Auctioning wind farms

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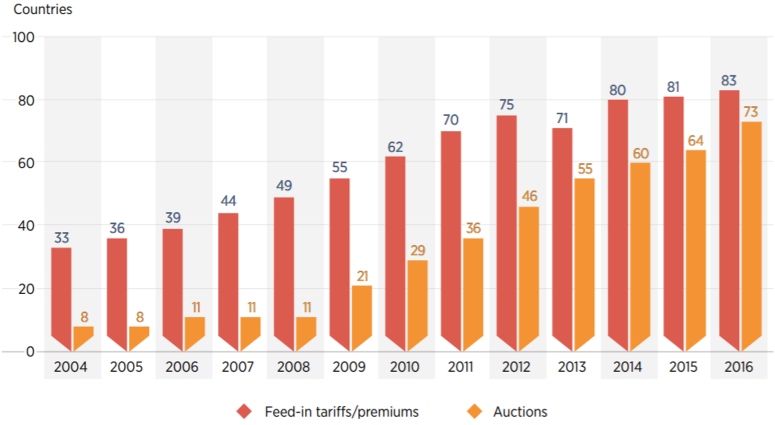
Auctions in the electricity sector



Source: REN21, 2005-17.

Getting information about wind profiles

Source: IRENA Renewable Cost Database and DWG, 2015.

Research question

- Compared to feed-in tariffs, auctions ensure a certain amount of wind farms in the system and are less information intensive for regulators

- More accurate information regarding wind speed is costly but can help regulators design a more efficient electricity system

- Firms face the standard trade-off between increasing the probability of winning and reducing the gains from winning

$\Rightarrow$ Do auctions incentivize firms to invest in information acquisition regarding their own potential profits?

Existing literature

- Auctions in the electricity sector

  Fabra et al. (2006), Fabra and Llobet (2019), Green and Newbery (1992)

- Information acquisition

  Ekmekci and Kos (2019), Engelbrecht-Wiggans et al. (1983), Bergemann et al. (2013), Shi (2012) Krähmer and Strausz (2011)

Model

- 2 risk-neutral firms with access to one site each, maximum capacity $K_i > 0$, bid b_i for energy produced if they build a wind farm
- Regulator asks for wind capacity $\theta \leq K_1 + K_2$ and sets a cap for bids P
- Marginal cost of installing wind capacity $\beta > 0$
- Fixed cost of information acquisition $\gamma > 0$

Model *cont'd*

- Firms care about the expected production of their site, μ_i, $i = 1, 2$ ▸ Wind production
- $f(\mu_i) = \frac{1}{\overline{\mu} - \underline{\mu}}$ is the prior probability density function of the sites, $\left[\underline{\mu}, \overline{\mu}\right] \subset R_{++}$ is the support of $f(.)$, μ_1 and μ_2 are i.i.d.
- If firm i decides to invest, the true value of expected production μ_i is revealed

Timing of the game

- Regulator announces wind capacity θ and an upper bound P for bids
- Firms decide to invest in information acquisition or not; this decision is observable
- After potentially receiving additional information, firms bid for a price of produced electricity and build $k_i = \theta$ or $k_i = K_i$
- First-price, discriminatory, sealed bid auction, with the outside option of not participating in the auction

Profit structure of firm i

Irrespective of firm j, when *not investing* in information acquisition, firm i has expected profits:

$$\mathbf{E}[\pi_i] = \begin{cases} (b_i\tilde{\mu} - \beta)\min\{\theta, K_i\}, & \text{if } b_i \leq b_j \\ (b_i\tilde{\mu} - \beta)\max\{0, \theta - K_j\}, & \text{if } \quad b_i > b_j \end{cases}$$

where $\tilde{\mu} \equiv \int_{\underline{\mu}}^{\overline{\mu}} xf(x)dx = \frac{\overline{\mu}+\underline{\mu}}{2}$

When *investing* in information acquisition, firm i has ex post profits:

$$\pi_i = \begin{cases} (b_i\mu_i - \beta)\min\{\theta, K_i\} - \gamma, & \text{if } b_i \leq b_j \\ (b_i\mu_i - \beta)\max\{0, \theta - K_j\} - \gamma, & \text{if } b_i > b_j \end{cases}$$

Different cases

The results of the analysis differ depending on pivotality:

