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Market Power in Double Price Cap electricity Market

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Abstract

In this paper, we examine double price cap electricity market from the viewpoint of non-pivotal firms. Collusive scarcity is developed by abolishing the widespread assumption that non-pivotal firms have not enjoyed a strategic behaviour of capacity withholding. In the context of the infinitely repeated game paradigm, the firms are presented with reinforcement learning and punishment policy framework, in that they attempt to learn how to tune the slope of bidding decisions and when to declare a collusive fictitious binding capacity constraint. The resulting bidding decisions explain the rationale of collusion behind capacity withholding and show to what extent non-pivotal firms can maintain stable collusive outcomes with punishment policy framework. A simulation using the generation portfolio of the Iranian electricity industry sheds light on why non-pivotal firms are capable of capacity withholding and how they maintain their collusive behaviour by exerting punishment policy.

Keywords: collusive *scarcity; punishment policy framework; reinforcement learning*

1. Introduction

In many electricity markets, a simple auction algorithm is the core element of electricity market design. However, electricity industry is a critical system on both technical and economical ground that a simple auction algorithm does not properly tackle the underlying abuse of market power. The epidemic proportions of price volatility, occasional sharp price spikes and poorly planned investment in generation have come as a surprise, persuading regulators to counter market power with every fiber of their beings [1], [2]. Various capped-auction methods for mitigating the effect of market power have been a persistent regulatory intervention [3]-[5]. Following [6] the basic intuitions are that by capping energy market and "pouring some installed capacity market oil on the troubled waters of power markets", the capacity shortage is less possible and so oligopoly players have less ability to create price spikes in the energy market. With a well developed installed capacity market escorting the capped energy market to the Promised Land of deregulation, market power is not eliminated, but is "bought out" in advance to reduce incentives to hurt economic efficiency and public confidence in the restructuring enterprise. While this suggests a pro-competitive effect in terms of lower price and less shortage, it does indicate the potential for unstable outcomes in mal-designed price caps, especially with strategic firms. Thus, although theoretical analysis of regulatory intervention has always been interesting, (e.g., [7], [8]), the work of Stoft [9] shows that electricity market design, policy making and price caps, without coordination and analysis of later consequence, can render deregulation less reliable. This initiated an active and topical stream of research. From the perspective of the repeated game paradigm [10], the regulator faces two types of problem while putting the price caps into effect: first, firms engage in tacit collusion inherent in repeated auction-based electricity market; second, the evolution of correct strategy is constrained by regulator's information processing capabilities. So, in addition to costs of intervention, the choice of a regulator depends on his answering two questions: whether the firms are inattentive to collusion; and whether the caps are elaborately designed. An objective of the design of a double price cap electricity market would be to alleviate market power while promoting system adequacy [11]. However, it is reasonable to expect that the repeated nature of electricity market will directly affect the way that the suppliers cope with the regulatory interventions of price caps. In this paper, the author intends to improve the method, proposed in his previous work [12] in two ways: First, to evaluate how well the non-pivotal firms collude with less withholding margin with higher profits for collusive behaviour of withholding. Second, how the firms maintain their collusion and punish the defectors who leave the collusive behavior and impose collapse of capacity shortage.

In this paper to deal with the problem of relatively high shortage margin of [12], the set of admissible bids are extended by an impulse control problem as a supporting tool for withholding with less capacity shortage. In addition to this extra bidding feature, a punishment policy framework has been added to reinforcement learning of the previous work that guarantees the stability of the collusive behavior by punishing the defectors.

2. Double price cap electricity market

First, Regulatory intervention of price caps has contributed to protect the customers. This appears, as it is pointed out in [12], to counter the economic intuition that strategic firms will raise electricity prices. When relative scarcity emerges, relatively high-cost suppliers are called into the market and, as a result, market clearing price rises. At such times, there is still adequate supply to serve the inelastic demand that is willing to pay the relatively high offer cap P_{c1} (see Fig. 1a). If, instead, market clearing is infeasible, owing to capacity shortage, a true scarcity situation arises. Economists depict this by showing a vertical segment of the supply curve to exhibit binding capacity constraint and unavoidable load shedding. The market price in this case is the administratively set market cap P_{c2} (see Fig. 1b). The caps satisfy $P_{c2} > P_{c1}$. This gives a scarcity rent, allowing promotion of investment and resource adequacy. Scarcity situations favor suppliers with extra profit. As a consequence, pivotal firms, whose unilateral capacity withholding would result in shortage, are tempted to withhold their capacity to give birth to capacity shortage.

