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On the Viability of Energy-Capacity Markets Under Decreasing Marginal Costs

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Abstract

This study undertakes a theoretical analysis of wholesale electricity markets which use uniform-price auctions. We study a model with marginal cost-based regulatory framework where marginal cost of electricity generation is actually decreasing. The energy-capacity wholesale electricity market of the Western Australia (WEM) is analysed for this purpose. Wholesale markets globally like the WEM need to remunerate electricity generators for the recovery of missing money in electricity generation to ensure resource adequacy as wholesale electricity prices also continue to decline. We show that marginal cost-based price regulation under decreasing marginal cost forces electricity generators to shut down as power producers cannot make a positive profit. The switch to average variable cost-based regulation also induces negative profit for electricity generators in some cases. We recommend that a market regulation under a uniform-price auction arrangement should include price caps to mitigate the high prices and volatility. In the long-term, the return to an energy-only market is a viable possibility.

Keywords: electricity markets; regulation; competition; marginal cost.

JEL Classification: L94, L51, D4.

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1 Introduction

Price discovery in liberalised wholesale power markets have relied on the principles of marginal-cost pricing to deliver a cost-effective short-term dispatch of electricity. An hourly or half-hourly spot price should reflect the operating and capital costs of generating, transmitting and distributing electric energy (Schweppe et al. 1988). The market clearing price of wholesale electricity based on marginal cost pricing was assumed to drive the principal decisions regarding power sector investments, electricity production, and electricity distribution and subsequently ensure reliability in power supply (Joskow, 2008). In electricity pools with uniform-price auctions as is the case of many power markets globally; a price-taking electricity generator seeking to maximize its profits is encouraged by the market rules to bid its power supply at its own marginal cost in the wholesale market (Borenstein, 2000). However, bidding at its own marginal cost under a uniform-price auction is not a guarantee that the firm would receive the desired bid price for its power as the market price received is a consequence of equating the entire supply and demand in the spot market auction (for instance, every half hourly or hourly).[1] Thus, a price-taking electricity generator is only willing to sell electricity so long as the market clearing price is above its own marginal cost. The question that then emerges is: How effective is the marginal-cost pricing rule under a uniform electricity auction when the marginal costs of the electricity generation firms are actually decreasing?

Wholesale electricity markets globally are also exposed to the increasing share of intermittent energy sources with low (or near zero) marginal costs of producing electricity questioning the efficacy of the traditional models of optimal pricing and investment based on marginal cost pricing (Joskow, 2019). For instance, wholesale electricity prices are being depressed due to factors such as lower-than-expected demand, historically low natural gas prices, and the adoption of near-zero marginal-cost variable renewable generation (Csereklyei et al. 2019; Bell et al. 2017; Milligan et al. 2017; Hibbard et al. 2017). Thermal generators also have a minimum generation level below which electricity production is not stable implying that production costs between zero and the minimum generation level must be averaged (Economic Regulation Authority, 2019). The increasing share of low cost electricity production in wholesale markets will thus continue to impact price discovery in electricity spot markets such as day-ahead markets and expose these wholesale markets to the sup-

[1]The awarded sales contract to the electricity generator then is equal to the electricity that the firm would generate at its marginal cost which could be less than or equal to the market price. So, the electricity generator will only produce electricity to the point where its marginal cost of production is lower than the market price.

ply security threats as a consequence marginal cost-based pricing (Pikk and Viiding, 2013). This is because depressing of wholesale electricity prices due to growing share of unpredictable generation will not entice entry for new investments as revenues continue to decline for power producers and thereby threatening the long-term energy policy objective of security of supply. Therefore, wholesale market pricing rules should balance the trade-off between short-run operational efficiency delivered by marginal cost-based pricing versus delivering the longer-term energy policies of supply security as wholesale power markets continue to evolve. What should the design of market pricing rules and auctions incorporate to strike such a balance between achieving the short-term and long-term power sector objectives?

Competitive wholesale electricity markets exposed to marginal-cost pricing suffering from a "missing money" problem is also already well known (Hogan, 2013; Hogan, 2017). The 'missing money' concept refers to the under-recovery of the all the costs by the set price, most importantly, the recovery of sunk costs such as capacity costs in the case of electricity generation. The growing share of low-cost intermittent electricity generation in wholesale electricity markets where generators bid at marginal cost will further exacerbate the 'missing money' problem given substantial sunk costs and low marginal running costs resulting in inadequate net revenues (Cramton and Stoft, 2006; Simshauser, 2019). To offset for such full cost non-recovery, some wholesale power markets are characterised by capacity payments (i.e. payments to generators for making the capacity available) as an alternative source of revenue to electricity generators (see Bublitz et al., 2019). The depression of wholesale electricity prices can also be recovered through capacity payments from consumers (Newbery, 2016) and preferably as a lump sum to not perturb the efficiency of market outcomes (Briggs and Kleit, 2013) but may necessitate reforms in capacity markets and scarcity pricing to ensure resource adequacy (Crampton et al. 2013; Joskow, 2019). Therefore, the capacity payments act as subsidies in a market where firms would make a loss without those payments. While it is hard to eliminate the capacity payments, the question is whether the existing regulatory regimes depress prices even further where larger capacity payments are required. In other words, an inefficient regulatory regime results in negative profits even in the short term where electricity generators would not be able to cover their short-term costs.

