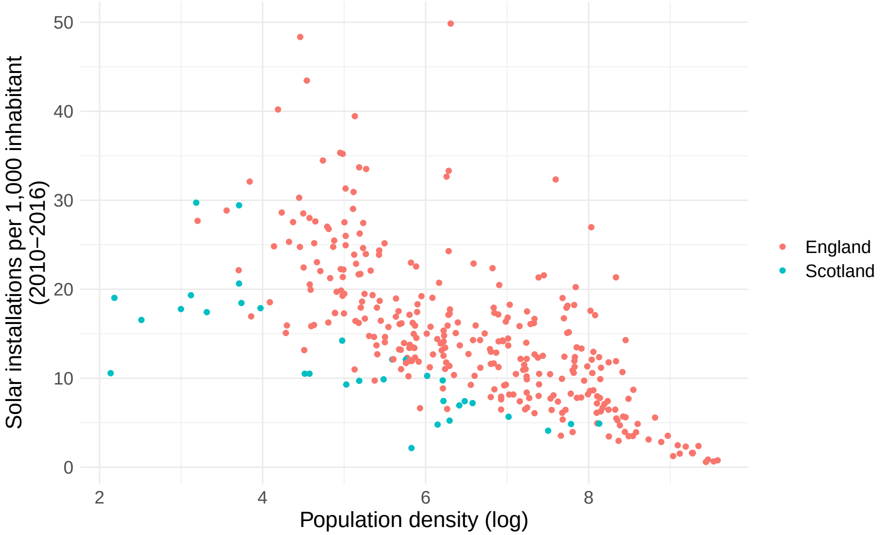
	Full sample	England	Scotland
Number of installations	1,076,072	865,540	94,854
Installations per 1000 people	16	15	17
Installation Costs (2010 £)			
Mean	5,512	5,725	3,952
Std. Dev.	5696.9	5790.1	4953.1
Share missing	0.59	0.62	0.42
Estimated Annual Generation (kWh)			
Mean	3,270	3,295	2,777
Std. Dev.	4551.7	4592.6	4117.6
Share missing	0	0	0

Back

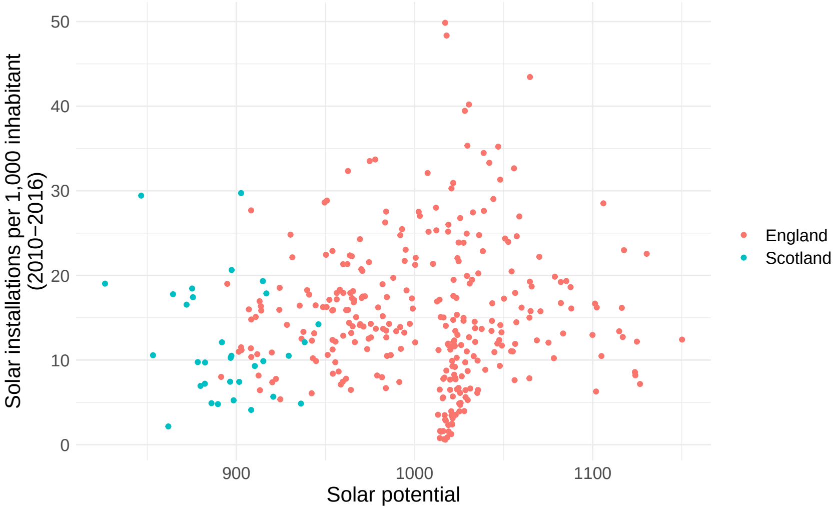
Solar PV installations as a function of income

◂ Back

Solar PV installations concentrate in rural LADs



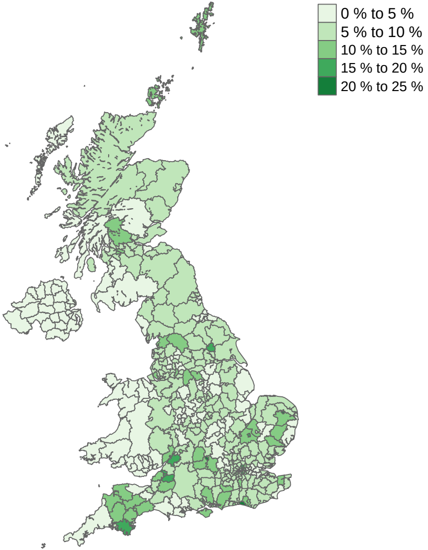
Solar PV installations vs solar potential



Back

Measuring green preferences

- Pre-existing **green preferences / values** can impact domestic solar PV installations
- Use **green vote** to instrument for green preferences
- Share of **Green Party vote** at the **2014 European Parliamentary** election in each **local authority council**



Back

Matching strategy: cardinality matching

- **Find the largest subset of units that satisfies balance constraints** (Visconti and Zubizarreta, 2018)