In addition to the case mentioned above, no sensible unilateral capacity withholding can be made longer without taking into account the capacity of a non-pivotal firm. That is, there is enough capacity for clearing market even if one non-pivotal firm withholds all its capacity from the market. In this case, repeated auction can provide the firms with collusive cooperation, tempting them into joining forces to give birth to a pivotal cartel capable of excluding an impressive capacity from the market and imposing shortage. In view of possible conflict between opposing firms, they are expected to defect from the cartel. To see what the defection is, we focus on Fig. 2, depicting a two player double price cap electricity market. As long as the quantity offered by the firms is withheld by fictitious binding capacity constraint, there is capacity shortage in the market and thy will enjoy reward payoff (RP, stripped and dotted region in Fig. 3a). If just one firm defects by offering full capacity, he will enjoy temptation payoff (TP, dotted region in Fig. 3b) while the withholder endures the sucker payoff (SP, stripped region in Fig. 3b). Simultaneous offering of full capacity delivers punishment payoff (PP, stripped and dotted region in Fig. 3c) to both firms. By TP>RP>PP>SP, the risk of choosing unilateral withholding action arises and the question of when the firms choose simultaneous capacity withholding could be of importance. The interested reader can find more details about payoffs in [12].

3. Design of bidding formulation and punishment policy framework

The performance of double price cap electricity market depends strongly on opposing firms' behavior. To address how a repeated auction might influence game-playing behavior, we develop an agent-based simulation framework wherein the firms learn through interaction to exploit certain features of price caps, based only on publicly available information:

3.1. Bidding formulation

The economic model of the market that is used as a starting point for the analysis is that of a double price cap energy only market, which is defined as a market in which the price for electric energy is the only source of revenue. We consider daily contracting where the firms make, at the beginning of each contracting round, the bidding decisions, and then, during each round, market operation of clearing process is implemented with inelastic demand d. Each firm i has constant marginal cost of production, mc_i, up to its available capacity constraint q_i^a. The supply function of each firm $S_i(p)$, which is required to be non-decreasing is defined as the amount the firm is willing to supply at market price p. As competitors follow the equilibrium, the inverse function comes into being and is denoted by $p(q_i)$, which is considered the bidding decision of each firm. Also, it is assumed that $S(p)$ denotes market aggregated supply function and $S_{-i}(p)$ rivals' supply function.

If one's focus is on what impact price caps have on firm's behavior, the extension of supply function by vertical segments is of interest because of its role in simulating capacity withholding and declaring fictitious binding capacity constraint. Mathematically speaking, introducing discontinuities of vertical segments in supply curves would run counter to differential equations ordinarily required for the standard SFE to apply [13], [14]. To overcome this shortcoming, $p(q_i)$ is embedded in an impulse control problem [15] as a state variable for making a determination on bidding decision. This allows for a comprehensive bidding implementation, i.e., a bidding decision can be made either with vertical segments, or with slope tuning. So, bidding decision of each firm i is formulated as an impulse control problem in a n-round repeated game paradigm as follows:

$$\max_{\psi_i, u_i} U_i = (1-\delta)\sum_{t=1}^{n} \delta^{t-1} \int_0^{q_i^a} (p(q_i) - mc_i)(d - S_{-i}(p(q_i)))\, dq_i \tag{1}$$

subject to the following constraints:

$$p'(q_i) = u_i(q_i), \quad p\left(q_{ij}^+\right) = p\left(q_{ij}^-\right) + w_{ij} F\left(q_{ij}, v_{ij}\right) \tag{2}$$

$$p(0) = mc_i, \quad p(q_i) \le P_{c1}, \quad w_{ij} \in \{0,1\} \tag{3}$$

$$\psi_i = \{(q_{ij}, v_{ij}, w_{ij})\} \tag{4}$$

where the continuous control $u_i(q_i)$ in addition to the impulse control $\psi_i = (\{q_{ij}, v_{ij}, w_{ij}\})$ characterizes optimal bidding decision $p(q_i)$ as the state variable of each firm. Eq. (1)

represents the game normalized average discounted utility function by discount factor δ where the first term under the integral represents the marginal benefit and the second term describes the residual demand of the market for firm i. Tuning the slope of the state variable, when capacity withholding cannot be optimal, is governed by the $u_i(q_i)$; otherwise, ψ_i with impulse quantity q_{ij}, impulse volume v_{ij} and binary impulse decision w_{ij} will lead state variable to vertical jump, making it similar to the case when capacity withholding occurs. j is the number of vertical jumps; q_{ij}^- is the pre-jump quantity; and q_{ij}^+ is the post-jump quantity. The impulse control is very effective to create multiple jumps in the state variable. However, in the special case of capacity withholding, only one vertical segment is sufficient. So j has the value 1 or 0. At vertical segment quantity q_{ij}, the system is controlled impulsively with the impulse scale v_{ij} with its effect $F(q_{ij}, v_{ij})$ if $w_{ij} = 1$. To understand the relationship between $S_{-i}(p(q_i))$ and $p(q_i)$, as the input and output of the impulse control problem, it is worthwhile to explicitly note the obvious following fact: as mentioned in section II, a firm will withhold capacity by exhibiting vertical segments in bidding decision if it believes its "pivotal position". In other words, if a firm takes "pivotal position" in estimating $S_{-i}(p(q_i))$, $p(q_i)$ with vertical segment is expected as the output of the impulse control problem. Thus the question of "how the estimation is founded on pivotal position" is a specialized version of the general question "how vertical segment is expected from the output of the impulse control problem". To address this question, one can use the estimation of $S_{-i}(p(q_i))$ based upon standard SFE assumptions as follows [16]:

$$S_{-i}(p(q_i)) = \frac{1-\alpha_i}{\beta_i}.\,[(p(q_i) - mc_i\, S(p(q_i))^{-\theta_i+1}) * 1/(\frac{p_{c1}}{S(p(q_i))^{\theta_i-1}} - mc_i\, S(p(q_i))^{-\theta_i+1})]^{\frac{1}{\theta_i-1}} \tag{5}$$

where α_i is the contribution of each firm to reflect its factitious pivotal position. So $(1-\alpha_i)$ of demand is open to competition between non-pivotal firms. As consequences, homogeneity condition $\beta_i + \beta_{-i} = (1-\alpha_i)$ will be held and $\theta_i = (1-\alpha_i)/\beta_i$.

The above-mentioned SFE is the core element of the rivals' estimation. This estimation, which contains α_i, is being applied as an input to the impulse control problem. The state variable $p(q_i)$, as the output, is dependent on α_i: a vertical segment in $p(q_i)$ is expected if the firm chooses a pivotal position $\alpha_i > 0$, and tuning the slope of $p(q_i)$ makes sense if $\alpha_i = 0$ is selected. If all players belong to non-pivotal firms, it is likely that they will choose contribution $\alpha_i = 0, \forall i$ to achieve the most possible portion of demand. So, it is not surprising that every non-pivotal firm, whose unilateral capacity withholding does not result in true scarcity, defect to full capacity bidding from capacity withholding. This implies that, as in the well-known Nash Equilibrium (NE) concept, double price cap electricity market involves non-pivotal firms in selecting the best response strategy $\alpha_i = 0$ in relation to other firms' strategies. In fact, NE concept shows that the combination of one-stage game with non-pivotal firms lead players to greedy optimization of selfish strategy selection and non-cooperative full capacity bidding. By contrast, repeated game, as in the case of actual electricity markets, offers the firms the opportunity to engage in collusion. If these contributions $\alpha_i > 0, \forall i$ can be selected in a tacitly colluded manner then a fraction of demand will be covered and capacity shortage is to be expected.

3.1. Punishment policy and simulation framework

To have an idea of how stable the collusive strategies are, we develop a punishment policy. This can be an effective way of frustrating those who defect to $\alpha_i = 0$. Defection from $\alpha_i > 0, \forall i$ suppresses capacity shortage and precipitates a decrease in rivals' profit. This allows every firm to detect any defection of other firms and indicates that it is time to punish the defector. The punishment policy has been developed based as follows. If firm i defects from $\alpha_i > 0$, its rivals retaliate by reverting to full capacity bidding for punishment period of T_{pun} rounds. Thus, the defector receives temptation payoff of TP_i when it defects, punishment payoff of PP_i for T_{pun} rounds when it is punished, and reward payoff of $(U_i - w)$ after its rivals desist from punishing. It is important to note that U_i coincides with reward payoff and, w, which is the difference of reward payoffs between pre- and post-punishment, is necessary to support a successful punishment policy. The average discounted defection utility $U_i^{\infty,d}$ can be expressed as:

$$U_i^{\infty,d} = TP_i + \frac{\delta(1-\delta^{T_{pun}})}{1-\delta} PP_i + \frac{\delta^{T_{pun}+1}}{1-\delta}(U_i - w) \tag{6}$$

If the firm remains loyal to the collusion $\alpha_i > 0$, it has average discounted loyalty utility $U_i^{\infty,lo}$:

$$U_i^{\infty,lo} = \frac{1}{1-\delta} U_i \tag{7}$$

So the gain of defection U_i^{dg} is given by:

$$U_i^{dg} = U_i^{\infty,d} - U_i^{\infty,lo} \tag{8}$$

Adding w to $U_i^{\infty,lo}$, one obtains an inequality equation (9) from the equality equation (8):

$$U_i^{dg} < TP_i + \frac{\delta(1-\delta^{T_{pun}})}{1-\delta} PP_i + \frac{1-\delta^{T_{pun}+1}}{1-\delta}(U_i - w) \tag{9}$$

