Optimal Pricing, Subsidies and Solar Panels

A two-sided market approach

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36th USAEE conference

Washington DC, September 24th 2018

Overview

Motivation

- Distributed Generation (DG) has become a popular option for many households
  - Solar PV (rooftop panels) is the top choice
- Emergence of new kind of agents: “producer-consumers” (prosumers)
- Why such an increase of popularity of DG (solar)?
  - Decrease in cost of solar panels –see IRENA (2017)
  - Subsidies are also key (abundant literature)

Motivation

- The emergence of solar panels has some positive effects
- But there is also an indirect negative impact on consumers:

The Cost Recovery problem

- *Customers with solar PV reduce their energy consumption and then reduce the contribution they make to the network costs*
- *The network costs that are under-recovered from customers with solar PV have to be paid by all other customers*

Australia's Energy Networks Association (2014)

- This problem is exacerbated w/ subsidies to solar panels

Research question and contributions

- Some papers already pointed out these distortions...

  ...but there is no formal model showing them

- We fill this gap by providing a model in which agents endogenously choose their "role" in the market

- For different policies we study:
  - Incentives for agents to become prosumers
  - Redistributional impact on all other consumers

- We model the electricity market as a two-sided one

Main features of two-sided markets

a) Two groups of end-users

b) Platform enables interaction between the groups of end-users

c) The groups of end-users provide each other network benefits

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Example: videogames

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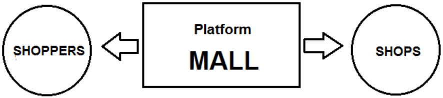
Example: shopping malls



Electricity Markets

Electricity markets can be seen as a two-sided market

- Weiller and Pollitt (2013) already suggested this idea

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c) End-users provide each other network benefits

An important clarification

- We study incentives/distortions created JUST by policies
- But we abstract away from
  - Potential costs or savings derived from energy prices
  - Other energy-related costs and prices
- Assumption: residential solar PV is at grid parity

Overview

Platform & Agents

- Independent Transmission system operator (TSO)
  - Monopoly platform
  - Connects generators (G) and consumers (C)
  - Manages the T&D of electricity

- A unit-measure, continuum of agents choose to become:
  a) Generators (join side G), N_G
  b) Consumers (join side C), N_C
  c) “Both” producers and consumers of electricity, N_X
     - *Prosumers* (rooftop solar panel owners)
  d) Not to join the platform (off-grid agents)

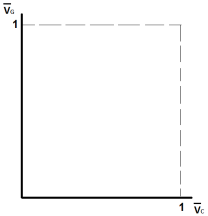
Prosumers

- *Prosumers* sell or buy depending on the sun (randomly)
  a) Sell with probability θ_i
  b) Buys with probability $(1 - \theta_i)$

- Selling/buying: a random variable $\sim$ Bernoulli distribution with parameter $\theta_i \in (0, 1)$

End users' valuations

- $\overline{v}_j$: agents' idiosyncratic surplus of joining side $j \in \{G, C\}$
  - Independent for each agent
  - Consumers are heterogeneous in both parameters
  - $\overline{\boldsymbol{v}} \equiv (\overline{v}_G, \overline{v}_C) \in \mathbb{R}^2$, drawn from a joint distribution $F(\cdot)$



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- *Prosumers*' idiosyncratic surplus = $\theta_i \overline{v}_G + (1 - \theta_i)\overline{v}_C$

Additional parameters

TSO fees

- Consumers and prosumers pay fees to the TSO
  - Fixed fee (lump-sum): F
  - Variable fee (per-unit of electricity): p
- Fees are set by the TSO to compensate for transmission, network expansion, O&M and other delivery costs

Cross-side positive network effect

- α_j for $j \in \{G, C\}$ = cross-side positive network effect

Market timing

1. TSO chooses fees $\boldsymbol{p} \equiv (p, F)$
2. Nature chooses $\bar{\boldsymbol{v}} \equiv (\bar{v}_G, \bar{v}_C)$
3. Agents observe $\boldsymbol{p}$, θ,α and $\bar{\boldsymbol{v}}$, and choose side
4. Agents interact, and payoffs are realized

