Procurement auctions for an electricity system with increased wind technology

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Abstract

Auctions are used in many countries as a policy measure to promote renewable energy. However, do auctions incentivize firms to invest in acquiring information regarding their own potential revenue? I use a first-price sealed bid auction model with two bidders to assess the effect of auctions on information acquisition, when procuring wind energy capacity. Preliminary results show that investing in information acquisition can be a dominant strategy, an effect policy makers need to take into account given that setting the price for renewables exogenously can result in inefficiencies.

1 INTRODUCTION

Auctions are more and more used to increase the share of wind energy production in the electricity sector throughout the world. For instance, in 2016 wind energy capacity has been auctioned in Canada, Chile, Denmark, Italy and the Netherlands, among other countries (IRENA, 2017; International Energy Agency, 2018). Compared to the feed-in tariff structure, auctions can increase competition, since they lead to the price received by firms being closer to their costs, and to the information asymmetry between firms and the regulator being reduced (Myerson, 1981; Milgrom and Weber, 1982; Green and Laffont, 1977). However, given the stochastic nature of wind, it is often the case that firms deciding to build a wind farm might not have complete information regarding its production. The main focus of this paper is to examine whether auctions incentivise firms to invest in acquiring information about their own potential revenue.

Firms have the option to invest in acquiring information regarding the wind characteristics of potential wind farm sites. Wind profiles can be directly linked to the electricity production of a wind farm, hence this kind of information can allow firms to ask for a higher price per unit of electricity produced without procuring less quantity[1]. Put differently, they can have a bidding strategy that will increase their produced quantity without necessarily compromising their revenues.

An extensive survey of the auction theory literature is provided by Klemperer (1999). Auctions in the context of electricity markets have been extensively studied by Green and Newbery (1992) and Green (1996), among others. Arozamena and Cantillon (2004) looks into

[1] See for example Krishna (2009) "An increase in the bid will increase the probability of winning while, at the same time reducing the gains from winning".

how the format of an auction changes a firm's decision to invest in cost reduction. Information asymmetry among bidders in different settings has been the main focus of numerous papers, such as Bennouri and Falconieri (2006); Engelbrecht-Wiggans et al. (1983); Shi (2012); Miettinen (2013); Bergemann et al. (2013).

This paper follows the approach of Fabra et al. (2006). Similar to their approach, I model procurement auctions as discriminatory, multi-unit, first-price sealed bid in a duopoly, with private values and private information. The main contribution of this paper is to investigate whether auctions affect the investment in acquiring information, when implemented at the stage of installing wind energy capacity, instead of the dispatching it.

2 MODEL

A standard duopoly model is used, where two firms, $i = 1, 2$, bid in order to build wind capacity, $\theta > 0$, demanded by the regulator. Each firm has access to one site on which they can decide how much wind capacity, $k_i \geqslant 0$, to install. Due to land availability and site topography, there is a maximum number of wind turbines that can be installed at each site; assuming that every wind turbine available to firms has the same nominal capacity, there is a maximum capacity, $K_i > 0$, that each firm can install. It is assumed that the sites available to firms can cover the demanded capacity, that is $K_1 + K_2 \geqslant \theta$. Furthermore, each additional turbine has the same installation cost, $\beta > 0$, i.e. the marginal cost of installing capacity is constant and positive.

In this model, each site has a different electricity production profile , meaning that the distribution of electric power produced by each wind turbine has different mean, μ_i, and standard deviation, σ_i. Assuming that firms are risk neutral, the only payoff-relevant part of the distribution is μ_i. Ex ante this parameter is unknown to both the firms and the regulator. However, both firms have a common belief on what its value is. Let $f(.)$ denote the prior probability density function of μ_i and $[\underline{\mu}, \overline{\mu}] \subset R_{++}$ be the support of $f(.)$, where μ_1 and μ_2 are i.i.d.

