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Abstract

When building a cross-border transmission line (a so-called interconnector) as a for-profit (merchant) project, where the regulator has required that capacity allocation be done non-discriminatorily by explicit auction, the identity of the investor can affect the profitability of the interconnector project and, once operational, the resulting allocation of its capacity. Specifically, when the investor is a generator (hereafter the integrated generator) who also can use the interconnector to export its electricity to a distant location, then, once operational, the integrated generator will bid more aggressively in the allocation auctions to increase the auction revenue and thus its profits. As a result, the integrated generator is more likely to win the auction and the capacity is sold for a higher price. This lowers the allocative efficiency of the auction, but it increases the expected ex-ante profitability of the merchant interconnector project. Unaffiliated, independent generators, however, are less likely to win the auction and, in any case, pay a higher price, which dramatically lowers their revenues from exporting electricity over this interconnector.

Keywords

Electricity markets, regulation, cross-border electricity transmission, vertical integration, asymmetric auctions, bidding behavior.

JEL classification code: D44, L43, L51, L94, L98, Q40.

1. Introduction[*]

The EU electricity market suffers from a severe shortage of cross-border transmission lines, called interconnectors, leaving the electricity networks of the national EU states insufficiently connected with one another (European Commission, 2007, p.174, European Climate Foundation, 2010). Sufficient interconnector capacity is vital for the realization of one of the main objectives of the EU: the creation of a single EU market in electricity (Directive 96/92/EC). EU law allows two types of projects for building new interconnectors: a public and a private one. The public type of interconnector projects are regulated projects implemented by national Transmission System Operators (hereafter TSOs). The private type of interconnector projects are for-profit, merchant projects implemented by commercial investors (European Commission, 2009a).

Merchant interconnector projects will likely play a significant role in providing at least a part of the much needed transmission capacity between EU member states in the near future, as TSOs seem not to have the proper incentives to invest in interconnector capacity (Buijs et al., 2007; Brunekreeft, 2004; Brunekreeft & Newberry, 2006; de Hauteclocque & Rious, 2009). Also, new research shows that an important argument against merchant interconnector investment is likely less serious than believed previously. Whereas Joskow & Tirole (2005) previously showed that commercial investors have the incentive to build a suboptimally small line, Parail (2010) has recently shown that this effect is rather small in practice. This makes merchant interconnector investment a more viable option. Indeed, in the last few years three merchant interconnectors, NorNed, Estlink, and Campocologno-Tirano, have been built, and several other projects have been proposed in Italy, England, Belgium, and France (Italian Regulator, 2009; OFGEM, 2010). The last example, Campocologno-Tirano, concerns a merchant interconnector that was built by electricity generators. This paper will address this type of merchant interconnector projects: where electricity generators own a merchant interconnector. It is likely that in the near future more electricity generators may want to build merchant interconnectors that they would use to transport their own electricity (de Hauteclocque & Rious, 2009). Marseglia, an Italian generation company, is an example of such a case. Marseglia has requested permission to built two 500MW merchant interconnectors that would connect Italy with Albania (Argus Power Europe, 19.02.2009).

EU law stipulates that when investors want to built a merchant interconnector, they must apply for permission from the national regulators (Regulation EC No 714/2009). Regulators are to review such an application on a case-by-case basis and, if they permit the project, set the conditions under which the merchant interconnection should operate. For example, the regulator usually limits the period for which the investors can collect the earnings from the interconnector and often obliges the investors to sell capacity in a non-discriminating auction. In addition, the regulator could impose a maximum of the possible profits, or a minimum size for the merchant interconnector. The conditions set by regulators affect a project's profitability. Regulators thus aim to set the conditions in such a way as to enable the merchant interconnector to collect the revenues to cover costs and risks. If regulators set the conditions too strictly, investors will bail and a welfare-increasing project will not be realized. If the regulators set the conditions too laxly, the merchant investors receive, at the cost of the end-consumers of electricity, a windfall profit unnecessary for the realization of the project. Regulators thus must make a careful assessment of what conditions to set and for how long. An especially interesting case is when the regulator has allowed the generator as a merchant investor(s) to keep profits, but insists on a non-discriminatory allocation of the interconnection capacity by explicit auction. This regulatory

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setting has been suggested in the EU laws and has been implemented by CRE, the French regulator (European Commission, 2004, art. 19 and art. 34; European Commission, 2009a, 2009b; CRE, 2010, p.4). It is an open question whether in such a case the allocation of capacity will be efficient and non-discriminatory. This paper, aiming to contribute to the deliberations regulators must make in their assessment to grant or withhold permission, address this question.

No earlier studies have addressed the effects of a merchant interconnection project by a generator in such a regulatory setting. Earlier papers focused on the effects of a generator having a financial stake in a transmission line on its behavior in markets with Cournot competition, mostly in the institutional setting of the US. For example, Joskow & Tirole (2000) and Sauma & Oren (2008) analyze the behavior of generators that, by holding so-called financial transmission rights, receive a part of the revenues of transmission line for different competition scenarios. Joskow & Tirole (2000) and Sauma & Oren (2008) use nodal pricing, which is realistic for markets with the US standard market design, but not for the EU markets, which exclusively uses zonal pricing, mostly in combination with explicit auctions, for the allocation of interconnector capacity. Their analysis, therefore, does not apply to the EU market. Höffler & Kranz (2007) model a generator which has a stake in the regulated revenues of a TSO and show that the generator will compete more aggressively in the electricity supply market. As a result the generator will supply more electricity, resulting in lower prices. In the model of Höffler & Kranz (2007), the transmission network has an unlimited capacity and its income is regulated. Their model thus does not apply to the allocation of capacity on congested merchant interconnectors, where the scarce capacity is allocated by explicit auction. In my model I let the allocation of capacity therefore take place by explicit auctions.

It should become clear, in the model section below, that explicit auctions with a generator that owns a part of an interconnector are mathematically identical with so-called toehold auctions. Toehold auctions have been analyzed mostly in the context of financial takeovers, where two bidders compete to buy a company and one or both bidders already own, by holding shares, a fraction of the company they want to take over (Klemperer, 1999; Bulow, Huang & Klemperer 1999; Burkart 1995; Ettinger 2002). The fraction of the company owned by the potential bidder(s) is called a toehold.

Burkart (1995) analyzed a second-price private value toehold auction with two bidders and finds that the bidder with a toehold bids more aggressively and increasingly so the higher its toehold. Ettinger (2002) compares first-price and second-price private value auctions with symmetrical toeholds and notes that, for strictly positive toeholds, the revenue equivalence theorem does not hold. Bulow et al. (1999) analyze common value toehold auctions, where both bidders have a toehold (and at least one bidder a strictly positive toehold) and show that the bidder with a larger toehold has a larger probability of winning the auction. Bulow et al. (1999) also show that the winning price is strongly affected by toeholds.

As Burkart (1995) uses general assumptions, he cannot give estimates of the size of the effects of toeholds on auction outcomes. In addition, he models an auction with only two bidders, while in auctions for interconnector capacity often more generators compete. I therefore model a set-up similar to that of Burkart (1995) but assume that values are uniformly distributed. This assumption allows me to derive explicit solutions when an arbitrary number of independent bidders takes part in the auction. First-price toehold auctions have not been analyzed before at all, and I present a general result for first-price auctions with an integrated bidder that fully owns the interconnector. Under more restrictive assumptions, I numerically solve such first-price auctions with partial integrated ownership, and show that the revenue equivalence theorem does not hold in such auctions.

My results are that the identity of the investor has a significant effect on the profitability and use of the interconnector. Specifically, when one of the investors is a generator in one of the countries connected by the interconnector, then such a generator (hereafter, the integrated generator) can be expected to bid more aggressively. The aggressive bidding increases the profitability of the interconnector. While it also lowers the profitability of the integrated generator, the net effect (profits of interconnector plus generator) is positive. The more aggressive bidding biases the auction outcomes in favor of the integrated generator, thus lowering the allocative efficiency of the auction and lowering the expected profits of other generators that are not involved as investors.