Sides' demands

- Let us denote u_j the utility of joining side $j \in \{G, C, X\}$
- Side j demand is given by a combination of
  a) A Participation Constraint (PC): $u_j > 0$
  b) An Incentive Compatibility Constraint (ICC): $u_j > u_{-j}$

Overview

Demand for solar panels

- No policies that promote solar panels

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Proposition

In the absence of environmental policies, then $N_X = 0$

If there are no policies, then there are no prosumers in equilibrium

- Recall: the implicit assumption $\rightarrow$ grid parity

But grid parity has been achieved in very few places

- Consistent w/ anecdotal evidence: Alabama, Oklahoma...

TSO's regulated pricing

- TSO's profit = fees raised from agents minus costs
  - Per-transaction cost: $c > 0$
  - Fixed cost per consumer: $C > 0$

TSO costs –> infrastructure costs, losses, O&M costs, etc.

- TSO = benevolent social planner
  - Fulfill the balanced-budget condition ($\pi = 0$)
  - Set fees such that Revenue = Costs

TSO's regulated pricing

- TSO's profit with no environmetal policies:

  (recall —> no prosumers in the market)

$$\pi = (\hat{p} - c)N_G N_C + (\hat{F} - C)N_C$$

where $\hat{p}$ and $\hat{F}$ TSO's fees

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$$\pi = (\hat{p} - c)N_G N_C + (\hat{F} - C)N_C$$

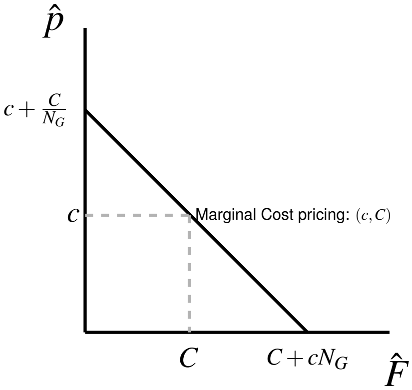
where $\hat{p}$ and $\hat{F}$ TSO's fees

TSO pricing such that $\pi = 0$:

$$\hat{p} = c + \frac{C - \hat{F}}{N_G}$$

TSO's regulated pricing

Figure: TSO's iso-profit line ($\pi = 0$)



All the $(\hat{p}, \hat{F})$ combinations in the line are equivalent

Overview

Environmental policies

1) Upfront installation-based (lump-sum) subsidies
    - California Solar Initiative (CSI)
    - Australian Solar Rebate
    - Greece (National Development Law 3908/2011)

Environmental policies: lump-sum subsidy

- Prosumer utility under upfront lump-sum subsidy
  - $u_X^u \equiv \theta_i[\overline{v}_G + \alpha_G N_C + \alpha_G(1-\theta)N_X] + (1-\theta_i)[\overline{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X] - F + \boldsymbol{S}$

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Proposition

If $S > \theta_i F \Rightarrow N_X > 0$

If subsidy is sufficiently large then there are prosumers in equilibrium

Lump-sum subsidy: TSO's regulated pricing

- TSO's profit with a lump-sum subsidy $S > \theta F$:

(recall —> now there are prosumers in the market)

$$\pi^u = (\hat{p}^u - c)\,(N_G + \theta N_X)\,[N_C + (1-\theta)N_X] \\ +(\hat{F}^u - C)N_C + (\hat{F}^u - \mathbf{S} - C)N_X$$

where $\hat{p}^u$ and $\hat{F}^u$ TSO's fees

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$$+(\hat{F}^u - C)N_C + (\hat{F}^u - \mathbf{S} - C)N_X$$

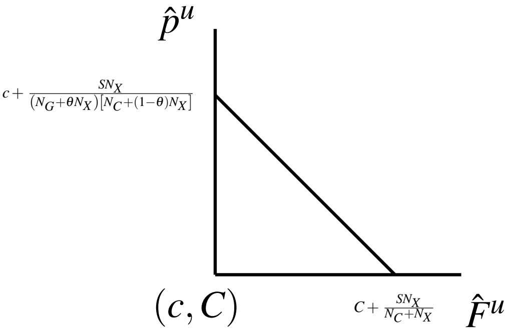
where $\hat{p}^u$ and $\hat{F}^u$ TSO's fees