The purpose of this article is to study the effectiveness of marginal cost pricing and design of optimal pricing rules under a uniform electricity auction arrangement. In particular, we study a market for electricity generation where generators have declining marginal costs and bid for the price of electricity production in a uniform-price auction. We study the benchmark of no regulations as well as two different types of marginal and average variable cost regulatory frameworks. Our results suggest that without regulation in most cases high prices for electricity is observed which is a reasonable justification for regulation. Under the marginal cost regulatory framework firms are not allowed to bid above their short run marginal cost of production. We show under reasonable conditions that the marginal cost regulatory framework results in negative profits in the short-run that would not cover short run costs of firms. Finally, under the average variable costs regulatory framework firms are not allowed to bid above their average variable cost of production. We show under this framework it is possible that some firms make a positive profit. However, firms with larger costs would not be able to make a positive profit in any equilibria.

To our knowledge this is the first theoretical study that considers declining marginal costs for power generators in an energy-capacity market. Our contribution is then to provide firms' optimal strategies when they face different regulatory regimes. We further provide results with regards to market equilibrium prices in different regulatory frameworks. Therefore, our study is novel as we consider the full cost recovery and beyond full cost recovery possibilities such as earning profits by the power plant producers in an energy-capacity market as wholesale electricity prices continue to decline. Furthermore, our results are not only directly applicable to the Western Australia Wholesale Market (WEM) which utilises similar regulatory frameworks, but also important and timely from a global perspective as the findings are relevant to all wholesale electricity markets with or without a separate capacity market. The WEM is a relatively newly established capacity-energy market that commenced operation after deregulation since September, 2006. The distinct feature of the WEM that differentiates this market from the Australian National Electricity Market (NEM) operating in the Eastern jurisdictions of Australia is its capacity market where electricity providers are remunerated for making the capacity available alongside a wholesale market where market participants interact to supply and purchase electricity on every half hourly basis. Capacity payments to electricity generation plants in the WEM occurs under the so-called reserve capacity mechanism (RCM) while the payments are based on predictions of future electricity needs. However, the predicted capacity estimates were too high in the WEM and resulting in overcapacity and higher bills for consumers (Schlandt, 2015). In contrast, the NEM is an energy-only wholesale market design with a uniform-price auction in play and is not the scope of this paper to neither study the NEM and nor compare an energy-capacity market such as WEM with an energy-only market like NEM. We solely focus our analysis to an emerging energy-capacity market which has received little or no attention although the NEM market design extensively features in the energy economics literature (Simshauser and Akimov, 2019; Simshauser, 2018a; Simshauser 2018b; Simshauser, 2017; Nepal and Foster, 2016; Do, Nepal and Smyth, 2020; Valadkhani, Nguyen and Smyth, 2018).

As wholesale electricity prices continue to decline, relevant auction designs and their impact on prices in wholesale electricity markets also merits revisiting. For instance, Bower and Bunn (2001) in the context of England and Wales electricity market showed that the discriminatory auction results in higher wholesale market prices than the uniform-price auction.[2] In contrast, Fabra et al. (2006) showed that uniform auctions result in higher average prices than discriminatory auctions even though the outcomes on productive efficiency also depends on other market design features such as the number of steps in suppliers' bid functions, the duration of bids, and the elasticity of demand. On the other hand, Crampton and Stoft (2007) have echoed that the arguments around uniform-price auction resulting in systematically too high electricity prices as being incorrect and suggest to continue with uniform-price auctions in electricity markets. Uniform pricing is also found to be preferable to discriminatory pricing for wholesale electricity buyers when producers' private signals are involved (Holmberg and Wolak, 2018). Rassenti et al. (2003), however, showed that a "pay-as-bid" or discriminatory price auction solves the problem of volatile wholesale electricity prices even though prices tend to converge with the high wholesale electricity prices observed under a uniform price auction. However, discriminatory auctions are significantly less efficient than uniform price auction under asymmetric information (Abbink et al. 2003). In the case of NEM, Yarrow (2014) argue that uniform auction is preferable to pay-as-bid auctions to deliver short-run economic efficiency although the duration of bids and the possibilities of re-bidding needs to be closely monitored to avoid inefficient outcomes from market power abuse.

The remainder of the paper is structured as follows. Section 2 provides an overview of WEM. Section 3 introduces a preliminary model to consider the important features of the WEM. Section 4 presents the results for a situation with no regulation. Section 5 analyses the marginal cost regulatory framework and Section 6 discusses the average variable cost framework. Finally in Section 7 we provide important policy implications of our findings.

