Demand Participation in Balancing Markets

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Content

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- Research Questions
- Models and Results
- Conclusions

Electricity Balancing

- Stakeholders
  - Balancing Responsible Parties (BRPs)
  - Transmission System Operators (TSOs)
  - Balancing Service Providers (BSPs)
- Procurement and Activation of Balancing Services
  - Balancing Capacity
  - Balancing Energy
- Imbalance Settlement
  - Single Imbalance pricing scheme
  - Balancing Energy pricing scheme

Institutional Framework

- European Legislation (2009/72/EC)
  - Procurement of Balancing Services has to occur through transparent, market-based mechanisms
- ACER's Framework Guidelines (2012)
  - Network Code on Electricity Balancing should allow and facilitate wider participation, specifically from load serving entities
  - Providers of demand-side resources may face important entry barriers and difficulties to compete on a level playing field with other resources
- Italian Regulatory Authority (AEEGSI, June 2016)
  - Consultation on the opening of the Italian Ancillary Service Market (MSD) to demand resources, intermittent renewable energy sources and distributed generation (DCO 298/2016/R/EEL)

Research Questions

- Individual perspective: what are the incentives for an energy market participant to become a BSPs?

- System perspective: what are the efficiency implications of procuring Balancing Services from providers who are not large, conventional generators?

Model — Main features

- Market Design
  - Day Ahead (DA) Market — day before delivery, $d-1$;
  - Balancing Market (BM) — day of delivery, d
- Participants
  - DA: a large number of units i ($i = 1, ...n$) of two types, consumption units and production units
  - BM: a TSO and a large number of units i ($i = 1, ...n$) of two types, BSP^{cu} and BSP^{pu}

Model — Assumptions

- A1: Consumption units
  - Consumer's inverse demand function: $p_i\left(q_{id}^{cu}, \epsilon_i^{cu}\right)$
  - $\partial p / \partial q_{id}^{cu} < 0$,
  - $q_{id}^{cu} \geq 0$ actual electricity consumption on day d
  - $|\epsilon_i^{cu}| > 0$ price elasticity of electricity demand
- A2: Production units
  - Multiplant production units: several thermal technologies and one renewable technology (wind)
  - Actual output of thermal plants, $q_{id}^{t} \geq 0$, is perfectly controllable and comes at a marginal production cost of $MC_i(q_{id}^{t}, \epsilon_i^{pu}) > 0$, with $\partial MC_i / \partial q_{id}^{t} > 0$, where $\epsilon_i^{pu} > 0$ is the price elasticity of thermal electricity supply
  - Actual output of wind turbines is unpredictable, $q_{id}^{w}(s) \geq 0$, depending on the state of the wind s, and comes at a marginal production cost of zero

- A3: The only source of uncertainty in the system is the output of the wind turbines (arbitrary probability distribution $F(s)$ and arbitrary correlation in wind turbines outputs)
- A4: Thermal power plants produce electricity in every state of the system
- A5: There is always enough thermal generation to balance the system (BSP^{pu} use thermal plants only)

DA market

- Consumption and production units sign binding contracts, i.e. a price-quantity combination (Q^*_{d-1}, p^*_{d-1}), where $Q^*_{d-1} = Q^t_{d-1} + Q^w_{d-1}$ is the total, scheduled electricity output
- Each unit is paid or pays its scheduled volumes of energy at price p^*_{d-1}
- Each unit acts as its own BRP for the volumes scheduled on the DA

Balancing Market

- TSO procures balancing capacity in advance — after DA market clearing — and balancing energy in real time — when the state of the system is known
  - TSO is the single buyer (seller) of a necessary service
- There are two possible states, k, of the system, resulting in two types, h, of balancing services:
  - $k = neg$ system is short and $h = up$ upward balancing services are necessary for a quantity $\mu^{up}(s) \equiv Q^w_{d-1} - Q^w(s) > 0$
  - $k = pos$ system is long and $h = up$ downward balancing services are necessary for a quantity $\mu^{dw}(s) \equiv Q^w_{d-1} - Q^w(s) < 0$

BM First Best

- Theoretical (first-best) implementation
- When the state of the system is known — by a system operator with perfect information on the demand and supply curves (Crampes and Léautier, 2012)

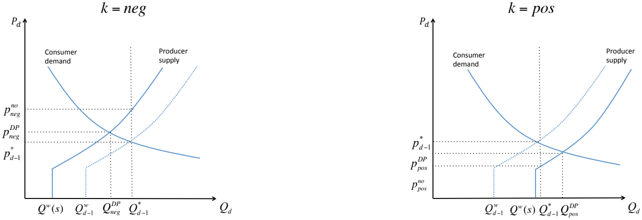
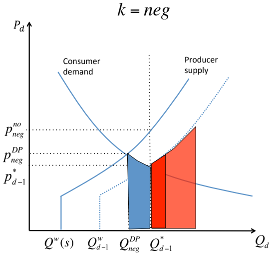


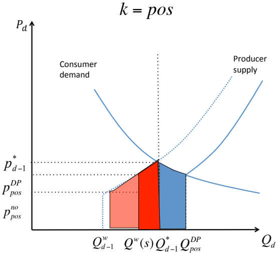
Figure 1: Model 1 — System is negative (left) positive (right)

- DP from a system perspective: foregone social welfare is lower
  - When $k = neg$, BSP^{cu} incur a lower loss in consumption utility (blue) than the additional production cost required to maintain the original consumption with BSP^{pu} (light red)