Each firm places a bid b_i which will be the price firm i will receive for its electricity production. The regulator sets a price cap for the bids, $b_i \leqslant P$, where the upper bound of the bids can be the level of the former feed-in tariff. The wind capacity each firm builds depends on the bids they place, according to:

$$k_i = \begin{cases} \min\{\theta, K_i\}, & \text{if } b_i < b_{-i} \\ \\ \max\{0, \theta - K_{-i}\}, & \text{if } b_i > b_{-i} \end{cases}$$

Without loss of generality, ties break in favour of firm $i = 1$; i.e. when $b_1 = b_2$, then $k_1 = \min\{\theta, K_1\}$ and $k_2 = \max\{0, \theta - K_1\}$.

Before the auction, each firm has the option to invest in information acquisition on the site's expected production. This investment costs $\gamma > 0$. Once firms pay γ, they observe a perfectly accurate signal, namely the realized value of their own expected production. Then, they decide on their bids. Note that in the setting of this paper, electricity production takes place within a given time duration, hence electric power and electricity production can be considered as the same quantities.

The timing of the game is as follows: Once the regulator announces θ and P, firms decide to invest in information acquisition or not. After firms potentially receive additional information about the site characteristics, i.e. the expected electricity production, they bid for the price per unit of electricity produced, b_i, and build k_i. There is the outside option of not participating in the auction; in that case firms do not build any capacity, but they bear the information acquisition costs if they decide to.

When firm i does not invest in information acquisition, its expected profit is:

$$\mathbf{E}[\pi_i] = Pr[b_i \leqslant b_{-i}](b_i\mu - \beta)\min\{\theta, K_i\} + (1 - Pr[b_i \leqslant b_{-i}])(b_i\mu - \beta)\max\{0, \theta - K_i\}$$

where $\mu \equiv \int_{\underline{\mu}}^{\overline{\mu}} x f(x) dx$.

On the other hand, when firm i does invest, expected profit is:

$$\mathbf{E}[\pi_i] = Pr[b_i \leqslant b_{-i}](b_i\mu_i - \beta)\min\{\theta, K_i\} + (1 - Pr[b_i \leqslant b_{-i}])(b_i\mu_i - \beta)\max\{0, \theta - K_i\} - \gamma.$$

3 INITIAL RESULTS & FURTHER WORK

The results of the analysis differ when $K_i \geqslant \theta$, $K_i < \theta$, or $K_i < \theta < K_{-i}$ for $i = 1, 2$. Let's first focus on $K_i \geqslant \theta$. The equilibrium outcomes of all the subgames need to be considered in order to find the subgame perfect equilibrium of this auction.

- **Both firms do not invest in information acquisition:** This case is similar to a Bertrand competition, since either firm can cover demand for capacity. When firms rely only on the prior expectation regarding their own and their opponents profits, the following equilibrium bids and expected profits result:

$$b_i^* = \frac{\beta}{\mu} \tag{1}$$

and

$$\mathbf{E}[\pi_i^*] = 0 \qquad \forall i, \qquad i = 1, 2. \tag{2}$$

If a specific prior probability density function, $f(.)$, is assumed, then bids can be also determined. For instance, a uniform distribution $f(\mu_i) = \frac{1}{\overline{\mu} - \underline{\mu}}$ results in bids $b_i^* = \frac{2\beta}{\overline{\mu} + \underline{\mu}}$.

To prove that these bids are best responses, consider whether a deviation of firm i can increase its expected profits. In case firm i increases its bid by ϵ, with $\epsilon \to 0$, it will lose the auction resulting in zero expected profits. On the other hand, if firm i decreases its bid by ϵ, it will win the auction, but it will have negative expected profits. Therefore, $b_i^* = \frac{\beta}{\mu}$, $i = 1, 2$, is a dominant strategy.

