Optimal Pricing, Subsidies and Solar Panels

A two-sided market approach

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Overview

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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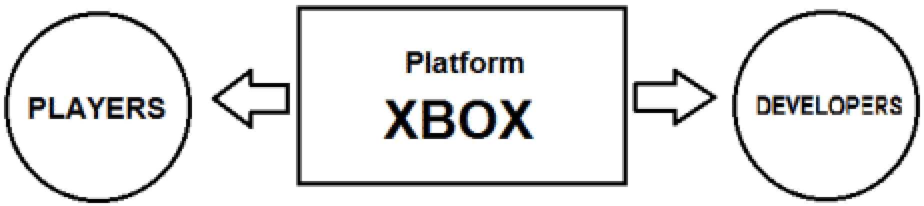
Example: videogames



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Example: shopping malls

Electricity Markets

Electricity markets can be seen as a two-sided market

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Electricity Markets as Two-sided Markets

- Additional, new feature: “on-site” (distributed) generation
  - Due to technology innovations
- A new kind of “hybrid” end-users in the platform
  - Consume or generate electricity randomly (weather)
- Prototypical example: solar panel owners (*prosumers*)
  - Generating or consuming electricity, depending on the sun

Challenges and Regulation of Distributed Generation

- Solar PV Regulation: a challenging issue
- Many countries –> policies to PROMOTE SOLAR PANELS
  - E.g. Net Metering, production-based subsidies (FiT), etc.
  - Goal: reduce generation from “pollutant” sources
- But at the same time –> how do we redistribute grid fees?
  - Challenging to agree on a “fair” solution to all grid consumers

Goals of this paper

- TSO's fees in a two-sided market in the presence of "hybrid" end-users (i.e. solar panel owners)
- **Tradeoff**: promoting "on-site" generation VS. potential "(un)fairness"/inefficiency
- Study agents' incentives to become a prosumers
- Focus on the effect of three main policies:
  - Upfront (installation-based) subsidies to prosumers
  - Production-based subsidies to prosumers
  - Net Metering

Overview of the results

- No subsidy $\Rightarrow$ no agent want to become a prosumer
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- Prosumers in the market in the presence of subsidies
  - Characterize the size and requirements of the subsidies such that prosumers are present in equilibrium
- Subsidies increase fees paid by non-solar-panel owners
  - Redistribution problems –see Borenstein and Davis (2016)

Fit in the literature

- Two-sided markets literature
  - Mixed two-sided markets by Gao (2018) IER
- Energy & Environmental literature
  - Brown et al. (2017) EJ /// Gautier et al. (2017) JRE

Overview

The Platform

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

- Generators produce/sell electricity that consumers enjoy...

  ...but they must use the platform (the grid) to trade

End-users' endogenous decisions

- 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*, who own a decentralized generation unit (rooftop solar photovoltaic panel)
  d) Not to join the platform (off-grid agents)

$N_i \in [0,1]$ $\qquad \sum_i N_i \leq 1$, for $i \in \{G, C, X\}$

Prosumers

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

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

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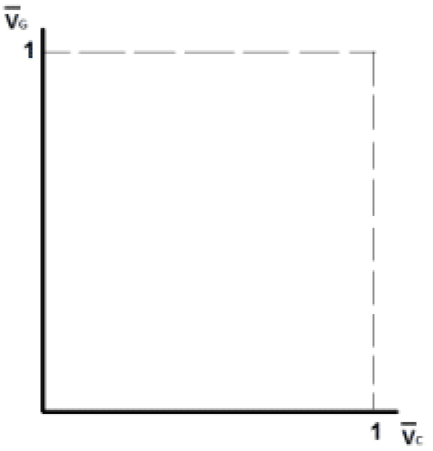
- Two alternative cases (similar results):
  - θ_j is independent for each prosumer $j \in [0, N_X]$
  - θ_j's are different but correlated across consumers

End users' valuations

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



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- Extension: additional surplus for prosumers $\bar{v}_X$
  - Preference towards solar panels (environmental preference)

Cross-side positive network effect

- A consumer is happy if an extra generator joins because
  - Increase in security of supply (reliability)
  - Increase in market competition

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- A generator is happy if an extra consumer joins because
  - Increase in the demand
- α_j for $j \in \{G, C\}$ = cross-side positive network effect