While $\delta \to 1$, we extract condition (10) under which the right hand side of (9) is less than zero:

$$T_{pun} > \frac{TP_i - (U_i - w)}{(U_i - w) - PP_i} \tag{10}$$

Under the condition of (10), the defection gain in (8) will be strictly less than zero, i.e., if punishing firms persist in punishment for T_{pun} rounds in accordance with (10), then any rational firm does not defect and a stable collusive behavior is to be expected. Learning and bidding decisions of the firms are characterized in Fig. 3. Agent-based simulation is born out of a need for reinforcement learning. The firms have to learn which the best $\alpha_i > 0$ is to adopt, based on the preferences of myopic and foresight sensing policies that were translated into low and high level of discount factors, respectively. Our goal is to find the best strategy for each firm, relative to how other firms play in the game. In order to do this, sliding reinforcement learning can be used through which rivals' strategies are learnt and then the best response can be constructed. As the only information the firm can observe is the effect of change of α_i on its own utility function, the best way to track cooperative contribution α_i is to gradually slide it and monitor if the utility function improves. Thus, if the utility functions increased (decreased) last round while the firms were increasing their contribution selection α_i, then they will increase (decrease) α_i this round. The first step in learning is the contribution selection of the pivotal position, where the firms decide on the level of demand at which rivals' capacities start binding in each hour of round, through the reinforcement learning method described above. That is, the contribution selection observes the discounted profit of each hour obtained in the previous auction round and adapts that contribution according to the change it caused in the profits. Once the contribution of pivotal position calculated, the second step is to estimate rivals' aggregated supply function. This estimated supply function forms the input for the third step in making the bidding decision $p(q_i)$ of each company; exhibit either a vertical segment to create capacity withholding or continuous segments to handle slope competition. To have a better view of the stable collusive behavior, in contrast to agent based simulation of [12], we incorporate punishment framework into agent-based simulation. When firms converge into selection of optimal collusive $\alpha_i > 0, \forall i$, this means that after 150 rounds elapsed since the game started, they need to check whether the high reward payoffs received by collusive contribution are stable. Regarding the low sucker payoff induced by rivals' defection, it is easy to find out that it is time for full capacity bidding, precipitating punishment period.

3. System details and simulation result

To have a comprehensive investigation, we consider different types of sellers of price taker and price makers to be included in system settings. To do this, Iranian generation side portfolio has been allocated among non-pivotal generation firms C1 as price taker and C2 to C9 as price makers (C6 to C9 are similar to C2 to C5 respectively). This allocation, arranged by marginal cost, is shown in Table I. A daily load duration curve with base, mid and peak segments was introduced and exposed to repeated double price cap gaming of generation side. The parameters for learning algorithm are listed as follows: $\varepsilon = 0.3$ and $\eta = 0.35$. The contribution selection was bounded by $\alpha_{i,\max} = 0.9$. Finally, all simulations were initiated with randomly distributed contribution selection and the discount factors set to 0.8. For the first results, in Fig. 4, we focus on analyzing capability of impulse control problem for creating vertical aggregated supply function (ASF), the rationale behind capacity withholding as well as full capacity bidding. When firms converge into selection of optimal contributions $\alpha_i, \forall i$, this means that after 150 rounds elapsed since the game started, they will determine what kind of strategic behavior is useful. From Fig. 4a, we can observe that when demand is in base segment, all of opposing firms have the same strategies. The capacity of price taker yields supply that enables it to meet 0.22 of base demand. So, even though price makers could radically supply 8*(1-$\alpha_{i,\max}$)=0.8 of the base load while 1-8*(1-$\alpha_{i,\max}$)=0.2 of demand is left without supply, the true scarcity is inaccessible. This ensures that, during base load segment, excess of supply can occur with at least margin of (80+22)%-100%=2%, which indicates that full capacity bidding is dominant, and, thus, $\alpha_i = 0, \forall i$ force price makers to just tune the slope of their bidding decisions. By contrast, in Fig. 4b, peak segment of the load give the price makers a chance of collusion to give birth to a pivotal cartel. Price taker meets 14% of the peak demand, and, thus, an extreme case of converging to $\alpha_{i,\max} = 0.9$ by price makers yields capacity withholding that leave 100%-(14+8*10)%=6% of peak demand without supply. Thus, it is sensible to expect learning of contributions which can create a shortage taking values in (0%, 6%] of peak demand.

