Bringing Breakthrough Technologies to Market: Evidence from Renewable Energy Feed-in-Tariffs

Sugandha Srivastav

DPhil, Postdoc - University of Oxford
Smith School of Enterprise and the Environment

sugandha.srivastav@ouce.ox.ac.uk

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Research Question

How effective are commercial feed-in-tariffs for the diffusion of early-stage clean energy technologies?

Does risk-reduction help create markets for early-stage technologies e.g. by filling a financing gap?

UK has target to decarbonize power sector by 2035.

Motivation

Challenges in the early days of commercial solar:

- Positive externalities
- Credit market imperfections
- Uncertainty and incomplete information

Project $\rightarrow$ demonstrate risks & returns $\rightarrow$ finance & insurance $\rightarrow$ more projects

Challenges in the early days of solar: commercially unproven - uncertain revenue stream

PROJECT RESULT / CASE STUDY

Investing in Solar Energy in Asia

As part of ADB's ongoing mission to promote solar investment across the region, experts and investors have gathered in Jodhpur, Rajasthan for the 4th Asia Solar Energy Forum to explore the latest trends and issues.

ADB

April 2012

What has been holding solar back in Asia?

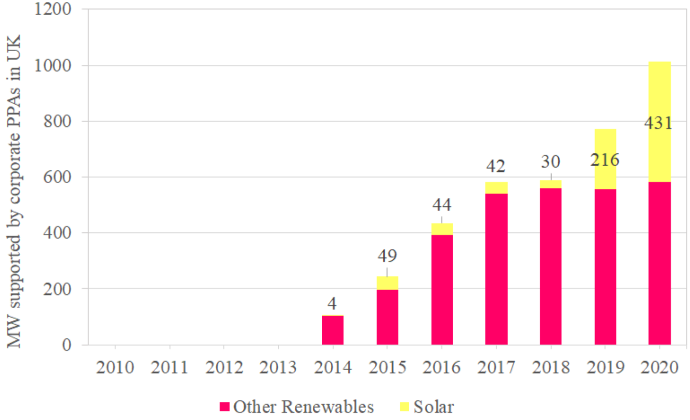
Solar is expensive and it requires long-term work to make it succeed in a systematic way. A lot of preparation is required before you can commission the first project and then say this is a worthwhile venture.

Solar Battle Heats Up

TOM JOHNSON, ENERGY/ENVIRONMENT WRITER | AUGUST 31, 2010 | ENERGY & ENVIRONMENT

New Jersey has set aggressive goals for its solar industry. The question now is can it afford to meet them

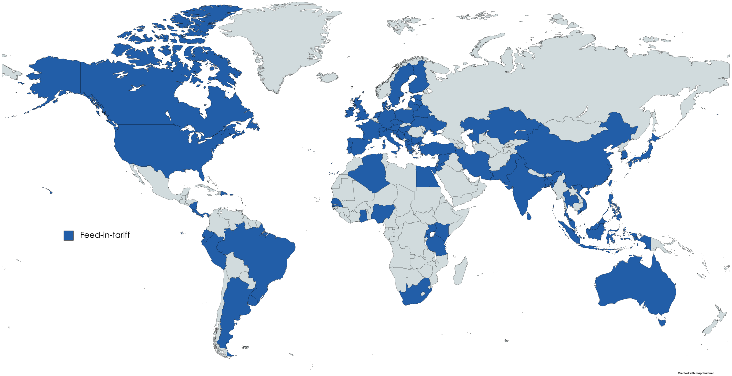
Private finance very limited



Hardly any insurance products for solar projects (Speer, Mendelsohn and Cory 2010).

Feed-in-tariffs are widely deployed but causal evidence is limited

Only cross country regressions: Jenner et al. 2013, Smith and Urpelainen 2014, Dijkgraaf et al. 2018.



Tricky to attribute effects to features of the policy.