TSO's fees

- Agents must pay fees to the TSO
  - Fixed fee (lump-sum): F_j for $j \in \{G, C\}$
  - Variable fee (per-unit of electricity exchanged): p
- Fees are set by the TSO to compensate for transmission, network expansion, O&M and other delivery costs

Market timing

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

Agents' utilities

- Joining side G:

$$u_G \equiv \bar{v}_G + (\alpha_G - p)N_C + (\alpha_G - p)(1-\theta)N_X - F_G$$

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- Joining side C:

$$u_C \equiv \bar{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X - F_C$$

- Joining both sides X:

$$u_X \equiv \bar{v}_X + \theta[\bar{v}_G + (\alpha_G - p)N_C + (\alpha_G - p)(1-\theta)N_X] +$$

$$+ (1-\theta)(\bar{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X) - F_G - F_C$$

Sides' demands

Side j demand is given by a combination of

a) A Participation Constraint (PC): $u_j > 0$
b) An Incentive Compatibility Constraint (ICC): $u_j > u_{-j}$

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- No policies that promote solar panels
  - Prosumers pay both access fees (F_G and F_C)

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Proposition

In the absence of environmental policies, if $\bar{v}_X = 0$, then $D_X(\boldsymbol{u}) = 0$

If agents have no "environmental preferences" ($\bar{v}_X = 0$), and there are no policies, then there are no prosumers in equilibrium

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- If $\bar{v}_X > 0$ (sufficiently high), we have $D_X(\boldsymbol{u}) > 0$

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, system services and losses, depreciation of capital, 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 (and $\overline{v}_X = 0$):

  (recall —> no prosumers in the market)

$$\pi = (2\hat{p} - c)N_G N_C + (\hat{F}_G - C)N_G + (\hat{F}_C - C)N_C$$

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

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TSO pricing:

$$\hat{p} = \frac{c}{2}$$

$$\hat{F}_j = C, \text{ for } j \in \{G, C\}$$

Sides Demands under TSO's regulated pricing

- Given TSO pricing $\hat{p} = \frac{c}{2}$ and $\hat{F}_j = C$, demands are:

$$D_G(\boldsymbol{u}) = pr\left(\bar{v}_G + (\alpha_G - c/2)N_C \geq \max\{\bar{v}_C + (\alpha_C - c/2)N_G, C\}\right)$$

$$D_C(\boldsymbol{u}) = pr(\bar{v}_C + (\alpha_C - c/2)N_G \geq \max\{\bar{v}_G + (\alpha_G - c/2)N_C, C\})$$

$$D_X(\boldsymbol{u}) = 0$$

Overview

Environmental policies

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

2) Production-based subsidies
    - Feed-in-tariffs (FIT) —> solar panel owners sell electricity to the grid with a premium over the retail price (e.g. Germany)

3) Net Mering
    - Extremely popular policy in the US (in many States)

Upfront installation-based (lump-sum) subsidy

Environmental policies: lump-sum subsidy

- Prosumer surplus under upfront lump-sum subsidy
  - $u_X^u \equiv \bar{v}_X + \theta[\bar{v}_G + (\alpha_G - p)N_C + (\alpha_G - p)(1-\theta)N_X] + (1-\theta)(\bar{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X) - F_G - F_C + \boldsymbol{S}$

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Proposition

If $S > (1-\theta)F_G + \theta F_C \Rightarrow D_X^u(\boldsymbol{u}) > 0$ *(even if* $\bar{v}_X = 0$*)*

If subsidy is sufficiently large, even if agents have no “environmental preferences” ($\bar{v}_X = 0$), then there are prosumers in equilibrium

Lump-sum subsidy: TSO's regulated pricing

- TSO's profit with a lump-sum subsidy $S > (1-\theta)F_G + \theta F_C$:

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

$$\pi^u = (2\hat{p}^u - c)\,(N_G + \theta N_X)\,[N_C + (1-\theta)N_X] +$$
$$+(\hat{F}^u_G - C)N_G + (\hat{F}^u_C - C)N_C + (\hat{F}^u_G + \hat{F}^u_C - S - 2C)N_X$$

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

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$$\hat{F}^u_j = C + \frac{SN_X}{N_C + N_G + 2N_X}, \text{ for } j \in \{G, C\}$$

