Economizing the Uneconomic: Dynamic Markets for Sustainable, Reliable and Price Efficient Electricity

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Electricity Policy Targets

Electricity policy target is providing reliable and sustainable electricity with efficient price to customers.
(United Nations Development Plan, 2015)

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- Incentive constraints: market competition, incentives and minimum regulations

Debates

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3. Quantity policy (carbon markets) for sustainability?
    - Charging carbon vs. supporting renewables for sustainability?

Contribution

We implement electricity policy targets (reliablity, sustainability and price efficiency) in a restructured industry with emerging technologies

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by designing electricity markets that are budget balanced, individually rational, and socially optimal,

using a uniform framework of auctions with constraints.

Model

$$\max_{\sigma_{n,t}\in\Sigma_{n,t},\gamma_{n,t}\in\Gamma_{n,t}:n\in N,t\in T} E_{\mathbf{w}_{1:T}}\Bigg[\sum_{t\in T}\beta^t U_t(\sum_{n\in N} e_{n,t},\mathbf{w}_t) - \qquad \text{(Socially Optimal)}$$

$$\sum_{t\in T}\sum_{n\in N}\beta^t\Big\{C^x_{n,t}(\Delta x_{n,t},\mathbf{w}_{t-1}) + C^e_{n,t}(e_{n,t},\mathbf{w}_t)\Big\} + \beta^{T+1}\sum_{n\in N}\eta(\mathbf{w}_T)x_{n,T}\Bigg]$$

$$s.t. \quad \forall t\in T, n\in N, \forall u,v\in V, w_{1:T}\in W_{1:T}$$

$$0\le e_{n,t}\le x_{n,0} + \sum_{\tau=1,\ldots,t}\Delta x_{n,\tau}$$

$$0\le \Delta x_{n,t}\le \overline{\Delta x}_{n,t}(\mathbf{w}_{t-1})$$

$$\sum_{n\in N} x_{n,t}\ge \underline{x_t}(\mathbf{w}_{t-1})$$

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Idea:

- Individual prices independent of one's own proposal for market power (Leonid Hurwicz)
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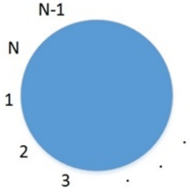

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$$\begin{aligned}
m_n &= (\hat{e}_n, \hat{p}_n) \\
e_n &= \hat{e}_n \\
r_n^{elas.} &= \hat{p}_{n+1}\hat{e}_n - \hat{p}_n^{-0.5} {\zeta_n^{elas.}}^2 \\
\zeta_n^{elas.} &= D(\hat{p}_{n+1}) - \sum_{n \in N} \hat{e}_n \\
D(\hat{p}) &= (U^{'})^{-1}(\hat{p}) \\
\hat{p}_{N+1} &:= \hat{p}_1
\end{aligned}$$

Efficient Auctions with Individual Constraints

$$\max_{e_n, \Delta x_n, n \in N} U(\sum_{n \in N} e_n) - \sum_{n \in N} C_n^e(e_n) - \sum_{n \in N} C_n^x(\Delta x_n)$$

$$s.t. \quad 0 \leq e_n \leq x_{n,0} + \Delta x_n \quad \forall n \in N$$

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- Efficient auction of electricity production also implements efficient expansion.

Efficient Auctions with Homogeneous Joint Constraints

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$$s.t. \quad 0 \leq e_n \leq x_{n,0} + \Delta x_n \quad \forall n \in N \tag{2}$$

$$0 \leq \Delta x_n \leq \overline{\Delta x}_n \quad \forall n \in N \tag{3}$$

$$\sum_{n \in N} (x_{n,0} + \Delta x_n) \geq \underline{x} \tag{4}$$

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followed by

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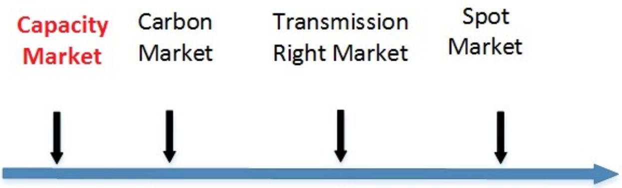
2. Single price for the homogeneous joint constraint that can be discovered using a separate auction

Design

Energy-and-capacity



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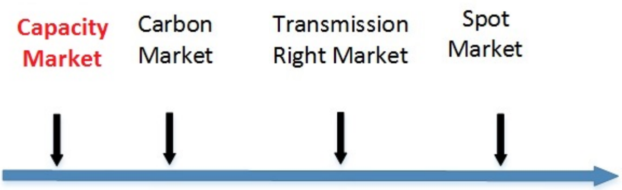

Energy-only

Contribution to the debates

- Price-cap and market monitoring for price efficiency? NO
- Direct capacity incentives for reliability? Capacity markets pay less subsidy than operation reserve market.
  - for price efficiency? NO
- Carbon markets for sustainability? YES
  - Charging carbon vs. supporting renewables for sustainability? We can provide efficient designs for both.

Thanks. Questions?