Another interesting application of the simulation consists in comparing the performance of the impulse control problem and the method used in [12] for creating less shortage margin. As can be seen from Fig. 5, while the method used in [12] is incapable of imposing a shortage, the impulse control problem of this paper create a collusive capacity withholding in mid-load and render high profits to collusive firms. All the above-mentioned results give the evidence of the possibility of exercising tacitly colluded capacity withholding by non-pivotal firms. One important question is: can non-pivotal firms keep the capacity withholding stable? To explore this question, it is attempted to form a plausible explanation to how punishment policy affects firms and when it guarantees a stable collusive behavior. To ensure consistency and eliminate errors due to randomly distributed initial selected contributions, the simulation results were averaged over 20 runs, lasting 600 rounds each. Concerning the 100 rounds that elapsed since the game started and a set of collusive contributions $\alpha_i > 0, \forall i$ was reached by the firms, we introduced a defection by firm C3 who reverted to choosing $\alpha_3 = 0$ at round 200. Then, it is interesting to see how the punishment policy activates by its rivals. Among those rivals, we focus on C2 as a representative sample of punishing firms. With discount factors close to 1, implying that foresight preferences govern the firms, Fig. 6(a) shows the average discounted loyalty utilities received by C3 and C2 per round when they remain loyal to $\alpha_3 > 0$ and $\alpha_2 > 0$, respectively. This evolutionary path contains a significant upward trend, indicating that the firms are eligible for convergence to the optimal capacity withholding strategy. In the case of defection, C3 experiences temptation payoff and, as a consequence, has an increase in discounted defection utility. C3's defection comes as a shock of sucker payoff to C2 and induces a decrease in its discounted utility. So, punishment policy of full capacity bidding comes into effect. The punishment is such as to gradually decrease the discounted defection utility of C3. Consistent with (10), if punishment was to persist for at least minimum required punishment rounds, punishment policy would guarantee that the discounted defection utility of C3 falls below the discounted loyalty utility. Such punishment strengths indicate that defection gain is strictly less than zero and no defection is more profitable than loyalty, implying that stable capacity withholding is collectively rational. With discount factors close to 0, implying that myopic preferences govern the firms, Fig. 6(b) shows that an effort to make the discounted defection utility of C3 intersects the discounted loyalty utility have been thwarted. As a consequence, capacity withholding is possible to develop, but the low discount factors bring positive profit of defection gain to the defector and make the sustainability of collusion look impossible. To have a better view of the successful punishment, at four typical rounds of a run, we focus on detailed bidding decision of C3 as defector and C2, C4 and C5 as representative sample of punishing firms. Fig. 7 shows that, at first, the firms engaged in collusion, giving birth to a capacity shortage (see Fig. 7a). Full capacity bidding of C3 simulated a defection, breaking up the collusion. As a consequence, market clearing process was feasible (see Fig. 7b) and defector was awarded temptation payoff. This caused sucker payoff for C2, C4 and C5. Then, punishment policy was activated by punishing firms C2, C4 and C5 (see Fig. 8a), decreasing the discounted defection utility of C3. Finally, when the punishment period elapsed, collective capacity withholding recovered (see Fig. 8b). Figs. 7a & 8a show different shares of C3. As can be seen, the difference between the shares of C3 in pre- and post-punishment explains the successful role of sliding reinforcement learning during the punishment periods. Fig. 8c sheds light on these different shares of market. That is, when the minimum required rounds for punishment elapsed, in comparison to pre-punishment contribution, C3 makes more contribution to capacity withholding, inducing it to acquire a less share of the market. As a consequence, this sharp distinction also emerges between reward payoffs in pre- and post-punishment. This is consistent with (6) where a successful punishment policy needs a post-punishment reward payoff of $(U_i - w)$.

4. Conclusion

In the context of the repeated game paradigm, this paper has examined the effect of regulatory intervention of price caps on tacit collusion and capacity withholding from the perspective of non-pivotal firms. To measure the economic and technical consequences of capacity withholding, we propose the vertical segments of supply curve. This gives a measure of the possibility of tacit collusion and capacity withholding in double price cap electricity market. Through agent-based simulation and implementation of a punishment policy, it is shown that there are non-pivotal firms whose abuse of market power can divert pro-competitive regulatory intervention to pro-collusive catalyst. Thus, the possibility of collusive behavior in repeated game paradigm, as in the case in actual electricity markets, shatters the illusions that the regulators can directly reduce price by price caps. The next step was to establish plausible reasons for resultant market outcomes, demonstrating a significant connection between punishment policy, capacity withholding, and price caps. It is shown that this punishment policy is suitable and versatile enough to deal with the critical issue of stable collusive behavior.