[2] Apart from wholesale electricity, uniform-price auctions have been commonly used in several markets such as emissions permit auctions (Khezr and MacKenzie, 2018). For a discussion about the performance of uniform-price auction versus discriminatory auction see Cumpston and Khezr (2020).

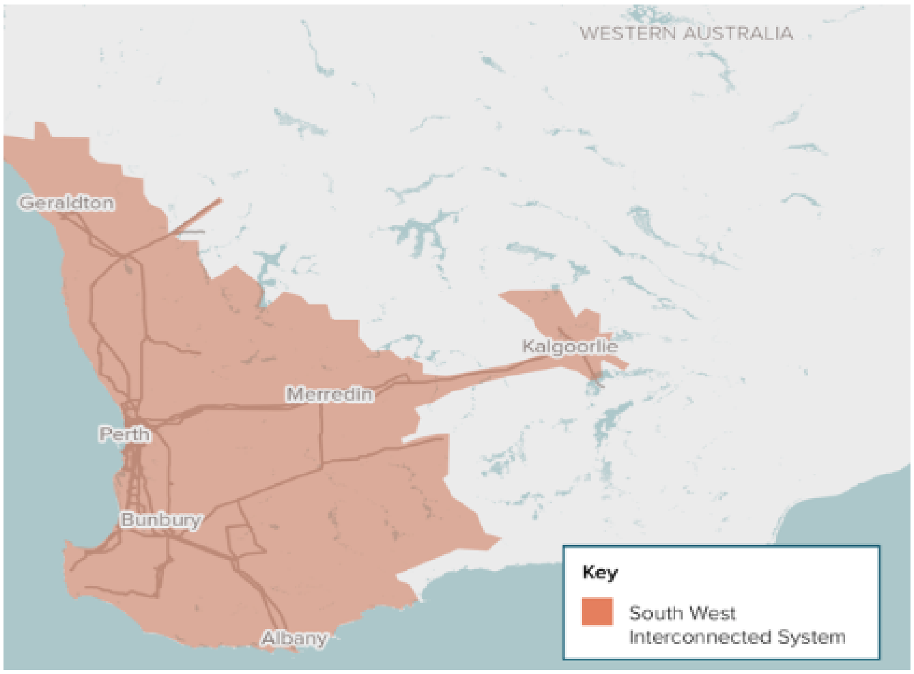
2 An Overview of WEM

The WEM is a wholesale electricity market for the South West Interconnected System of Western Australia (SWIS). The objectives of the market are summarised in the Electricity Industry Act 2004 (Wholesale Electricity Market Rules, 2020). The primary function of the WEM is to sell wholesale electricity within the SWIS between the sellers and buyers consisting of generators and demand side management facilities and retailers and large users respectively. The WEM has around 1.1 million customers (households and businesses) and supplies around 20 Terawatt hours (TWh) of electricity annually (on average) with the SWIS spanning over 7,800 kilometres (kms) of transmission lines and 64,000 kms of distribution lines (AEMO Fact Sheet, 2020). Figure 1 below shows the geographical coverage of the SWIS and is clear that SWIS remains a geographically isolated electricity system. The WEM relies primarily on thermal generation sourced from coal and gas as 90% of electricity generation in 2017 was sourced from coal and gas. The remaining 10% were sourced from renewables in the WEM with wind supplying around 8.5% of electricity. Solar installations are on the rise in the in the state of Western Australia as a whole with 25% of the houses in the SWIS has rooftop solar panels. The SWIS has over 800 MW of installed solar panels making this the single largest electricity generator in the SWIS (AEMO Fact Sheet, 2020). Thus, the WEM is poised for more uptake of renewable and distributed energy sources like wind and solar.

The design for the WEM is unique as the wholesale market comprises a wholesale electricity trading component and a capacity component. The wholesale electricity market design summary captures the important design features of the WEM market while the capacity payments are estimated on the predictions of future electricity needs of the system (Wholesale Electricity Market Design Summary, 2012). The capacity component is based on the Reserve Capacity Mechanism (RCM) which aims to ensure that sufficient generation is available to meet demand at all times. The WEM is a 'summer peaking system', with peak demand around 4,000 MW and average demand around 2,000 MW (AEMO Fact Sheet, 2020). The Australian Energy Market Operator (AEMO) is responsible for operating the wholesale electricity market as per the WEM rules (Wholesale Electricity Market Rules, 2020) and WEM market procedures.

In the next section we start the analysis by providing a preliminary model that mirrors electricity market. We note the following important points to apply the model to the electricity market. First note that electricity is a non-storable product, and demand has to meet with supply at real-time. Demand for electricity is price inelastic and therefore at any given time-frame we deal with a vertical demand. Finally, the

Figure 1: Geographical coverage of WEM



Source: Australian Government (2020)

generation segment of the electricity supply industry is open to competition as a result of market-based reforms but the market concentration is usually high.