TSO pricing such that $\pi = 0$:

$$\hat{p}^u = c + \frac{(C - \hat{F}^u)(N_C + N_X) + SN_X}{(N_G + \theta N_X)[N_C + (1-\theta)N_X]}$$

Lump-sum subsidy: TSO's regulated pricing

Figure: TSO's iso-profit line ($\pi = 0$) with lump-sum subsidy



- *Fees to consumers are greater in comparison to the no policy case*
- *All $(\hat{p}^u, \hat{F}^u)$ combinations in the line are not equivalent anymore*

Environmental policies

2) Production-based subsidies

- Feed-in-tariffs (FIT) –> solar panel owners sell electricity to the grid with a premium over the retail price
- Germany

Environmental policies: production-based subsidy

- Prosumer utility under production-based subsidy
  - $u_X^p \equiv \theta_i[\overline{v}_G + (\alpha_G + \mathbf{s})N_C + (\alpha_G + \mathbf{s})(1-\theta)N_X] + (1-\theta_i)[\overline{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X] - F$

Environmental policies: production-based subsidy

- Prosumer utility under production-based subsidy
  - $u_X^p \equiv \theta_i[\overline{v}_G + (\alpha_G + \mathbf{s})N_C + (\alpha_G + \mathbf{s})(1-\theta)N_X] + (1-\theta_i)[\overline{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X] - F$

Proposition

If $s > \frac{F}{N_C + (1-\theta)N_X} \Rightarrow N_X > 0$

If subsidy is sufficiently large then there are prosumers in equilibrium

Production-based subsidy: TSO's regulated pricing

- TSO's profit with a production-based subsidy $s > \frac{F}{N_C+(1-\theta)N_X}$:

  (recall —> now there are prosumers in the market)

$$\pi^p = (\hat{p}^p - c)N_G\left[N_C + (1-\theta)N_X\right] +$$
$$+(\hat{p}^p - s - c)\left(\theta N_X\right)\left[N_C + (1-\theta)N_X\right] + (\hat{F}^p - C)(N_C + N_X)$$

where $\hat{p}^p$ and $\hat{F}^p$ TSO's fees

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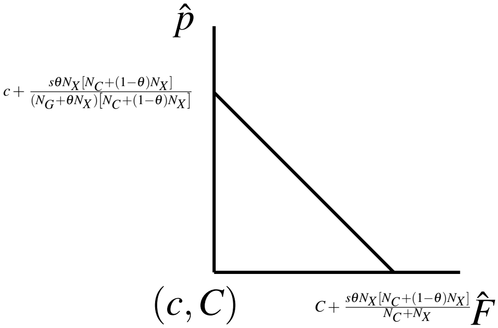
where $\hat{p}^p$ and $\hat{F}^p$ TSO's fees

TSO pricing such that $\pi = 0$:

$$\hat{p}^p = c + \frac{s\theta N_X[N_C + (1-\theta)N_X] + (C - \hat{F}^p)(N_C + N_X)}{(N_G + \theta N_X)\left[N_C + (1-\theta)N_X\right]}$$

Production-based subsidy: TSO's regulated pricing

Figure: TSO's iso-profit line with Upfront Subsidy



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- *All* $(\hat{p}^p, \hat{F}^p)$ *combinations in the line are not equivalent anymore*

Environmental policies

3) Net Mering

- Extremely popular policy in the US (in many States)
- We show that this policy provides an implicit subsidy to solar panel owners
- Work in progress...

Overview

Conclusions

- First paper that models the electricity market as two-sided
- Study agents' incentives to become a prosumers
  - Prosumers in the market ONLY if there are subsidies
- Fees to consumers (not to prosumers) are greater in comparison to the no enviromental policy case
  - Consumers pay the extra burden generated by the subsidy
  - Subsidies increase fees to those that cannot afford solar panels

Conclusions

- Wrap up the Net Metering case
- Compare the three policies (numerical simulation?)
- Model extensions

Thanks! Questions?

Your feedback is much appreciated: rbajo@unav.es