Bringing Breakthrough Technologies to Market: Feed-in Tariffs for Solar Power

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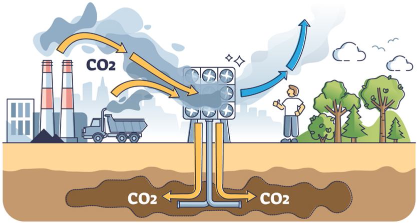
Reaching net zero by 2050 will require bringing many new technologies to market



Technologies with limited prior commercial history face challenges in coming to market

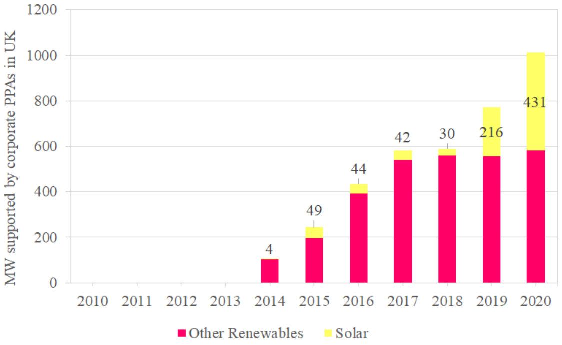
Market failure: incomplete information → limited finance and insurance for new tech. For new technologies, it takes time to develop "market infrastructure" i.e. set of ancillary services to support the technology.

Examples of complementary market infrastructure: solar output forecasting, solar insurance, specialised solar finance, solar consulting

Chicken-egg problem: Projects → demonstrate risks & returns → create more information → emergence of complementary market infrastructure → more projects

In the early years of UK solar, commercial risk hedging instruments were highly limited

Fig 1. Commercial power purchase agreements for renewables:



Solar insurance products were also scarce (Speer, Mendelsohn and Cory 2010).

Renewable exchange (marketplace for PPAs) only introduced in 2016.

Address the market failure through temporary risk-reduction for early-stage clean technologies

In 2010, feed-in tariffs introduced for solar power in the United Kingdom.

- Fixed tariff ($\bar{p}$) for 25 years instead of volatile market price (p_t)
- Eligibility: All renewable energy $\leq$ 5 MW

Feed-in tariff features:

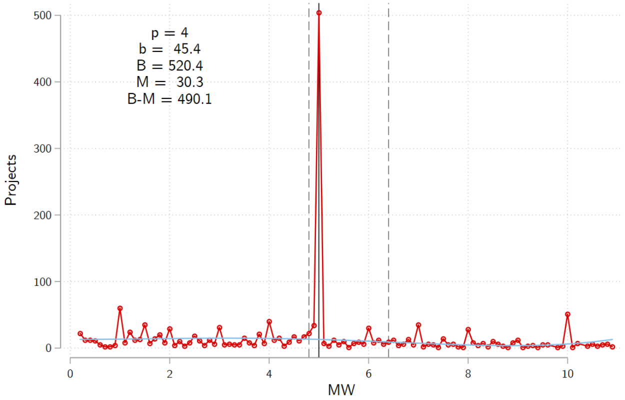
- Subsidy if $\bar{p} \geq \mathbb{E}_t(\mathbf{p})$
- Risk reduction by removing exposure to volatility in market price $\rightarrow$ lower cost of capital (risk-averse investors/CAPM)

In this paper: the second moment is not second order

Research questions: How effective is the feed-in tariff in inducing entry and investment into the solar industry? To what extent are results driven by risk reduction vs. the subsidy?

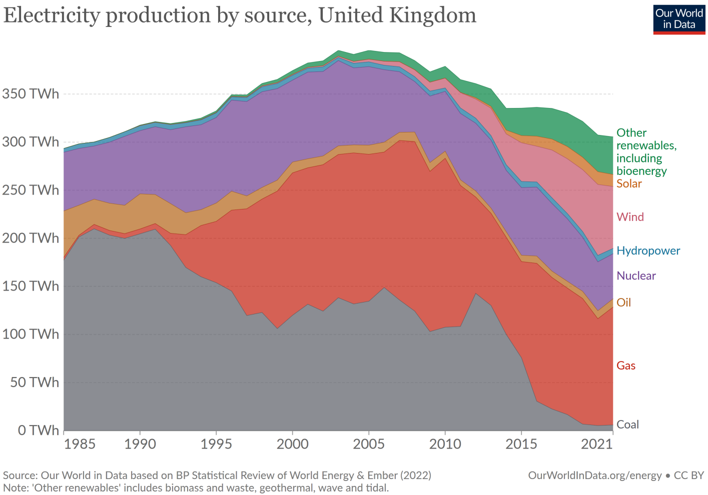
Method: Exploit bunching at eligibility threshold to measure impact of feed-in tariff on entry and investment in utility-scale solar power where entry is number of new solar projects and investment is proxied by installed capacity . Use presence of variable subsidy to back out effect of risk reduction.