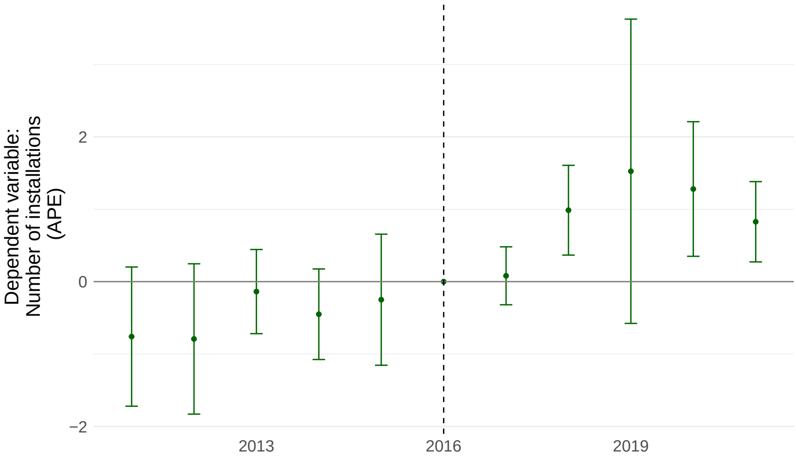
$$
\begin{aligned}
\max_{\mathcal{T},\mathcal{C}} & \sum_{t \in \mathcal{T}} \mathbf{1}_t + \sum_{c \in \mathcal{C}} \mathbf{1}_c \\
\text{s.t.} & \sum_{t \in \mathcal{T}} \mathbf{1}_t = \sum_{c \in \mathcal{C}} \mathbf{1}_c, \\
& \left| \frac{\sum_{t \in \mathcal{T}} \mathbf{1}_t x_{tp}}{\sum_{t \in \mathcal{T}}} - \frac{\sum_{c \in \mathcal{C}} \mathbf{1}_c x_{cp}}{\sum_{c \in \mathcal{C}}} \right| < \varepsilon_p
\end{aligned}
$$

- Here we minimize **absolute mean standardised difference** between control and treated groups for each covariate p

- Each ε_p is chosen to ensure that all standardized differences in means are < 0.1 (Rosenbaum and Rubin 1985)

◂ Back

Average partial effects of the HES Loan on the number of solar PV installations per 1000 people



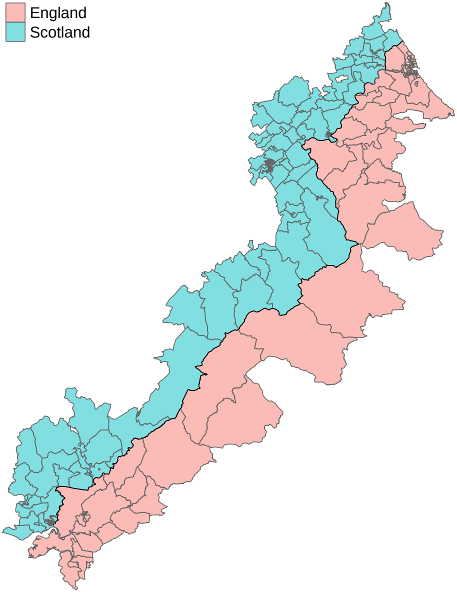
Event study results: Number of installations per 1000 cap

	Installations per 1,000 cap			Avg total annual generation (kWh)		
	(1)	(2)	(3)	(4)	(5)	(6)
2009 x Scotland	-2.077***	-2.089***		-1.227**	-1.202**	
	(0.738)	(0.751)		(0.500)	(0.492)	
2010 x Scotland	-0.669***	-0.685***		-0.102	-0.070	
	(0.247)	(0.245)		(0.235)	(0.216)	
2011 x Scotland	0.037	0.018		0.041	0.077	
	(0.243)	(0.237)		(0.283)	(0.312)	
2012 x Scotland	-0.037	-0.057		0.116	0.152	
	(0.210)	(0.205)		(0.199)	(0.218)	
2013 x Scotland	0.011	-0.009		0.047	0.073	
	(0.251)	(0.249)		(0.174)	(0.182)	
2014 x Scotland	-0.307	-0.327		-0.016	0.003	
	(0.342)	(0.344)		(0.186)	(0.194)	
2015 x Scotland	-0.023	-0.032		-0.242	-0.236	
	(0.183)	(0.183)		(0.188)	(0.186)	
2017 x Scotland	0.707***	0.717***	0.821***	-0.691***	-0.698***	-0.761***
	(0.254)	(0.253)	(0.295)	(0.227)	(0.226)	(0.215)
2018 x Scotland	1.337***	1.382***	1.492***	-0.697***	-0.720***	-0.816***
	(0.224)	(0.228)	(0.340)	(0.224)	(0.219)	(0.199)
2019 x Scotland	1.457***	1.531***	1.647***	-1.001***	-1.031***	-1.162***
	(0.388)	(0.405)	(0.541)	(0.202)	(0.196)	(0.181)
2020 x Scotland	1.733***	1.842***	1.965***	-0.916***	-0.950***	-1.118***
	(0.280)	(0.279)	(0.482)	(0.168)	(0.171)	(0.204)
2021 x Scotland	1.523***	1.578***	1.709***	-0.634***	-0.651***	-0.854***
	(0.291)	(0.298)	(0.540)	(0.215)	(0.212)	(0.239)
Density		0.002***	0.002***		0.000***	0.000***
		(0.000)	(0.000)		(0.000)	(0.000)
Ghdi		0.000***	0.000***		0.000***	0.000**
		(0.000)	(0.000)		(0.000)	(0.000)
Scotland x Year			-0.007			0.035
			(0.058)			(0.025)
N	416	416	416	416	416	416
AIC	952	952	942	181,949	180,019	194,571
Year FE	X	X	X	X	X	X
LAD FE	X	X	X	X	X	X