- **Both firms invest in information acquisition:** Firm i decides to pay the cost of information acquisition γ and therefore knows the realization of the expected production μ_i. Additionally, firm i has a belief on the expected production of the other firm $(-i)$, expressed through the prior probability density function $f(.)$. Now, the expected profits of firm i are given by:

$$\mathbf{E}[\pi_i] = \Pr[b_i \leqslant b_{-i}]\,(b_i\mu_i - \beta)\,\theta - \gamma \tag{3}$$

Assuming firms only play pure strategies and that bids are strictly decreasing in the observed μ_i, there is a function such that $b_i = B_i(\mu_i)$, $B_i^{'}(\mu_i) < 0$. Expected profits can be rewritten as:

$$\mathbf{E}[\pi_i] = F\left(B_{-i}^{-1}(b_i)\right)(b_i\mu_i - \beta)\,\theta - \gamma \tag{4}$$

where B_i^{-1} is the inverse function of B_i and the function F is the CDF corresponding to f. Many common cumulative distribution functions, such as the uniform or the Gaussian, are logconcave, hence let $F(.)$ be logconcave as well. Consequently, the objective function (4) is quasiconcave and maximised when

$$\frac{dF\left(B_{-i}^{-1}(b_i)\right)}{db_i}(b_i\mu_i - \beta) + F\left(B_{-i}^{-1}(b_i)\right)\mu_i \quad = \quad 0 \tag{5}$$

Firms are ex ante symmetric, therefore when considering symmetric strategies, i.e. $B_i(.) = B_{-i}(.) = B(.)$, the FOC becomes:

$$\begin{aligned}
F^{'}(\mu_i)\frac{1}{B^{'}(\mu_i)}(b_i\mu_i - \beta) + F(\mu_i)\mu_i &= 0 \Leftrightarrow \\
F^{'}(\mu_i)\left(B(\mu_i)\mu_i - \beta\right) + F(\mu_i)B^{'}(\mu_i)\mu_i &= 0 \Leftrightarrow \\
\mu_i\left(B(\mu_i)F(\mu_i)\right)^{'} - \beta F^{'}(\mu_i) &= 0
\end{aligned} \tag{6}$$

The solution to this differential equation gives the bidding strategy of each firm after they have observed μ_i, $b_i^* = B^*(\mu_i)$. For example, assuming again the uniform distribution, (6) becomes:

$$B^{'}(\mu_i)(\mu_i - \underline{\mu})\mu_i + B(\mu_i)\mu_i - \beta = 0 \tag{7}$$

to which the solution is:

$$b_i^* = B^*(\mu_i) = \begin{cases} \beta/\underline{\mu} & \text{if } \mu_i = \underline{\mu} \\[2ex] \dfrac{\beta\left(\log(\mu_i) - \log(\underline{\mu})\right)}{\mu_i - \underline{\mu}} & \text{if } \underline{\mu} < \mu_i \leqslant \overline{\mu} \end{cases} \tag{8}$$

It should be noted that the initial condition for $B^*(\mu_i)$ was chosen so that for every realization of μ_i there is a bid that does not tend to infinity and that $B^*(\mu_i)$ is a continuous function. Proving that $B^*(\mu_i)$ is indeed a decreasing function, as assumed, is straightforward from (8).

Equilibrium expected profits are then given by

$$\mathbf{E}[\pi_i^*] = \begin{cases} -\gamma & \text{if } \mu_i = \underline{\mu} \\[2ex] \dfrac{\mu_i - \underline{\mu}}{\overline{\mu} - \underline{\mu}}\left(\dfrac{\beta\mu_i\left(\log(\mu_i) - \log(\underline{\mu})\right)}{\mu_i - \underline{\mu}} - \beta\right)\theta - \gamma & \text{if } \underline{\mu} < \mu_i \leqslant \overline{\mu} \end{cases} \tag{9}$$