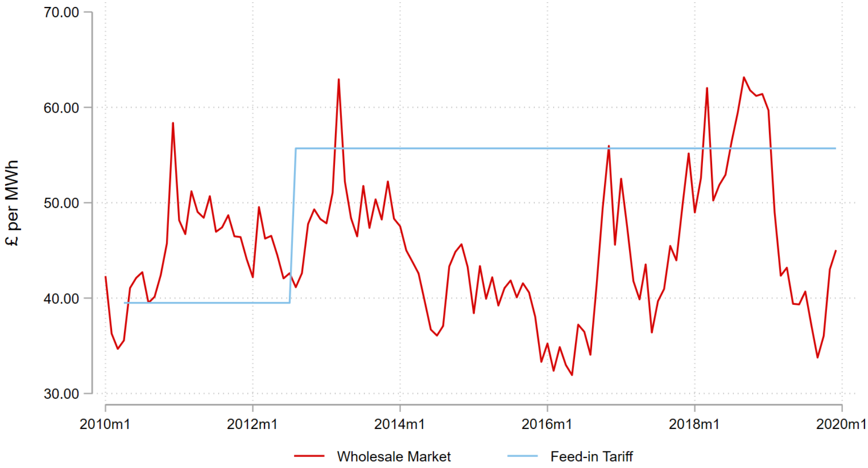
Features of Commercial Feed-in-Tariffs in the UK

- Offer a fixed tariff for electricity sold by eligible clean generators
- Duration of contract: 20 years
- Eligibility criteria: ≤ 5 MW; all renewable energy
- Funding mechanism: costs borne by electricity suppliers

Is it a **subisdy**? Depends on whether fixed tariff exceeds wholesale electricity price! Always a **risk reduction** instrument.

The UK also has a residential feed-in-tariff. I only examine the commercial FiT for utility-scale solar.

Variation in effective FiT subsidy



Methodology

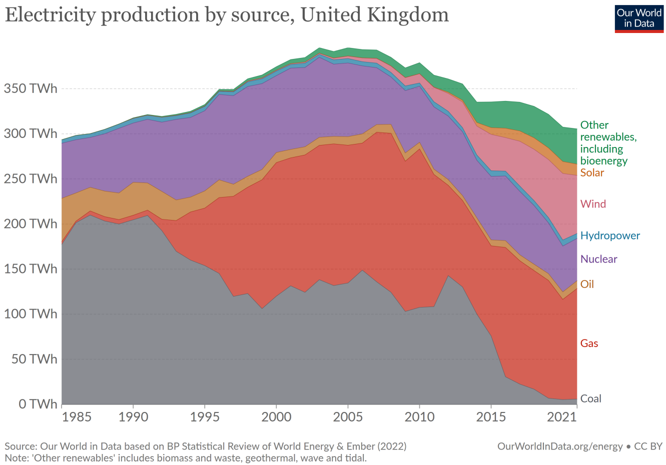
Event study, bunching estimator and Poisson regression to estimate impact of FiT on solar project entry and investment.

Identifying variation:

- presence of bunching at FiT eligibility threshold of 5 MW
- variation in the extent to which the FiT is a subsidy driven by exogenous changes in wholesale price
- an exogenous change in the accreditation process

Dataset: Renewable Energy Planning Database maintained by UK Government (BEIS): record of all commercial renewable energy projects, project characteristics, geo-location, policy support. Time period: 2010 - 2019

UK's Power Mix



First solar project comes online in 2010, same year FiT is introduced and it benefits from the policy.

Relevant Literature

Institutional: UK Decarbonisation Policy

- Martin et al. 2014, Calel 2020, Leroutier 2022

Empirical: Bunching

- Saez 2010, Chetty et al 2011, Kleven and Waseem 2013, Kleven 2016

Thematic:

- Renewable Energy Finance: Howell 2017, Gaddy et al. 2017, Cumming et al. 2017, Steffan 2018, Steffan 2020, Polzin et al. 2018
- Investment under Uncertainty: Dixit and Pindyck 1994, Kellogg 2014, Boomsma et al 2012, Chronopoulos et al. 2016, Boomsma and Linnerud 2015
- Economics of Renewable Energy: Baker et al. 2013, Hughes and Podolefsky 2015, De Groote and Verboven 2019; Gillingham and Tsvetanov 2019, Gerarden 2021, Aldy et al 2021