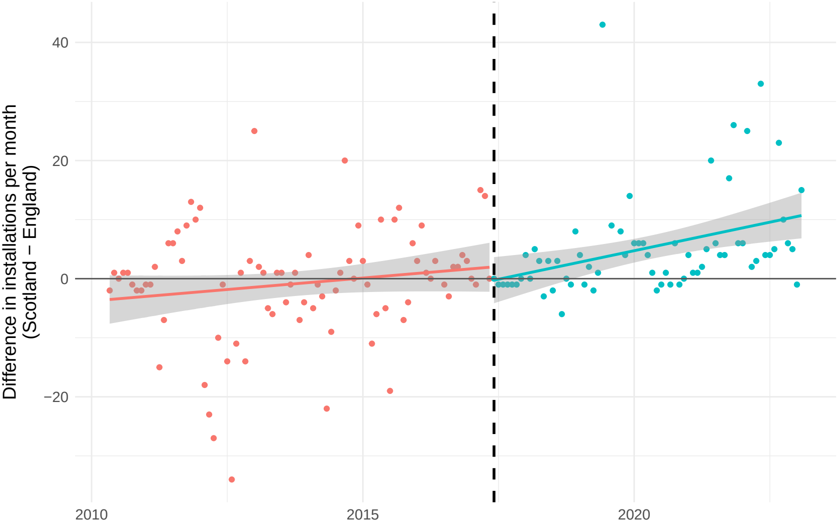
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Back

Regression discontinuity design – 10km band

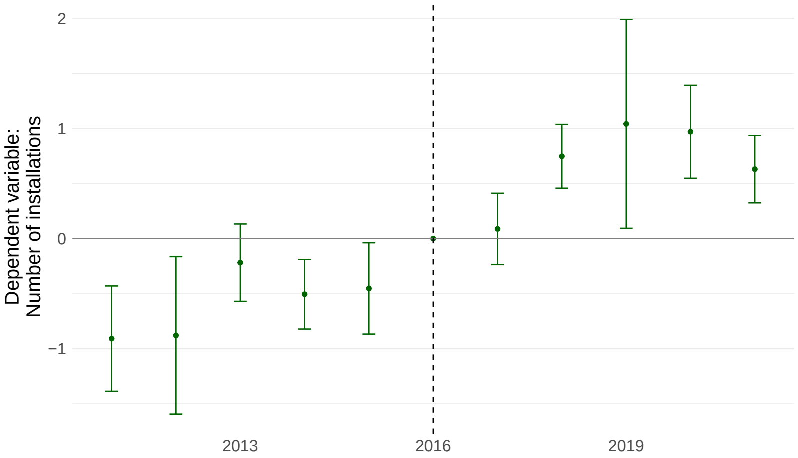


Regression discontinuity design – Results



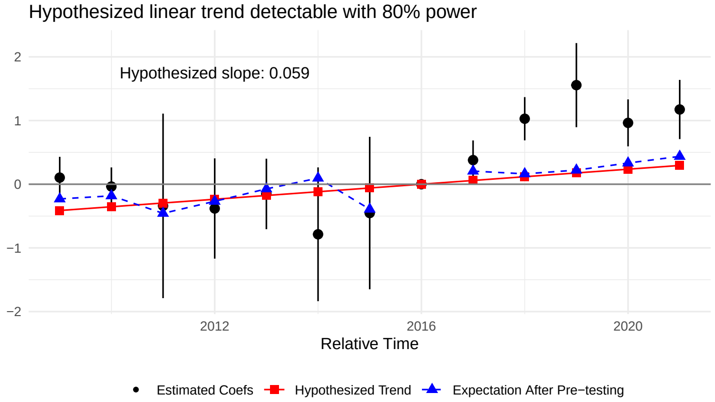
Back

OLS: Impact on number of installations (per 1,000 cap)



◂ Back

Roth (2022) pretrends test: How big would a violation of parallel trends need to be to detect it 80% of the time?