The analysis presented here applies when capacity is allocated by explicit auctions, but not when allocated by implicit auctions. Explicit auctions are a much used form of allocating capacity on interconnectors (Helm, 2003; Newberry, 2003; Stern & Turvey, 2003; Yarrow, 2003). While there are interconnectors in the EU where implicit auctions are used for the day-ahead market, even there the long-term contracts for interconnector capacity (weekly, monthly, annual and multi-annual) are allocated by explicit auctions. For example, as the electricity markets of Belgium, France and the Netherlands have been coupled, the capacity of their interconnectors is said to be allocated by implicit auctions. This is, however, true for only 10% of the capacity; the other 90% is allocated by explicit auction (Commission for Energy Regulation, 2009, p.18).

The remainder of this paper is organized as follows. In the next section I describe the setup of my model. Then I analyze first-price and second-price formats of the main auction model. In the conclusion, besides the usual summary, I suggest ways in which EU energy regulators could take into account the findings of this paper when dealing with new proposals for merchant interconnector projects by generators.

2. The Model[1]

2.1 Assumptions

In the main application of my model, a generator bids to obtain capacity on an interconnector in order to sell electricity in the country on the other side of the connector. The profitability of the transaction depends, among other things, on the costs of generating electricity. I will assume that the cost of generating electricity differs among generators.[2] This implies that generators value the interconnector capacity differently. The value of capacity is the profit that could be earned by selling electricity abroad. This profit is equal to the difference between the price abroad and the costs of the generator.[3]

I will assume that a generator knows its own value, but not the value of the competing generator. In my model this implies that a generator does not know its competitor's marginal cost of producing electricity (except for a common, identical cost factor such as gas or oil prices). In older models stemming from the time electricity generator markets were tightly regulated (Green & Newbery 1993; von der Fehr & Harbord 1993), it was usual practice to assume that marginal costs are common knowledge; however, since the electricity industry has become competitive, information on the cost structure of electricity generation has strategic value and is therefore carefully guarded (Léautier 2001, 34). Parisio & Bosco (2008)[4] add: "generators frequently belong to multi-utilities [integrated generators] providing similar services often characterized by scope and scale economies (Fraquelli et

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1 See section 8 for a notation overview.

2 The value of the good to a generator is dependent on the costs of generating electricity. As a generator does not know the cost of its competitors, he treats it as a random variable, drawn from a distribution that, for the sake of simplicity, I will assume to be uniform. The random costs drive the dynamics of the bidding behavior. In electricity generation, there is also a common cost component, mainly gas or oil prices. I assume that the size of these common cost components are common knowledge and that they are identical for all generators. As shown in footnote 7, these common cost components are therefore inconsequential for the bidding behavior; this is determined by the unknown private value factors.

3 In line with the empirical evidence, I assume that, as transmission capacity is fixed and small relative to total demand, buyers cannot influence the final price in distant locations (see e.g. Consentec, 2004).

4 See page 1765 of Parisio & Bosco (2008).

al., 2004, among others). The cost of generation therefore can vary across firms because firms can exploit production diversities in ways that are not perfectly observable by competitors." In this line of thought, competitors can only make an estimate of each others' marginal costs (Schöne, 2009).

One of the bidders is an integrated generator; a generator that owns (a part of) the merchant interconnector. I denote with parameter γ the proportion of the interconnector firm that the integrated generator owns. Generators are risk-neutral and have private values that are independently and uniformly distributed on the interval $[0,1]$. Bidders are thus, at the outset, symmetrical; they have identical, value distributions that are independent (apart from an identical, common cost component that is common knowledge). I assume that interconnector capacity is sold as one indivisible good.[5] As usual in auctions, the highest bidder wins the good, which reflects that the firm operating the interconnector capacity auctions does not favor the integrated generator. Given its value realization, the integrated generator Y chooses its optimal bid b_Y. In line with the literature, I assume that there exists a continuously differentiable, strictly increasing bidding strategy $b_Y[\cdot]$ that maps the integrated bidder's realized value $v_Y \in [0,1]$ onto its bid $b_Y[v_Y]$. The bidding strategy $b_Y[\cdot]$ has an inverse, $y[\cdot]$, such that $y[b_Y[v_Y]] = v_Y$. Analogously, the optimal bid of an independent generator X, b_X, is determined by its bidding strategy $b_X[\cdot]$ that maps its realized value $v_X \in [0,1]$ onto its bid $b_X[v_X]$. The strategy $b_X[\cdot]$ has an inverse, $x[\cdot]$, such that $x[b_X[v_X]] = v_X$.

2.2 The second-price auction

In a second-price auction where one integrated generator has an ownership share, the integrated generator, when it loses, is not indifferent to the price for which the interconnector capacity is sold (see also Burkart, 1995). When the integrated generator loses, it would like the capacity to be sold for as high a price as possible. This gives the integrated generator an incentive to bid more aggressively. As Proposition 1 shows, this effect is relatively strong even when there is more than one independent generator competing.

Proposition 1: *For any $n \geq 1$, in a second-price auction with n+1 bidders, one integrated bidder who receives a share γ of the auction revenue and n independent bidders, where values are distributed independently and uniformly on [0,1], the independent bidders bid their values, and the integrated bidder bids $b_Y[v] = v + \gamma \frac{1-v}{\gamma+1}$. As a result, with increasing γ for all $n \geq 1$:*

a) *The expected auction revenue, $m^{(n)}[\gamma]$, increases,*

b) *The expected profit of Y, $\pi_Y^{(n)}[\gamma]$,increases,,*

c) *The expected profit of X_i, $\pi_{X_i}^{(n)}[\gamma]$, decreases for all i,*

d) *Efficiency, $W^{(n)}[\gamma]$, decreases,*

e) *The profit from optimizing total profits (bidder profit and γ times auction revenue) increases relative to optimizing the profit of only the bidder*

$$\pi_{Y\,strategic}^{(n)}[\gamma] = \pi_Y^{(n)}[\gamma] - \left(\pi_{X_i}^{(n)}[0] + \gamma m^{(n)}[0]\right).$$

Proof: *See Appendix.*

[5] Generators are usually not symmetric, and transmission capacity is usually not sold as one indivisible good, but as multiple units. Also the assumption of a uniform distribution of costs is a simplification. These simplifying assumptions serve to focus the analysis on the effect of an ownership share, and likely do not affect the qualitative results.

The intuition for Proposition 1 is as follows. Independent generators bidding their own bid in a second-price auction is a standard result.[6] The profit function for the integrated generator Y is given by[7]

$$1)\quad \pi_Y^{(n)}[b_Y, v_Y] = \Pr[Y \text{ wins}] \cdot (v_Y - (1-\gamma) \cdot \mathbf{E[\text{highest bid from n bidders | Y wins}]})$$

$$+\gamma \cdot \Pr[Y \text{ has } 2^{\text{nd}} \text{ highest bid}] \cdot \boldsymbol{b_Y}$$

$$+\gamma \cdot \sum_{i=3}^{n+1} \Pr[Y \text{ has i}^{\text{th}} \text{ highest bid}] \cdot \mathbf{E[\text{2nd highest bid from n - 1 bidders | Y has i}^{\text{th}}\text{highest bid}]}$$

The parts in bold in this equation are the expected payments for each case. The first line gives the part of the profit in case Y wins; Y then receives its value v_Y minus the money it must pay that it does not receive back through its ownership of the interconnector; this is equal to $1-\gamma$ times the highest expected bid from the *n* competing independent bidders. The expression in the second line gives the part of the auction revenue Y receives in case it has the 2nd highest bid. In this case, Y loses the auction and sets the price to be paid by the winner of the auction; Y thus receives the ownership share γ times its bid b_Y. The expression in the third line gives the expression in case Y has a bid lower than the 2nd highest bid and thus Y loses the auction and does not set the price. When Y has the *i*th highest bid (with $3 \le i \le n$), the expected payment by the winner is the 2nd highest bid from the (*n*-*i*) bidders that have a higher bid than Y. The total expected profit for Y in this case is thus its ownership share γ times the summation of the probability of Y having the (*i*+1)th highest bid times the expected 2nd highest bid from the (*n*-*i*) bidders.