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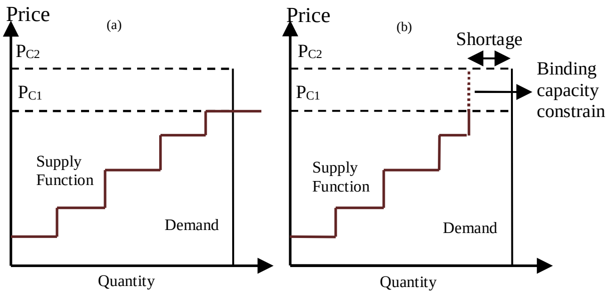

Fig. 1 : Double price cap electricity market

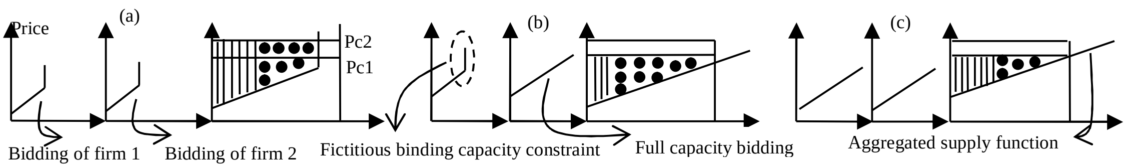

Fig. 2 : (a) Capacity withholding and (b), (c) defection to full capacity bidding