Notes: Expectation after pre-testing = expected coefficients conditional on not finding a significant pre-trend if in fact the hypothesized trend is true. OLS specification with number of installations per 1000 inhabitants as the dependent variable.

Back

Rambachan and Roth (2023): Robustness of estimates to smoothness restrictions on slope of pre-treatment trends

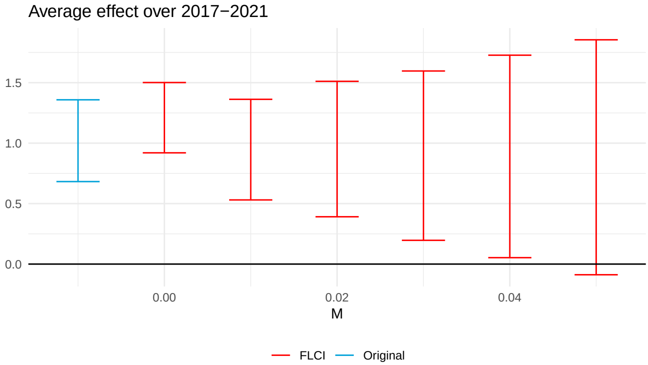
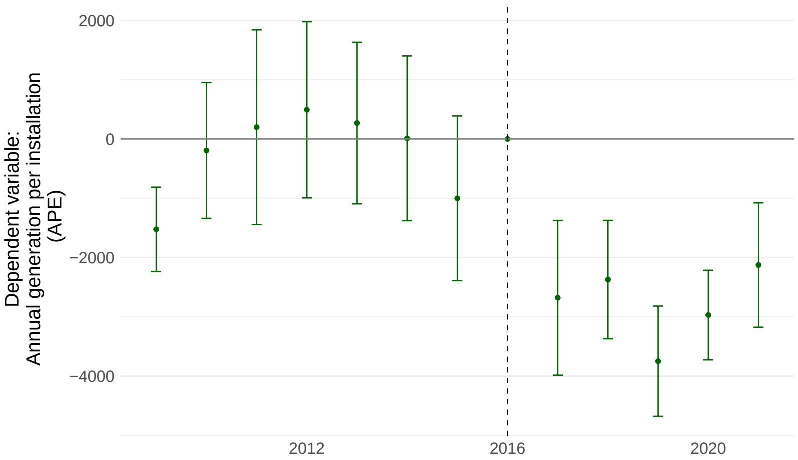


Figure 3: Adjusted estimates and confidence intervals on average effect of HES Loan on number of installations per 1000 people over 2017-2020, imposing that the slope of the difference in trends changes by no more than M between periods.

