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FROM UNIFORM AUCTION TO DISCRIMINATORY AUCTION: AN ASSESSMENT OF THE RESTRUCTURING PROPOSAL FOR THE ITALIAN ELECTRICITY DAY-AHEAD MARKET

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From Uniform Auction to Discriminatory Auction: an Assessment of the Restructuring Proposal for the Italian Electricity Day-Ahead Market

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Abstract

In the context of the 2009 debate on reforming the Italian market, a realistic agent-based computational model of the day-ahead market session of the Italian wholesale electricity market is simulated to compare market performances between uniform-price and pay-as-bid clearing mechanisms. An empirical validation of computational results at a macro-level is performed to test for accuracy of simulated outcomes with historical ones. The level of prices are accurately reproduced except for few peak hours. As far as concerns pay-as-bid auction, the computational experiments point out that it results in higher market prices than the uniform-price auction. In the pay-as-bid mechanism, sellers' endeavours to maximize their profits are more costly thus leading to higher price levels.

Keywords

Electricity markets, agent-based computational economics, auction design, uniform auction, discriminatory auction, reinforcement learning

Introduction

One of the key aspect in the mechanism design of power auctions is related to the pricing method. Standard practice has been to adopt uniform prices ("system marginal price" or pay the market clearing price) or discriminatory prices ("pay as bid" or pay the bid price). In the economic literature, there is no general consensus in which solution is most efficient, anyhow the uniform price mechanism has become more popular. Nowadays, all major European power markets adopt it. However, both discriminatory and uniformly priced auctions have advantages and disadvantages which may be determined or enhanced by specific market settings and conditions. For instance, the inherent nature of the power market to be an "infinitely" repeated market mechanism may provide strong incentives to tacit collusion. The repeated interaction among bidders expands the set of signalling and punishment strategies available to them, and allows them to learn to cooperate (Klemperer [1999], Klemperer [2002], Fabra [2006]).
In March 2001 the U.K. electricity regulator replaced the uniform-price clearing mechanism system by a discriminatory auction, because the Office of Gas and Electricity Markets (OFGEM) have been believed that uniform auctions are more subject to strategic manipulation and can fall prey to some kind of "tacit collusion". On the contrary, they supposed that discriminatory auction would have weaken the opportunity to tacit collusion, because bids can no longer be used as costless threats. Within such context, several authors have analyzed the 2001 reforms in the UK and in some case argued against the proposed reform. For instance, Wolfram [1999] asserted that given the strongly concentrated UK market structure, a small number of generating companies dominate the market, the switch to discriminatory pricing was unlikely to solve the problem of high prices. Bower and Bunn [2001b, 2000] even suggested that the reform would have actually increased market prices. Their analysis is based on an agent-based simulation model. The main rationale is that market prices are not publicly available and agents with a large market share gain a significant informational advantage in a discriminatory auction, thereby facing less competitive pressure.
In Italy, the liberalization process arrived with some delay if compared to other European countries. The Italian power exchange (IPEX) started on April 1^{th}, 2004 run by the Gestore Mercato Elettrico (GME), i.e., the Italian market operator. IPEX market design has been conceived according to common practice guidelines adopted in different European electricity market restructuring proposals. Several subsequent market sessions for both trading energy and managing critical services, e.g., reserves and real-time balancing, are run daily. These are the Day-Ahead Market session - (DAM), (*Mercato del Giorno Prima* - MGP), the Adjustment Market sessions and the Ancillary Services Market. The most important (liquid) session is the day-ahead market which is organized as a uniform price double-auction market where approximately 60 percent of national production is traded. According to the Law dated 27 January 2009 converting the Law Decree n. 185/2008, better known as "Decreto anti-crisi", i.e, "Anti-Crisis Decree", the Italian authority for energy is required to assess the opportunity to introduce from the 1st April 2012 the pay-as-bid mechanism in the *Mercato del Giorno Prima*. This reform goes against the mainstream, in all European Market power the uniform-price mechanism is the standard *de facto* for DAM.
This paper addresses this compelling issue and proposes an agent-based computational model of the day-ahead market session of the Italian wholesale electricity market to assess the validity of such restructuring proposal. An empirical validation at a macro-level is firstly performed to test the accuracy of the proposed model in the case of uniform auction. In particular, the level of the "*Prezzo Unico Nazionale*" (PUN), i.e., National single prices, for the Wednesday December 20^{th}, 2006, are used so to compare simulation results with historical performances. It is worth noting that the daily spot price dynamic of the electricity markets presents repetitive patterns because power prices are mainly driven by an inelastic and strongly seasonal (also at a daily level) demand. Thus this paper proposes the empirical validation with respect to a representative day.
This paper adopts the agent-based computational approach for the sake of realism, in order to provide an adequate answer to the economic issue considered. The appealing perspective of modeling complex market models, such as electricity markets, from a bottom-up perspective motivates the adoption of a computational approach in economics and in particular in the study of wholesale electricity markets (Guerci et al. [2009]). In such artificial computational environments, autonomous, self-interested, adaptive and heterogeneous market agents may interact repeatedly among each other, thus reproducing a realistic economic dynamic system (Tesfatsion and Judd [2006]). Several works in the literature, e.g., (Bower and Bunn [2000, 2001a], Bunn and Day [2009], Conzelmann et al. [2005], Genoese et al. [2005], Rastegar et al. [2009], Sun and Tesfatsion [2007], Veit et al. [2006] and Weidlich and Veit [2008]), have proposed detailed model of national wholesale electricity markets, but very few address the issue of validating empirically the predic-