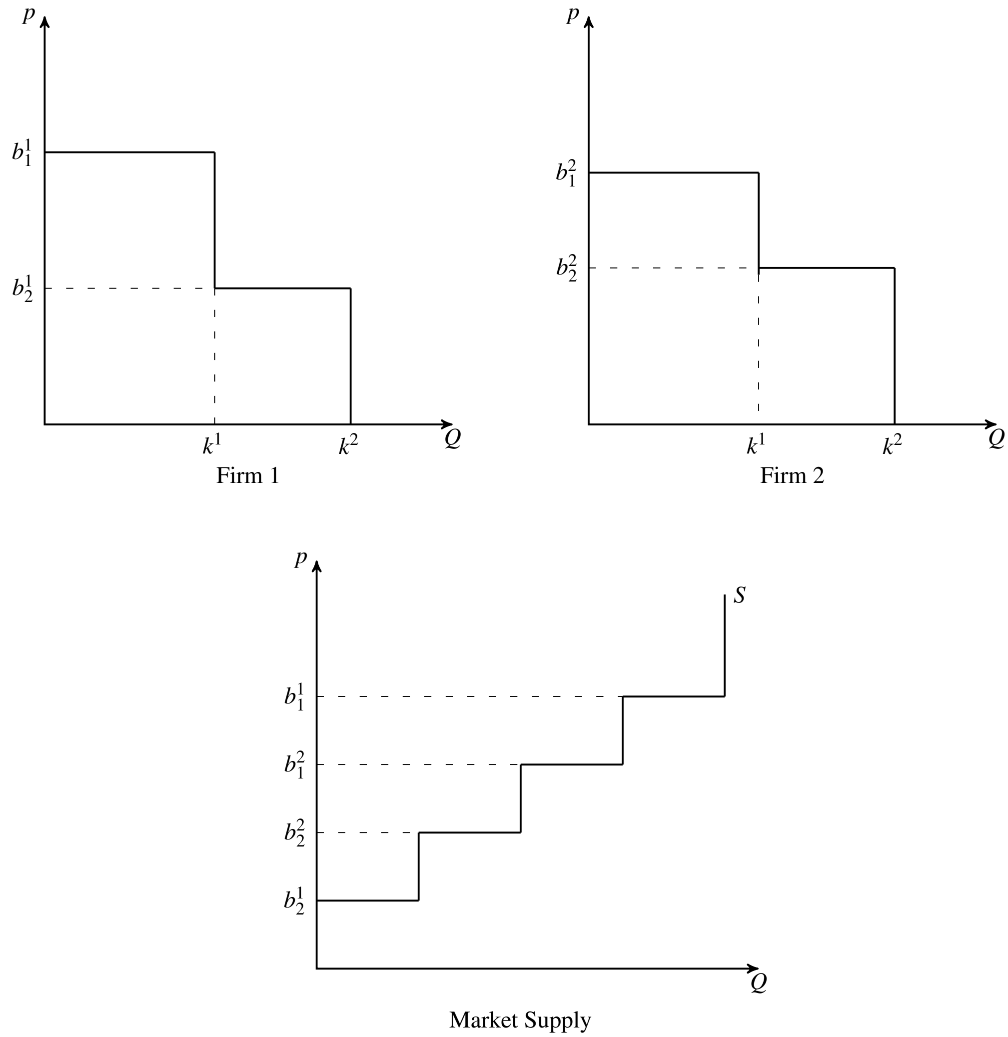
3 Model

Suppose there are two independent electricity generators indexed by $i = 1, 2$ with fixed and equal capacities. We assume that each generator has two production levels. While generator's marginal costs are constant within a production level, they have different marginal costs for every production level. In particular, suppose the marginal cost of firm i for the first and second production levels are c_1^i and c_2^i respectively. We assume firms have decreasing marginal costs for further production levels, that is, $c_1^i > c_2^i$.[3] Further denote v_1^i and v_2^i as firm i's average variable costs with $v_1^i > v_2^i$. Note that since marginal costs are decreasing, average variable costs are

[3]This assumption reflects the fact that generators are built such that their marginal costs decrease when production increases in a step-wise fashion (see ERA, 2019).

also decreasing and larger than the marginal costs at any given level of production. Without loss of generality suppose firm 1 has lower costs than firm 2, that is, $v_1^1 < v_1^2$ and $v_2^1 < v_2^2$. Also the same relation is true for marginal costs. Finally, suppose the costs of the first production level for both firms are larger than those for the second production level.