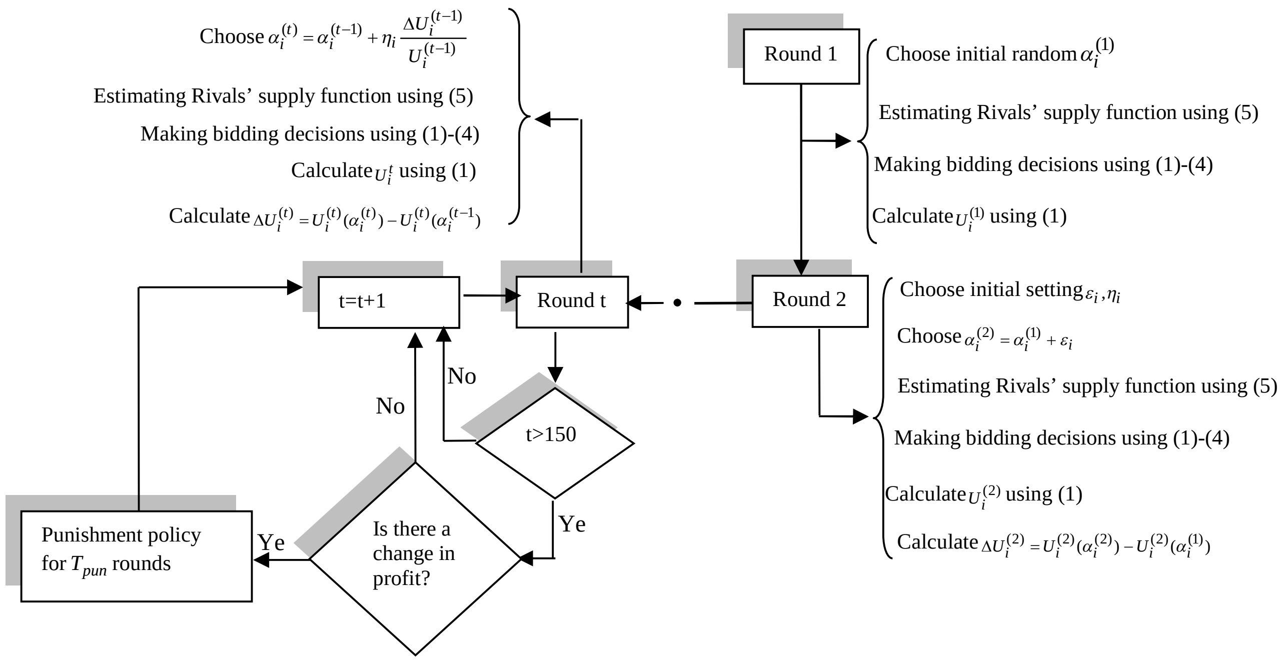

Fig. 3 : Agent-based simulation with punishment policy framework

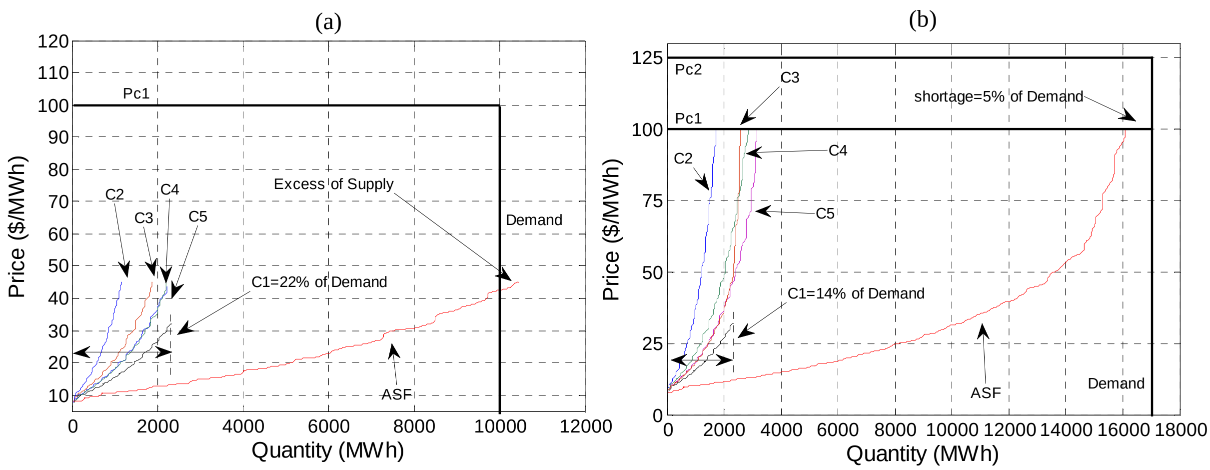

Fig. 4 : ASF of (a) base and (b) peak load

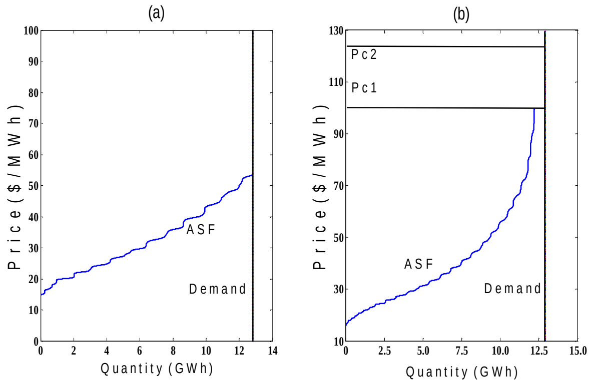

Fig. 5 : (a) Incapability of [12] and (b) capability of impulse control problem in mid-load capacity withholding

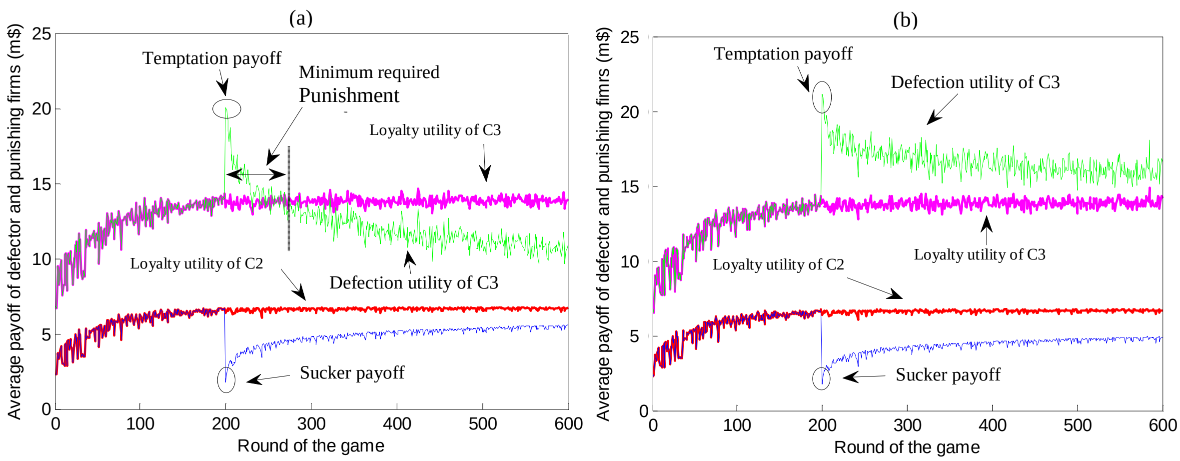

Fig. 6 : (a) Average payoff of defector and punishing firms with (a) foresight and (b) myopic preferences

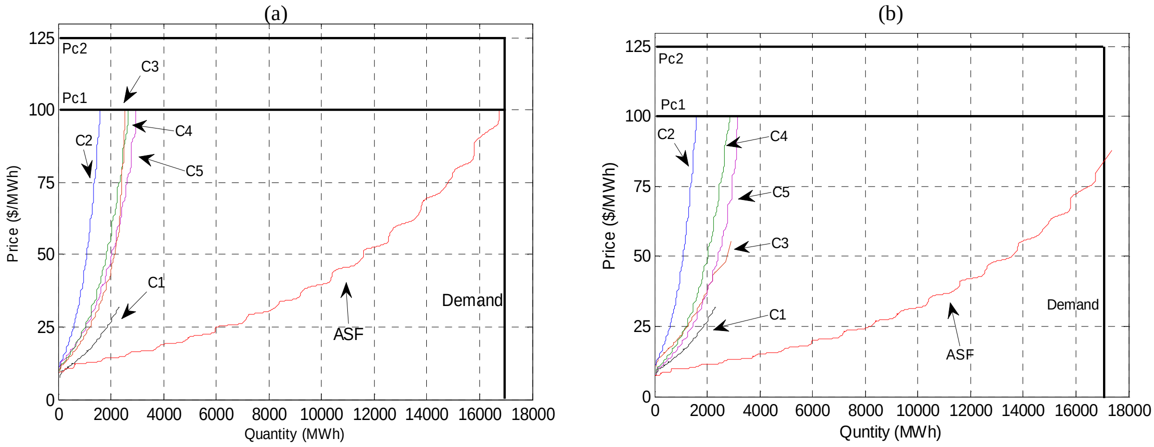

Fig.7 : (a) Tacit collusion and collective capacity withholding and (b) defection of C3