Coal	Gasoline	Gas	Oil
2.3	10.5	6.3	5.3

Table 1: Fuel prices (FP_t) at year 2005 [€/GJ]. These values have been used in the computational experiments.

tive power of the computational model. In order to better replicate the real features of the Italian market, a data-driven computational model is adopted where historical data of the IPEX at year 2006 are used to build the artificial economic environment. The proposed Italian wholesale electricity market model implements a realistic MGP clearing procedure (entailing the zonal market structure and the relevant transmission network) and is endowed with historical zonal loads and the set of all major Italian thermal power-plants at year 2006 (i.e., 158 generating units). It is worth noting that electricity generation in Italy is mainly characterized by fossil fuel generation, i.e., coal, natural gas, oil, gasoline, which covered at year 2006 almost 74 percent of the national gross generation capacity. Renewable generation is almost irrelevant except for hydro generation which corresponds to approximately 24 percent of the total gross generation capacity.
The paper is organized as follows. Section 1 presents the physical constrained market model, the Italian grid model, the agent based computational model and the learning algorithm employed. Section 2 describes the computational experiment settings and it presents and discusses results. Concluding remarks are pointed out in Section 3.

1 ACE Model

1.1 Market model

In the following, the market clearing procedure for the DAM is detailed.
Each i^{th} generator ($i = 1, 2, ..., N$) submits to the DAM a bid consisting of a pair of values corresponding to the limit price $\hat{P}_i$ ([€/MWh]) and the maximum quantity of power $\hat{Q}_i$ ([MW]) that he is willing to be paid and to produce, respectively[1]. We assume that each generation unit has lower $\underline{Q_i}$ and upper $\overline{Q_i}$ production limits, that define the feasible production interval for its hourly real-power production level $\underline{Q_i} \leq \hat{Q}_i \leq \overline{Q_i}$ ([MW]).
The total cost function of i^{th} generator is given by

$$TC_i(Q_i) = FP_l \cdot (a_i \cdot Q_i + b_i), \text{ [€/h]}, \tag{1}$$

where FP_l ([€/GJ]) is the price of the fuel (l) which is used by the i^{th} generator. The coefficients a_i ([GJ/MWh]) and b_i ([GJ/h]) are assumed constants. This pair of coefficients (a_i, b_i) vary with respect to the efficiency and technology of the power plant. The constant term $FP_l \cdot b_i$ corresponds to no-load costs Kirschen and Strbac [2004], i.e., quasi-fixed costs that generators have if they keep running at zero output. However, these costs vanish once shut-down occurs. Finally, Table 1 reports the fuel prices (FP_t) considered in the simulation which corresponds at the year 2005, thus assuming that generation companies sign yearly contracts for the provision of such fuels.
The constant marginal costs MC_i for the i^{th} generator can be easily derived from the associated total cost function $TC_i(Q_i)$:

$$MC_i = FP_l \cdot a_i, \text{ [€/MWh]}. \tag{2}$$

After receiving all generators' bids the DAM clears the market by performing a social welfare maximization subject to the following constraints: the zonal energy balance (Kirchhoff's laws), the maximum and minimum capacity of each power plant and the inter-zonal transmission limits. The objective function takes into account only the supply side of the market, because the demand is assumed price-inelastic. Therefore, the social welfare maximization can be transformed into a minimization of the total production costs (see eq. 3). This clearing mechanism is also standardly named as DC optimal power flow (DCOPF) procedure for determining both the unit commitment for each generator and the Locational Marginal Price (LMP) for each

[1]The supply bidding format in MGP is a step-wise function defined by a maximum of four points (P_i, Q_i). However, a simple statistical analysis performed on 2006 historical data shows that almost 75 percent of the offers are composed by a single point bid.

bus. However, the Italian market introduces two slight modifications. Firstly, sellers are paid at the zonal prices, i.e., LMP, whereas buyers pay a unique national price (PUN, Prezzo Unico Nazionale) common for the whole market and computed as a weighted average of the zonal prices with respect to the zonal loads. Secondly, transmission power-flow constraints differ according to the flow direction. In the following the exact formulation is presented.

$$\min \sum_{i=1}^{N} \hat{P}_i \cdot Q_i, \quad \text{[MW]}, \tag{3}$$

subjected to the following constraints:

- Active power generation limits:
  $\underline{Q_i} \leq Q_i \leq \hat{Q}_i, \quad$ [MW],

- Active power balance equations for each zone z:
  $\sum_{i \in z} Q_i - Q_{z,load} = Q_{z,inject}, \quad$ [MW],
  being $Q_{z,load}$ the load demand and $Q_{z,inject}$ the net oriented power injection in the network at zone z. $Q_{z,inject}$ are calculated with the standard DC Power flow model.

- Real power flow limits of lines:
  $Q_{l,st} \leq \overline{Q}_{l,st}, \quad$ [MW],
  $Q_{l,ts} \leq \overline{Q}_{l,ts}, \quad$ [MW],
  being $Q_{l,st}$ the power flowing from zone s to zone t of line l and $\overline{Q}_{l,st}$ the maximum transmission capacity of line l in the same direction, i.e., from zone s to zone t. $Q_{l,st}$ are calculated with the standard DC Power flow model.