Figure 2: Firms' bids and the market supply

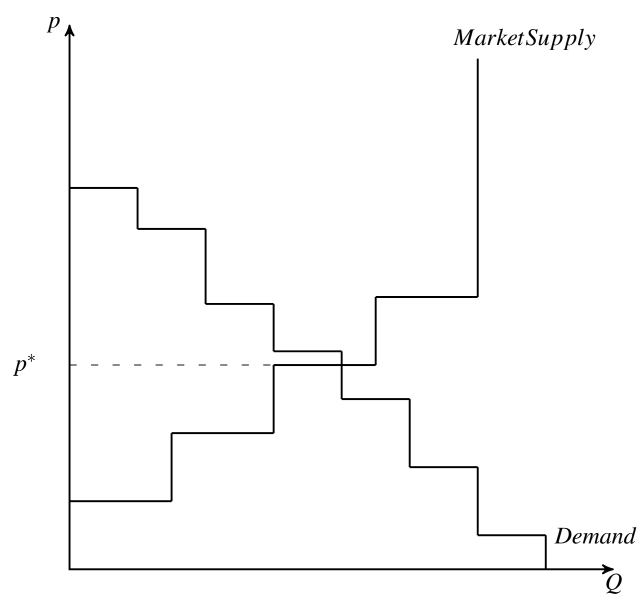


For each firms' capacity denote k^1 and k^2 as the capacity of each production level. The market demand at any time interval t is given by D_t which is perfectly inelastic. Firms compete to supply electricity via a sealed-bid uniform-price auction.

In particular, each firm i submits two bid prices b_1^i and b_2^i, one for each production level respectively, in any given time-frame to supply electricity. The market operator clears the market by starting from the lowest bid price until supply becomes equal to demand. Note that firms may place their bids in a decreasing order, given that their marginal costs are decreasing. However, the market operator clears the bids from the lowest to the highest. Figure 2 illustrates the situation where firms' bids are decreasing but at the market level they are cleared from the lowest to the highest. Also note that firms may submit flat bids, that is, similar amount of bid for both production levels. In that case, the market would have fewer steps and the supply becomes flatter at some of the steps.

The price for all units of electricity is set equal to the highest price of a production level that was supplied. Figure 3 depicts the situation in a supply-demand diagram. In the case that the supply is flat at the margin, there will be excess supply. If there are two firms that bid at this price the market operator chooses one firm to produce randomly. Furthermore, denote $\bar{p}$ as the market cap price for the highest possible price. To avoid exclusion of firms, suppose the market cap $\bar{p}$ is large enough and above the highest average variable cost.

Figure 3: Market clearing rule



We start by studying a case with no regulation and then extend the analysis to two different regulatory regimes, marginal cost and average variable cost regulatory frameworks. The aim is to compare these two regulatory frameworks with each other as well as the benchmark with no regulation to investigate the performance of the market in all situations.

4 No regulation

Suppose there is no regulation in this market and firms are free to submit any bid price in the auction to supply electricity. Similar to Fabra et al. (2006) we consider cases with different quantity of demand D_t relative to the capacity of firms. The following Proposition characterises the equilibrium market clearing prices in all different cases.

Proposition 1.

(i) If $D_t = k^1$, there is a class of equilibria where the market clearing prices range between $p^* \in [v_1^2, \bar{p}]$.

(ii) If $D_t = k^1 + k^2$, there is a class of equilibria where the market clearing price ranges between $p^* \in [\bar{v}^2, \bar{p}]$, where $\bar{v}^2$ is the mean of the average variable costs of firm 2.

(iii) If $D_t > k^1 + k^2$, then the equilibrium market clearing price is always equal to $p^* = \bar{p}$.

Proof. Part (i): When demand is $D_t = k^1$ only one production level will be dispatched. Also firms would not bid below their average variable costs to avoid a negative profit. Firm 1 can guarantee the dispatch of the first production level if they bid equal to the average variable cost of the first production level. Note that since this bid would never set the price for firm 1, they only need to make sure firm 2 cannot underbid it. In this case firm 2 does not have any incentives to bid below v_1^2, because in case they win they will incur a negative profit. Therefore any bid $b_1^1 < v_1^2$ guarantees winning the first production level for firm 1 and the best response of firm 1 is to bid any amount less than v_1^2. The best response of firm 2, although they are not going to win anything, is to bid weakly above v_1^2. For the second production level, firm 1's best response is to bid equal to $\bar{p}$. This is because there's no chance that this bid becomes winner since the demand is low. However, there is a chance that this bid weakly increases the price paid for the first production level. Thus the best response of firm 1 is to raise this bid as much as possible. However, firm 2 is indifferent between bidding any amount as long as it is above v_1^2. Since bids are in decreasing orders, the second bid must be at least as much as the first bid. As a result, the equilibrium clearing price can be any amount between $[v_1^2, \bar{p}]$

Part (ii): In this case the demand is $D_t = k^1 + k^2$ there are two possibilities: one firm dispatches both production levels and the other nothing or both firms dispatch the first production level. Denote $\bar{v}^i$ as the mean of the average variable costs of firm i for both production levels. At a price equal to $\bar{v}^i$ firm i receives zero profit if they dispatch both production levels. It is straightforward to check $\bar{v}^1 < \bar{v}^2$. Also $\bar{v}^1$ is less than v_1^2. Therefore firm 1 can guarantee the dispatch of both levels by bidding $\bar{v}^1$. Firm 2 cannot underbid this amount and make a positive profit. The best response of firm 1 is to bid equal to $\bar{v}^1$ for both production levels. Firm 2 is indifferent to bid any amount above $\bar{v}^2$. Since firm 2's bid would set the market clearing price, the price can range between $\bar{v}^2$ and $\bar{p}$.