Lump-sum subsidy: TSO's regulated pricing

We can show that:

$$\hat{F}_j^u = C + \frac{SN_X}{N_C + N_G + 2N_X} > C = \hat{F}_j$$

- Fees to generators and consumers (not to prosumers) are greater in comparison to the no enviromental policy case
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Production-based subsidy

Environmental policies: production-based subsidy

- Prosumer surplus under production-based subsidy
  - $u_X^p \equiv \bar{v}_X + \theta[\bar{v}_G + (\alpha_G - p + \mathbf{s})N_C + (\alpha_G - p + \mathbf{s})(1-\theta)N_X] + (1-\theta)(\bar{v}_C + (\alpha_C - p)N_G + (\alpha_C - p)\theta N_X) - F_G - F_C$

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Proposition

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Production-based subsidy: TSO's regulated pricing

- TSO's profit w/ production-based subsidy $s > \frac{(1-\theta)F_G+\theta F_C}{\theta[N_C+(1-\theta)N_X]}$:

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Net Metering

Environmental policies: Net Metering

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- Net Metering is like a “clock”
- Prosumer surplus under Net Metering
  - $u_X^{nm} \equiv \bar{v}_X + \theta[\bar{v}_G + \alpha_G(N_C + (1-\theta)N_X)] + (1-\theta)[\bar{v}_C + \alpha_C(N_G + \theta N_X)] - \boldsymbol{p}|\boldsymbol{\theta} - (\mathbf{1}-\boldsymbol{\theta})|\boldsymbol{A} - F_G - F_C,$

    where
    $A \equiv \mathbb{1}_{\theta-(1-\theta)>0} * (N_C + (1-\theta)N_X) + \mathbb{1}_{\theta-(1-\theta)<0} * (N_G + \theta N_X)$
- If $\theta \approx 0.5 \Rightarrow$ prosumers pay no variable fee

Environmental policies: Net Metering

- We can show that NM implies a subsidy for prosumers:

Proposition

$u_X^{nm} > u_X$ *for all* $\theta \in (0,1)$

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Proposition

$u_X^{nm} > u_X$ *for all* $\theta \in (0,1)$

- Are there prosumers in equilibrium (with $\bar{v}_X = 0$)?

Proposition

If $p\{\theta[N_C + (1-\theta)N_X] + (1-\theta)(N_G + \theta N_X) - |\theta - (1-\theta)|A\} > (1-\theta)F_G + \theta F_C \Rightarrow D_X^{nm}(\boldsymbol{u}) > 0$ *(even if* $\bar{v}_X = 0$*)*

If $\theta \approx 0.5$ and/or p is high, even if agents have no "environmental preferences" ($\bar{v}_X = 0$), then there are prosumers in equilibrium

Net Metering: TSO's regulated pricing

- TSO's profit with Net Metering:

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

$$\pi^{nm} = (2\hat{p}^{nm} - c)N_G N_C +$$
$$+(\hat{p}^{nm} + \hat{p}^{nm}|\theta - (1-\theta)| - c)[N_G(1-\theta)N_X + \theta N_X N_C] +$$
$$+(2\hat{p}^{nm}|\theta - (1-\theta)| - c)(\theta N_X(1-\theta)N_X) +$$
$$+(F_G - C)N_G + (F_C - C)N_C + (F_G + F_C - 2C)N_X$$

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

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$$\hat{F}^{nm} = C + \frac{c(1-|\theta-(1-\theta)|)\left[\frac{1}{2}[(1-\theta)N_G+\theta N_C]+\theta(1-\theta)N_X\right]N_X}{N_G+N_C+2N_X}$$, for $j \in \{G, C\}$

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- Generators and consumers pay the extra burden generated by the subsidy

Equivalence between the three policies?

Equivalence between the three policies?

- Lump-sum subsidy (S) and production-based subsidy (s) equivalent if

$$S = s\theta[N_C + (1-\theta)N_X]$$

  - Same sides demands and same TSO's profit

- Net Metering is "uncontrollable"
  - Once implemented the number of solar panels depends on market conditions

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
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Conclusions

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- Work in progress...

Thanks! Questions?

Your feedback is much appreciated: rbajo@unav.es