- Non-pivotal firms, $K_i \geq \theta$
- Pivotal firms, $K_i < \theta$ with $K_1 + K_2 > \theta$ for $i = 1, 2$

Invest in information acquisition?

		firm j	
		yes	*no*
firm i	*yes*	$\pi(1,1), \pi(1,1)$	$\pi(1,0), \pi(0,1)$
	no	$\pi(0,1), \pi(1,0)$	$\pi(0,0), \pi(0,0)$

$K_i \geq \theta$, none invests

This case is a Bertrand competition case

Firms maximize:

$$\pi(0,0) = \quad Pr[b_i \leq b_j](b_i\tilde{\mu} - \beta)\theta$$

Bids in equilibrium:

$$b^*(0,0) = \frac{\beta}{\tilde{\mu}}$$

Expected profits in equilibrium:

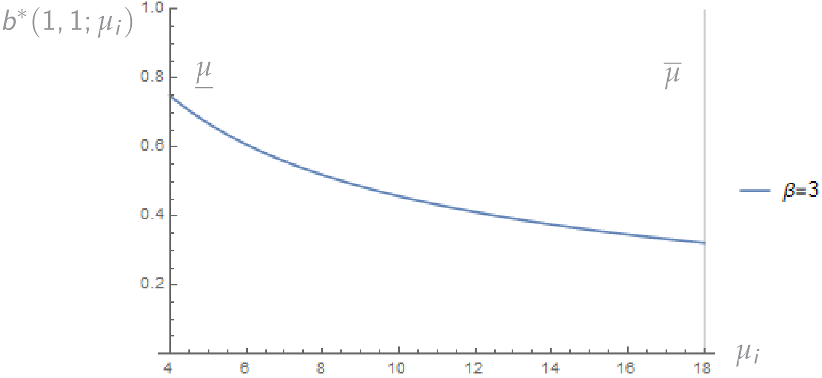
$$\pi^*(0,0) = 0$$

$K_i \geq \theta$, both invest

Firms maximize:

$$\pi(1,1) = \int_{\underline{\mu}}^{\overline{\mu}} Pr[b_i \leq b_j](b(\mu_i)\mu_i - \beta)\theta dF(\mu_i) - \gamma$$

Considering only pure, symmetric strategies results in bidding:

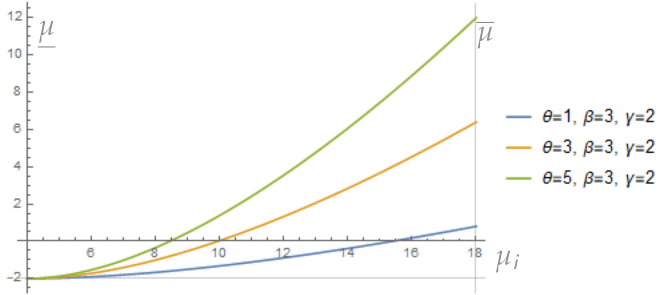


Bidding function

$K_i \geq \theta$, both invest *cont'd*

Sensitivity Analysis

$$Pr[b_i \leq b_j](b(\mu_i)\mu_i - \beta)\theta - \gamma$$

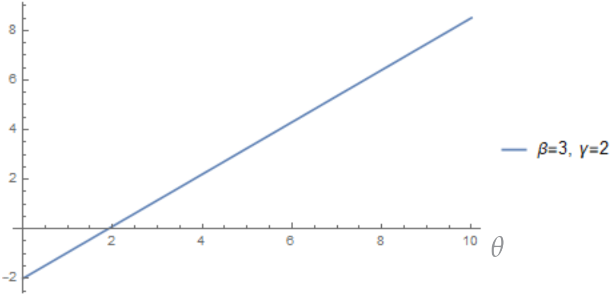


$\Rightarrow$ Participating in the auction is optimal behaviour

Functional form

$K_i \geq \theta$, both invest *cont'd*

$$\pi^*(1,1) = \int_{\underline{\mu}}^{\overline{\mu}} Pr[b_i \leq b_j](b(\mu_i)\mu_i - \beta)\theta dF(\mu_i) - \gamma$$