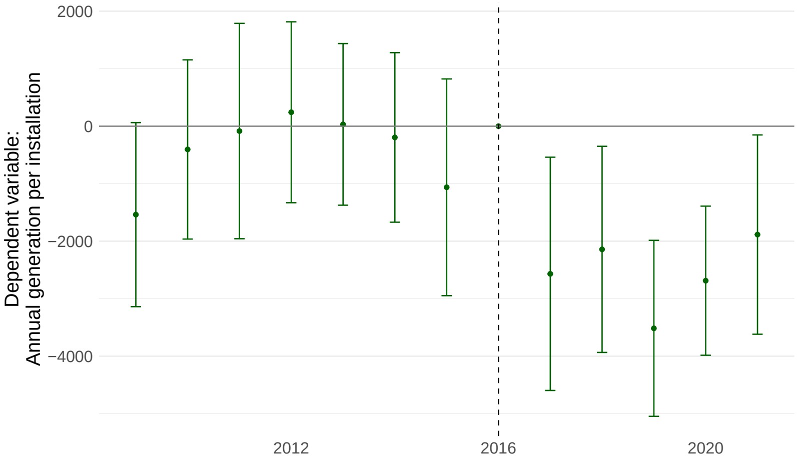
Back

Average partial effects of the HESL on average annual generation per system



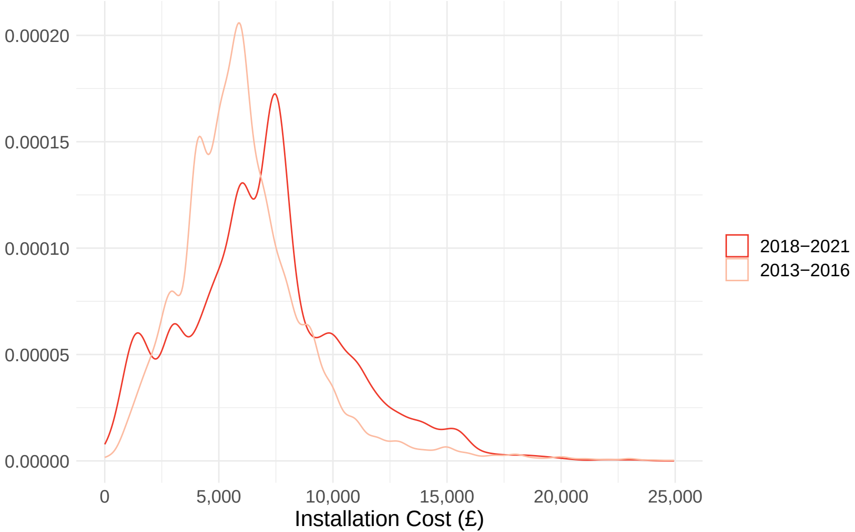
Back

OLS: Impact on average annual generation per system



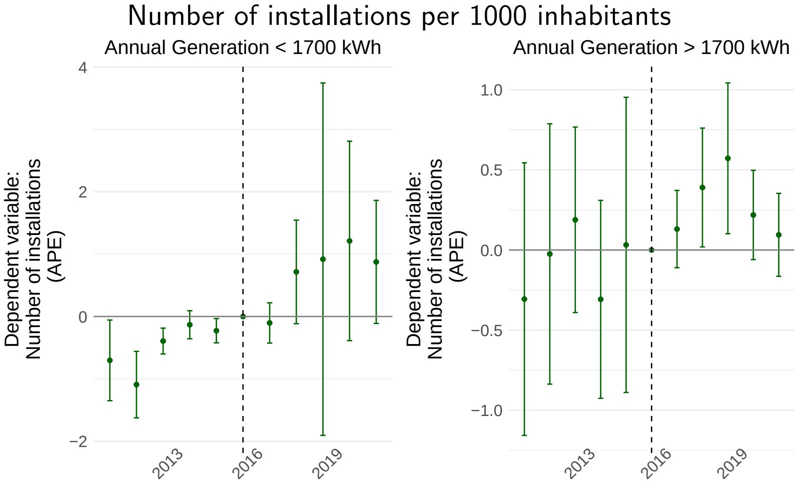
Back

Distribution of installation costs in England



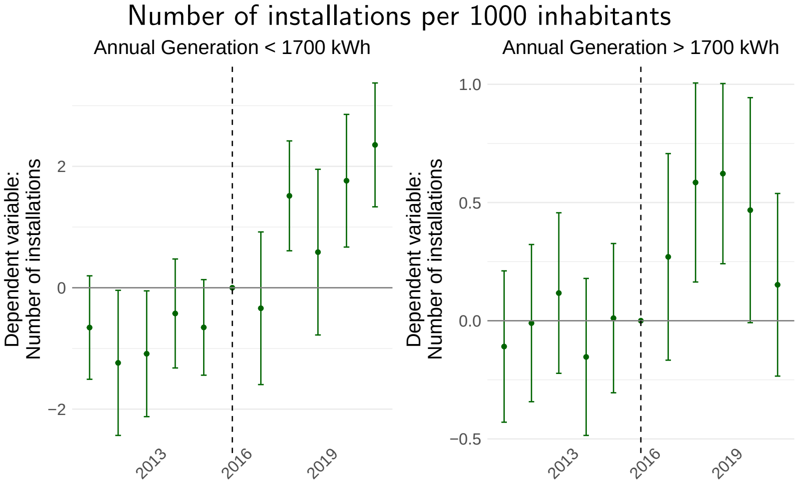
◂ Back

Split sample results: Average partial effects



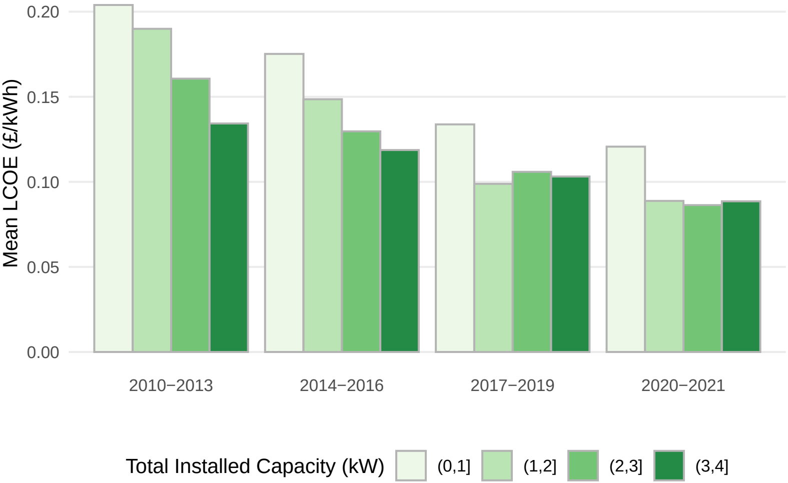
Back

Split sample results: OLS specification



Back

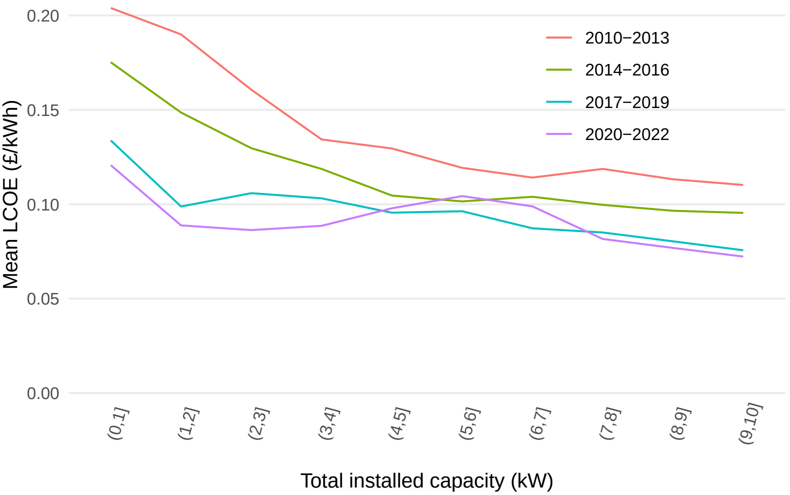
For smaller systems, economies of scale have dwindled