The Environment

1. Generators are price-takers
2. Generators decide on installed capacity, q_i
3. Electricity price is volatile $p_t \sim F(\mu_p, \sigma^p)$
4. capacity factor η is known with certainty in a given time period
5. A FiT gives fixed price $\bar{p}$ if $q_i \leq \bar{q}$
6. Firm-specific fixed cost shocks, $\chi_{it} \sim G(\mu_\chi, \sigma^\chi)$
7. Fixed costs depend on installed capacity, price volatility and cost shocks $I_{it}(\chi, q, \sigma^p)$

The Value Functions

The value functions

1. Wait
$$\max_q V_t^w = \beta\{V_{t+1}^w, V_{t+1}^F, V_{t+1}^I\} = \beta \max \hat{V}^{FiT}, \hat{V}^I$$

2. Invest with FiT
$$\max_q V_t^F = \bar{p}\eta q_i^F + \textstyle\sum_s \beta^s \bar{p}\eta q_i^F - I_{it}(\chi_{it}, q_i^F, 0); \quad q^F \leq \bar{q}$$

3. Invest without FiT
$$\max_q V_t^I = p_t \eta q_i + \eta q_i (\textstyle\sum_s \beta^s \mathbb{E} p_{t+s}) - I_{it}(\chi_{it}, q_i, \sigma^p)$$

Firm chooses max$(\mathrm{V}_t^W, V_t^F, V_t^I)$

Entering with a FiT

Define $R \equiv V_t^F - V_t^I$.

$$R \equiv \underbrace{\frac{\bar{p}q_i^F}{1-\beta} - q_i(p_t + \frac{\beta\mu_p}{1-\beta})}_{\text{revenue difference}} - \underbrace{\frac{\chi_{it}}{\eta}(f(q_i^F) - f(q_i)g(\sigma^p)}_{\text{cost difference}} \geq 0 \qquad (1)$$

$$\frac{\partial R}{\partial \mu^p} = -q_i \frac{\beta}{1-\beta} < 0$$

$$\frac{\partial R}{\partial \sigma^p} = \frac{\chi_t}{\eta} f(q_i) > 0$$

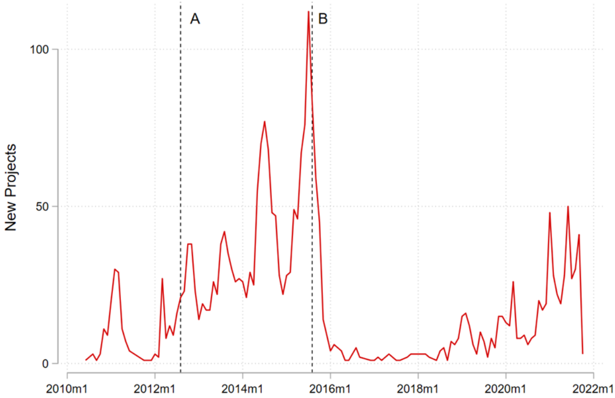
$$\frac{\partial R}{\partial \bar{p}} = \frac{q_i^F}{1-\beta} > 0$$

$$\frac{\partial R}{\partial \bar{q}} = \frac{\bar{p}}{1-\beta} - \frac{\chi_t}{\eta} f'(\bar{q})$$

Model Predictions

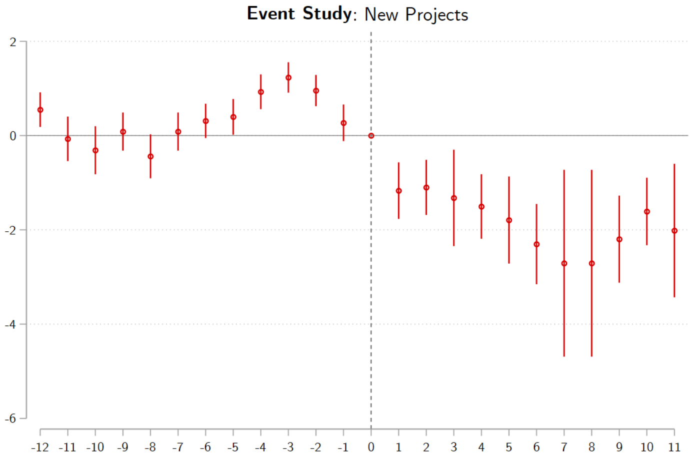
- Bunching behaviour: $\bar{q} + \Delta \rightarrow \bar{q}$
- More timely entry with a FiT if $\bar{p} \geq \mu_p$

Policy shock: pre-accreditation was removed in 2016



90% drop in new solar projects year after pre-accreditation was removed.
Solar entry rates never recover to previous levels.