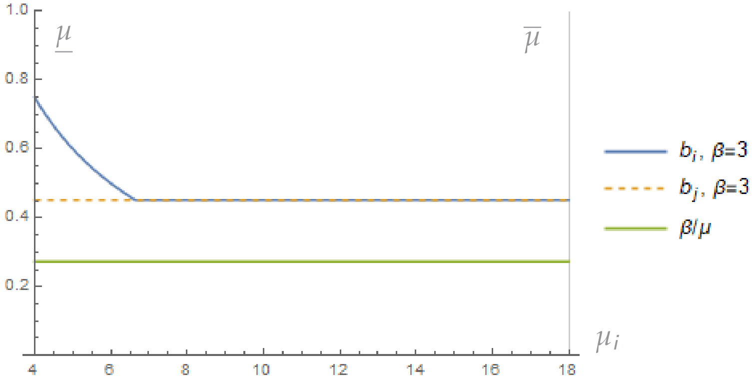
Threshold for θ, such that $\pi^*(1,1) > 0$:

$$\theta > \frac{4\gamma(\overline{\mu}^2 - \underline{\mu}^2)}{\beta\left[2(\ln\overline{\mu} - \ln\underline{\mu})\overline{\mu}^2 - (\overline{\mu} - \underline{\mu})(3\overline{\mu} - \underline{\mu})\right]} > 0$$

▸ Ex ante profit

$K_i \geq \theta$, i invests & j does not

Bidding of firms



Bidding of uninformed firm:

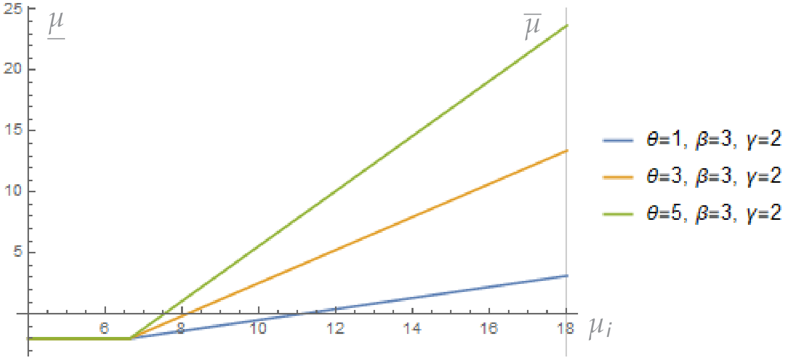
$$b^*(0,1) = \frac{\beta}{\sqrt{\tilde{\mu}\underline{\mu}}} > \frac{\beta}{\tilde{\mu}}$$

▸ Bidding functions

$K_i \geq \theta$, i invests & j does not *cont'd*

Sensitivity Analysis for informed firm

$$Pr[b_i \leq b_j](b(\mu_i)\mu_i - \beta)\theta - \gamma$$



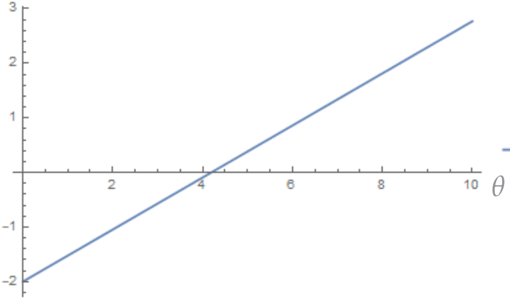
⇒ Again, participating in the auction is optimal behaviour

▸ Profit functions

$K_i \geq \theta$, i invests & j does not *cont'd*

Expected profits

$$\pi^*(1,0) = \int_{\underline{\mu}}^{\overline{\mu}} Pr[b_i \leq b_j](b(\mu_i)\mu_i - \beta)\theta dF(\mu_i) - \gamma \qquad (1)$$



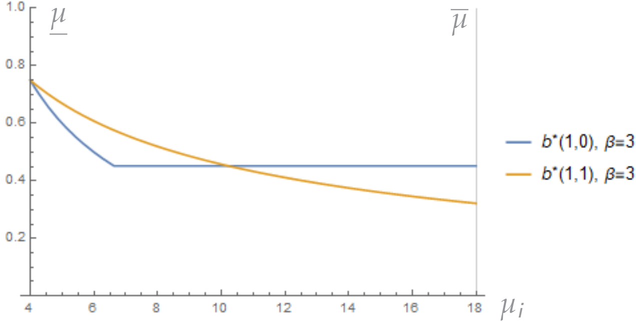
Threshold for θ, such that $\pi^*(1,0) > 0$:

$$\theta > \frac{2\gamma(\overline{\mu} - \underline{\mu})\sqrt{\tilde{\mu}\underline{\mu}}}{\beta\left(\overline{\mu} - \sqrt{\tilde{\mu}\underline{\mu}}\right)^2} > 0$$

