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Efficiency in Deregulated Electricity Markets: Offer Cost Minimization vs. Payment Cost Minimization Auction

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Abstract

A payment cost minimization (PCM) auction has been proposed to solve the problem of inflated wholesale electricity prices. In the electricity industry, where even small changes in $/MW are worth tens of millions of dollars, it is highly important that policy makers have a good understanding of the tradeoffs and impacts of new institutional rules. In this paper we examine efficiency performance of the proposed PCM auction in contrast with the offer cost minimization (OCM) auction currently used by most independent system operators (ISOs) in the United States. For most of the analysis we concentrate on production efficiency, which is attained when a product is supplied to the market by the suppliers that have the smallest average total cost (ATC). An electricity market is efficient if there is no generator that could produce electricity cheaper than the chosen generators do. Production efficiency is desired because 1) it guarantees that market output is produced using the least-cost combination of inputs, thus resources are not wasted, 2) it also rewards the low-cost suppliers and provides the incentives to search for production techniques with even lower costs. [*excerpt*]

Keywords

Electricity, Cost Effective Solutions, Auctions, Efficiency

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Efficiency in Deregulated Electricity Markets: Offer Cost Minimization vs. Payment Cost Minimization Auction

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A payment cost minimization (PCM) auction has been proposed to solve the problem of inflated wholesale electricity prices. In the electricity industry, where even small changes in $/MW are worth tens of millions of dollars, it is highly important that policy makers have a good understanding of the tradeoffs and impacts of new institutional rules. In this paper we examine efficiency performance of the proposed PCM auction in contrast with the offer cost minimization (OCM) auction currently used by most independent system operators (ISOs) in the United States. For most of the analysis we concentrate on production efficiency, which is attained when a product is supplied to the market by the suppliers that have the smallest average total cost (ATC). An electricity market is efficient if there is no generator that could produce electricity cheaper than the chosen generators do. Production efficiency is desired because 1) it guarantees that market output is produced using the least-cost combination of inputs, thus resources are not wasted, 2) it also rewards the low-cost suppliers and provides the incentives to search for production techniques with even lower costs.

Deregulated U.S. wholesale electricity markets (e.g. the day-ahead, hour-ahead, and real-time markets) operated by ISOs generally adopt an auction mechanism to select generation offers and demand bids for energy and ancillary services. In the day-ahead energy markets, all selected suppliers are paid at a uniform market clearing price (MCP), usually the price of the most expensive selected offer. Currently, most ISOs adopt the OCM auction by using the traditional unit commitment approach[1]. It has been pointed out by Yan and Stern (2002) that this auction does not ensure the lowest procurement costs of electricity to consumers for a given set of offers. This motivated Luh et

[1] For a bibliographical survey on the unit commitment problem see Padhy (2004).

al (2005a) to develop a market clearing algorithm that minimizes actual procurement costs. They showed that the new method is viable, and can lead to significant savings for consumers for the given set of offers since it considers the impact of MCPs on total payment costs while OCM does not. Knoblauch (2005) pointed out that if suppliers tailor their offers to the type of auction they face, it is no longer obvious that the PCM algorithm will generate lower procurement costs. A game theoretic approach was used to analyze how the new auction affects market participant behaviors. The results demonstrated that adding competing suppliers increases the advantage of the new method over the traditional with respect to procurement costs even when strategic behavior is taken into account.

Proponents of the OCM auction claim that if offer prices represent true production costs, then this mechanism maximizes total producer and consumer surplus, or in other words, achieves allocative efficiency (Arroyo & Conejo 2002, Alonso et al. 1999). However, the 2000-01 California energy crisis shows us that offers frequently have nothing to do with the actual cost of generation units and can vary greatly even among units with similar costs (Stern 2001). In our attempt to capture strategic behavior of market participants, we use a game theoretic approach to investigate production efficiency performance of two auctions. Following the above mentioned studies, we assume that market demand is given, i.e. perfectly inelastic, and therefore demand bids are not considered for the most of the paper. This assumption implies that our production efficiency analysis is equivalent to the allocative efficiency analysis. With that said, if market demand is not perfectly inelastic, this generalization can not be made. However, at the end of this paper, we look at allocative efficiency performance of two auctions with downward sloping market demand curve as well.