- **Firm i invests in information acquisition, and firm $-i$ does not:** Without loss of generality, let's assume that firm 1 invests and firm 2 does not; their choices are common knowledge. Due to information asymmetry, firms cannot play symmetric strategies any more. Firm 1 conditions its equilibrium bid on the observed value μ_1 according to:

$$b_1^* = B_1^*(\mu_1) = \begin{cases} \dfrac{\beta}{\mu_1}, & \text{if } \underline{\mu} \leqslant \mu_1 < \mu \\ \\ \dfrac{\beta}{\mu}, & \text{if } \mu \leqslant \mu_1 \leqslant \overline{\mu} \end{cases} \tag{10}$$

whereas firm 2 only takes into account the expected value, i.e. μ, and bids:

$$b_2^* = \frac{\beta}{\mu}. \tag{11}$$

For these strategies to be an equilibrium, firms should not have an incentive to deviate. Fixing the strategy for firm 2, when $\underline{\mu} \leqslant \mu_1 < \mu$, firm 1 cannot bid lower than $\frac{\beta}{\mu_1}$ because this bid will result in negative profits, while bidding higher will not cause the firm to win the auction. When $\mu \leqslant \mu_1 \leqslant \overline{\mu}$, firm 1 does not have an incentive to bid lower than $\frac{\beta}{\mu}$, since this deviation will result to lower profits.

On the other hand, firm 2 only considers the prior probability density function f, hence it cannot increase its profits by deviating. Hence, there is no profitable deviation for either firm and the aforementioned strategies constitute an equilibrium.

Expected profits for the firms are:

$$\mathbf{E}[\pi_1^*] = \begin{cases} -\gamma, & \text{if } \underline{\mu} \leqslant \mu_1 < \mu \\ \\ \dfrac{\mu_1 - \mu}{\mu}\beta\theta - \gamma, & \text{if } \mu \leqslant \mu_1 \leqslant \overline{\mu} \end{cases} \tag{12}$$

$$\mathbf{E}[\pi_2^*] = 0 \tag{13}$$

Put differently, when firm 1 observes μ_1 greater than μ, then it can bid $\frac{\beta}{\mu}$. As a result, firm 1 wins the auction and has expected profit greater than $-\gamma$. When $\mu_1 < \mu$, then the dominant strategy is to bid higher than firm 2 and have expected profit of $-\gamma$, which is the same profit as choosing not to participate in the auction. Firm 2 is uninformed, therefore has always an expected profit of 0. This result is in accordance with the literature.

If the uniform distribution is used as an example, then $\mu = \dfrac{\overline{\mu} + \underline{\mu}}{2}$ and expected profits of firm 1 become:

$$\mathbf{E}[\pi_1^*] = \begin{cases} -\gamma, & \text{if } \underline{\mu} \leqslant \mu_1 < \mu \\ \\ \dfrac{2\mu_1 - (\overline{\mu} + \underline{\mu})}{\overline{\mu} + \underline{\mu}}\beta\theta - \gamma, & \text{if } \mu \leqslant \mu_1 \leqslant \overline{\mu}. \end{cases} \tag{14}$$

Comparing the results of the three subgames, it can be seen that investing in information acquisition is the dominant strategy when relative to the expected value μ, cost γ is low, marginal capacity cost β is high, and demand for wind capacity θ is high, too. Additionally, firms are ex ante symmetric resulting in them playing the same strategy. Therefore, if the auction designer aimed at incentivising firms to invest in information acquisition, she would need to consider the relative values of these parameters and adjust the value of demanded capacity θ. In case $\frac{\gamma}{\beta\theta}$ has a low enough value, the expected profits of the firms are given by:

$$\mathbf{E}[\pi_i^*] = \begin{cases} -\gamma & \text{if } \mu_i = \underline{\mu} \\ \\ \dfrac{\mu_i - \underline{\mu}}{\overline{\mu} - \underline{\mu}} \left(\dfrac{\beta\mu_i \left(\log(\mu_i) - \log(\underline{\mu})\right)}{\mu_i - \underline{\mu}} - \beta \right) \theta - \gamma & \text{if } \underline{\mu} < \mu_i \leqslant \overline{\mu} \end{cases} \tag{15}$$

Further work on this paper includes solving the differential equation (6) under a general distribution. Additionally, the cases when $K_i < \theta \leqslant K_{-i}$ and $K_i < \theta$ need to be analysed for this work to be complete. An extension of this work will look into heterogeneous companies in terms of marginal capacity costs, i.e. $\beta_i < \beta_{-i}$, and how the investment decision changes when a higher γ results in acquiring more accurate information regarding the expected production.

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