Notes: Assumes a 25-year lifetime, £0 per year operating costs and an 5% discount rate.

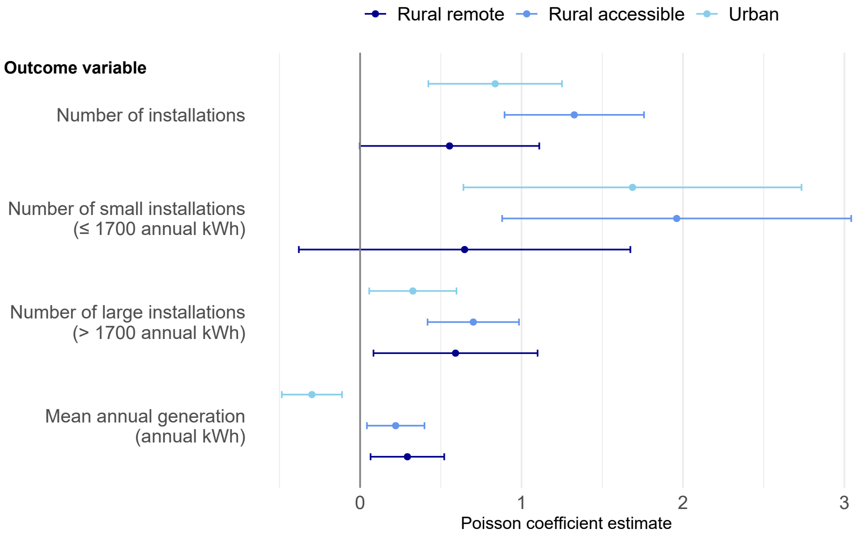
Back

Economies of scale still exist for systems > 6 kW



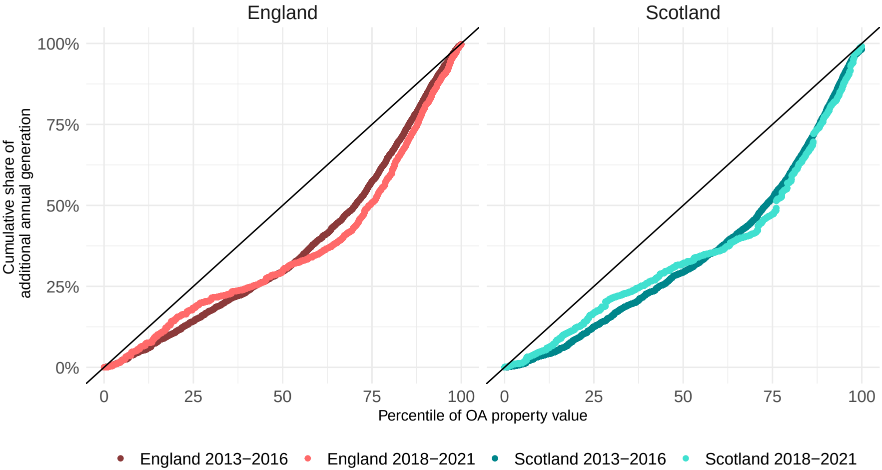
Back

Output area results: Urban versus rural heterogeneity



Back

Joint distributions of generation and property value



Back

Distributional impacts – Specification

- For each OA j within our matched LSOAs and period t, we regress:

$$y_{jdt} = \sum_{d=1}^{10} \beta_d^{HESL} \delta_{jd} \times \mathbb{1}_{jt}^{HESL} + \epsilon_{jdt}$$