In the day-ahead energy markets, all generating units submit their offers for every hour. Offer information includes a set of energy blocks and their corresponding prices. A generator may also declare technical constraints and a start-up price, which is paid to the generator if the offer is selected. The later feature of offers distinguishes wholesale electricity auctions from other quantity-price bid auctions. Therefore, it is critical to evaluate allocative efficiency properties of the OCM and the PCM algorithms in the context of electricity market design. We demonstrate in this paper that the OCM approach does not necessarily lead to the maximum of total surplus for market participants. This is true even if offer prices reflect true production costs.

The remainder of this paper is organized as follows. In Section II, a motivating example from Yan and Stern (2002) is used to demonstrate the difference between the OCM and the PCM auctions and to stress the need to consider strategic behavior as we compare the two. In Section III, using Knoblauch's (2005) game theoretic model, we present a surprising case where the OCM outcome is less efficient than the PCM one if strategic behavior is taken into account. Section IV demonstrates that in a simple Two-Supplier Auction Model, which better describes more concentrated markets, both formulations can generate production inefficient outcomes. Competition impacts on production efficiency are analyzed in Section V. The results suggest that as competition in the market increases, a market designer will likely face a tradeoff between two objectives: to minimize procurement cost of electricity and to seek production efficient allocations. In Section VI, Yan and Stern's example is extended to include the demand side of the market. We show the case where the PCM auction outperforms the OCM auction on allocative efficiency even if offer prices reflect true production costs. Conclusions are drawn in Section VII.

Electricity Auction with Strategic Behavior. Example 1

In this section, a simple example from Yan and Stern (2002) is used to highlight the differences between the OCM and the PCM.[1] The authors take offers as given and do not account that generators might tailor their offers to the type of auction they face. We demonstrate how the outcomes from the auctions might change if strategic behavior is considered.

Assume a power system for one hour with four units and perfectly inelastic system demand of 100MW. The costs and characteristics of the four units are summarized in Table 1.

Table 1. *Costs and Characteristics of Four Units*

	Capacity (MW)	Energy Price ($/MW)	Start-up Cost ($)
Unit A	45	10	0
Unit B	45	20	0
Unit C	50	100	20
Unit D	80	30	2,000

Let's say for now that all generators submit offers that reflect their true production costs. The OCM algorithm selects offers so as to minimize total offered cost calculated from submitted energy prices and start-up costs. However, all suppliers are paid the MCP, i.e. the highest accepted energy price, for their supplied electricity. The PCM algorithm assigns contracts in order to minimize the actual final payment which is based on the MCP. It is important to note that in both auctions, actual payment is made at MCP. The solutions for the OCM and the PCM formulations are provided respectively in Tables 2 and 3.

[1] For mathematical formulation of two auctions see Luh et al. (2005a).

Table 2 *Optimal Solution for the OCM Auction*

	Unit Commitment				Pay the MCP = \$100/MW		
	Energy Schedule (MW)	Energy Cost (\$)	Start-up Cost (\$)	Sub-Total (\$)	Energy Cost (\$)	Start-up Cost (\$)	Sub-Total (\$)
Unit A	45	450	0	450	4,500	0	4,500
Unit B	45	900	0	900	4,500	0	4,500
Unit C	10	1,000	20	1,020	1,000	20	1,020
Unit D	0	0	0	0	0	0	0
Total	100	2,350	20	**2,370**	10,000	20	**10,020**

Table 3. *Optimal Solution for the PCM Auction*

	Unit Commitment				Pay the MCP = \$30/MW		
	Energy Schedule (MW)	Energy Cost (\$)	Start-up Cost (\$)	Sub-Total (\$)	Energy Cost (\$)	Start-up Cost (\$)	Sub-Total (\$)
Unit A	45	450	0	450	1,350	0	1,350
Unit B	45	900	0	900	1,350	0	1,350
Unit C	0	0	0	0	0	0	0
Unit D	*10*	*300*	*2,000*	*2,300*	*300*	*2,000*	*2,300*
Total	*100*	*1,650*	*2,000*	***3,650***	*3,000*	*2,000*	***5,000***