The solution consists of the set of the active powers Q_i^* generated by each power plant and the set of zonal prices ZP_k (LMPs) for each zone $k \in \{1, 2, ..., K\}$.
The profit per hour R_i for the i^{th} generator belonging to zone k in the uniform price clearing mechanism is obtained as follows:

$$R_i = ZP_k \cdot Q_i^* - TC_i(Q_i^*) \quad \text{[€/h]}. \tag{4}$$

While the profit per hour in the pay as bid clearing mechanism is given by:

$$R_i = \hat{P}_i \cdot Q_i^* - TC_i(Q_i^*) \quad \text{[€/h]}. \tag{5}$$

1.2 Grid model

The adopted market clearing procedure requires the definition of a transmission network. The grid model considered in this paper (Figure 1) reproduces exactly the zonal market structure and the relative maximum transmission capacities between neighboring zones of the Italian grid model. It corresponds at the grid model defined by the Italian transmission system operator, i.e., TERNA S.p.A., at the end of the year 2006 which is adopted by the market operator. The grid comprises 11 zones (BRNN (BR), Central North (CN), Central South (CS), FOGN (FG), MFTV, North (NO), PRGP (PR), ROSN (RS), Sardinia (SA), Sicily (SI), South (SO)) and 10 transmission lines depicting a chained shape which connects the North to the South of Italy. The different values of maximum transmission capacities for both directions of all transmission lines are also reported. Figure 1 further shows also the distribution of generators in the network and the representative load serving entities (LSE) at a zonal level. To be precise Calabria zone, two national virtual zones (TBRV and PBNF) and neighboring country's virtual zones[2] have been neglected in the definition of the grid model, but their contributions to national loads or production capacities have been adequately included in the simulations. Finally, transmission losses have been neglected in the model.

[2]National Virtual Zone are "Point of Limited Production". Neighboring Country's Virtual Zone are point of interconnection with neighboring countries. Please refers to www.mercatoelettrico.org.

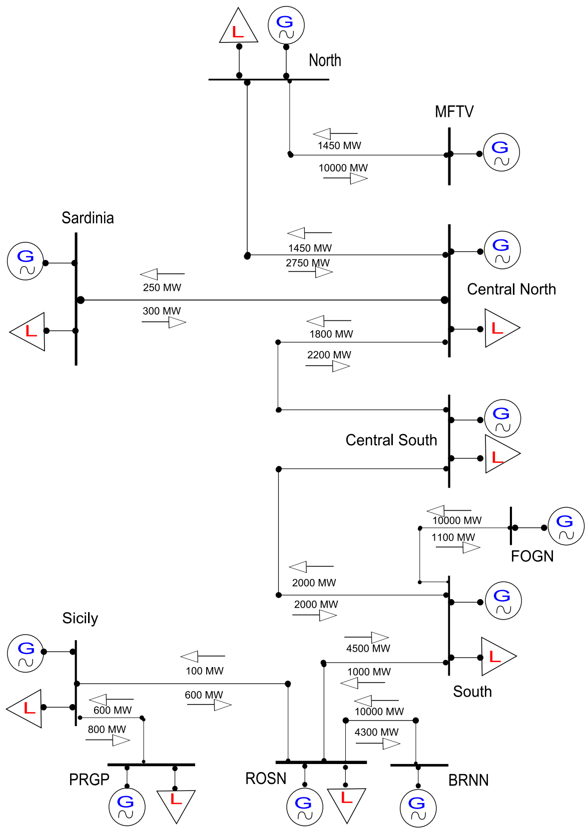

Figure 1: The Italian grid model adopted for the computational experiments comprising 11 zones (buses) and 10 transmission lines. Circles define the presence of generators located in the zone, whereas triangles highlight the aggregate load serving entities (LSE) for each zone. The numbers above and below of the lines correspond to the lines' maximum transmission capacity constraints for both directions at hour 3 p.m.. Arrows indicate the power-flow direction relative to each transmission capacity constraints.

1.3 Agent model

Two types of agents are modeled, buyers and sellers. Buyers are considered as representative LSEs aggregated at a zonal level. Their quantity bids are assumed price-inelastic and have been calibrated on the exact values of the daily load profile for the 20 of December, 2006 (Gestore Mercato Elettrico [2006]). Table 2 reports the load values considered. MFTV and FOGN zones, which are national virtual zones, have no load, therefore are not reported in the Table.

The supply side of the market is composed by generation companies submitting bids for each of their power plants. Only thermal power plants are considered, because they represent almost three fourth of the national gross production capacity, furthermore the remaining national production (hydro, geothermal, solar, wind) and imported production is easily modeled as quantity bids at zero price. Import corresponds in general to power generated abroad by cheap technologies such as hydro or nuclear power plants coming mainly from France and Switzerland. In any case, exact historical values have been assumed for determining all these latter contributions (TERNA S.p.A. [2006]).