Having more independent bidders participating in the auction has opposing effects on the bidding function of the integrated bidder Y. On the one hand, having more bidders lowers the risk for the integrated bidder Y to win the auction with a bid higher than its value (the first line in the equation), and thus gives Y an incentive to bid more aggressively. On the other hand, having more independent bidders lowers the probability that Y will be setting the price by having the 2nd highest bid (the second line in the equation), and thus gives Y an incentive to bid less aggressively. Interestingly, for values being independent and uniformly distributed the two opposite effects cancel out, and the integrated bidder Y chooses an identical bidding function for any number of competing independent bidders: $b_Y[v_Y] = v_Y + \gamma \frac{1-v_Y}{\gamma+1}$. Figure 1 illustrates the bidding by the integrated bidder and the independent bidders.

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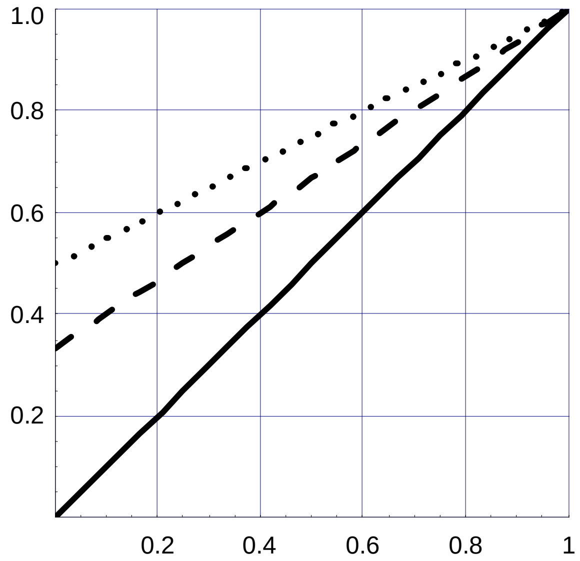
6 See, for example, Krishna (2002).

7 An identical, fixed, commonly known value component *R* in addition to the random private values does not change the bidding behavior of any of the buyers. Imagine that all buyers have an extra identical, fixed, commonly known value component *R* (for example, gas prices fall and lower the cost of generating electricity identically for all generators). In that case the profit function of integrated generator Y, $\tilde{\pi}[b_Y, v_Y]$ is different from the profit function in equation 1; the value of Y, and the bids of all independent generators – who bid their value – are higher by *R*. Because *R* is a constant it can be taken out of the expectations operator and as a result $\tilde{\pi}[b_Y, v_Y] = \pi[b_Y, v_Y] + \gamma R$, which implies that $\frac{d\tilde{\pi}[b_Y, v_Y]}{db_Y} = \frac{d\pi[b_Y, v_Y]}{db_Y}$.

Figure 1: The bidding function of integrated bidder Y in second-price auctions.



••• bidding function of Y when $\gamma = 1$

-- bidding function of Y when $\gamma = 0.5$

— bidding function of Y when $\gamma = 0$

As a result of its aggressive bidding, the auction revenue increases (Prop. 1a). Notably, for an auction with two bidders (thus with one competing independent bidder) and $\gamma = 1$, the auction revenue is equal to $\frac{11}{24}$,[8] which is different from the auction revenue in a first-price auction shown below. Also, the total profit of the integrated bidder (the profit of its generation activity plus its share of the auction revenue) is higher (Prop. 1b). The profit of each independent bidder X_i is now lower, X_i is less likely to win, and if it wins, it pays a higher price (Prop. 1c). The auction is now inefficient because there are some cases where Y wins without having the highest value. The more aggressively Y bids, the more often this happens, and thus efficiency decreases further (Prop. 1d). The last expression (Prop. 1e) shows that the strength of the incentive for Y to bid more aggressively increases in its ownership share γ.[9] The strength of this incentive, which I call the "strategic profit", is the difference in profits between using a strategy of maximizing total profits (generator profits and γ times auction revenue) and of using a strategy (which I call the naïve strategy) of maximizing the profit of only the generator. The strategic profit is thus given by $\pi^{(n)}_{Y\,strategic}[\gamma] = \pi^{(n)}_{Y}[\gamma] - \left(\pi^{(n)}_{Y}[0] + \gamma m^{(n)}[0]\right)$. The first expression is its profit when maximizing total profits and the second part is its profit when maximizing only the profit of the generator.

8 This result can be obtained for $n = \gamma = 1$ by using the formula in the proof of Proposition 1b on page 16 in the Appendix.

9 This is an important indicator for external validity of the model; experimental evidence has shown that the strength of incentives is important for theoretical predictions to show in real settings (Hertwig & Ortmann, 2001; Smith & Walker, 1993).

Figure 2: Outcomes in second-price auctions with one independent bidder.

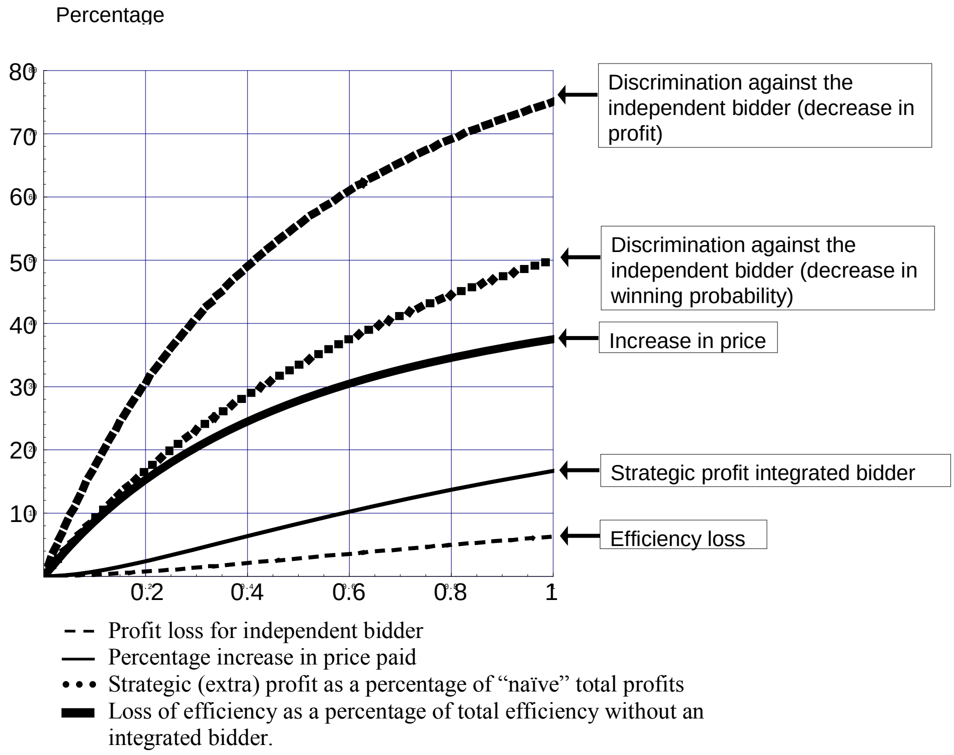
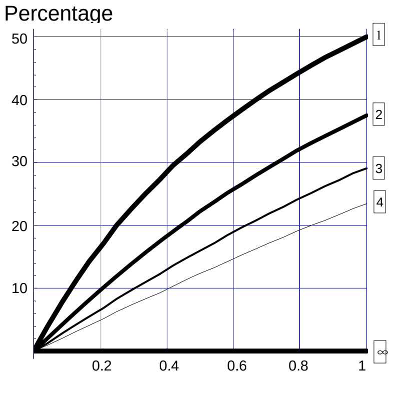


Figure 2 shows the effect of ownership share on auction outcomes when the integrated bidder competes with one independent bidder. The price of the interconnector capacity is strongly affected; it can increase by up to 37.5%. The gain for the integrated generator given by the strategic profit[10] is also considerable; an integrated generator can, by bidding more aggressively, increase its profit by up to 16.7%. This is a mixed blessing. The increase of profitability makes a merchant interconnector project more attractive ex-ante, and this can thus be expected to boost investment in interconnectors, alleviating the severe shortage of interconnectors.

[10] The strategic profit percentage is calculated as $\frac{\pi_{Y\ Strategic}}{\bar{\pi}_{Y\ Naïve}}$.