In this paper: at least one-fifth of all solar is due to the policy

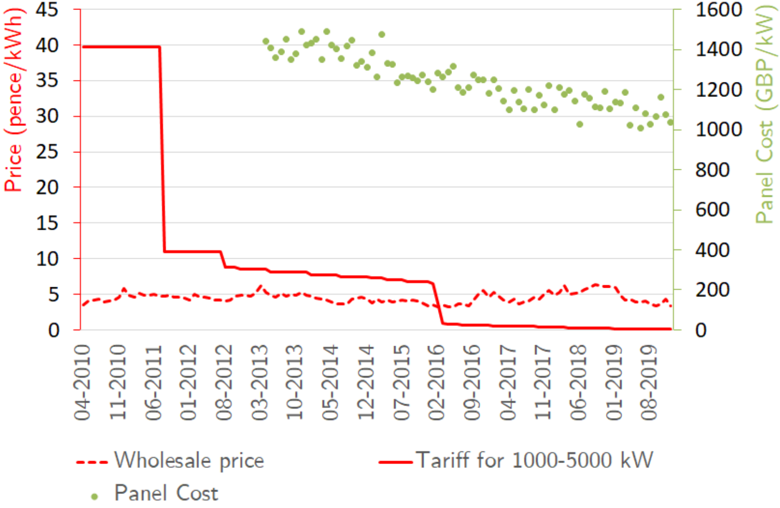


- FiT: + 2.3 GW solar ≈ 20% of all solar today (lower bound)
- New entry rather than strategic downsizing
- Net benefit for £100/tCO_2 upwards (excluding potential GE effects)

Solar is a very small part of the UK grid, therefore a price-taker



Feed-in tariffs for projects at or under 5 MW



Firms have three choices in each period

1. **Invest with FiT today ($\mathbf{V}_t^F$)**
   - Revenue: $\bar{p} q_i *$
   - Investment cost: $I_{it}(q^F, X_{it}, \alpha_t, r_t(\sigma_{\bar{p}}))$ where $\sigma_{\bar{p}} = 0$
   - $q* \leq 5$
2. **Invest without FiT today ($\mathbf{V}_t^M$)**
   - Revenue: $p_t q_i$
   - Investment cost: $I_{it}(q^I, X_{it}, \alpha_t, r_t(\sigma_p))$ where $\sigma_p > 0$
3. **Wait ($\mathbf{V}_t^W$)**
   - max $\mathbb{E}_t(V_{t+1}^W, V_{t+1}^F, V_{t+1}^M)$

- p_t is market price, $\bar{p}$ is FiT (subsidy effect)
- r_t is interest rate and σ is price volatility, with $r'(\sigma) > 0$ (volatility effect)
- α_t is cost of solar panel, I_{it} are investment costs, X_{it} is generator specific cost shocks
- q is installed capacity

Model Predictions

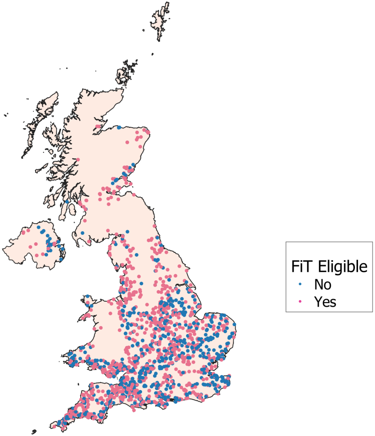
Incentive to enter with FiT $\uparrow$ in $\bar{p} - p_t$ and σ_p

- **Bunching** behaviour:
  - Strategic downsizing: $\bar{q} + \Delta \rightarrow \bar{q}$ $\rightarrow$ lost capacity, lost abatement
  - New entry $\rightarrow$ new capacity, additional abatement

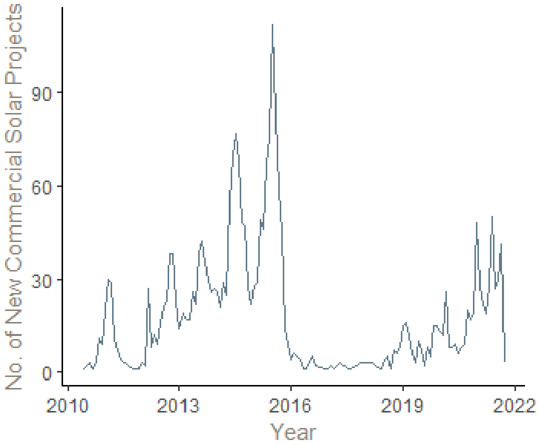
Data: 2010 - 2021

Day-time electricity prices at 30-minute frequency from Aurora Energy.