Event Study



Controls for seasonality (in winter fewer solar projects). Estimates are upper bound due to plausible anticipation.

Bunching estimation: exploiting a discontinuity in incentives

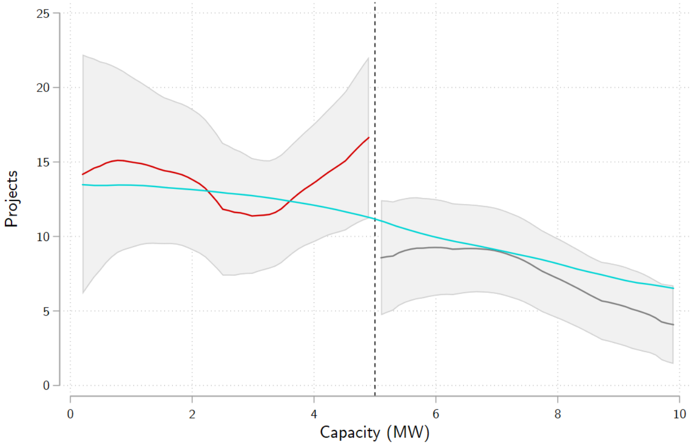
Create a no-FiT counterfactual and compare it to observed "with-FiT" data; disentangle "intensive" margin response (downsizing) from "extensive margin" (new entry).

$$c_j = \sum_{i=0}^{n} \gamma_i (q_j)^i + \sum_{r \in N} \rho_r \cdot 1[q_r] + \sum_{i=q-}^{q+} \psi_i \cdot 1[q_j = i] + v_j$$

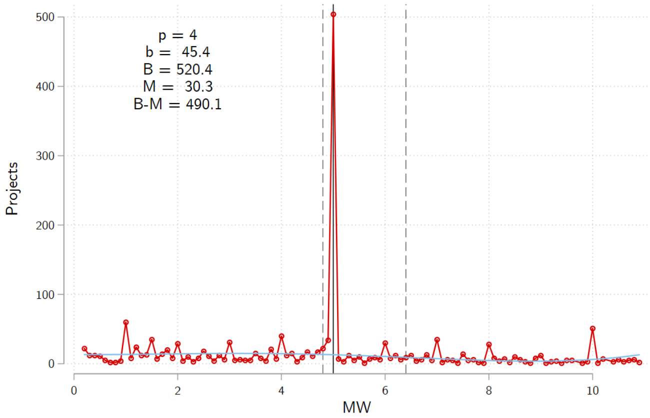
where c_j is the number of generators in bin j, q_j is the installed capacity, n is the order of the polynomial, $[q-, q+]$ is the excluded range, and N is the set of round numbers.

The estimate of the counterfactual distribution is defined as the predicted values from the regression above omitting the contribution of the dummies around the notch (third term), but keeping the contribution of round-number dummies (second term).