These two methods produce different unit schedules with a significant impact on cost. The OCM contract allocation results in a \$100.2/MW final price to consumers and a \$23.7/MW average generation cost; the PCM results in \$50/MW and \$36.5/MW respectively. This example suggests that there might be a tradeoff between lower procurement costs of electricity and production efficiency. However, a question here is whether the offer strategies to bid true generation costs correspond to Nash equilibria. Can any supplier benefit from changing their offer strategies unilaterally? Generators could restrict their generation output, change the energy cost and/or start-up cost. ISOs usually demand an explanation if generators change their start-up costs or generation capacity, so strategic behavior is somewhat limited in these activities. Therefore, in this paper, we consider only energy cost offer strategies.

Assume that market participants have perfect information about electricity production costs in the various types of generator units. In both auctions, A and B sell their full capacity and earn profit since the MCP price is higher than their energy cost. They cannot benefit from changing their offers. By doing so, they might risk some or all of their profits. D is a marginal generator in the PCM allocation and earns no economic profit. D could offer higher energy cost and still be selected for 10MW of generation. It is in the interest of D to slightly underbid the total payment of $10,020 when C is selected. If D offers $80/MW, the total payment is $10,000 (<$10,020) and its economic profit is $500. C cannot benefit by changing its offer, since bidding below its costs would result in economic loss. On the other hand, C is a marginal generator with zero economic profit in the OCM allocation. It is in the interest of C to slightly underbid the total offer cost of $3,650 when D is selected. If C offers $227/MW, the total offer cost is $3,620 (<$3,650) and its economic profit is $1,270. D cannot improve its payoff in this case. Note that the final payment to consumers amounts to $22,720. Do these new sets of offer strategies correspond to Nash equilibria? The answer is closer to yes.

In this particular example, the cost impact of two auctions is even higher if we account for strategic behavior. The OCM contract allocation results in a $227.2/MW final price to consumers and a $23.7/MW average generation cost; the PCM results in $100/MW and $36.5/MW respectively. In this case, switching from the OCM to the PCM auction would cause an increase of $12.8/MW in average production costs and a reduction of $127/MW in consumer price of electricity. It has to be noted that consumer savings here are at the expense of smaller generator profits and an increase in average production costs are at the expense of allocative efficiency. This paper explores a tradeoff between lower procurement costs and production efficiency again later. In Section VI, we extend this example by including demand bids and demonstrate that lower consumer prices from PCM does not necessarily lead to a loss in allocative efficiency.

This simple example underscores the importance of considering strategic behavior when evaluating the performance of different power market institutions. It also suggests that market supervisors should keep a sharp eye on the marginal generators if market behavior becomes a concern. In the next section, we present a surprising case where the OCM outcome is less production efficient than the PCM if strategic behavior is taken into account.

Can an OCM Allocation Be Less Production Efficient than a PCM? Example 2

In a one-person game, Knoblauch (2005) shows that, counterintuitively, the PCM generates higher procurement costs than the OCM. We present a similarly surprising case where the OCM is less production efficient than the PCM. One would expect low-cost generators to underbid high-cost generators in order to be selected by the OCM auction. Especially because high-cost suppliers would most likely be setting the MCP and economic profits would be earned.