The considered set of thermal power plants consists of 158 generating units comprising five different technologies, i.e., Coal-Fired (CF), Oil-Fired (OF), Combined Cycle (CC), Turbogas (TG) and Repower (RP). These power plants were independently or jointly owned at year 2006 by 16 different generation companies (Gencos). However, in our simulation, the power plant's ownership has been assumed unique for each power-plant by assigning to each power-plant the Genco with the largest share. In order to reduce the number of agents, we have defined 53 agents by grouping thermal power-plants according to the zone in which they inject power, to the technology of production and to the owner, that is, Genco. Table 3 reports the maximum and minimum generation capacities for each zone and technology, respectively, by aggregating

	CN	CS	NO	PR	RS	SA	SI	SO
1	3714	3284	17924	145	371	1535	1995	4282
2	3643	3097	17808	290	334	1456	1828	4365
3	3509	2958	17507	290	316	1416	1723	4208
4	3515	2908	17404	435	308	1399	1682	4169
5	3529	2913	17562	435	310	1400	1686	4257
6	3686	3020	18501	290	334	1445	1767	4463
7	4319	3579	21018	0	409	1595	2058	4749
8	4844	4318	25473	0	504	1698	2475	5009
9	5531	4734	28266	0	564	1792	2732	5470
10	5802	5005	28996	0	571	1799	2795	5637
11	5837	5038	28955	0	552	1755	2723	5549
12	5799	4996	28747	0	539	1728	2662	5500
13	5326	4871	25981	0	529	1693	2619	5470
14	5085	4725	26250	0	520	1652	2574	5294
15	5394	4752	27396	0	533	1664	2621	5382
16	5543	4794	27765	0	543	1677	2684	5568
17	5764	5017	28564	0	589	1700	2829	6029
18	6066	5371	29483	0	656	1834	3100	6450
19	5867	5348	28287	0	648	1870	3105	6343
20	5544	5246	26671	0	641	1867	3126	6166
21	5097	4905	25031	0	621	1833	3060	5848
22	4771	4553	23305	0	578	1730	2908	5441
23	4373	4130	21090	0	518	1628	2648	4970
24	3979	3693	19428	0	440	1653	2299	4303

Table 2: Zonal loads ([MW]) for all 24 hours of Wednesday 20 of December, 2006.

all agents' contributions. In particular, the g^{th} Genco owns $N_{g,z,f}$ thermal power plants in zone z with technology f. We group all $N_{g,z,f}$ thermal power plants in 53 different autonomous, self-interested, adaptive and heterogeneous agents.
Each j^{th} agent ($j = 1, 2, ..., 53$) bids to the DAM a pair of values corresponding to a limit price $\hat{P}_{j,i}$ ([€/MWh]) and a quantity of power $\overline{Q}_{j,i}$ [MW] (they are assumed to bid the maximum capacity of their power-plants) that is willing to produce for each agent-owned power plant $i \in \{x_{1_j}, \ldots, x_{N_j}\}$. N_j is the number of agent-owned power plants and if agent j is owned by g^{th} Genco and has its power plants located in zone z with technologies f, then $N_j = N_{g,z,f}$. Furthermore, $\hat{P}_{j,i} = m_j \cdot MC_{j,i}$, where $m_j \in \mathcal{A}_j$ (action space of agent j) is a mark-up value common to all power-plants owned by agent j and $MC_{j,i}$ is the marginal cost of the i^{th} power plant owned by agent j. Finally, $\hat{Q}_{j,i}$ corresponds to the maximum production capacity for each i^{th} power plant owned by agent j. Thus, agents are assumed to bid always the maximum production capacities and a common mark-up value for all their power-plants. In the computational experiments we have assumed $\mathcal{A}_j = \{1.00, 1.05, 1.10, \ldots, 3.00\}$ corresponding to a mark-up increase value of five percent and a maximum mark-up value of 300 percent with respect to the marginal cost. Therefore the cardinality of agents' action space is equal, i.e., $|\mathcal{A}_j|$ =M= 60 for all j.
Accordingly, we define the profit $\mathcal{R}_j$ of each agent j^{th} as follows:

$$\mathcal{R}_j = \sum_{i \in \{x_{1_j}, \ldots, x_{N_j}\}} R_i. \text{ [€/h]} \tag{6}$$

1.4 Learning model

Agents/sellers submit simultaneously 24 bids one for each hourly DAM session. They learn independently to bid strategically on each hourly market, i.e., no interrelationship is considered among such markets. In Italy, the hourly bids are submitted simultaneously and furthermore, no block bidding is enabled. Agents are

	CF	CC	RP	OF	TG	Total
BR	(3026, 1136)	(1110, 690)	0	0	0	(4136, 1826)
CN	(136, 64)	(373, 220)	0	(1565, 490)	(298, 0)	(2372, 774)
CS	0	(1256, 741)	(3288, 980)	0	(910, 0)	(5454, 1721)
FG	0	(360, 220)	0	0	0	(360, 220)
MF	(316, 220)	0	0	(620, 300)	0	(936, 520)
NO	(2641, 1682)	(14000, 8265)	(796, 220)	(3051, 902)	(449, 0)	(20937, 11069)
PR	0	(750, 360)	0	0	0	(750, 360)
RS	0	0	(1660, 688)	0	0	(1660, 688)
SA	(789, 236)	0	0	(740, 232)	(256, 0)	(1785, 468)
SI	0	(480, 282)	0	(1525, 647)	(176, 0)	(2181, 929)
SO	0	(1516, 900)	0	(195, 63)	(334,) 0	(2045, 963)
Total	(6908, 3338)	(19845, 11678)	(5744, 1888)	(7696, 2634)	(2423, 0)	(42616, 19538)