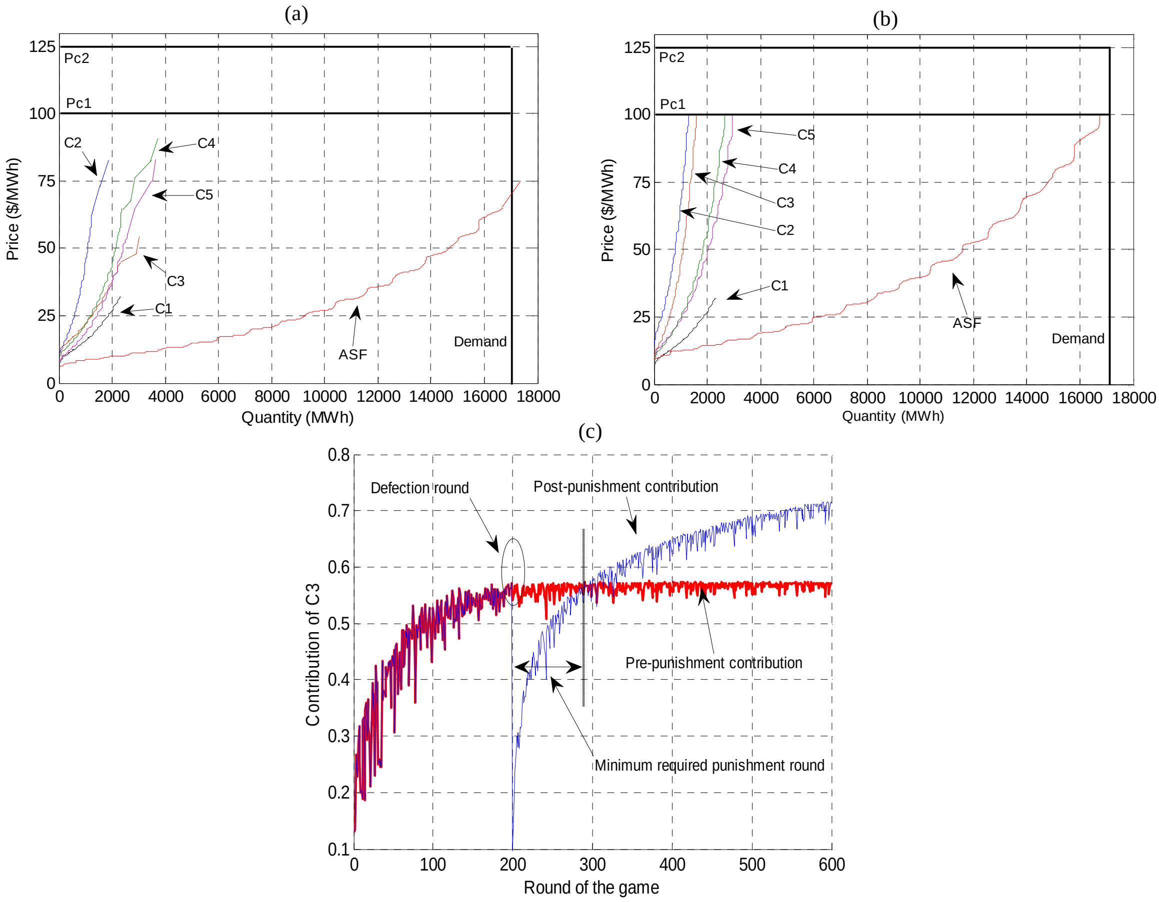

Fig.8 : (a) Activation of punishment policy, (b) recovered capacity withholding and (c) utility of pre- and post-punishment periods

Table 1. Capacity (GW) and number (in parentheses) of units

$/MWh	C1	C2	C3	C4	C5
0-15	1.5(1)	1(2)	2.2(2)	3.1(1)	1.5(1)
15-20	0.2(1)	0.3(2)	0.11(1)	0.21(1)	0.3(3)
20-25	0.26(1)	0.11(2)	0.35(3)	0.7(1)	0.26(3)
25-30	0.4(3)	0.8(2)	0.55(1)	0.56(2)	0.4(2)