Part (iii): In this case the demand is large enough such that both firms can win in the auction. The best response of firm 1 is again to bid equal to $\bar{v}^1$ to guarantee the dispatch of both levels. Firm 2 knows their bids would set the price for their production level no matter if they dispatch one or two levels. So the best response of firm 2 is to bid equal to $\bar{p}$ to set the price as high as possible. Thus the market clearing price becomes equal to $\bar{p}$.

□

The above Proposition shows that when there is no regulation the market clearing price could be different depending on the quantity of demand. When the demand is large enough firms bid such that they guarantee the highest possible price. Of course this situation is not desirable since not only the price is very volatile but at times we would observe the highest possible price. In fact, in the absence of regulation, firms use their market power to increase the price to its maximum level.

There are several ways that a regulator can potentially control prices in a wholesale electricity market. However, in this paper we specifically investigate two particular frameworks. In the first case firms are not allowed to bid above their marginal costs, and if so, they will be accused of the violation of regulatory rules (ERA, 2019). In the second case firms are allowed to bid above their marginal costs but not more than their average variable costs. These two regulatory frameworks have been suggested on the Western Australian Wholesale Electricity Market (ERA, 2019). In the next two sections we study both of these cases and characterise equilibrium behaviour of firms.

5 Marginal cost regulatory framework

Suppose firms are not allowed to bid above their marginal costs of each level (Wholesale Electricity Market Rules (2020), Clause 7A.2.17). We know if the price is equal to the marginal cost at each level of production, given that the marginal cost is decreasing, firms would incur a negative profit. However, given the auction rules, it is possible that the price is set by the marginal cost of another firm. We first show that firms must only bid for one production level to avoid violating the rules.

Proposition 2. *Firms must either bid for one production level or submit a flat bid equal to their lowest marginal cost to avoid violation of the rules with certainty.*

Proof. First note that marginal costs are decreasing, that is, $c_1^i > c_2^i$. Also note that bids are ordered from the lowest to the highest, that is, the regulator starts from the lowest bid and dispatches the production levels. So it not possible for firm i to bid $b_1^i = c_2^i$ and $b_2^i = c_1^i$. This would count as a violation of the rules if the second production level is dispatched since $b_2^i > c_2^i$. Further note that if firm i bids flat and equal to the lowest marginal cost, c_2^i, they would be better off not entering the auction if the demand is low such that only the first production level is dispatched. Therefore, when demand is low, the only possible strategy remaining for firm i is to either bid for only the first production level or not enter the auction. However, when demand is large enough such that firm i's own bid for two production levels no longer set the price, it is possible that they bid for both production level. In this case the only possible way to avoid bidding above marginal costs is to submit a flat bid equal to the lowest marginal cost. To see this, again note that bids are cleared from the lowest to the highest. This means that the smaller bid is set for the first (higher cost) production level and the larger bid is set for the second (lower cost) production level. Therefore to avoid violating the rule, the second bid must be less or equal to c_2^i. Since the first bid cannot be larger than the second bid, and given that the cost of the first production level is larger, that is, $c_1^i > c_2^i$, biding equal to c_2^i for both production levels (flat) is the best strategy of firm i.

□

Proposition 2 shows that the marginal cost regulatory framework would not allow firms to dispatch both of their production levels in all possible cases. The intuition behind this result comes from the decreasing marginal values assumption. In fact, if a firm wants to bid for both production levels, they must submit a flat bid equal to the lowest marginal cost to avoid violating the rule. Since as shown in Proposition 2 bidding for both levels requires lowering the bid for the first level, as a result there will be cases where firms are better off not bidding for the second production level. Further since firms must submit bids equal to their marginal costs, the next question is whether it is possible to make a positive profit in equilibrium. The following proposition shows under what conditions a positive profit is not achievable.