- Two periods: 2013-2016 and 2018-2021
- $\mathbb{1}_{jt}^{HESL}$ is the treatment indicator, $= 1$ for 2018-2021 in Scotland
- δ_{jd} indicates whether OA j falls in property value decile d
- Standard errors are clustered at the matching subclass level

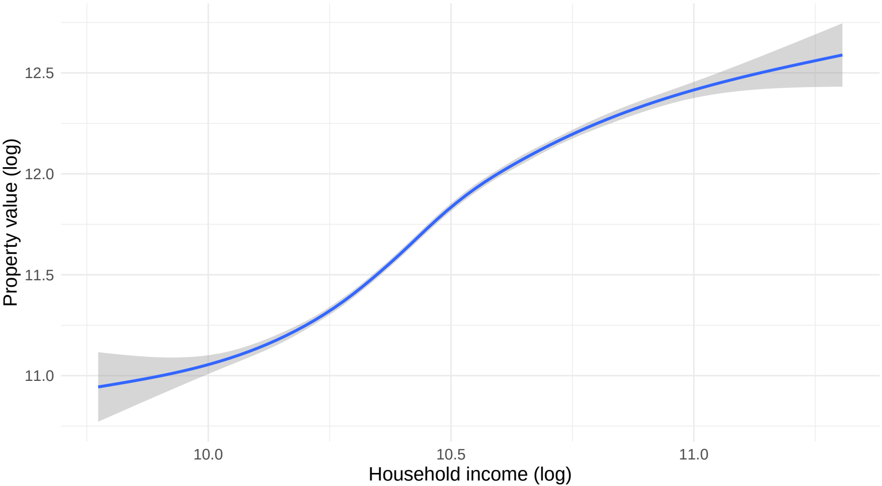
Back

Comparison of property deciles in England and Scotland

Decile	England	Scotland	Difference
1	56,817	51,760	9.8%
2	79,272	71,385	11.0%
3	94,730	87,183	8.7%
4	107,940	102,906	4.9%
5	119,435	119,124	0.3%
6	133,215	136,296	-2.3%
7	148,367	156,950	-5.5%
8	166,303	182,799	-9.0%
9	196,358	222,951	-11.9%
10	289,251	338,838	-14.6%