Consider an electricity market for one hour with two generators. Supplier 1 has start-up cost zero and energy cost $25/MW. He can supply 0, 1 or 2MW of energy. Supplier 1 has two strategies, offer low $O_l(1)= O_l(2)=\$25$ and offer high $O_h(1)= O_h(2)=\$40$. Supplier 2 has start-up cost $20 and energy cost $10/MW. She can supply 1MW of energy and always submits her true generation cost structure. The demand is inelastic and equal to 2MW. Notice that Supplier 1 has lower average total cost than Supplier 2, therefore he is relatively more efficient. An allocation of contracts would be production *inefficient if Supplier 2 generated electricity while Supplier 1 was idle.*

Game 1: The OCM Auction

The ISO calculates the minimum of the offered cost of buying 1MW from each supplier and the offered cost of buying 2MW from Supplier 1.
If Supplier 1 submits O_l, the ISO calculates offered cost as
Min{20+10+25, 2(25)}=2(25)=50 and Supplier 1's payoff is 50-2*25=0.
If Supplier 1 submits O_h, the ISO calculates offered cost as
Min{20+10+40, 2(40)}= 20+10+40=70 and Supplier 1's payoff is 40-25=15.
Therefore, in equilibrium Supplier 1 offers high, the MCP is \$40/MW and the actual procurement cost is \$100. Notice, that this allocation is *not* production efficient, since Supplier 2, with relatively higher average total cost, is serving 1MW, while Supplier 1, with relatively lower average total cost, is idle.

Game 2: The PCM Auction

The ISO calculates the minimum of the procurement cost of buying 1MW from each supplier and the procurement cost of buying 2MW from Supplier 1.

If Supplier 1 submits O_l, the ISO calculates procurement cost as

Min{20+2max{10,25}, 2(25)}=2(25)=50 and Supplier 1's payoff is 50-2*25=0.

If Supplier 1 submits O_h, the ISO calculates procurement cost as

Min{20+2max{10,40}, 2(40)}=2(40)=80 and Supplier 1's payoff is 80-2*25=30.

Therefore, in equilibrium Supplier 1 offers high, the MCP is \$40/MW and the actual procurement cost is \$80. Notice that this allocation is production efficient, since there is no way to serve 2MW cheaper than the chosen supplier does.

In this case, the OCM generates both less efficient allocation and higher procurement costs than the PCM. In both auctions Supplier 1 offers high. This implies that neither auction can guarantee to eliminate strategic market behavior. Supplier 1 could underbid Supplier 2 in the OCM auction to capture the whole market, but it appears that it is more profitable to sell less at a high price rather than more at a low price. In Section IV, it will be shown that both auctions can generate production inefficient outcomes in small and concentrated markets. When a competitor for Supplier 1 is added to the market, no analog of the discussed case exists.

Simple Two-Supplier Auctions

To see if Example 2 is typical, we adopt Knoblauch's (2005) game theoretic approach and investigate the simplest two-supplier auctions. We examine games which are identical to Games 1 and 2.

Consider an electricity market for one hour. The demand is inelastic and equal to 2MW. Supplier 1 has zero start-up costs and energy cost $L_1>0$. He can supply 0, 1 or 2MW of energy. Supplier 1 can offer low $O_l(1)= O_l(2)=L$ or offer high $O_h(1)= O_h(2)=H$. Supplier 2 has start-up cost S and energy cost A>0. She can supply 1MW of energy and always submits her true generation cost structure. Supplier 1's offer has to be at least L_1, i.e. $L_1 \le L < H$, otherwise Supplier 1 will not cover his generation costs.

To evaluate production efficiency we need to look at five cost structure cases.[1]

<u>*Case 1:*</u> $S+A<L_1$ *(i.e.* $ATC_2 < ATC_1$*)*

This is the case in which Supplier 2 is relatively more efficient than Supplier 1. Since $L_1 \le L < H$, it follows that $S+A<L$. This is equivalent to Case 1 in Knoblauch (2005, section 3).

Game 3: The OCM Auction

$$O_l\text{: } \min\{S+A+L,\ 2L\}=S+A+L \qquad \pi_1=L-L_1$$
$$O_h\text{: } \min\{S+A+H,\ 2H\}=S+A+H \qquad \pi_1=H-L_1$$

Since $L-L_1<H-L_1$, Supplier 1 offers high, procurement cost is S+2H and allocation is efficient.

Game 4: The PCM Auction

$$O_l\text{: } \min\{S+2\max\{A,L\},\ 2L\}=2L \qquad \pi_1=2(L-L_1)$$
$$O_h\text{: } \min\{S+2\max\{A,H\},\ 2H\}=2H \qquad \pi_1=2(H-L_1)$$

Since $2(L-L_1)<2(H-L_1)$, Supplier 1 offers high, procurement cost is 2H and allocation is inefficient.