Proposition 3. *With the marginal cost regulatory framework there is no equilibrium in which either of firms make a positive profit.*

Proof. First we show that firm 2 cannot make a positive profit in any scenario. If firms bid only for one production level, firm 2 must bid c_1^2. Given that this is larger than any marginal cost of firm 1, the price is set by c_1^2 which results in negative profit for firm 2. Also when firms bid for both production levels, according to Proposition 2 their optimal strategy to avoid violating the rules is to submit a flat bid equal to the marginal cost of second production levels, c_2^i. So if firms submit flat bids for both production level, firm 2's bid would be equal to c_2^2. In this case again the only way that firm 2 can win is to set the price. However, at a price equal to c_2^2 firm 2 would make a negative profit for producing either of the production levels. Therefore, firm 2 can never make a positive profit and would be better off by not bidding in the auction. Given that firm 2's best strategy is not entering, then firm 1 can only win and pay their own marginal cost which also results in negative profits.

□

The above Proposition suggests that the marginal cost regulatory framework could result in the shut down of the market: when firms cannot make a positive profit in the short term, they will shut down production. One possible way of keeping firms active is to provide lump sum capacity payments that would compensate firms, conditional on keeping the production. With such lump sum capacity payments a regulator could keep the market performing at a cost. If firms are incentivised to produce electricity with lump sum payments then according to Proposition 2 we know their optimal strategy to avoid violating the rules. The next proposition shows under what conditions firms would not be able to make a positive profit in the short-run.

Proposition 4.

(i) The firm with the higher cost can never make a positive profit.

(ii) When firms only bid for one production level, as long as the marginal cost of firm 2 for the first production level, c_1^2 is smaller than v_1^1, there is no equilibrium in which any firms can make a positive profit.

(iii) When firms bid for both production levels there is no equilibrium in which any firms can make a positive profit as long as $c_2^2 - v_1^2 < v_1^1 - c_2^2$.

Proof. First note that if there exist an equilibrium price in which a firm makes a positive profit, that firm must be firm 1 with the lower costs. This is because if both firms bid equal to their marginal costs firm 1's bid is below firm 2. Therefore the price is never above firm 2's marginal cost. Consider a situation where both firms only bid for their first level and the price is set by the marginal cost of firm 2, that is, c_1^2. As long as $c_1^2 < v_1^1$ firm 1 could never make a positive profit.

When firms bid for both production levels, to avoid violating the rules, they must submit a flat bid equal to the marginal cost of second production levels, c_2^i (Proposition 2). In case where demand is lower than the capacity of firm 1 it is easy to check that firm 1's profit is negative: the price is equal to c_2^1 which is lower than c_1^i. In case where the demand is high enough the price is set by the bid of firm 2, that is, c_2^2. It is straightforward to conclude that firm 1 always makes a loss for the first production level, because $c_1^1 > c_2^2$. With regards to the second production level, if $v_1^2 > c_2^2$ then firm 1 certainly makes a negative profit. If $v_1^2 < c_2^2$ then firm 1 would make a positive profit for the second production level. However the total profit is negative as long as the profit for the second production level is lower than the loss of the first production level, that is, $c_2^2 - v_1^2 < v_1^1 - c_2^2$.

□

Proposition 4 provides the conditions under which firms make a short term loss when they are incentivised to produce electricity with capacity payments. Note that these capacity payments must be large enough to justify the short term losses especially for firms with higher marginal costs.

Overall the results of this section shows under the marginal cost regulatory framework firms fail to operate unless there are other compensation methods such as capacity payments. Even with compensation one would argue there is no justification for a regulatory framework that would result in short term losses for firms. In fact, a more reasonable framework is the one that results in zero or close to zero short term profits. In the next section we study an alternative regulatory approach that aims at zero short-run profits.

6 Average variable cost regulatory framework

Another possible regulatory framework we analyse in this paper is the average variable cost (AVC) framework. As we showed in the previous section pricing at marginal costs could result in short term negative profits which is not a desirable outcome for firms even with capacity payments. According to ERA guideline (ERA (2019), page 6), pricing at average variable costs is considered acceptable for non-violation of the WEM rules. This is mainly justified by the fact that when marginal costs are decreasing, pricing at marginal cost would result in short-term losses. Thus in this section we assume firms are allowed to bid larger than their marginal costs but not above their average variable costs. The next proposition characterises bidding behaviour by firms within the AVC framework.

Proposition 5. *Given the AVC framework, the optimal strategy of firms is to either only bid for the first production level, or submit flat bids for both production levels equal to v_2^i to avoid violation of the rules.*

Proof. First note that the bid for the second production level for each firm has to be at least as large as the one for the first production level. Also the cost of the second production level is lower than the first one. We start with the second bid. Since the average variable cost for the second level is v_2^i for firm i, this firm cannot bid above v_2^i. Given that the first bid has to be weakly lower and the variable cost for the first production level, v_1^i is larger than the one for the second production level, firm i cannot bid above v_2^i. Thus the optimal bidding strategy is to submit a flat bid equal to v_2^i for both production levels.