Table 3: Maximum and minimum (max, min) generation capacities for each zone and technology. Technologies are Coal-Fired (CF), Oil-Fired (OF), Combined Cycle (CC), Turbogas (TG) and Repower (RP)

modeled as adaptive agents by implementing a classical reinforcement learning algorithm originally proposed by Roth and Erev [1995]. In this learning model, three psychological aspects of human learning are considered: the power law of practice (i.e., learning curves are initially steep and tend to progressively flatten out), the recency effect (i.e., forgetting effect), and an experimentation effect (i.e., not only experimented action but also similar strategies are reinforced). Nicolaisen et al. (Nicolaisen et al. [2001]) proposed some amendments to the original algorithm in order to play a game with zero and negative payoffs. This paper considers the modified formulation.

For each strategy $a_j \in \mathcal{A}_j$, a propensity value $S_{j,t}(a_j)$ is defined. At every round t, propensities $S_{j,t-1}(a_j)$ are updated according a new vector of propensities $S_{j,t}(a_j)$ by

$$S_{j,t}(a_j) = (1-r) \cdot S_{j,t-1}(a_j) + E_{j,t}(a_j) \tag{7}$$

where $r \in [0,1]$ is the recency parameters which contributes to decrease exponentially the effect of past results. The second term of equation 7 is called the experimentation function and is given by

$$E_{j,t}(a_j) = \begin{cases} \Pi_{j,t}(\hat{a}_j) \cdot (1-e) & a_j = \hat{a}_j \\ S_{j,t-1}(a_j) \cdot \frac{e}{\mathrm{M}-1} & a_j \neq \hat{a}_j \end{cases}$$

where $e \in [0,1]$ is the experimentation parameter (which assigns different weights between the played action and the non played actions), M is the number of actions and $\Pi_{j,t}(\hat{a}_j)$ is the reward obtained by playing action $(\hat{a}_j)$ at round t. Rewards are computed as the profits per unit of power ([MW]) by

$$\Pi_{j,t}(\hat{a}_j) = R_j(\hat{a}_j)/\overline{R}_j, \tag{8}$$

where $\overline{R}_j$ is the maximum profit achievable by agent j^{th}, i.e., when ZP_k is equal to price cap and $Q^*_{j,i} = \overline{Q}_{j,i}$ in equation 6. The rationale is for uniforming convergence times among the agents due to their heterogeneity in power plants' capacities and technological efficiency.

Propensities are then normalized to determine the probabilistic action selection policy $\pi_{j,t+1}(a_j)$ for the next auction round, i.e.,

$$\pi_{j,t+1}(a_j) = \frac{e^{S_{j,t}(a_j)/\lambda_t}}{\sum_{a_j} e^{S_{j,t}(a_j)/\lambda_t)}}. \tag{9}$$

where

$$\lambda_t = c \cdot t^{-d} \tag{10}$$

The time varying parameter λ_t is a cooling parameter that affects the degree to which j^{th} agent makes use of propensity values in determining its probabilistic action selection policy. $\lambda_t \to 0$ entails that the probabilistic action selection policy become increasingly peaked over the particular action (a_j) having the highest propensity values $\pi_{j,t+1}(a_j)$, thereby increasing the probability that these action will be chosen.

2 Results

The agent-based computational model described in previous sections enables to study the relative performance of Italian whole-sale electricity market, i.e., under uniform price and discriminatory price mechanisms. Furthermore, the simulation results are compared to real market performances and a cost based simulation scenario. The empirical validation is performed only at an aggregate level by considering national prices, PUNs. Three simulation settings are run in order to validate empirically the model and compare the performances of the two auction mechanisms. The first is a cost based model where all agents are assumed to bid the marginal costs of their power plants. Then, two strategic models are considered implementing uniform and discriminatory price mechanisms, where agents learn to play optimally for maximizing their profits by considering total costs of production (see equations 4 and 5). For the two strategic models, 100 computational experiments have been carried out independently and ensemble averages have been computed to estimate market outcomes. The profit-seeking agents learn over time the bidding price to submit to the IPEX using the reinforcement learning algorithm described in previous section. Learning parameters c and d (see equation 10) have been calibrated so as to guarantee the convergence within the length of each experiment of the action selection policies of all 53 agents towards peaked distributions, i.e., the probability associated to one action is greater than 99.9 percent. Each computational experiment is composed by 10000 iterations. The large number of iteration is mostly due to the learning procedure, as at each iteration an agent updates only one of the 60 actions of the action space. If an agent was capable of inferring potential profits for all 60 actions of each iteration, then only 10000 divided by 60, i.e., 167, equivalent iterations could have been sufficient, thus corresponding to less than 6 months. Indeed, sellers in reality can infer potential profits for a large number of alternative actions. For instance all actions/bids below the accepted bid have a determinable profit.
Table 4 reports the values of parameters adopted for all simulations. It is worth remarking that agents are homogeneous with respect to the learning model.
Figure 2 compares the 24 PUNs for the two simulation frameworks to the historical data and cost-based model. The results of the uniform-price clearing mechanism are in good correspondence with historical data, in particular for off-peak demand hours. For few peak hours, 17 p.m., 18 p.m., 19 p.m., the results do not reproduce accurately the level of prices, the simulated PUNs are significantly lower. It is worth noting that in the simulation all power plants bid throughout the entire computational experiment, but in reality planned or accidental plant's outages are common. In the simulation, power plants which were probably off during that day are considered on. In these hours, PUN is more sensitive to plant outages because marginal power plants are less dense. This aspect is highlighted by the behavior of the two standard deviation curves. A greater variability in the selected long-run equilibrium solution is evident during peak hours rather than off-peak hours. Furthermore, the proposed model is not adequate to reproduce neither collusive behavior among agents nor capacity withholding bidding behavior (power plants bid always their maximum capacity). The latter behavior can raise PUN by increasing zonal market prices when transmission constraints between neighboring zones are satisfied. From this point of view, it is worth considering how supplier agents are defined (see section 1.3), that is, by grouping thermal power-plants according to the zone in which they inject power, to the technology of production and to the owner (Genco). Table 5 shows the number of agents , i.e., 53 independent agents, and their location in each zone. Each agent is independent to the others, even if belonging to the same Genco. Many Gencos own power-plants in single zones, so the assumed notion of agent may appropriately represents from a strategic point of view the Genco. Therefore, strategic opportunities to manipulate prices between zones is limited to a restricted number of player. In particular, the incumbent operator "Enel Produzione" (ENELP) and other few big market player may play strategically on the basis of their heterogenous pools of production installed in the different zones. In any case, the proposed model adequately reproduces the level of PUN for the majority of the 24 hours. The remarkable difference in the level of PUNs between the cost based and the strategic case, the latter is more than twice the level of the former, is determined by both a correct modeling of the competitive environ-