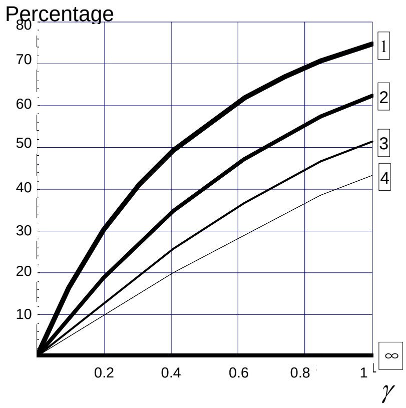
Figure 3: Outcomes in second-price auctions with 1, 2, 3, 4, and ∞ independent bidders.

a) Discrimination winning



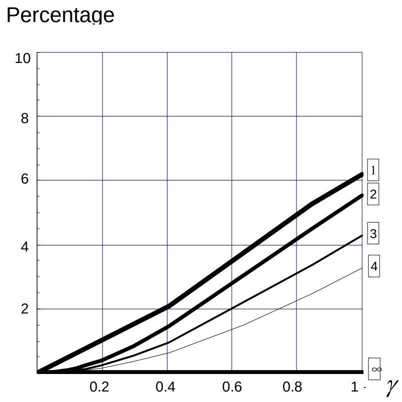
Relative loss in winning probability for each competing independent bidder X

b) Discrimination profit



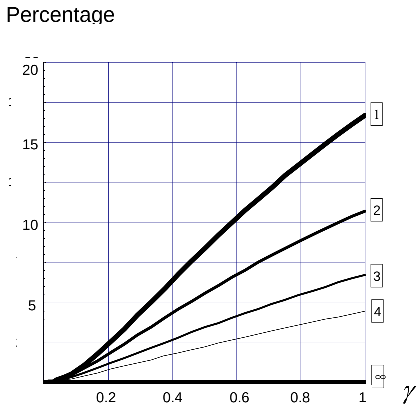
Relative loss in profit for each competing independent bidder X

c) Inefficiency



Loss in efficiency

d) Profitability boost



The increase of profitability as given by the strategic profit as a percentage of the naïve profit

There is, however, also a considerable efficiency loss,[11] up to 6.25%. Moreover, the independent generators experience strong discrimination, both in the probability that they win the auction and in their expected profitability. As can be seen in Figure 2 the probability of the independent bidder winning decreases by up to 50%. Not only do independent generators win less often, but when they win, they make less profit. Figure 2 shows that the decrease in profit can be up to 75%. Also at moderate levels of ownership integration discrimination is considerable; even with an ownership share of only 50%, the independent generator has a probability of winning that is lower by 35% and a profit that is lower by 56%. The ownership of the merchant interconnector thus leads to outcomes that violate the requirement of the regulator for the merchant interconnector to provide non-discriminatory allocation of capacity.

Figure 3 shows that when the number of competing independent bidders goes to infinity all effects disappear, thus perfect competition in the generation markets would eradicate these effects. With more

[11] The efficiency loss percentage is calculated as $\frac{W[0]-W[\gamma]}{W[0]}$, which is equal to $\frac{25\gamma^2}{(1+\gamma)^2}$.

realistic numbers in the electricity market, however, effects are strong. The discrimination effect of integrated ownership is remarkably strong. Graph (a) shows the loss in expected probability of winning for each competing independent generator, which is high — between 39% and 29% — with as many as two or three competitors. As shown in Graph (b), with one competing generator the loss in profit can be as high as 75%. With two competing independent generators, each of them has a decrease in profits of up to 62.5%. Even with as many as three competing independent generators, a rather generous assumption as the markets for electricity generation are rather concentrated in the EU,[12] each has a decrease in profits of up to 52%. Even for a moderate ownership share the discrimination effect is rather strong; for example when γ=0.5, each independent generator experiences a decrease in expected profits of 34% with three competing independent generators, and 65% with one competing independent generator. Graph (c) shows the loss in efficiency, which represents a considerable social loss. Remembering that strategic profit is the extra profit over naïve profit derived from ownership, Graph (d) shows the strength of incentives for Y to bid more aggressively as given by the strategic profit as a percentage of the naïve profit. The incentive is considerable for reasonable values of the ownership share and the number of competing independent generators; when the ownership share is above γ=0.5, and there are no more than two independent generators, then Y can increase its profit by 5.6% or more.

2.3 The first-price auction

In this section, I will analyze the effect of ownership integration in first-price auctions.[13] When Y fully owns the interconnector, a general result can be established for first-price auctions. Remarkably, Proposition 2 shows that Y bids as if taking part in a second-price auction.

Proposition 2: *When the values of X and Y, v_X and v_Y, are independently distributed without any further restrictions on the possible distribution, then when the integrated bidder Y, receives the full auction revenue such that $\gamma = 1$, Y bids its own value in a first-price auction.*

Proof: *See appendix.*

To further analyze the bidding functions of X and Y, I assume that the values of X and Y, v_X, v_Y, are independently and uniformly distributed on [0,1]. In first-price auctions, the expected profit of Y is given by:

1) $\pi_Y[b_Y] = \Pr[\text{Y wins}] \cdot E[v_Y - (1-\gamma)b_Y \mid b_Y > b_X] + \gamma(\Pr[X \text{ wins}]) \cdot E[b_X \mid b_Y < b_X]$.

The first part of Equation 1 is the probability that Y wins times its expected profit in that case; this profit is equal to the value of the good on auction minus its bid plus the part of the bid it "pays to itself" through its ownership of the merchant interconnector, altogether $v_Y - (1-\gamma)b_Y$. The second part is the probability that Y loses times its expected profit in that case; this profit is equal to the ownership share times the payment by X, γb_X. Y wins the auction with bid b_Y when the bid of X is lower, $b_X[v_X] < b_Y$. Applying the inverse bidding function $x[\cdot] \equiv b_X^{-1}[\cdot]$ on both sides of the equation gives $v_X < x[b_Y]$. Y thus wins for value realizations of X with $v_X < x[b_Y]$. Equation 1 can then be written as

2) $\pi_Y[b_Y] = \int_0^{x[b_Y]} (v_Y - (1-\gamma)b_Y) dz + \gamma \int_{x[b_Y]}^1 b_X[z] dz$.

[12] The average Hirsch-Herfindahl Index (HHI) for the old (West-European) EU members in 2006 was equal to 3786, which is close to the case where three symmetrical firms compete (HHI=3333). The new (Central- and East European) EU members had in 2006 a HHI equal to 5558, which is closer to the case where two symmetrical firms compete (HHI=5000) (Van Koten & Ortmann, 2008).

[13] In a first-price auction the highest buyer wins and pays its own bid.

Solving the first integral and substituting $v_X \equiv x[b_Y]$ in the second integral and integrating by parts results in

3) $$\pi_Y[b_Y] = x[b_Y]\left(v_Y - \left(1-\gamma\right)b_Y\right) + \gamma\left(\bar{b} - b_Y \cdot x[b_Y] - \int_{b_Y}^{\bar{b}} x[q]dq\right),$$

where $\bar{b}$ is the maximum bid.

To determine the first-order condition for profit maximization for Y, differentiate equation (3) with respect to b_Y, set it equal to zero and substitute $y[b_Y] \equiv b_Y^{-1}[b_Y]$ for v_Y:

4) $$(y[b_Y] - b_Y)x'[b_Y] = (1-\gamma)x[b_Y].$$

The profit maximization problem for X is identical to that for Y with the ownership share set to zero, i.e. $\gamma = 0$, therefore the first-order condition for profit maximization for X is:

5) $$(x[b_Y] - b_Y)\cdot y'[b_Y] = y[b_Y].$$

When $\gamma = 0$, the problem is symmetrical for X and Y and both have bidding function $b[v] = \frac{1}{2}v$. Under full ownership, when $\gamma = 1$, Y bids its value, and thus, using (5), X bids $b_X[v_X] = \frac{1}{2}v_X$. The more aggressive bidding by Y has several interesting effects on price, competition, profits and efficiency. Proposition 3 summarizes the main effects.

Proposition 3: *In a first-price auction with one competing independent bidder X and an integrated bidder Y who has full ownership, $\gamma = 1$, bids its value, while the independent bidder bids $b_X[v_X] = \frac{1}{2}v_X$. As a result of the more aggressive bidding of Y,*

a) The expected profit of Y, $\pi_Y[\gamma]$, increases,

b) The expected auction revenue, $m[\gamma]$, increases,

c) The expected profit of X_i, $\pi_{X_i}[\gamma]$, decreases,

d) Efficiency, $W[\gamma]$, decreases,

e) The strategic profit – the extra profit that can be earned by bidding more aggressively – increases relative to optimizing the profit of only the generator..