The OCM picks 1MW from each supplier, and the PCM picks 2MW from Supplier 1. The PCM allocation *is not* production efficient, since Supplier 2 could produce electricity cheaper than the chosen Supplier 1 does ($S+A<L_1$). The OCM allocation *is* production efficient, since there is no way to produce electricity cheaper than the chosen suppliers do (production cost = $S+A+L_1$).

In the following 4 cases Supplier 1 is relatively more efficient than Supplier 2 (i.e. $ATC_1 < ATC_2$).

[1] The less likely knife-edge cases such as S+A=L have been omitted.

Case 2: $L_1 < S + A < L < H$

Since $S + A < L$, similarly to Case 1, the OCM picks 1MW from each supplier and the PCM picks 2MW from Supplier 1. The OCM allocation *is not* production efficient, since Supplier 1 could produce 1MW cheaper than the chosen Supplier 2 does ($L_1 < S + A$). The PCM allocation *is* production efficient, since there is no way to produce electricity cheaper than the chosen supplier does ($2L_1$). Procurement cost is S+2H in the OCM auction and 2H in the PCM auction.

Case 3: $L_1 \leq L < S + A < H$ and $2L - H < L_1$

Game 3: The OCM Auction

$$O_l\text{: } \min\{S+A+L,\ 2L\}=2L \qquad \pi_1=2(L-L_1)$$
$$O_h\text{: } \min\{S+A+H,\ 2H\}=S+A+H \qquad \pi_1=H-L_1$$

Since $2(L-L_1)<H-L_1$, Supplier 1 offers high, procurement cost is S+2H and allocation is inefficient.

Game 4: The PCM Auction

$$O_l\text{: } \min\{S+2\max\{A,L\},\ 2L\}=2L \qquad \pi_1=2(L-L_1)$$
$$O_h\text{: } \min\{S+2\max\{A,H\},\ 2H\}=2H \qquad \pi_1=2(H-L_1)$$

Since $2(L-L_1)<2(H-L_1)$, Supplier 1 offers high, procurement cost is 2H and allocation is efficient.

The OCM picks 1MW from each supplier and the PCM picks 2MW from Supplier 1. The OCM allocation *is not* production efficient, since Supplier 2, with relatively higher average total cost, is serving 1MW, while Supplier 1, with relatively lower average total cost ($L_1 < S + A$), is idle. The PCM allocation *is* production efficient, since there is no way to produce electricity cheaper than the chosen supplier does ($2L_1$).

Case 4: $L_1 \leq L < S + A < H$ and $2L - H > L_1$

Game 3: The OCM Auction

$$O_l\text{: } \min\{S+A+L,\ 2L\}=2L \qquad \pi_1=2(L-L_1)$$
$$O_h\text{: } \min\{S+A+H,\ 2H\}=S+A+H \qquad \pi_1=H-L_1$$

Since $2(L-L_1)>H-L_1$, Supplier 1 offers low, procurement cost is 2L and allocation is efficient.

Game 4: The PCM Auction

$$O_l: \min\{S+2\max\{A,L\},\ 2L\}=2L \qquad \pi_1=2(L-L_1)$$
$$O_h: \min\{S+2\max\{A,H\},\ 2H\}=2H \qquad \pi_1=2(H-L_1)$$

Since $2(L-L_1)<2(H-L_1)$, Supplier 1 offers high, procurement cost is 2H and allocation is efficient.

Both auctions pick 2MW from Supplier 1. Both the OCM allocation and the PCM allocation *are* production efficient, since there is no way to produce electricity cheaper than the chosen supplier does ($2L_1$).

<u>Case 5:</u> $L_1 \le L < H < S + A$

Since $H < S + A$, both auctions pick 2MW from Supplier 1. Both the OCM allocation and the PCM allocation *are* production efficient. Procurement cost is 2H in both auctions.