$S_{j,0}$	**r**	**e**	**c**	**d**
0.6	**0.97**	**0.04**	**0.035**	**0.05**

Table 4: Parameters' values of the adopted learning model.

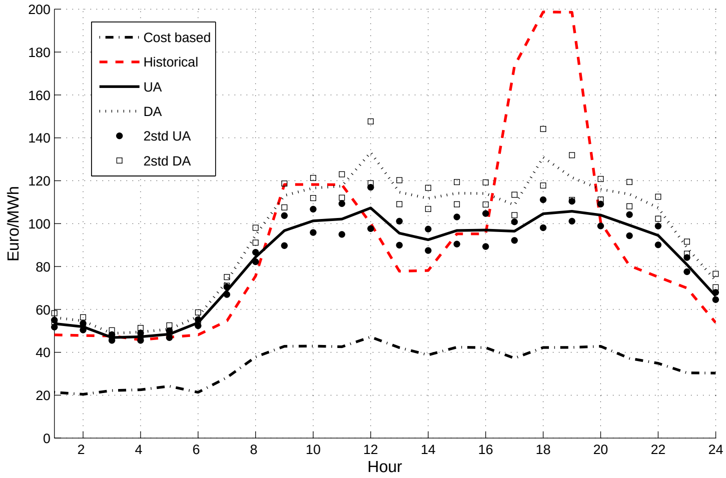

Figure 2: PUN for the 24 hours corresponding to real and simulated values for Wednesday 20 of December, 2006. The red dashed line correspond to the historical performance. The dot-dash line shows the cost based model simulation results. The continuous line and the dotted one corresponds to the strategic model simulation results for the uniform and discriminatory auction, respectively. The filled circles and the empty square represent the interval of two standard deviations with respect to the UA and DA strategic model simulations, respectively.

ment and a correct estimation of total cost functions (including quasi-fixed costs, i.e, no-load costs) of each power plant. Results thus stress the importance of considering no-load costs in the decision-making process of generation companies. Figure 2 enables also to compare the performance of the two double-auction mechanisms considered. Discriminatory auction exhibits the highest PUNs for every hour. Thus, the results of the proposed model agree with previous studies which stated that discriminatory auction may determine higher prices. In order to better understand the rationale of such rise in prices, graphs 3 and 4 are proposed. The first one shows the distribution of zonal prices for the 100 computational experiments. The considered hour is 6 p.m., where a greater variability is showed. It is evident by comparing the behavior in both auctions that the distributions of DA are more peaked and shifted towards higher average prices. This occurs in all zones except in Sicily where the distributions are similar. Central north (CN), central south (CS) and south (SO) have the same distribution because no market splitting occurs among these zones in this hour. The average zonal prices are realistic in the terms that the north zone is the cheapest and Sicily is the most expensive. The plots show the tendency of agents in DA to increase bid-prices in the attempt to bid as closer as possible to the marginal unit price. These sellers' endeavours push up average prices thus reinforcing sellers' choices to bid up. This behavior is more detailed in Figure 4 where a representative supply curve of hour 3 p.m. is plotted and agents' bids are highlighted also with respect to their technologies. Uniform-auction simulation reproduces the cost-based model in terms of power plants behavior, i.e., coal-fired are the lowest bid, then combined cycle power plants, oil-fired, repower and finally turbogas power plants which are the most expensive. On the contrary, the greater competition among agents in the discriminatory auction scenario, determines mainly that combined cycle power plants, oil-fired and repower bid at the same level of prices. In particular, combined cycle power plants, that represent the most installed technology in terms of production capacity, rise their bid price up to repower power plants and oil-fired bid prices. Combined cycle power plants results thus the most profitable technology under this market setting. In Figure 5 an average hourly profits per MW for each of the five technologies considered by aggregating power plants of every market zones. CF and OF technologies have significantly higher profits among five different technologies in uniform and discriminatory auctions results respectively. However, RP and CF gain lowest profits in average for all 24 hours in these clearing mechanisms respectively. Furthermore, TG power plants, which are almost off during off-peak demand hours in both clearing mechanisms, obtain almost the same profit in average of 24 hours. The performance of CC technology is close to the best performance in both clearing mechanisms, but it is even better in discriminatory auction in comparison with the uniform one. The latter is