Universe of commercial solar projects (BEIS): Name of firm, installed capacity, geo-location, key dates, planning authority, etc. $\rightarrow$ 2,481 commercial solar projects

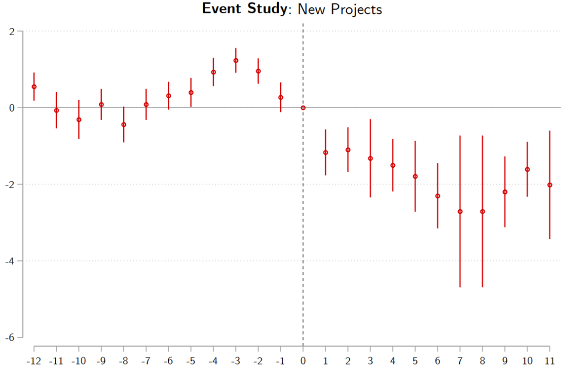


Descriptive statistics: feed-in tariff heavily diluted in 2016 and solar entry rates fell



In 2016, feed-in tariff became lower than average wholesale electricity price and pre-accreditation gaurantee removed.

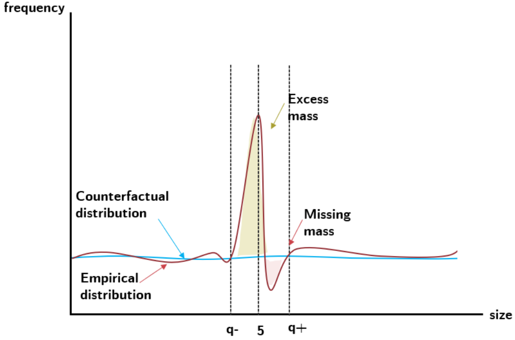
Anticipatory entry before dilution of feed-in tariff, followed by substantial decline in new projects.



But this is not the main identification strategy... let's move on.

Bunching estimation: widely used in income tax literature

Create a "no feed-in tariff" counterfactual, compare to "with feed-in tariff" data to estimate overall impact of policy on entry (Saez 2010; Chetty, Friedman, Olsen, and Pistaferri 2011; Kleven 2016).



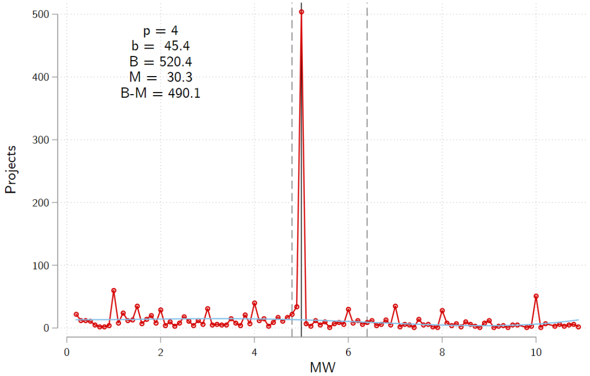
Bunching estimation II

$$c_j = \underbrace{\sum_{i=0}^{n} \gamma_i (q_j)^i}_{\text{Polynomial}} + \underbrace{\sum_{r \in N} \rho_r \cdot \mathbb{1}[q_r]}_{\text{Round Numbers}} + \underbrace{\sum_{i=q-}^{q+} \psi_i \cdot \mathbb{1}[q_j = i]}_{\text{Exclusion Zone}} + \epsilon_j$$

c generators in bin j, n order of polynomial, q is size, N round numbers, $[q-, q+]$ is excluded range.

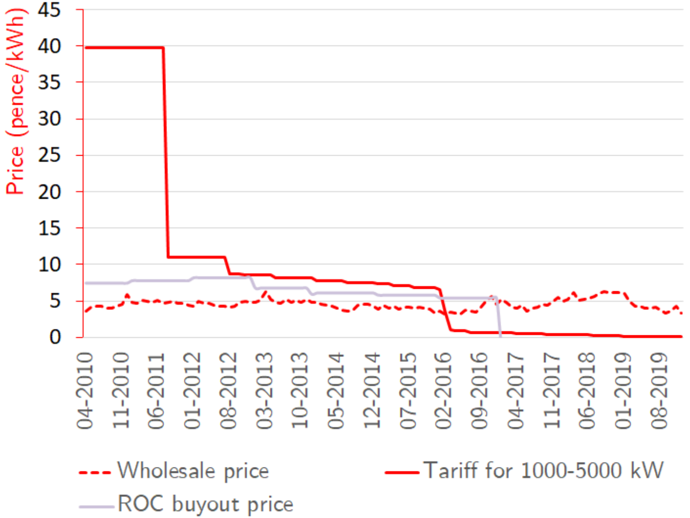
At least 40 times more solar capacity due to FiT relative to no-FiT counterfactual

Sharpest bunch observed in bunching literature - firms responding strongly to feed-in tariff incentive.