The outcomes of the OCM and the PCM auctions are summarized in Table 4.

Table 4. *The Outcomes of the OCM and the PCM Auctions*

Auction	Case 1		Case 2		Case 3		Case 4		Case 5	
	$	Efficient	$	Efficient	$	Efficient	$	Efficient	$	Efficient
OCM	S+2H	Yes	S+2H	No	S+2H	No	2L	Yes	2H	Yes
PCM	2H	No	2H	Yes	2H	Yes	2H	Yes	2H	Yes

In summary, if we consider Cases 1-5, which were constructed using Example 2 as a template, sometimes the PCM is less efficient and sometimes the OCM is less efficient. This indicates that in small, concentrated and simple markets, neither algorithm could guarantee production efficient allocations if strategic behavior takes place. The results hold even if we allow energy price offers to be increasing or decreasing step functions of electricity quantity, or if we let the strategy sets for energy prices to be continuous.

In Section V, we show that when another competitor of Supplier 1 type is introduced, there are no cases in which the OCM generates less production efficient allocations than the PCM. This suggests that in a market with completely inelastic demand, an increase in competition will likely lead to an advantage of the OCM auction over the PCM auction with respect to efficiency.

An Added Competitor

To see how competition impacts the efficiency of the OCM and the PCM auctions, we extend our analysis from a two supplier market to a wholesale electricity market with three suppliers. An added competitor is identical to Supplier 1. We call these twin suppliers without start-up costs Supplier 1a and Supplier 1b. We refer to the supplier with start-up costs as Supplier 2. The suppliers of type 1 have a continuum of strategies. They can offer energy price p \$/MW, where p is real. The demand for 2MW is inelastic, however, there is a maximum willingness to pay of N \$/MW, where $N>L_1$.

Knoblauch (Proposition 1, 2005) proves that, in the unique Nash equilibrium, Supplier 1a and Supplier 1b will submit the offers that reflect their true energy generation cost (L_1). This result makes our analysis simpler than in the two-supplier auctions.

To evaluate efficiency we need to look at two cost structure cases.

<u>*Case I:*</u> $S+A<L_1$ *(i.e.* $ATC_2<ATC_1$*)*

In this case, Supplier 2 is relatively more efficient than Supplier 1a and Supplier 1b. The OCM auction picks 1MW from Supplier 2, ½MW from Supplier 1a and ½MW from Supplier 1b. The PCM auction picks 1MW from Supplier 1a and 1MW from Supplier 1b. The PCM allocation *is not* production efficient, since Supplier 2 could produce 1MW cheaper than the chosen suppliers do ($S+A<L_1$). The OCM allocation *is* production efficient, since there is no way to produce electricity cheaper than the chosen suppliers do (production cost = $S+A+L_1$). Procurement cost is $S+2L_1$ in the OCM auction and $2L_1$ in the PCM auction.

<u>*Case II:*</u> $L_1<S+A$ *(i.e.* $ATC_1<ATC_2$*)*

In this case, Suppliers 1a and 1b are relatively more efficient than Supplier 2. Both auctions pick 1MW from Supplier 1a and 1MW from Supplier 1b. Both allocations *are* production efficient. Procurement cost is $2L_1$ in both auctions.

In summary, if $ATC_2<ATC_1$, then the OCM auction is more efficient; and if $ATC_1<ATC_2$, then both auctions generate equally efficient allocations of contracts. In other words, when Supplier 1 has a competitor, there is no analog to Example 2; the OCM auction outperforms the PCM auction with respect to efficiency.

In Case II, both auctions achieve the same procurement cost and efficiency. In Case I, the OCM attains a more efficient allocation and the PCM produces a lower procurement cost to consumers. This suggests that as competition in the market increases, a market designer will likely face a tradeoff between two objectives: to minimize procurement cost of electricity or to seek production efficient allocations. Up to this point we assumed that market demand is given, i.e. perfectly inelastic. This implies that our production efficiency analysis is equivalent to the allocative efficiency analysis. Therefore, those who use allocative efficiency as a measure for social welfare would argue that competitive markets should favor the OCM auction over the PCM. We address this issue in more detail in the next section.