Now if the demand is low and does not require the dispatch of second production levels, firms strictly prefer to submit a single bid equal to v_1^i because it reduces the chance of negative payoff and strictly increase the price. Also it does not violate the rules since v_1^i is the AVC of the first production level. □

Proposition 5 raises an important issue with regards to the AVC regulation. Since average variable costs are decreasing, and bids are cleared in an increasing fashion, firms cannot submit bids for both production levels equal to their average variable costs and guarantee not to violate the rules. In fact, in this case the bid for the second production level is strictly above the average variable cost of the second production level which is a violation of the rules. Therefore, firms must either bid for only one production level or submit flat bids equal to the smallest average variable cost.

Proposition 6. *There are circumstances where the firm with the lower cost can make a positive profit. However, it is impossible that both firms make a positive profit.*

Proof. There are two possible situations to investigate. First when firms only submit one bid for the first production level, and second, when firms submit a flat bid for both production levels. If firms submit only one bid, then firm 1 can guarantee winning by bidding equal to v_1^1 no matter what the demand is. Note that in this case, according to Proposition (5) the demand must be low. For firm 2 no matter if the demand is enough to win or not, they cannot bid above their average variable costs according to the rules. Bidding below the average variable cost is also not optimal since it could result in negative profit for them. Thus firm 2's optimal strategy is to bid v_1^2. In this case firm 1 receives a positive profit because the price is above their average variable cost. However, firm 2 cannot make a positive profit because the maximum possible price is v_1^2. Second, when firms submit flat bids equal to the lowest average variable cost, v_2^i, again firm 2 cannot make a positive profit because in any event that they win, they set the price which is v_2^2 and guarantees negative payoff. However, if $v_2^2 \geq v_1^1$ firm 1 makes a positive profit.

□

According to Proposition 6 there are now less cases where firm 2 makes a loss in the short-run, and firm 1 usually receives a positive profit. The AVC regulatory framework is able to solve some of the issues that firms faced in the marginal cost framework. However, it is still possible that the firm with higher costs make short term losses. Thus the lump sum capacity payments is still essential to keep firms operating in the industry.

7 Policy Implications and Conclusions

This is the first paper to consider the effectiveness of marginal cost-based pricing in a wholesale electricity market with uniform price auctions where electricity generators face a declining marginal cost curve. The declining marginal cost assumption is necessary in electricity markets analysis as wholesale electricity prices are continuing to decline with the increasing penetration of low-cost and intermittent energy sources in the wholesale markets. Markets viability and long term supply security threats are looming in the context of declining wholesale prices due to the exacerbation of the 'missing money' problems, especially in an energy-capacity market. The model we study is directly applicable to the Western Australian Wholesale Electricity Market (WEM). Our findings are as follows. First, wholesale markets when not regulated contributes to the volatile and extremely high prices as firms bid such that the equilibrium price becomes equal to the highest possible price when the demand is large enough. Second, an alternative approach studied is the marginal cost-based pricing regulation. However, under declining marginal costs, we find that electricity generators are poised for shut down as firms cannot make a positive profit. Therefore, lump sum payments such as capacity payments that are paid to generators for making the capacity available must be exercised. However, what is the appropriate reserve capacity remuneration mechanism so that optimal capacity is incentivised? Third, another alternative is to not allow electricity generators bid above their average variable costs (i.e. average cost based regulation instead of marginal cost). However, this regulatory mechanism induces negative profit for high-cost electricity generators.

These findings give rise to four important policy implications. Firstly, lump sum payments such as capacity payments to recover the missing money problem and wholesale price depression in energy capacity markets are desirable as long as payments to the power plants are estimated correctly. In the case of the WEM, capacity payments under the so-called reserve capacity mechanism (RCM) are based on future power needs predictions but the estimates were too high and thereby resulting in overcapacity and higher consumer bills. Second, marginal cost regulatory framework results in short-term losses for firms. This is not desirable even with lump sum payments. Average variable cost framework is suggested as an alternative to resolve this issue faced by the marginal cost framework. AVC pricing regulatory framework may solve some of the MC pricing issues but it is still possible that firms receive negative profits in the short term. Therefore, even the AVC framework must include capacity payments to prevent firms with higher costs from shutting down. Also note that wholesale electricity auctions occur with very high frequency (usually every half hour). Therefore, monitoring firms' bids which is essential in both AVC and MC regulatory frameworks requires significant and costly efforts by the regulator. Finally, given all the points raised, a uniform-price auction with price caps could be a better solution for energy–capacity markets to mitigate the high prices as well as simpler structure for implementation. For example, a study by Vossler et al. (2009), in the context of Californian electricity market show that offer curves become flat when prices are driven above the soft cap and therefore market prices become relatively insensitive to both generation costs and reductions in demand. Fourth, a uniform price auction in the price caps in the interim paves way for a transition to an energy only market in the longer term. Therefore, energy-capacity market like the WEM have the possibility to return to an 'energy-only' market in the long run.

Future research on WEM can focus on the impact of the different auction designs on wholesale market outcomes and the appropriate design mechanism for determining the capacity payments as the findings will be relevant to all energy-capacity markets across the globe.

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