	BR	*CN*	*CS*	*FG*	*MF*	*NO*	*PR*	*RS*	*SA*	*SI*	*SO*
A2A	0	0	0	0	2	2	0	0	0	0	0
ACEA	0	0	2	0	0	0	0	0	0	0	0
ACEGAS	0	0	1	0	0	1	0	0	0	0	0
AES	0	0	0	0	0	0	0	0	1	0	0
ATELACTV	0	0	0	0	0	1	0	0	0	0	0
EDIPOWER	1	0	0	0	0	2	0	0	0	1	0
EDISON	0	1	0	1	0	1	0	0	0	0	1
ELECTRAB	0	0	0	0	0	1	0	0	0	0	0
ENELP	1	4	2	0	0	4	1	1	3	1	2
ENERGIA	0	0	0	0	0	0	0	0	0	0	1
ENIPOWER	1	0	0	0	0	1	0	0	0	0	0
EON	0	0	0	0	0	2	0	0	3	1	0
ERG	0	0	0	0	0	0	0	0	0	1	0
IRIDE	0	0	0	0	0	2	0	0	0	0	0
SARPOM	0	0	0	0	0	1	0	0	0	0	0
TIRRENOP	0	0	1	0	0	1	0	0	0	0	0

Table 5: The sum of all numbers is equal to 53 that is the number of agents. Each cell indicates the number of technologies installed for each Genco in each zone zone. Zones are BRNN (BR), Central North (CN), Central South (CS), FOGN (FG), MFTV, North (NO), PRGP (PR), ROSN (RS), Sardinia (SA), Sicily (SI), South (SO).

also true for RP technology power plants. Conversely, the performance of CF technology in uniform price is significantly lower in compare with discriminatory auction. These outcomes reflect the characteristics of the Italian electricity production pool, e.g., TG power plants have parameter b in the total cost function and minimum capacity production almost equal to zero.

3 Conclusions

This paper aims to assess whether a switch from the uniform price mechanism to a pay as bid mechanism in the day-ahead market session of the Italian power exchange (IPEX) should be encouraged. A realistic agent-based computational model of the Italian market scenario is adopted to study in detail market performances. Computational results show that the market model is able to simulate real market performances to a greater extent than a perfect competition model. In the proposed strategic model, agents are able to achieve higher prices by learning and reinforcing bidding strategies in order to achieve prices above marginal costs. In their adaptive learning procedure sellers consider their total cost of production, comprising no-load costs, which play an important role in the decision-making process of generation companies. The results show that the 24 aggregate market prices (PUNs), under both auctions, are significantly higher than the ones obtained by means of the cost based model. Furthermore, the simulated PUNs for the uniform auction reproduce accurately the historical price dynamic, except for some peak hours. During these hours of highest demand, some modeling aspect, neglected in the current model, may be determinant for forming the prices. Plant's planned or accidental outages of low- or mid-merit power plants might have occurred in the considered day, thus engendering a rise in the price. On the contrary, in the proposed model all power plants have been considered to bid throughout the entire simulation. Another important determinant might be found in the features of the agent's model. In the current framework, agents do not represent exactly Gencos, but each agent represent only a subset of Genco's power plants grouped by technologies and zone. Thus, some strategic decision, for instance decisions related to inter-zonal optimal dispachment, are discarded in our modeling framework. Within such context, the current model does not implement a behavioral rule considering quantity withholding bidding behavior which may be adopted by major GenCos in order to force inter-zonal transmission constraints so to increase zonal prices. In any case, the accurate prediction of prices support the adoption of the model to assess which market mechanism determines lower market prices. Under this aspect, computational results clearly show that changing the settlement procedure i.e.,

uniform-price to Pay as Bid, induces a significant rise in prices. The main rationale is due to the collective learning model. Sellers trying to guess the marginal price and to bid close to it, reinforce their strategy to bid up. This collective action performed by all power plants, including low- and mid- merit thermal technologies, enables the sustainability of the increased level of prices. This rise in prices modifies also the profitability of the different production technologies. As far as concerns profit per MWh for the five technologies, simulation results in uniform-price auction highlight that coal-fired and Repower technologies obtain the highest and lowest profitable technologies respectively. In the other hand in discriminatory auction, oil-fired, combined cycle and Repower technologies are the more profitable.
Future extensions of the proposed model will certainly address the issues of reproducing more accurately market performances during peak hours. This task can be achieved mainly by enriching the seller's behavioral model. the adoption of more complex bidding strategies may be necessary to provide explanation for the peak in prices in few hours of the day. Last but not least, the empirical validation needs to be performed over longer periods at both macro and micro level in order to further validate the proposed model.

