

Moral Hazard in the Electricity Capacity Markets

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Abstract—This paper investigates the ways in which an electricity capacity market design may encourage generators to exaggerate their available capacity. For concrete analysis, a simple two-player game model is introduced, focusing on two pure strategy Nash equilibria: an equilibrium at which generators offer their true capacities, and an equilibrium at which generators offer exaggerated capacities. The latter case is caused by asymmetries of information between players and called ‘moral hazard’ in the economics literature. Our consideration of the practical electricity markets reveals that the moral hazard case is highly probable. Moreover, consideration of the current capacity market design in the real world led us to conclude that the better the electricity energy market performs, the higher the risk of moral hazard becomes. For illustration, a numerical example is presented.

Index Terms—Electricity capacity markets, game theory, Nash equilibrium, moral hazard.

I. INTRODUCTION

ONE of the most controversial issues in electricity industry deregulation is capacity market design. Some argue that there is no need for the capacity markets [1], while others argue that they are essential for reliable system operation [2]. Responding to the controversy, many studies have been performed on capacity markets [3-7].

Creti and Fabra analyzed studied capacity markets (ICAP) and addressed regulatory issues such as the optimal choice of the reserve margin and the capacity deficiency rate [3]. Stoft investigated the operating reserve markets and analyzed the working conditions for capacity markets [4]. Oren [5] and Chao and Wilson [6] suggested the call-option approaches instead of capacity markets. Cramton and Stoft investigated flaws in early capacity markets and proposed a capacity market for New England [7].

Many problems related with the capacity markets including market power exercise and price distortion have been addressed in the literature. However, there is another possible problem in the conventional capacity markets rarely found in the literature: exaggerated capacity offer.

Consider the following capacity market. In the electricity markets, an independent system operator (ISO) has the responsibility of the provision of adequate capacity resources for ensuring the security of the system. In order to procure the required capacity, the ISO opens the capacity markets where generators compete to each other in order to provide the capacity. The demand in the capacity market is fixed as determined by the ISO. The capacity market is cleared by a uniform price auction.

In this capacity market, a generator possibly has incentives to offer capacity more than its true capacity. Unless the ISO actually issues dispatch instructions to the generator to produce more than it can produce, the generator will receive the capacity payments for the capacity it exaggerated. In the game theory literature, this kind of problem is known as ‘moral hazard’ [8].

The term moral hazard originates in the insurance literature, which investigated information imperfections between an insurance company and the insured [8]. The principal cause to moral hazard is asymmetries of information between players. In some cases, informational asymmetries result in a player’s behavior such that the player takes advantage of other players’ ‘observability’ problem [8]. In such cases, moral hazard arises.

Traditionally, in the literature, two types of informational problems have been distinguished: the problems resulting from ‘hidden actions’ and those resulting from ‘hidden information’. The literature’s use of the term moral hazard is not entirely uniform. Some authors use moral hazard to refer only to the hidden action case, while others use the term to refer to either of the hidden action or hidden information [9].

The problem of exaggerated capacity offer in the electricity capacity markets is an informational problem resulting from hidden information, since the problem arises from the informational asymmetry between generators and an ISO such that only generators have the knowledge of their true capacities. This paper follows the broader use of the term moral hazard and, therefore, the problem of exaggerated capacity offer is referred to by moral hazard.

This paper presents a simple capacity market model. In this paper, we examine the presented capacity market by adopting a two player game model. The solution of the game is defined by Nash equilibrium. In this setup, we focus on two pure strategy Nash equilibria: an equilibrium at which generators offer their true capacities, and an equilibrium at which generators offer the exaggerated capacities. We show that the moral hazard case is more probable in practical electricity markets. We also show that, with the considered capacity

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market design, the better the electricity market performs, the higher the risk of moral hazard becomes.

This paper is organized as follows. Section II briefly describes the capacity market model that is considered in the paper. In section III, we describe a two player game model following the capacity market model and present equilibrium analysis. Section IV presents a numerical example for illustration. Finally, the conclusion drawn from the study is provided in Section V.

II. CAPACITY MARKET MODEL

We consider the electricity markets where an ISO opens the capacity markets in a form of a uniform price auction where generators compete to each other in order to provide the capacity. The demand in the capacity market is fixed in terms of MW as determined by the ISO.

In order for simplicity of the analysis, we assume that among all generators in the capacity market only two generators are strategically seeking an opportunity for making money by offering capacity more than the amount that they can actually provide when the ISO issues dispatch instructions to them. Furthermore, two strategic generators are assumed to be identical. That is, two generators have the same cost function and the available capacities of two generators for the capacity market are the same. The other generators are assumed to offer their true available capacities.

Both strategic generators are assumed to have two options in the capacity market: either to offer its true capacity C_T or to offer more than true capacity C_E , where $C_T < C_E$. We assume that the generators are able to follow ISO's dispatch instruction in the real time market only when the instructed dispatch is less than or equal to C_T . Therefore, the generators will fail to follow ISO's dispatch instruction when the instructed dispatch is greater than C_T .