Can the PCM Outperform the OCM on Allocative Efficiency if Offer Prices Reflect True Production Costs? Example 3

In the previous sections we argued that if strategic behavior takes place then both auctions might produce inefficient production allocations. It has been shown that an increase in competition will likely lead to an advantage of the OCM over the PCM with respect to production efficiency and allocative efficiency if the market demand is perfectly inelastic. In the partial equilibrium analysis, as opposed to general equilibrium analysis, allocative efficiency is a measure of total surplus, a sum of producer and consumer surpluses. Sometimes it is used as a proxy for social welfare (Arroyo & Conejo 2002, Alonso et al. 1999). Proponents of the OCM see this as a strong argument for their case. In this section, we consider demand bids for electricity and reexamine the claim that in competitive markets the OCM auction outperforms the PCM auction on allocative efficiency.

This analysis is different from other allocative efficiency investigations of auctions because electricity suppliers submit not only energy price offer curves, but also start-up costs which are reimbursed to generators if their offers are selected. If all suppliers are paid a uniform market clearing price, then the funds to pay for their start-up costs must be obtained from consumers by charging them a higher price than what generators receive.

Recall a power system from Example 1 in Section II. The costs and characteristics of the four units are summarized in Table 1. Five demand bids are summarized in Table 5. Market demand and supply is depicted in Figure 1.

Table 5. *Values and Demand Quantities of Five Consumers*

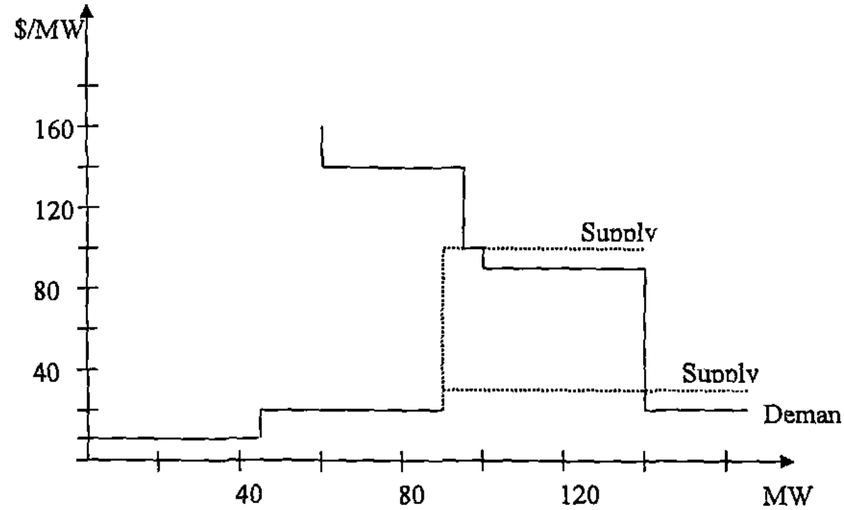
	Demand (MW)	Value ($/MW)
U	60	160
X	35	140
Y	5	100
Z	40	90
W	30	20

Assume for now that the market is competitive, all generators submit offers that reflect their true production costs and all consumers submit bids that reflect their true values. Example 1 demonstrated that the OCM auction would sell 100MW for $10,020. However, if all consumers are paying a uniform price, they would pay at most $10,000 for 100MW. Therefore, the OCM auction is able to sell only 95MW for $9,520. So, consumers pay $100.21/MW and the average generation cost is $19.68/MW. In this case, the total surplus is (160*60+140*35)-(10*45+20*45+100*5+20)=$12,630.

Recall that the PCM auction sells 100MW for $5,000, which is less than what consumers are willing to pay. Moreover, the PCM auction sells 140MW for $6,200, which is also less than what consumers would pay ($12,600). Therefore, the auction allocates 140MW for $44.29/MW. The average generation cost is $34.64/MW. In this case, the total surplus amounts to

(160*60+140*35+100*5+90*40)-(10*45+20*45+30*50+2,000)=$13,750. This example demonstrates that the PCM can outperform the OCM on allocative efficiency even if production prices reflect true production costs.