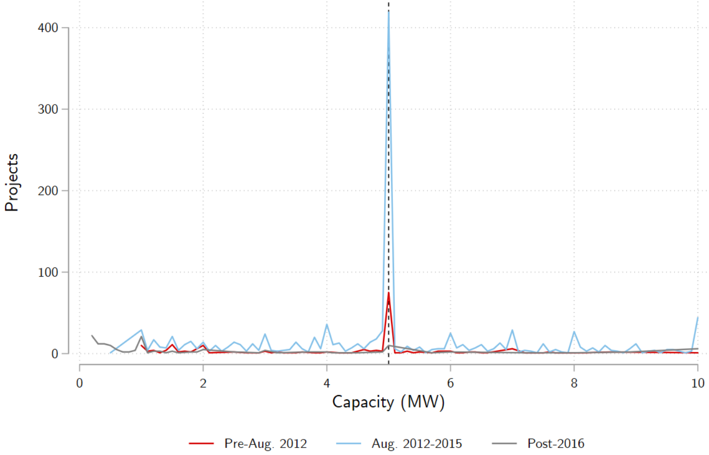


Only 6% of generators strategically downsize. Net addition equal to at least 2.3 GW of solar between 2010-2015 ≈ 20% of total solar capacity.

Disentangling risk from subsidy effect: tradable renewable energy certificates for all projects regardless of size

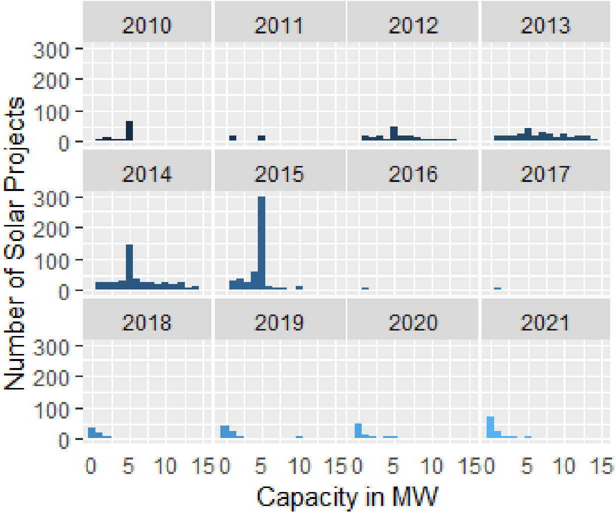


Bunching over different periods of time



When ROCs provided similar subsidy at time t, most firms still bunched.
Pre-2012, 27x. Between 2012-15, 40x.

Evolution of project sizes before and after FiT



Inefficiency of extensive margin bunching capped by the costs of going too large

Feed-in tariff resulted in **new entry** being concentrated at 5 MW.

Inefficiency of extensive margin bunching capped by:

- **System costs**: in UK it is costly to integrate very large generators on a transmission and distribution network that is fixed (Aurora Energy Interview, 2022)
- **NIMBYism**: higher permitting costs, lower amenity values (Jarvis 2022)

Value for Money: Back of the Envelope Calculation

Using **lower bound** estimate of solar capacity additions, I calculate climate and air pollution benefit of the FiT against its costs (i.e. subsidy during observed years $\bar{p} > p_t$).

Social cost of carbon worth £100/tCO2 to make the FiT a "net benefit", in narrowly defined environmental terms.

Estimate **ignores** the "market creation" benefits of the FiT such as:

1. learning-by-doing externalities
2. innovation spillovers
3. grid stability through diversification of generation sources.

Conclusion

1. + 2.3 GW of solar between 2010-2015 $\approx$ 20% of total solar capacity today, net benefit for SCC worth £100 per $tCO2$
2. FiT minimally supported inframarginal firms; effect driven by new entry at 5 MW
3. When tradable clean energy certificates provided similar subsidies at point of entry (and in expectation), firms still selected around FiT due to volatility-reduction over 25 years
4. Can abstract away from general equilibrium effects of dampening price volatility given solar is very small share of market (early-stage tech). We do not want to do risk reduction for mature tech with high market shares!