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What makes grids really smart?

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(Work in progress)

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Motivation: how the environment changed

- With the liberalization process, a number of new agents entered (and still enter) the market

- In the same years, high incentives for RES installation affect the generation mix, making system managing more challanging

  - People started discussing about a **Smart Grid (SG)**, that will help in managing the system, solving new challanges and integrating all the agents in the market, that **collaborate** to grid management

  - **Efficiency** and **flexibility** are major advantages of the new grid setup

  - Many **technologies** involved in the process (smart meters and demand response, batteries, smart inverters, remote control tools…)

Motivation: market heterogeneity

Despite the presence of intense regulation, **competition** in electricity markets is still worth to be analyzed

Looking at the Italian market:

- about **140** DSOs (according to AEEG and Terna data), that differs in different aspects (dimensions, grid extension, integration, groups…)
- more than **48.000** producers (Chamber of Commerce databases), of which:
  - **28.000** registered energy production as first activity;
  - **20.000** registered energy production as secondary activity.
  - Producers’ presence and concentration on «local» markets is heterogeneous, and their characteristics varies too (size, sources, purposes, etc.)

  - Literature: Traditional regulation theories; evidences from Joskov(2012), Lo Schiavo (2014), but also Ambrosius (2017, in progress)

Aim of the work

- Given the heterogeneity of Italian market, we want to analize the relationships between market competition and SG investments at a local level
    - The intuition is that SG could have an impact on operators willigness to enter the market, expecially on the production side
- **What we want to do**

We want to analyze the market with a medium term perspective, looking at agents interactions

- In this first analysis, we will focus on DSO as SG investor, and on energy supply firms (producers or retailers)

- **What we don't**

Our work will not take into consideration short term dynamics (e.g. balancing issues)

A definition of grid *Smartness*

EU definition: “Energy networks that can automatically **monitor** energy **flows** and **adjust** to **changes** in energy supply and demand **accordingly**”

=>Technologies used and main targets vary depending on the context; researchers, practitioners, politicians: the use of the word «smart» has a lot of meanings and applications

In our work,

⇒the less the market is uncertain, the more the grid is *smart*

- ⇒The definition is not connected to a specific technology, not to a business model
- ⇒*Smartness* is signalled by market varaibles
- ⇒ (intuition: variance in market prices – wrt the short term, because in the short term we observe the kind of variability we need to identify *smartness*)

The model

- A DSO, which is the grid manager and the SG investor
- A number of firm selling energy

The model

- Inverse electricity demand function:

$$p(\tilde{Q}) = a - b\tilde{Q}$$

$$\tilde{Q} = Q + \theta\epsilon$$

Demand is equal to electricity produced, plus an exogenous supply (or demand) *shock ε*, whose effect has weight θ in terms of market equilibrium.

⇒θ is an inverse measure of grid *smartness*

- Cost function is the same for each firm;
- Risk aversion is different for each firm.
- Each firm maximizes its profit:

$$\tilde{\pi}_i = p(\tilde{Q})q_i - K - \frac{c}{2}q_i^2$$

The model

- In our model, investments in smart grid can be done (and paid) by the DSO of the grid
- DSO's profit is given by a fixed (by law) remuneration, minus variable managing cost and investments

$$\tilde{\Pi} = T - d\tilde{Q} - I$$

- DSO's has a very low risk aversion, that corresponds to the minimum level of producers' risk aversion
- Re-writing the DSO's profit in terms of a certain-equivalent of a CARA function, we get:

$$E(u(\tilde{\Pi}_i)) = T - dQ - I - \frac{r}{2}d^2\theta^2$$

The model

- DSO and firm play a Stakelberg game

⇒DSO set the level of smart grid investment

⇒firms decide whether to enter the market or not

  ⇒Once in the market, firms compete *à la Cournot*

Equilibria are determined by backward induction

Proposition (1/2)

The number of firms entering the downstream market decreases in the weight of random shocks.

To prove this, it is sufficient to prove that the equilibrium utility of any firm, including the marginal one, decreases as the weight of the random shock increases

$$\frac{dq_i^*}{d\theta^2} = -\frac{ib^2 r q_i}{2b + c + irb^2\theta^2}$$

Then, we look at the objective function of a generic firm i:

$$\frac{dE(u(\tilde{\pi}_i^*))}{d\theta^2} = q_i^* \left[\frac{ib^2 r}{2} q_i^* + (2b + c + irb^2\theta^2)\frac{dq_i^*}{dr}\right]$$

$$\frac{dE(u(\tilde{\pi}_i^*))}{d\theta^2} = q_i^* \left[\frac{ib^2 r}{2} q_i^* - ib^2 r q_i^*\right]$$

$$\frac{dE(u(\tilde{\pi}_i^*))}{d\theta^2} = -q_i^{*2}\frac{ib^2 r}{2} < 0$$

The equilibrium utility of all firms and then also of the marginal one decreases with the weight of the random shock

Proposition (2/2)

DSO invests **before** firms decide their strategies. Solving by backward induction, we first derive the optimal qi decided by the generic firm and the optimal number of firms entering the downstream market, n, conditional on smart grid investment, I.

The higher the investment in Smart Grid chosen by the DSO, the higher the level of the equilibrium supply of electricity, and the higher the number of firms entering the downstream market.

Proof:

As we know, the higher the variance of exogenous shocks, the lower the level of the equilibrium supply of electricity, and the lower the number of firms entering the downstream market.

Then, knowing that the variance of exogenous shocks decreases in the level of investment in smart grid, it is straightforward to conclude that Q and the number of firms in the market increase in I.

Concluding

- Liberalization process let new agents enter the market, expecially on the supply side
- The entrance of small, dispersed, often unpredictable production plants created new challanges for the system
- We need to invest in a *Smart Grid* to manage all system actors and guarantee system security and reliability
- While considering which technologies shall be used and which investment shall be put in place, we must analyse the effects that the SG could have on market competition, carefully analyzing agents reactions to environmental changes

⇒Grid *smartness* influence firms entrance; firms expected reactions have an effects on DSOs optimal investment decisions

⇒Regulation must consider agents reactions to incentivate correctly SG investments

Next Steps

- Model improvements
- Empirical simulations

Thank you for your attention!

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