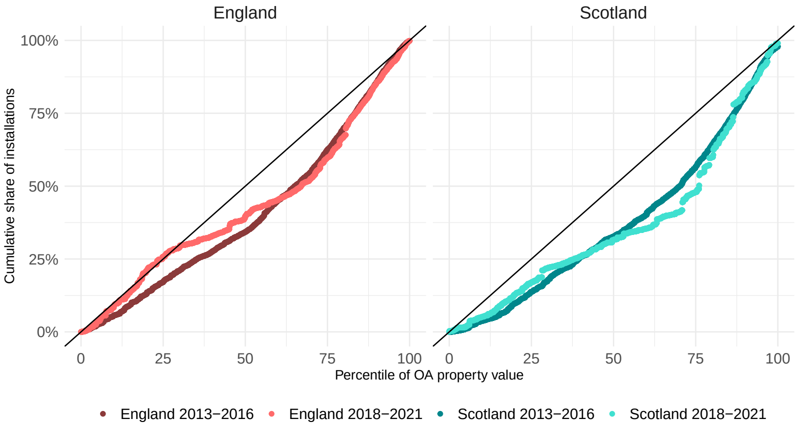
Back

Household income vs property value in Scottish LSOAs



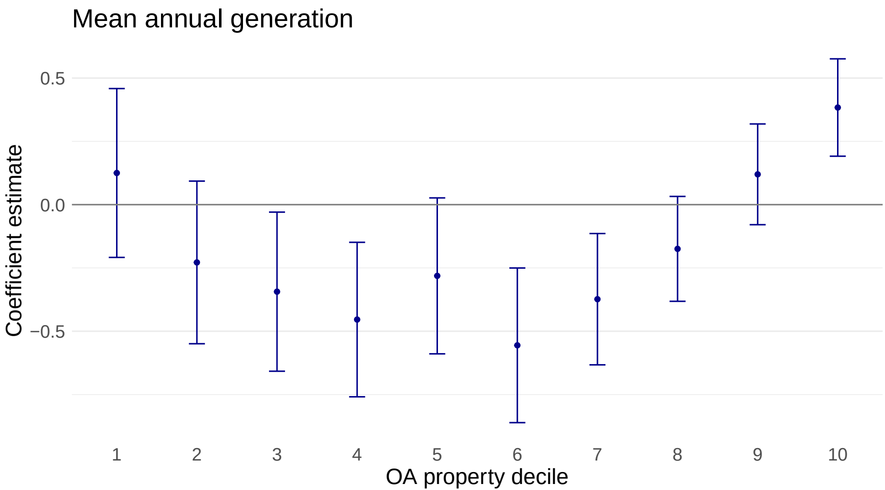
Back

Joint distributions of installations and property value



▸ Annual generation ◂ Back

Installation size shrunk in the middle deciles

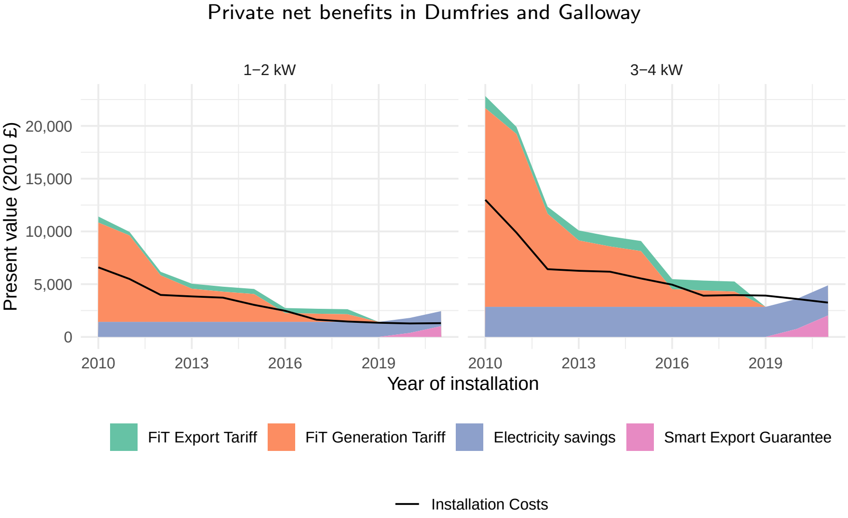


Back

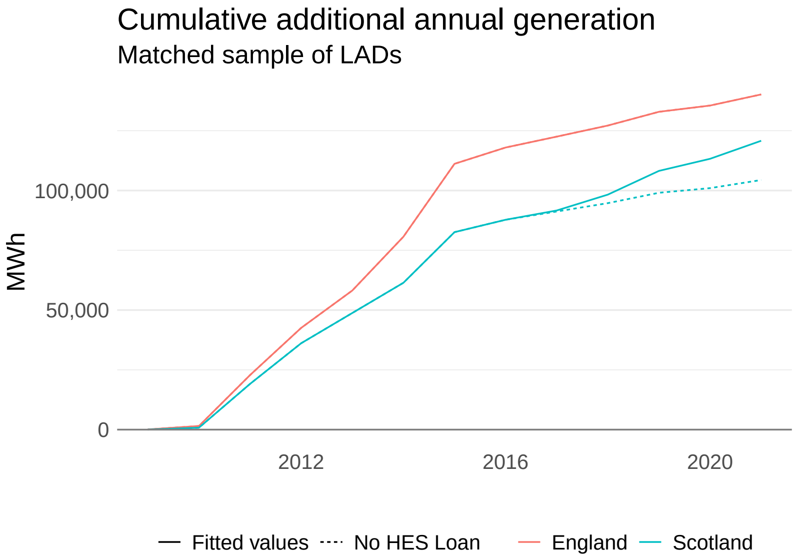
Unconditional distributions of new generation per LSOA

Back

Cost advantage of large installations declined with FiT payments



Cumulative additional solar PV generation due to the HES Loan



Calculating cost effectiveness

- Back-of-envelope approach: **Cost per tonne of CO_2 abated**
- Assume treatment effect is the same in matched and unmatched LADs
- CO_2 abatement depends on the evolution of carbon intensity of the UK electricity sector over the lifetime of the additional solar capacity
  - **Two scenarios**: (1) Net Zero and (2) No furtbher decarbonisation
- **Cost of the policy**
  - No household-level data on subsidy payments
  - Use MCS data to infer total installation costs of additional capacity

Back of the envelope calculations

CO_2 emissions avoided due to 2017-2021 HELS-funded solar PV:

$$Abatement = \sum_t \mu_t Q_t$$

- Q_t **is the additional generation** in year t due to the HELS scheme
  - Estimate new generation added due to the policy each year from 2017-2021 using the matching DiD strategy
  - Assume 25 year lifetime, starting the year after installation
- μ_t **is the carbon intensity** of the UK electricity sector in year t
  - For 2018-2022, National Grid data on actual carbon intensity
  - From 2023 onward, two scenarios for carbon intensity:
    1. Assume Net Zero by 2050: UK CCC Sixth Carbon Budget projections
    2. Assume no further decarbonisation: carbon intensity remains at 2022 levels

Cost-benefit analysis: Takeaways

Cost per tonne of CO_2 avoided was reasonable...

- Reduced solar PV potential in Scotland (relative to south of England) doesn't strongly impact cost effectiveness
- Interest-free loans helped to keep costs down relative to a grant scheme

◂ Back