Proof: *See Appendix.*

Quantitatively, with Y bidding its value, its profit is equal to the auction revenue. Furthermore, the auction revenue increases by 62.5% from $\frac{1}{3}$ to $\frac{13}{24}$, the profit of X falls by 50% from $\frac{1}{6}$ to $\frac{1}{12}$, efficiency falls by 4.2% from $\frac{2}{3}$ to $\frac{15}{24}$, and the strategic profit increases from 0 to $\frac{1}{24}$. Interestingly, the auction revenue when Y has full ownership is different in a first-price auction than in a second-price auction.

Corollary 1: *Revenue equivalence between first and second-price auctions does not hold.*

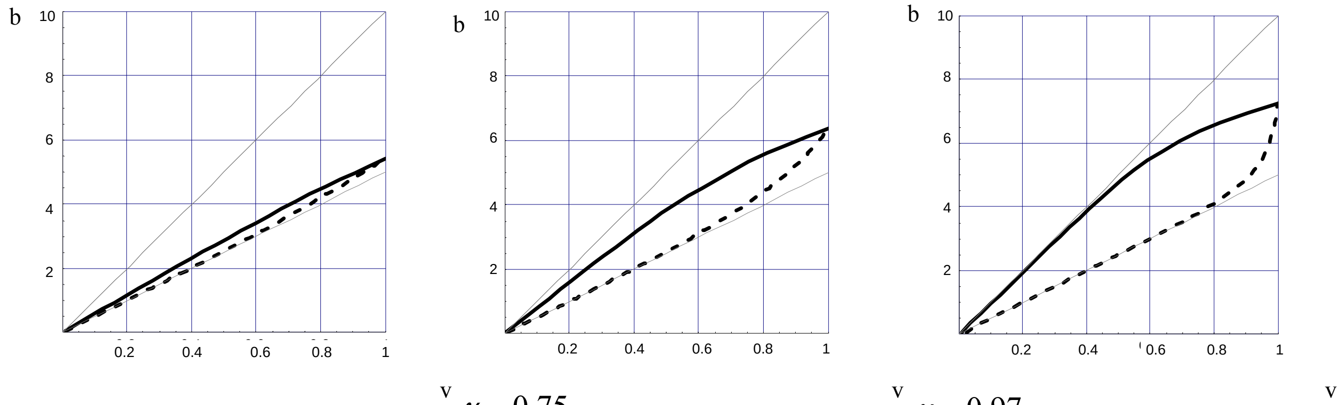
Proof: *See appendix.*

Outcomes for $\gamma : 0 < \gamma < 1$ lie in between the extremes of no ownership, $\gamma = 0$, and full ownership, $\gamma = 1$. Equations (4) and (5) can be solved numerically for $x[b_Y]$ and $y[b_Y]$ for $\gamma : 0 < \gamma < 1$.[14] Figure 3 shows numerical approximations of the bidding functions for $0 < \gamma < 1$.[15]

[14] To my best knowledge there exists no explicit analytical solution for the bidding function in first-price auctions with $\gamma : 0 < \gamma < 1$. Proposition 4 in the Appendix lays out the necessary restrictions that the bidding strategies must fulfill.

The bidding functions in Figure 4 demonstrate that an increased ownership share in the interconnector in the integrated bidder Y bidding more aggressively. Y maximizes profits given by $\Pr[Y\,\text{wins}\,|\,b_Y]\cdot(v_Y-(1-\gamma)b_Y)+\Pr[X\,\text{wins}\,|\,b_Y]\cdot(\gamma b_X)$. A higher ownership share, $\gamma>0$, increases the gain of winning, $v_Y-(1-\gamma)b_Y$. This gives Y the incentive to sacrifice a part of this gain by bidding stronger and increasing its probability of winning. This incentive is partly countered by the income Y earns when it loses; the ownership share times the bid of X, γb_X. All in all, Y bids stronger. The stronger bidding by Y lowers the profits of X, $\Pr[X\,wins\,|\,b_Y]\cdot(v_X-b_X)$, by lowering the probability of X winning the auction. This gives X the incentive to sacrifice a part of its earnings by bidding stronger and increasing its probability of winning.

Figure 4: the bidding functions for independent bidder X and integrated bidder Y in first-price auctions.



$\gamma=0.3$
$\bar{b}\approx 0.542$

$\gamma=0.75$
$\bar{b}\approx 0.637$

$\gamma=0.97$
$\bar{b}\approx 0.725$

— bidding function Y
- - bidding function X
— bidding functions X and Y when $\gamma=1$

3. Conclusion

My analyses suggest that an integrated generator, a generator that owns a merchant interconnector and thus receives the auction revenues of the capacity allocation, bids more aggressively. Consequently, the profit of the integrated generator increases at the expense of an independent generator, thus curbing competition and causing efficiency losses. The aggressive bidding also drives up the price of the interconnector capacity. The results are relevant for EU electricity markets when merchant

(Contd.)

15 Note that there is a discontinuity at $\gamma=1$. If and only if $\gamma=1$, then bidding $b_Y=v_Y$ is a weakly dominant strategy for Y. Suppose $\gamma=1-\delta$ (for small $\delta>0$), then if X sticks with its strategy $b_X=\frac{1}{2}v_X$, Y would still bid its value as long as $v_Y<\frac{1}{2}$, to ensure that X wins when X has a bid higher than the value of Y. For $v_Y\geq\frac{1}{2}$, the bid of X cannot be larger than the value of Y, and bidding its value has thus no gain anymore for Y, but carries a cost as Y now pays a fraction δ of its bid. Y therefore bids $b_Y=\frac{1}{2}$ for $v_Y\geq\frac{1}{2}$, thus creating a mass point. However, this would create an incentive for X to overbid Y whenever its value is larger ($v_X>\frac{1}{2}$). Therefore, once $\gamma<1$, bidding $b_Y=v_Y$ cannot be an equilibrium strategy for Y. For an equilibrium in pure strategies to exist at all when $\gamma<1$, the bidding functions of X and Y must have the same bid for $v_Y=v_X=1$. This is the case in the strategies shown in Figure 3; there are no mass points, and the density of Y's bids is continuous, excluding the possibility for X to improve its profits by deviating from its strategy.

interconnectors are allowed to keep the auction revenues in full, but are obliged to allocate the capacity non-discriminatory by explicit auction.[16]

There are a few possible solutions to remedy the negative results found in this analysis. Firstly, a regulator could set a cap on the amount of capacity the generator can win. This would make it impossible for the integrated generator to bid for capacity above its allotment and thus for such capacity the discrimination and inefficiency effects found above would not occur. It may, however, be difficult to determine the optimal cap. Secondly, a regulator could insist that all generators in a country participate in an merchant interconnector project. Ettinger (2002) has analyzed such a setup and finds that in this case there is no discrimination and no efficiency loss. Giving equal shares thus provides a solution but makes the realization of the merchant interconnector project dependent on the cooperation between generators. Thirdly, the regulator could cap the revenues or shorten the period over which investors are allowed to keep the revenues, and thus compensate for the increased expected profitability. While such restrictions do not eliminate the discrimination and inefficiency effects, a limit on the period that investors are allowed to keep the profits (such as 20 or 25 years) also puts a limit on the accrued losses due to the discrimination and efficiency effects. In the light of the severe shortage of interconnector capacity in the EU, these accrued losses may be minor relative to the welfare increase of the interconnector being built at all.

[16] The results may be relevant for certain regulated interconnector projects, as OFGEM (2010) has indicated to consider using incentives for these projects. If a TSO may keep a part of the profits of an interconnector and the TSO is still integrated with a generator company, than the same type of analysis as developed above applies.