Figure 1. *Market Demand and Supply*



Next we can ask the same question as in Section II: "Do the offer strategies to bid true generation costs correspond to Nash equilibria?"

Assume that market participants have perfect information about electricity production costs in the various types of generator units and about electricity benefits to consumers. In both auctions, A and B sell their full capacity and earn profit since MCP price is higher than their energy cost. They cannot benefit from changing their offers. By doing so, they might risk some or all of their profits. D is a marginal generator in the PCM allocation and earns no economic profit. D could offer higher energy cost and still be selected for 50MW of generation. It is in the interest of D to bid as close as possible to $12,600, the amount that consumers are willing to pay for 140MW. If D offers $75/MW, the total payment is $12,500 (<$12,600) and its economic profit is $2,250. C cannot benefit by changing its offer, since bidding below its costs would result in economic loss. On the other hand, C is a marginal generator with zero economic profit in the OCM allocation. It is in the interest of C to bid as close as possible to $13,300, the amount that consumers are willing to pay for 95MW. If C offers $139/MW, the total payment is $13,225 (<$13,300) and C's economic profit is $195. D cannot improve its payoff in this case.

To sum it up, the OCM contract allocation results in a $139.21/MW final price to consumers and a $19.68/MW average generation cost; the PCM results in a $89.29/MW and a $34.64/MW respectively. In this case, switching from the OCM to the PCM auction would lead to an increase of $14.96/MW in average production costs and a reduction of $49.92/MW in the consumer price of electricity. However, in this case consumer savings and higher production costs under the PCM auction are not in expense of allocative efficiency. On the contrary, the PCM outperforms the OCM on allocative efficiency.

One could argue that consumers might bid strategically as well. In that case, electricity prices might be lower than those discussed above, when only suppliers act strategically. However, qualitative results on allocative efficiency would persist.

It is not the intention of this paper to state that the PCM auction would always outperform the OCM auction on allocative efficiency if implemented in practice. To answer that question, empirical investigation for the specific wholesale power market has to be done. But it is clear from the example that a proper algorithm for electricity allocation should take into account the total consumer payment and whether consumers are willing to pay that much (e.g. Luh et al. 2005b), if indeed market demand has at least some responsiveness to electricity price.

Conclusions

It has been shown that the proposed payment cost minimization auction can significantly reduce inflated wholesale electricity prices. Critics claim that the auction is inefficient and that it would compromise social welfare in a competitive market. The goal of this paper was to investigate the efficiency performance of the current OCM auction versus the proposed PCM auction.

The importance of considering strategic behavior in the analysis of deregulated electricity market was emphasized multiple times. We employed game theoretic approach that allowed for strategic behavior by suppliers. An example was presented in which, counterintuitively, the OCM auction generated less production efficient allocation of contracts than the PCM auction. It was shown that neither formulation can guarantee production efficient outcomes in small and concentrated markets. Next, we showed that as competition increases, the production efficiency performance of the current mechanism versus the proposed auction improves. The results suggest that a market designer might face a tradeoff between lower procurement cost of electricity and production efficiency. Advice for market supervisors would be to keep a sharp eye on the marginal generators if market behavior becomes a concern. Finally, it was demonstrated that the PCM auction can outperform the OCM auction on allocative efficiency even if offers reflect true generation costs. If indeed market demand is not perfectly inelastic, an allocation algorithm that maximizes total surplus should account for the total consumer payment and check whether consumers are willing to pay that much. It is important to remember that the use of allocative efficiency as a measure for social welfare is limited to partial equilibrium analysis as opposed to general equilibrium analysis.

It should be noted that the total value of energy dispatched in these systems is tens of billions of dollars annually. Even a small change in the efficiency of market clearing algorithm is worth tens of millions of dollars.

Further empirical research should be done to evaluate potential gains from switching to the new auction in the markets that are considering a change. It was not the purpose of this paper to quantify the gains, but rather to highlight the efficiency enhancing potential of the PCM auction.

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