BM Theoretical Implementation

- DP from a system perspective: foregone social welfare is lower
  - When $k = pos$, BSP^{cu} value the extra output more (blue) than the additional cost savings by BSP^{pu} (light red)



BM Auction

- Auction design
  - Separate, voluntary auctions for upward ($h = up$) and downward ($h = dw$) balancing services
  - BSPs indicate a single quantity and price pair for each auction: (r^h, p^h), where prices are in Euros/MWh
  - In real time TSO activates a subset of the accepted bids, in increasing order of prices until $\mu^{up}(s)$ is met (in decreasing order of prices until $\mu^{dw}(s)$ is met)
  - TSO pays to the activated bids (receives the market price from the activated bids) a price per MWh activated (depending on the pricing rule)
  - Pricing rule: marginal pricing or pay-as-bid (Cramton and Stoft, 2007)

BM Auction

- To cap the tax burden the TSO sets a minimum bid quantity $\mu_{i,min}^h \leq r_i^h$ for each BSPs. This quantity is chosen so that:
$$\sum_{i \in N} \mu_{i,min}^h = \bar{\mu}^h + max\{\mu_{i,min}^h\}$$
where $\bar{\mu}^h$ is the worst system imbalance scenario

BM Upward Auction

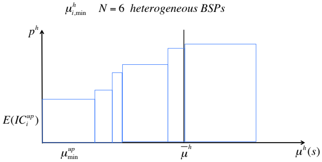


Figure 2: Minimum quantity with heterogeneous BSPs

BM Upward Auction

Bidders offer the quantity r_i^h against the price p_i^h satisfying

$$p_i^h \int_{s \in S^k} f(s) r_i^h \, ds = \int_{s \in S^k} f(s) \big[C(q_{i,d-1}^t + r_i^h) - C(q_{i,d-1}^t) \big] ds$$

$$p_i^h \int_{s \in S^k} f(s) r_i^h \, ds = \int_{s \in S^k} f(s) \big[U(q_{i,d-1}^{cu}) - U(q_{i,d-1}^{cu} - r_i^h) \big] ds$$

respectively for BSP^{pu} and BSP^{cu}, where S^k denotes the set of states s such that $\mu^h(s) > 0$

Lemma 1 — Cap on the auction price

The same auction has a maximum price limit:

$$p^{up} \leq max\{\mathbf{E}(IC(\mathbf{r}^{up}, \mathbf{p}^{up}, \epsilon^{pu}); \mathbf{E}(IU(\mathbf{r}^{up}, \mathbf{p}^{up}, \epsilon^{cu})\}$$

where IC is the expected average incremental costs for a production unit and IU is the average forgone utility for a consumption unit p^{up} is either the pay-as-bid or marginal price

Individual incentives for BSPs

- Let us consider a simple case where
  - BSP^{pu} have the same ϵ^{pu} and BSP^{cu} the same ϵ^{cu}
  - Consumption unit are less flexible: $\epsilon^{pu} > \epsilon^{cu}$
  - Minimum quantities $\mu^{up}_{min} = \frac{\bar{\mu}^{up}}{(n-1)}$
- With no DP, all BSP^{pu} bid the minimum quantity μ^{up}_{min} and the equilibrium price coincides with the expected average IC
  - No profit from participation (participation fee)
- With DP, two issues arise
  - At the minimum quantity for all BSPs, DP leads to a different equilibrium price (average forgone utility for μ^{up}_{min}), not necessarily lower than without DP
  - Expanding the quantity bid, BSP^{pu} might exclude BSP^{cu}

Individual incentives for BSPs

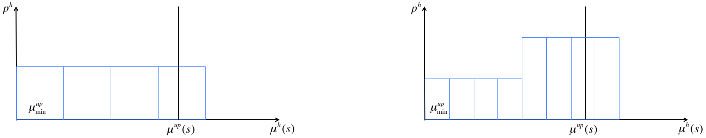


Figure 3: Minimum quantity without DP (left) and with DP (right)

Theoretical (first-best) outcome

- In the theoretical (first-best) outcome different quantities are allocated to production and consumption units, according to their respective elasticities

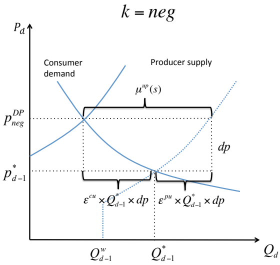


Figure 4: Optimal outcome

Proposition 1 — Optimal BM Auction

An optimal BM auction defines different minimum quantities for consumers and producers (BSPs with different elasticities)

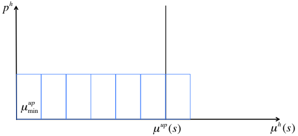
For small $\bar{\mu}^{up}$ the optimal quantity allocated to consumption units, $\bar{\mu}^{up}_{cu}/\bar{\mu}^{up}$, is given by

$$\frac{\bar{\mu}^{up}_{cu}}{\bar{\mu}^{up}} = \frac{\epsilon^{cu}}{\epsilon^{cu} + \epsilon^{pu}}$$

Given $\bar{\mu}^{up}_{cu}$, minimum quantities are defined for the individual consumption units

Conclusions

- DP in an optimal auction increases social welfare, reduces the tax burden and elicits voluntary participation against a zero economic profit
- Implications for market design



Thank you!

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