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5. Appendix

Proposition 1: *For any $n \geq 1$, in a second-price auction with n+1 bidders, one integrated bidder who receives a share γ of the auction revenue and n independent bidders, where values are distributed independently and uniformly on [0,1], the independent bidders bid their value, and the integrated bidder bids $b_Y[v_Y] = v_Y + \gamma \frac{1-v_Y}{\gamma+1}$. As a result, with increasing γ for all $n \geq 1$:*

a) *The expected profit of Y, $\pi_Y^{(n)}[\gamma]$, increases,*

b) *The expected auction revenue, $m^{(n)}[\gamma]$, increases,*

c) *The expected profit of X_i, $\pi_{X_i}^{(n)}[\gamma]$, decreases,*

d) *Efficiency, $W^{(n)}[\gamma]$, decreases,*

e) *The profit of optimizing total profits (generator profits and γ times auction revenue) increases relative to optimizing the profit of only the generator.*

Proof: *Independent bidders bidding their own bid in a second-price auction is a standard result.*[17] *The profit function for the integrated bidder Y is given by*

$$\pi_Y^{(n)}[b_Y, v_Y] = \Pr[Y \text{ wins}] \cdot (v_Y - (1-\gamma) \cdot \mathbf{E[highest\ bid\ from\ n\ buyers\ |\ Y\ wins])}$$
$$+ \gamma \cdot \Pr[Y \text{ has } 2^{\text{nd}} \text{ highest bid}] \cdot \boldsymbol{b_Y}$$
$$+ \gamma \cdot \sum_{i=3}^{n+1} \Pr[Y \text{ has i}^{\text{th}} \text{ highest bid}] \cdot \mathbf{E[2nd\ highest\ bid\ from\ n-1\ bidders\ |\ Y\ has\ i^{th}\ highest\ bid]}$$

The parts in bold in this equation are the expected payments for each case. Writing out $\pi_Y^{(n)}[b_Y, v_Y]$, filling in the probabilities and expected values, taking into account that values are uniformly distributed on the interval [0,1,] and that independent bidders bid their own value, results in the following expression:

$$\pi_Y^{(n)}[b_Y, v_Y] = b_Y^n \left(v_Y - (1-\gamma) \frac{1}{b_Y^n} \int_0^{b_Y} n z^{n-1} z dz \right)$$
$$+ j \left(n b_Y^{n-1} (1-b_Y) b_Y \right)$$
$$+ j \sum_{i=2}^{n} \left(\frac{n!}{(n-i)!i!} b_Y^{n-i} (1-b_Y)^i \int_{b_Y}^{1} \frac{i(i-1)(1-z)(z-b_Y)^{i-2}}{(1-b_Y)^i} z dz \right).$$

In the first line, the probability of Y winning with bid b is equal to b_Y^n and the expected price is equal to $\frac{1}{b_Y^n} \int_0^{b_Y} n z^{n-1} z dz$, where $n z^{n-1}$ is the probability distribution function of the highest value of the n

[17] See, for example, Krishna (2002).

independent bidders. In the second line, the probability of Y having the 2nd highest bid is equal to $nb_Y^{n-1}(1-b_Y)$*, and the payment by the winner of the auction is the bid b of Y. In the third line, the probability of Y having the* i*th highest bid (*$3 \le i \le n$*) is equal to* $\frac{n!}{(n-i)!i!} b_Y^{n-i}(1-b_Y)^i$*, and the expected 2nd highest bid of n-i bidders is equal to* $\int_{b_Y}^{1} \frac{i(i-1)(1-z)(z-b_Y)^{i-2}}{(1-b_Y)^i} zdz$*, where* $i(i-1)(1-z)(z-b_Y)^{i-2}$ *is the probability distribution function of the 2nd highest value of n-i independent bidders. Solving the integrals in the first and third line, and collecting the elements multiplied with the ownership share* γ *gives the following expression:*

1) $\pi_Y^{(n)}[b_Y, v_Y] = b_Y^n v_Y - \frac{n}{n+1} b_Y^{n+1} + \gamma \left(\frac{n}{n+1} b_Y^{n+1} + nb_Y^{n-1}(1-b_Y)b_Y + \frac{n-1}{n+1}(1-(n+1)b_Y^n + nb_Y^{n+1} \right),$

where $\frac{n}{n+1} b_Y^{n+1}$ *is the expected price Y must pay when it wins and* $\frac{n-1}{n+1}(1-(n+1)b_Y^n + nb_Y^{n+1}$ *is the s expected payment when Y has a bid lower than the 2nd highest bid (the third line in the above equation). Differentiating the equation with respect to b, setting it equal to zero, and solving for b results in a bidding function given by* $b[v_Y] = v_Y + \gamma \frac{(1-v_Y)}{\gamma+1}$*. Differentiating* $\pi_Y^{(n)}[b_Y, v_Y]$ *twice and substituting* b_Y *with* $b[v_Y] = v_Y + \gamma \frac{(1-v_Y)}{\gamma+1}$ *gives* $\frac{d^2\pi_Y^{(n)}[b_Y, v_Y]}{(db_Y)^2} = -(1+\gamma)n\left(\frac{j+v_Y}{j+1}\right)^{n-1} < 0$*, which establishes that the found bidding function is a global optimum. The inverse bidding function* $y[\cdot]$ *such that* $y[b[v_Y]] = v_Y$ *is given by* $y[b_Y] = (1+\gamma)b_Y - \gamma$*.*

As a result, with increasing γ*, for all* $n \ge 1$*:*

a) The expected profit of Y, $\pi_Y^{(n)}[\gamma]$ ***,increases.*** *The expected profit of Y,* $\pi_Y^{(n)}[\gamma] = \frac{1}{(n+1)(n+2)}\left\{1+\gamma\left(n^2+n+\gamma-\gamma(\tfrac{\gamma}{1+\gamma})^n\right)\right\}$*, can be found by substituting* b_Y *with the optimal bidding function* $b_Y[v_Y] = v_Y + \gamma \frac{1-v_Y}{\gamma+1}$ *in equation 1 above, and integrating over the value realizations of Y from 0 to 1:* $\pi_Y^{(n)}[\gamma] = \int_0^1 \frac{(z+\gamma)^{n+1}}{(n+1)(1+\gamma)^n} + \gamma\frac{n-1}{n+1} dz$*.*

b) The expected auction revenue, $m^{(n)}[\gamma] = \frac{1}{(n+1)(n+2)(1+\gamma)^{n+1}}\left\{(1+\gamma)^{n+1}\left(n^2+n+2\gamma\right) - \gamma^{n+1}\left(n+2\gamma+2\right)\right\}$***, increases.*** *The expected payment by Y,* $m_Y^{(n)}[\gamma]$*, is equal to the bolded portion of the first line of equation (1) (the case that Y* *wins the auction, in other words, equal to equation (1) with* $v_Y = 0$ *and* $\gamma = 0$*), substituting* b_Y *with the optimal bidding function* $b_Y[v_Y] = v_Y + \gamma \frac{1-v_Y}{\gamma+1}$*, and integrated over the value realizations of Y from 0 to 1:* $m_Y^{(n)}[\gamma] = \int_0^1 \left(\frac{n}{n+1} b_Y^{\,n+1} \right) dv_Y = \frac{n}{(n+1)(n+2)(1+\gamma)^{n+1}} \left((1+\gamma)^{n+2} - \gamma^{n+2} \right)$.

The expected payment by all independent bidders together is equal to the second and third line of equation (1) (in other words, equal to equation (1) with $v_Y = 0$ *and* $\gamma = 1$*), substituting* b_Y *with the optimal bidding function* $b_Y[v_Y] = v_Y + \gamma \frac{1-v_Y}{\gamma+1}$*.The expected payment by a independent bidder i* ($1 \le i \le n$)*,* $m_{X_i}^{(n)}[\gamma]$*, is thus equal to this expression divided by the number of independent bidders, n,*

$$m_X^{(n)}[\gamma] = \tfrac{1}{n} \int_0^1 \left(n b_Y^{\,n-1} (1-b_Y) b_Y + \frac{n-1}{n+1} (1-(n+1) b_Y^{\,n} + n b_Y^{\,n+1} \right) dv_Y \, .$$