If both of two strategic generators offer truthfully in the capacity market, both generators receive capacity award C_{TT}^A with the capacity market clearing price P_{TT} . The capacity award C_{TT}^A is less than or equal to the capacity offer C_T . Then, the capacity payments π_{TT} for each generator are determined as:

$$\pi_{TT} = P_{TT} C_{TT}^A. \quad (1)$$

Since $C_{TT}^A \leq C_T$, both generators will successfully follow to ISO's dispatch instruction in the energy market and, therefore, there will be no charge for failure to follow the ISO's instructions.

On another hand, suppose that one of two strategic generators, generator 1, makes the exaggerated offer C_E , while the other generator 2 offers its true available capacity C_T . Due to the offer capacity increase, the capacity market clearing price P_{ET} would not be greater than P_{TT} . The awarded capacities for generator 1 and 2 are $C_{ET}^{A,E}$ and $C_{ET}^{A,T}$, respectively. We assume that $C_{ET}^{A,E} > C_T$ and $C_{ET}^{A,T} < C_T$.

Furthermore, $C_{ET}^{A,T} < C_{TT}^A$ due to the increased capacity award of generator 1. The capacity payments π_{ET}^E and π_{ET}^T of generator 1 and 2, respectively, are determined as:

$$\pi_{ET}^E = P_{ET} C_{ET}^{A,E}, \quad (2)$$

$$\pi_{ET}^T = P_{ET} C_{ET}^{A,T}. \quad (3)$$

In this case, it is clear that $\pi_{ET}^T < \pi_{TT}$. However, π_{ET}^E can be either greater or lower than π_{TT} . Here, we assume that π_{ET}^E is higher than π_{TT} . This assumption is plausible because the generator with an exaggerated offer will take some part of the capacity demand that would have been served by the truthfully offered generator if both generators offered truthfully.

However, generator 1 has a risk on this strategic behavior. If ISO actually issues dispatch instructions for production more than generator 1's truly available capacity in the energy market, generator 1 will fail to follow the ISO's dispatch instructions, and should pay a penalty F for the dispatch deviation. We assume that this case will happen with probability of prb_{ET} .

The case where generator 2 offers C_E and generator 1 C_T is the exactly symmetric case of the previous case, and the same analysis results hold in a symmetric manner.

Finally, consider the case where both of strategic generators make exaggerated offers C_E . The capacity award for each generator is C_{EE}^A , and we assume that C_{EE}^A is greater than C_T . The capacity market clearing price in this case is denoted by P_{EE} . The capacity payments of both generators are the same and defined by π_{EE} :

$$\pi_{EE} = P_{EE} C_{EE}^A. \quad (4)$$

Here, π_{EE} is assumed to be higher than π_{TT} , but to be less than π_{ET}^E . It is plausible since the additional capacity award to a generator by offering exaggerated capacity would decrease when the other generator also offers exaggerated capacity compared to the otherwise case. Furthermore, in this case, the probability prb_{EE} of failing to follow the ISO's dispatch instructions and paying the penalty F for the dispatch deviation would be greater than prb_{ET} . This is because of the larger amount of the exaggerated capacity in the total awarded capacity.

III. GAME ANALYSIS

A. Two Player Game Model

Following the market model, a two player game model is set up. Two strategic generators are modeled as players. Each player has two strategies: either to offer its true capacity (C_T) or to offer an exaggerated capacity (C_E). Each player's strategy is denoted by s_i , $i = 1, 2$. Each player's payoff π_i , $i = 1, 2$, is his profits from the capacity market considering the penalty for failing to follow ISO's dispatch instructions.

Each player aims to maximize his expected payoff in this game. From the market model setup, a normal form representation of this game is:

TABLE I
NORMAL FORM REPRESENTATION OF THE GAME

(π_1, π_2)	C_T	C_E
C_T	(π_{TT}, π_{TT})	$(\pi_{ET}^E - prb_{ET}F, \pi_{ET}^T)$
C_E	$(\pi_{ET}^T, \pi_{ET}^E - prb_{ET}F)$	$(\pi_{EE} - prb_{EE}F, \pi_{EE} - prb_{EE}F)$

In the normal form representation of the game shown in Table I, the strategies in rows are generator 1's strategies while those in columns are generator 2's. Note that, whenever player's payoff involves the penalty for failing to follow ISO's dispatch instructions, the expected value of the payoff is obtained and written at the corresponding cell. For a solution of the game, we adopt Nash equilibrium concept.

B. Equilibrium Analysis

The Nash equilibrium of the game shown in Table I will be different according to the market parameters. In this paper, we investigate two cases of unique pure-strategy Nash equilibrium¹ and one of these cases corresponds to so called 'moral hazard' [8].