Determining Behavioural Response Window



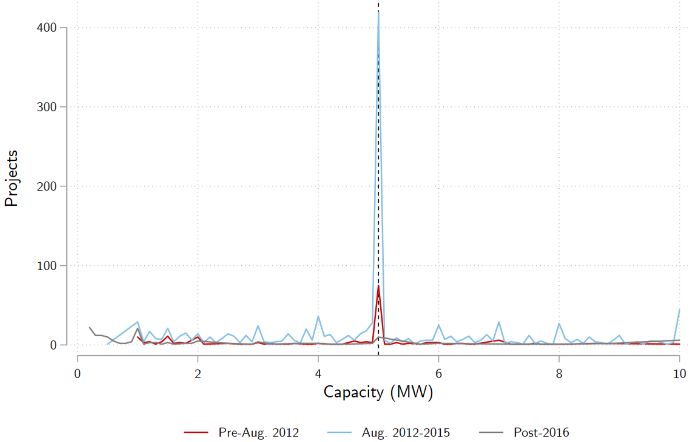
Bunching over whole sample



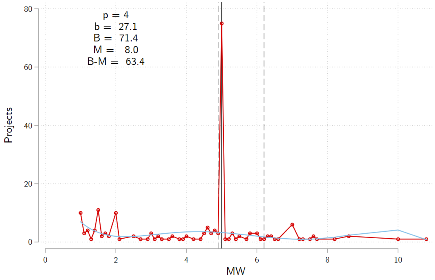
Some generators start bunching at 4.9 MW because they misunderstand the eligibility criterion.

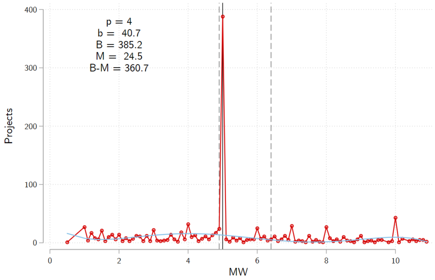
Bunching over different time periods

Even when the FiT is lower than the realised wholesale electricity price, there is significant net new capacity relative to no-FiT world.



Bunching over different time periods II





Poisson Estimation

Lagged specification, using quarterly moving averages.

	Pre-2016 Entry ≤ 5MW Poisson (I)	Pre-2016 Entry ≤ 5MW Poisson (II)
σ^p	0.00839	0.26778*
	(0.1432)	(0.15743)
Export subsidy	0.08462***	0.08808**
	(0.0269)	(0.03672)
Generation subsidy	0.03572	0.03069
	(0.0246)	(0.02771)
Constant	Yes	Yes
Year fixed effects	Yes	Yes
Seasonality	No	Yes
R^2	0.29	0.34
N	64	64

A 1% increase in the export subsidy induces a 0.84% increase in entry.
A 1% increase in price volatility induces a 1.5% increase.

Value for Money: Back of the Envelope Calculation

6% of generators strategically downsize and 94% are new entrants resulting in 2.3 GW of net capacity (one-fifth of the UK's total solar capacity)

Using this lower bound estimate of net capacity additions, we can calculate emissions displaced due to the FiT's impact on new solar energy.

Cost of policy is the net subsidy: on average £6/MWh

Net benefit at £16-26 per tonne of CO_2 (taking average carbon intensity of the grid - lower and upper bound b/w 2010-2019)

Conclusion I

Did the FiT bring breakthrough clean energy technology to market: **Yes**.

Did it result in a lot of strategic downsizing and subsidisation of inframarignal generators: **No.**

How much new solar capacity can be attributed to the FiT after accounting for strategic downsizing? **At least 2.3 GW from 2010-2015, equal to one-fifth of all solar capacity today.**

Conclusion II

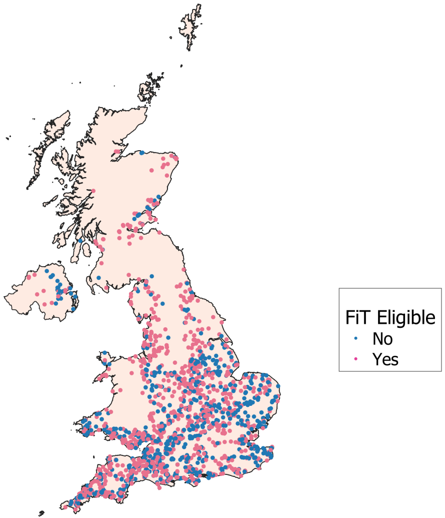
Did the removal of the FiT affect entry? **Yes. Substantially.**

Did the FiT incentivise too much solar investment? **Depends. FiT available to all renewable energy. Government target to achieve 100% low-carbon power by 2035.**

What is the optimal deployment of the FiT? **Not modelled in this paper. For higher marketshares we cannot abstract away from general equilibrium effects of dampening price volatility anymore. E.g. This can disincentivise investment in energy storage; affect system balancing, etc.**

The End

Geographic Distribution of Solar Projects



Tests

Cheating? Only 3% of projects in my sample are suspiciously close to each other.