The expected auction revenue, $m^{(n)}[\gamma]$*,is equal to these expected payments added for all participants, thus* $m^{(n)}[\gamma] = n \cdot m_X^{(n)}[\gamma] + m_Y^{(n)}[\gamma]$*, which is equal to*

$$m^{(n)}[\gamma] = \tfrac{1}{(n+1)(n+2)(1+\gamma)^{n+1}} \left\{ (1+\gamma)^{n+1} \left(n^2 + n + 2\gamma \right) - \gamma^{n+1} \left(n + 2\gamma + 2 \right) \right\}.$$

c) The expected profit of X_i***,*** $\pi_{X_i}^{(n)}[\gamma] = \frac{1}{n(n+1)(n+2)(1+\gamma)^{n+1}} \left\{ (1+\gamma)^{n+1} \left(n - 2\gamma \right) + \gamma^{n+1} \left(n + 2\gamma + 2 \right) \right\}$, ***decreases.*** *The expected profit of* X_i *is equal to its expected value minus its expected payment, thus* $\pi_{X_i}^{(n)}[\gamma] = v_{X_i}^{(n)}[\gamma] - m_{X_i}^{(n)}[\gamma]$*. The expectation of the value an independent bidder* X_i *assigns to the good when it wins,* $v_{X_i}^{(n)}[\gamma]$*, is equal to the probability of winning times the expected value conditional on winning. The probability of* X_i *winning requires the remaining n-1 independent bidders to have a lower value (the first element in the integral below), and the integrated bidder Y to have a lower bid (the second element in the integral below). Thus:*

$$v_{X_i}^{(n)}[\gamma] = \Pr[X_i \text{ wins}] \cdot E[v \mid X_i \text{ wins}] = \int_{\frac{j}{j+1}}^{1} v_Y^{\,n-1} \cdot y[v_Y] \cdot v_Y dv_Y \, .$$

Note that the integration runs from $\frac{\gamma}{1+\gamma}$ *to 1, as the value of* X_i *must be higher than the lowest bid of Y, given by* $\frac{\gamma}{1+\gamma}$*. The expected payment of* X_i*,* $m_{X_i}^{(n)}[\gamma]$*, was derived in (b). The expected profit of* X_i*, is then equal to* $\pi_{X_i}^{(n)}[\gamma] = v_{X_i}^{(n)}[\gamma] - m_{X_i}^{(n)}[\gamma]$.

d) Efficiency, $W^{(n)}[\gamma]$***, decreases.*** *Efficiency,* $W^{(n)}[\gamma]=\frac{n+\gamma+1}{(n+1)(n+2)}\left\{n+1+\gamma\left(n-1+(\frac{\gamma}{1+\gamma})^n\right)\right\}$*, can be calculated by summing over profits and auction revenues:*

$W^{(n)}[\gamma]=\pi_Y^{(n)}[\gamma]+(1-\gamma)m^{(n)}[\gamma]+\sum_{i=1}^{n}\pi_{X_i}^{(n)}[\gamma]$*. This expression is decreasing in* γ*.*

e) The profit of optimizing total profits (generator profits and γ ***times auction revenue) increases relative to optimizing the profit of only the generator.*** *The difference between profits when maximizing total profits minus that when maximizing the profit of only the generator is what I call the strategic profit and is given by* $\pi_{Y\,strategic}^{(n)}[\gamma]=\pi_Y^{(n)}[\gamma]-\left(\pi_Y^{(n)}[0]+\gamma m^{(n)}[0]\right)$*. The first part of the expression is the profit when maximizing total profits, as* $\pi_Y^{(n)}[\gamma]$ *includes the ownership share times the auction revenue. The second part is the profit when maximizing only the profit of the generator. In that case, the auction revenue is given by* $m^{(n)}[0]$*, and the profit of Y, which I call the naïve profit, is given by* $\pi_Y^{(n)}[0]+\gamma m^{(n)}[0]$*. Using (a) and (b) for substituting into the strategic profit it can be shown to be increasing in* γ*.*

Proposition 2: *When the values of X and Y,* v_X *and* v_Y*, are independently distributed without any further restrictions on the possible distribution, then when the integrated bidder Y, receives the full auction revenue such that* $\gamma=1$*, Y bids its own value in a first-price auction.*

Proof: *When* $\gamma=1$*, Y receives the full amount of any bid paid. Therefore Y does not have to take bidding costs into account and, regardless of its bid, earns at least* $\min[v_Y,b_X]$*. Now an argument similar to that for truthful bidding in second-price auctions applies. Suppose Y has value* v_Y*. If Y makes a bid lower than its value* $b_Y<v_Y$*, then with a positive probability X wins with a bid* b_X*,which is higher than the bid of Y but lower than the value of Y,* $b_Y<b_X<v_Y$*. In this case Y can guarantee itself a higher profit at no cost by bidding its value,* $b_Y=v_Y$*. A similar argument establishes that Y will not make a bid higher than its value. Hence, Y bids* $b_Y=v_Y$ *and earns* $\max[v_Y,b_X]$

Proposition 3: *In a first-price auction with one competing independent bidder X and an integrated bidder Y who has full ownership,* $\gamma=1$*, bids its value, while the independent bidder bids* $b_X=\frac{1}{2}v_X$*. As a result of the more aggressive bidding of Y,*

a) The expected profit of Y, $\pi_Y[\gamma]$*,increases,*

b) The expected auction revenue, $m\ [\gamma]$*, increases,*

c) The expected profit of X_i*,* $\pi_{X_i}[\gamma]$*, decreases,*

d) Efficiency, $W\ [\gamma]$*, decreases,*

e) The profit of optimizing total profits (generator profits and γ *times auction revenue) increases relative to optimizing the profit of only the generator.*

Proof: *Proposition 2 established that Y bids its own value,* $b_Y[v_Y]=v_Y$*,and the inverse bidding function of Y is thus* $y[b_Y]=v_Y$*. Substituting for Y in the first order condition as derived at page 10,*

$(x[b_Y]-b_Y)\cdot y'[b_Y]=y[b_Y]$, *results in* $x[b_Y]-b_Y=b_Y$. *The inverse bidding function of the independent bidder X is* $x[b_X]=2b_X$ *and its bidding function is thus given by* $b_X[v_Y]=\frac{1}{2}v_Y$.

a) The expected profit of Y, $\pi_Y[\gamma]$***, increases.*** *In the case of no ownership, it is equal to*

$\pi_Y[\gamma=0]=\frac{1}{6}$. *In the case of full ownership,*

$$\pi_Y[\gamma=1]=\int_0^{\frac{1}{2}} p^{Y\,wins}\left(b_Y\left[v_Y\right]\right)dv_Y+\int_{\frac{1}{2}}^{1} p^{Y\,wins}\cdot\left(b_Y\left[v_Y\right]\right)dv_Y+\left(\int_0^1 p^{X\,wins}\left(b_X\left[v_Y\right]\right)dv_Y\right)$$

$$=\int_0^{\frac{1}{2}} 2v_Y\left(v_Y\right)dv_Y+\int_{\frac{1}{2}}^{1} 1\cdot\left(v_Y\right)dv_Y+\left(\int_0^1 \tfrac{1}{2}v_Y\left(\tfrac{1}{2}v_Y\right)dv_Y\right)$$

$$=\left[\tfrac{2}{3}v_Y{}^3\right]_0^{\frac{1}{2}}+\left[\tfrac{1}{2}v_Y{}^2\right]_{\frac{1}{2}}^{1}+\left(\left[\tfrac{1}{12}v_Y{}^3\right]_0^1\right)$$

$$=\tfrac{13}{24}.$$

Where the probability of Y winning with value v_Y *is given by*

$p^{Y\,wins}[v_Y]=b_X{}^{-1}\circ b_Y[v_Y]=2\cdot v_Y$ *when* $v_Y\le\frac{1}{2}$

$p^{Y\,wins}[v_Y]=1$ *when* $v_Y>\frac{1}{2}$

Once Y has a value higher than $\frac{1}{2}$ *it can be sure of winning as the highest bid of X is* $b_X[1]=\frac{1}{2}$. *The probability of X winning with value* v_X *is given by* $p^{X\,wins}[v_X]=b_Y{}^{-1}\circ b_X[v_X]=\frac{1}{2}v_X$.

b) The expected auction revenue, $m^{(n)}[\gamma]$***, increases. As Y bids and pays its realized value, auction revenue is equal to profit of Y,*** $m\left[\gamma=1\right]=\pi_Y[\gamma=1]=\frac{13}{24}$.