▸ Expected profit

Strategic effect of information acquisition

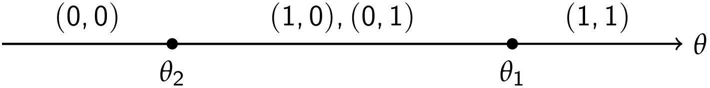
- Firm i acquires information, firm j changes decision



- Firm i does not acquire information, firm j changes decision

$$b^*(0,1) = \frac{\beta}{\sqrt{\tilde{\mu}\underline{\mu}}} > b^*(0,0) = \frac{\beta}{\tilde{\mu}}$$

Subgame Perfect Equilibrium



The regulator can affect the equilibrium by her choice of wind capacity demand θ

Strategic complementarity or substitutability of actions depends on θ

For $\theta > \theta_1$ there is only 1 equilibrium where both firms invest in information acquisition

Expressions for θ_1, θ_2

Conclusions

- Auctions are a useful tool for a transition to a low carbon electricity system with intermittent renewables
- When the auction is designed appropriately:
  - Regulators can incentivise firms to acquire information
  - Firms indirectly reveal this information

Thank you for your attention

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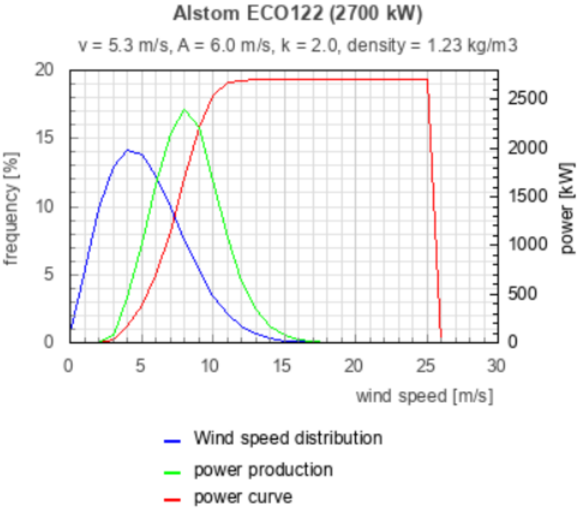
Wind production



source: The Swiss Wind Power Data Website (2018)

Model

$K_i \geq \theta$, both invest

Bidding under pure, symmetric strategies

$$b^*(1,1;\mu_i) = \begin{cases} \beta/\underline{\mu}, & \mu_i = \underline{\mu} \\ \dfrac{\beta\left(\ln \mu_i - \ln \underline{\mu}\right)}{\mu_i - \underline{\mu}}, & \underline{\mu} < \mu_i \leq \overline{\mu} \end{cases} \tag{2}$$

where $\dfrac{db^*(1,1;\mu_i)}{d\mu_i} < 0$

Non-pivotal results

$K_i \geq \theta$, both invest *cont'd*

Ex post profit when firm i wins the auction

$$\pi^*(1,1;\mu_i) = \begin{cases} -\gamma, & \mu_i = \underline{\mu} \\ \beta\theta \dfrac{\left(\ln \mu_i - \ln \underline{\mu}\right)\mu_i - \left(\mu_i - \underline{\mu}\right)}{\mu_i - \underline{\mu}} - \gamma, & \underline{\mu} < \mu_i \leq \overline{\mu} \end{cases} \tag{3}$$

where $\dfrac{d\pi_i^*(1,1;\mu_i)}{d\mu_i} > 0$

▸ Non-pivotal results cont'd

$K_i \geq \theta$, both invest *cont'd*

Expected profit conditional on revealed value of μ_i

$$\pi^*(1,1;\mu_i) = \begin{cases} -\gamma, & \mu_i = \underline{\mu} \\ \beta\theta \dfrac{\left(\ln \mu_i - \ln \underline{\mu}\right)\mu_i - \left(\mu_i - \underline{\mu}\right)}{\overline{\mu} - \underline{\mu}} - \gamma, & \underline{\mu} < \mu_i \leq \overline{\mu} \end{cases} \tag{4}$$

where $\dfrac{d\pi^*(1,1;\mu_i)}{d\mu_i} > 0$

▸ Non-pivotal results sensitivity

$K_i \geq \theta$, both invest, unconditional expectation on profit

Ex ante profit is given by:

$$\pi^*(1,1) = \int_{\underline{\mu}}^{\overline{\mu}} \left[\beta\theta \frac{\left(\ln \mu_i - \ln \underline{\mu}\right)\mu_i - \left(\mu_i - \underline{\mu}\right)}{\overline{\mu} - \underline{\mu}} \right] \frac{1}{\overline{\mu} - \underline{\mu}} d\mu_i - \gamma$$

$$= \frac{\beta\theta \left[2(\ln \overline{\mu} - \ln \underline{\mu})\overline{\mu}^2 - (\overline{\mu} - \underline{\mu})(3\overline{\mu} - \underline{\mu}) \right]}{4(\overline{\mu} - \underline{\mu})^2} - \gamma \qquad (5)$$

$$\theta > \frac{4\gamma(\overline{\mu}^2 - \underline{\mu}^2)}{\beta\left[2(\ln \overline{\mu} - \ln \underline{\mu})\overline{\mu}^2 - (\overline{\mu} - \underline{\mu})(3\overline{\mu} - \underline{\mu})\right]} \Leftrightarrow \pi^*(1,1) > 0$$

▸ Non-pivotal results unconditional profit

$K_i \geq \theta$, 1 invests – 2 does not

Bidding under asymmetric decisions and uniform pdf

$$
\begin{aligned}
b^*(1,0;\mu_i) &= \begin{cases} \dfrac{\beta}{\mu_i}, & \underline{\mu} \leq \mu_i < \sqrt{\tilde{\mu}\underline{\mu}} \\ \\ \dfrac{\beta}{\sqrt{\tilde{\mu}\underline{\mu}}}, & \dfrac{\overline{\mu}+\underline{\mu}}{2} < \mu_i \leq \overline{\mu} \end{cases} \\
b^*(0,1) &= \frac{\beta}{\sqrt{\tilde{\mu}\underline{\mu}}} \qquad (6)
\end{aligned}
$$

▸ Asymmetric decisions

$K_i \geq \theta$, 1 invests – 2 does not *cont'd*

$$\pi^*(1,0;\mu_i) = \begin{cases} -\gamma, & \underline{\mu} \leq \mu_i < \sqrt{\tilde{\mu}\underline{\mu}} \\ \left(\frac{\mu_i}{\sqrt{\tilde{\mu}\underline{\mu}}} - 1\right)\beta\theta - \gamma, & \sqrt{\tilde{\mu}\underline{\mu}} \leq \mu_i \leq \overline{\mu} \end{cases} \tag{7}$$

$$\begin{aligned} \pi^*(1,0) &= -\gamma + \int_{\sqrt{\tilde{\mu}\underline{\mu}}}^{\overline{\mu}} \left[\left(\frac{\mu_i}{\sqrt{\tilde{\mu}\underline{\mu}}} - 1\right)\beta\theta\right] \frac{1}{\overline{\mu} - \underline{\mu}} d\mu_i \\ &= -\gamma + \frac{\beta\theta\left(\overline{\mu} - \sqrt{\tilde{\mu}\underline{\mu}}\right)^2}{2(\overline{\mu} - \underline{\mu})\sqrt{\tilde{\mu}\underline{\mu}}} \end{aligned} \tag{8}$$

$$\pi^*(0,1) = \frac{\left(\sqrt{\tilde{\mu} - \underline{\mu}}\right)^2}{\overline{\mu} - \underline{\mu}}\beta\theta \tag{9}$$

▸ Asymmetric decisions

$K_i \geq \theta$, thresholds for θ

$$\theta_1 \equiv \frac{4\gamma(\overline{\mu}-\underline{\mu})^2}{\beta\left[2\overline{\mu}(\ln\overline{\mu}-\ln\underline{\mu})-(3\overline{\mu}-\underline{\mu})(\overline{\mu}-\underline{\mu})-4(\overline{\mu}-\underline{\mu})(\sqrt{\tilde{\mu}}-\sqrt{\underline{\mu}})^2\right]} \quad (10)$$

$$\theta_2 \equiv \frac{2\gamma(\overline{\mu}-\underline{\mu})\sqrt{\tilde{\mu}\underline{\mu}}}{\beta\left(\overline{\mu}-\sqrt{\tilde{\mu}\underline{\mu}}\right)^2} \quad (11)$$

▸ Subgame perfect equilibrium

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