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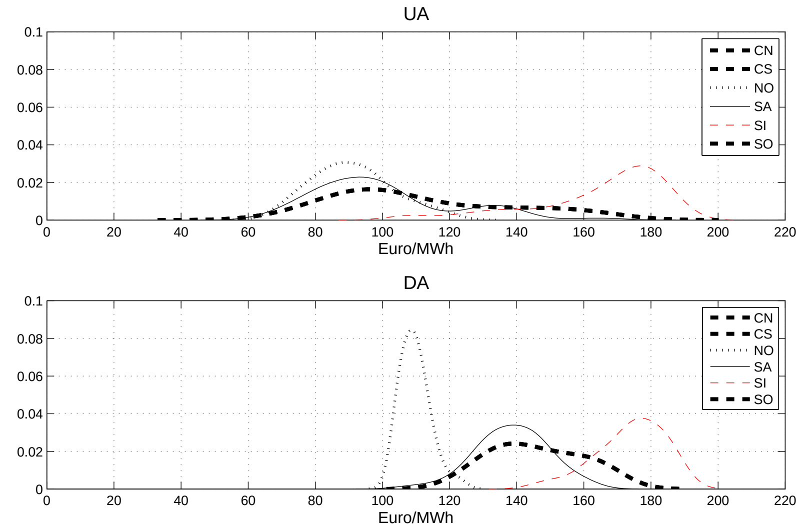

Figure 3: Distribution of LMPs for the major Italian zones, i.e., Central North (CN), Central South (CS), North (NO), Sardinia (SA), Sicily (SI), South (SO)). 100 computational experiments have been carried out. The last LMPs for each zone and experiment are considered. Upper axis refers to UA simulation, whereas lower axis to DA simulation. The considered representative hour is 6 p.m.

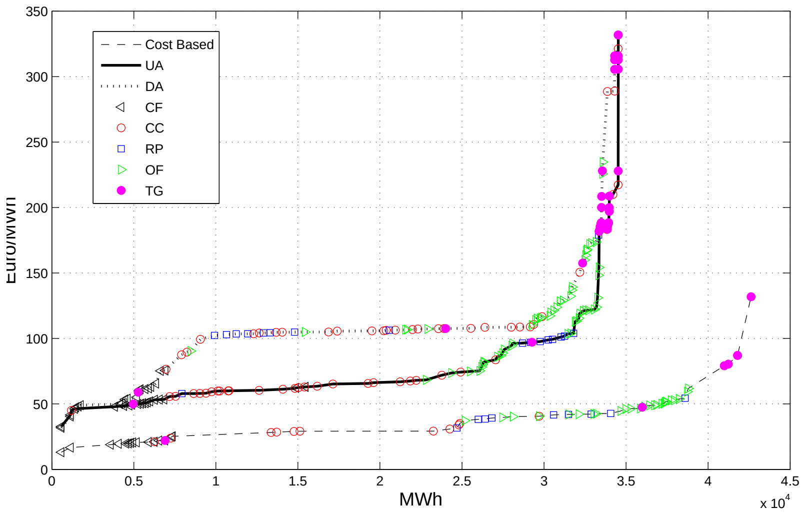

Figure 4: Simulated supply functions for the three computational experiments. The dashed line correspond to the cost based simulation. The continuous line and the dotted one corresponds to the simulation results for the uniform and discriminatory auction, respectively. The bids corresponding to each of the five technologies are separately highlighted (Coal-Fired (CF), Oil-Fired (OF), Combined Cycle (CC), Turbogas (TG) and Repower (RP)). The considered representative hour is 3 p.m.

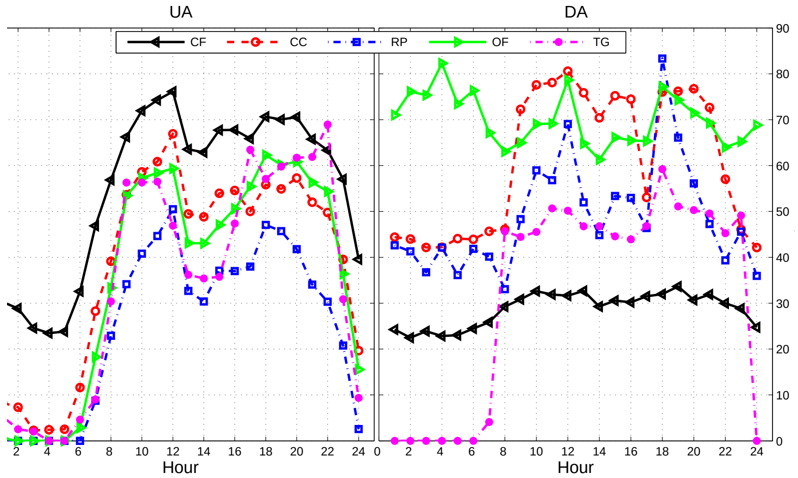

Figure 5: Profits per MW for the 24 hours for the five technologies considered, i.e., Coal-Fired (CF), Oil-Fired (OF), Combined Cycle (CC), Turbogas (TG) and Repower (RP) for uniform auction (left axis) and discriminatory auction (right axis).

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