1) when $\pi_{TT} > \pi_{ET}^E - prb_{ET}F$ and $\pi_{ET}^T > \pi_{EE} - prb_{EE}F$: In this case, the unique Nash equilibrium of the game is (C_T, C_T) . That is, both generators will offer their true capacities at equilibrium. In the point of market operation view, this equilibrium is the most preferable. In this sense, ISO will try to achieve this equilibrium. Fortunately, there is a parameter that ISO can control: the penalty F . By setting F to very high value, the conditions for case 1 will be always satisfied and the only market equilibrium will be truthful offer.

However, there is a practical difficulty for this solution. When the probabilities prb_{ET} and prb_{EE} are usually very small, the value for F in order to satisfy the case 1 conditions might become unreasonably high so that market participants are not willing to accept such penalty. Moreover, the measurement of capacity availability in the capacity markets is poor. Due to this poor measurement, generators might unintentionally fail to follow ISO's dispatch instructions. This also makes market participants reluctant to agree with very high penalty.

2) $\pi_{TT} < \pi_{ET}^E - prb_{ET}F$ and $\pi_{ET}^T < \pi_{EE} - prb_{EE}F$: In this case, the unique Nash equilibrium is (C_E, C_E) . That is, both generators will offer the exaggerated capacities. The actual dispatch with very low probability makes generator's true capacity availability 'hidden information' that is moral hazard [8].

The risk of moral hazard in the capacity markets would be high if the probabilities prb_{ET} and prb_{EE} is small. These

probabilities will be small when the electricity energy market is well operated. That is, these probabilities will be low when the demand is correctly forecasted and when the power system components are well maintained and, therefore, their forced outage rates are small. This implies an intrinsic flaw of the considered capacity market design. With such market design, the better the electricity energy market is operated, the more attractive moral hazard in the capacity market is.

IV. NUMERICAL EXAMPLE

We present a numerical example in order to illustrate the analysis results. As in the model, we consider two strategic generators 1 and 2, both of which have available capacity of 100 MW for the capacity market. Both generators have two strategies: offering 100 MW truthfully and offering over-capacity of 150 MW. Suppose that the capacity market clearing price is 10 \$/MW regardless of generators strategy selections and that $C_{TT}^A = 100$ MW, $C_{ET}^{A,E} = 130$ MW, $C_{ET}^{A,T} = 80$ MW, and $C_{EE}^A = 110$ MW. Then, following (1), (2), (3), and (4), the capacity payments are $\pi_{TT} = \$ 1,000$, $\pi_{ET}^E = \$ 1,300$, $\pi_{ET}^T = \$ 800$, and $\pi_{EE} = \$ 1,100$. Suppose the penalty F is \$ 10,000.

First, consider a case where $prb_{ET} = 0.05$ and $prb_{EE} = 0.1$. In this case, the normal form representation of the game is shown in Table II.

TABLE II
NORMAL FORM REPRESENTATION OF THE EXAMPLE

(π_1, π_2)	C_T	C_E
C_T	(\$ 1,000, \$ 1,000)	(\$ 800, \$ 800)
C_E	(\$ 800, \$ 800)	(\$ 100, \$ 100)

From Table II, we can easily verify that (C_T, C_T) is the Nash equilibrium. That is, the Nash equilibrium strategy for both generators is to offer their available capacity truthfully.

Now, consider a case where $prb_{ET} = 0.005$ and $prb_{EE} = 0.01$, and the normal form representation of the game is presented in Table III.

TABLE III
NORMAL FORM REPRESENTATION OF THE EXAMPLE

(π_1, π_2)	C_T	C_E
C_T	(\$ 1,000, \$ 1,000)	(\$ 1,250, \$ 800)
C_E	(\$ 800, \$ 1,250)	(\$ 1,000, \$ 1,000)

The unique Nash equilibrium of this game is (C_E, C_E) , that is, the Nash equilibrium strategy for both generators is to offer more than their available capacity.

The above two cases illustrate that, when prb_{ET} and prb_{EE} is low, the moral hazard case occurs. This, in turn, shows that the better the electricity energy market is operated, the more attractive moral hazard in the capacity market is.

¹ The remaining case involves mixed strategy equilibrium. This case is intentionally excluded in this paper since the case will make the analysis complex without any useful interpretation.

V. CONCLUSIONS

Capacity markets are regarded as an essential part of restructured electricity markets [7]. However, in order for the capacity market to perform successfully, the market should be designed properly.

In this paper, we have demonstrated a possibility of new weakness of a simple capacity market design: moral hazard. We have provided a simple capacity market model and a two player game model in this paper. Two types of pure strategy equilibria and the conditions for each equilibrium have been provided. We have also provided separate analysis results for two pure strategy Nash equilibria. One type of equilibrium corresponds to moral hazard, and consideration of practical electricity markets suggests that the moral hazard case might be more probable. The analysis on the conditions for the moral hazard equilibrium shows that the better the electricity energy market performs, the more attractive the moral hazard equilibrium in the capacity market becomes. Finally, a numerical example was presented for illustration.

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