c) The expected profit of X_i***,*** $\pi_{X_i}^{(n)}[\gamma]$***, decreases.*** *In the case of no ownership the expected profit of X is given by* $\pi_X[\gamma=0]=\frac{1}{6}$. *With full ownership, the profit is equal to*

$$\pi_X[\gamma=1]=\left(\int_0^1 P^{X\,WINS}\left(v_X-b_X\left[v_X\right]\right)dv_X\right)$$

$$=\int_0^1 \tfrac{1}{2}v_x\left(\tfrac{1}{2}v_x\right)dv_x=\tfrac{1}{12}.$$

d) Efficiency, $W^{(n)}[\gamma]$***, decreases.*** *In the case of no ownership efficiency is equal to the expected value of the highest out of two signals which is equal to* $W\left[\gamma=0\right]=\frac{2}{3}$. *In the case of full ownership, by* $W\left[\gamma=1\right]=\frac{5}{8}$. *The efficiency is equal to the profits of X and Y together, that is, the full auction revenue is accounted for in the profit of Y, and thus* $W\left[\gamma\right]=\pi_X\left[\gamma\right]+\pi_Y\left[\gamma\right]=\frac{13}{24}+\frac{1}{12}=\frac{5}{8}$.

e) The profit of optimizing total profits (generator profits and γ times auction revenue) increases relative to optimizing the profit of only the generator $\pi^{(n)}_{Y\,strategic}[\gamma] = \pi^{(n)}_{Y}[\gamma] - \left(\pi^{(n)}_{X_i}[0] + \gamma m^{(n)}[0]\right)$**.** *In the case of no ownership the strategic profit is by definition equal to* $\pi_{Y\,Strategic}\left[\gamma = 0\right] = 0$*, and, in the case of full ownership, by* $\pi_{Y\,Strategic}\left[\gamma = 1\right] = \frac{1}{24}$*. Total profits of Y are equal to* $\pi_{Y}[\gamma = 1] = \frac{13}{24}$*,and the naïve profit is equal to* $\overline{\pi}_{Y\,Naïve}\left[\gamma\right] = \pi^{Y}\left[0\right] + \gamma m\left[0\right] = \frac{1}{6} + \frac{1}{3} = \frac{1}{2}$*,thus the difference is equal to* $\pi_{Y\,Strategic}\left[\gamma = 1\right] = \pi^{Y}\left[\gamma = 1\right] - \overline{\pi}_{Y\,Naïve}\left[\gamma = 1\right] = \frac{13}{24} - \frac{1}{2} = \frac{1}{24}$.

Proposition 4: *Given a value of the ownership share,* $\gamma : 0 < \gamma < 1$*, the inverse bidding functions* $x[b]$ *and* $y[b]$ *and the maximum bid* $\overline{b}$ *for all bids* b *can be found by solving the following set of equations:*

4) $(y[b] - b) \cdot x'[b] = (1-\gamma)x[b]$*;*

5) $(x[b] - b) \cdot y'[b] = y[b]$*;*

6) $x[\overline{b}] = y[\overline{b}] = 1$*;*

7) $\overline{b} = \frac{1}{2}\left(1 + \gamma \int_0^{\overline{b}} x[\beta] d\beta\right)$.

Proof: *Equation (4) and (5) are the first-order conditions on p. 10. Equation (6) states that a bidder only makes the maximum bid* $\overline{b}$ *when it has the highest possible value, which is one. This follows from the fact that it is a Nash equilibrium to bid equal or lower than the highest bid. Equation (7) puts a restriction on the maximum bid that can be derived from the fact that a bidder with value 0 bids 0,* $x[0] = y[0] = 0$*, and the first-order conditions (4) and (5). Rewriting (4) and (5) gives*

$$x'[b] \cdot (y[b] - b) = (1-\gamma) \cdot x[b] \Leftrightarrow$$

8) $(x'[b] - 1) \cdot (y[b] - b) = (1-\gamma) \cdot x[b] - y[b] + b$,

$$y'[b] \cdot (x[b] - b) = y[b] \Leftrightarrow$$

9) $(y'[b] - 1) \cdot (x[b] - b) = y[b] - x[b] + b$.

Summing up 8) and 9) gives

$$(x'[b]-1) \cdot (y[b]-b) + (y'[b]-1) \cdot (x[b]-b) = 2b - \gamma x[b] \Leftrightarrow$$

10) $\frac{\partial}{\partial b}(x[b] - b) \cdot (y[b] - ab) = 2b - \gamma x[b]$.

Integrating equation (10) over 0 to the maximum bid $\overline{b}$ *gives*

$$(1-\overline{b}) \cdot (1-\overline{b}) = \overline{b}^2 - \gamma \int_0^{\overline{b}} x[b] \Leftrightarrow$$

7) $\overline{b} = \frac{1}{2}\left(1 + \gamma \int_0^{\overline{b}} x[b]\right)$.

Corollary 1: *Revenue equivalence between first and second-price auctions does not hold.*

Proof: *When Y has full ownership, $\gamma = 1$, then in a first-price auction Y and X have bidding functions $b_Y[v_Y] = v_Y$ and $b_X[v] = \frac{1}{2}v_X$, while in a second-price auction they have $b_Y[v_Y] = \frac{v_Y}{2} + \frac{1}{2}$ and $b_X[v] = v_X$. The expected revenue in a first-price auction can be calculated using the formula derived in Proposition 3b, which results in $\frac{13}{24}$.*

Observe that such high auction revenue cannot be realized in a likewise second-price auction. The highest possible auction revenue possible is equal to $\frac{1}{2}$, and can be realized only by Y bidding aggressively enough to win with probability one (e.g., by bidding one or higher for all its realized values), in which case X loses the auction with probability one and thus the expected second highest price, given by the expected value of X, is equal to $\frac{1}{2}$.

The expected revenue in a second-price auction is given by the formula derived in Proposition 1b in the Appendix, $m_Y^{(n)}[\gamma] = \frac{n}{(n+1)(n+2)(1+\gamma)^{n+1}}\left((1+\gamma)^{n+2} - \gamma^{n+2}\right)$,and substituting n=1 (one competing bidder) and $\gamma = 1$ (full ownership) results in a revenue equal to $\frac{11}{24}$.

6. Notation

γ	$\gamma \in [0,1]$ is the ownership share that the integrated generator holds in the interconnector. The integrated generator therefore receives the portion γ of the auction revenue.
b_i	$b_i \in [0,\bar{b}] \subseteq [0,1]$, with $i \in [X,Y]$, is the officially stated bid offered by a bidder. $\bar{b} \in [0,1]$ is the maximum bid in the auction.
$b_Y[v_Y]$	The optimal bid of the integrated bidder Y given its realized value $v_Y \in [0,1]$. This strategy $b_Y[\cdot]$ has the inverse $y[\cdot]$ (such that $y[b_Y[v_Y]] = v_Y$).
$b_X[v_X]$	$b_X[v_X]$ is the optimal bid of the independent bidder X given its realized value $v_X \in [0,1]$. This strategy $b_X[v_X]$ has the inverse $x[\cdot]$ (such that $x[b_X[v_X]] = v_X$).
$m[\gamma]$	$m[\gamma] = m_Y[\gamma] + m_X[\gamma]$ is the ex-ante expected revenue of the bidder when its ownership share is γ, where $m_Y[\gamma]$ ($m_X[\gamma]$) is the ex-ante expected payment of bidder Y (X) when the ownership share of Y is γ.
v_i	$v_i \in [0,1]$, with $i \in [X,Y]$, is the value of the good on auction for bidder *i*. It is a random variable independently and uniformly distributed on $[0,1]$.

$W[\gamma]$	The expected efficiency.
$\pi^Y[\gamma]$	The expected compound profit of the integrated bidder Y.
$\overline{\pi}_{Y\,Naïve}[\gamma]$	The naïve compound profit of the integrated bidder, $\overline{\pi}_{Y\,Naïve}[\gamma]=\pi_Y[0]+\gamma m[0]$, is the compound profit when the integrated bidder has an ownership share of γ, but bids as if the ownership share is zero (it maximizes its bidder profit ignoring the effect on the auction revenue).
$\pi_{Y\,Strategic}[\gamma]$	The strategic profit, $\pi_{Y\,Strategic}[\gamma]=\pi_Y[\gamma]-\overline{\pi}_{Y\,Naïve}[\gamma]$, is the extra profit that can be made when the integrated bidder Y maximizes the compound profit (bidder *plus* its ownership share times the auction revenue) instead of the naïve profit (only bidder profit).

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