Comments on the paper
"High wind penetration in an agent-based model of the electricity market: the case of Italy" by E. Guerci and A. Sapio

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The paper presents a very detailed agent-based model of the day-ahead Italian electricity market. The model accounts in particular for:

— physical components: structure of the power transmission grid, partition of the country into zones, location and capacity of each thermal and wind power plant ;

— industrial components: oligopolistic power generating companies (gencos hereafter), repartition of power plants among gencos, production technique in each power plant ;

— institutional components: feed-in tariffs for wind-generated electricity, market clearing mechanism for thermal-generated electricity (total cost minimization). In this setting, the authors focus on price formation. Each genco is a player in a game, which corresponds to one hour of operation of the electricity market. Nature first chooses electricity demand and wind- generated electricity supply. Gencos then strategically choose their bids: supply prices (or equivalently markup over the marginal production cost) for each of the thermal power plant they control. The market operator then determines zonal prices for thermal- generated electricity and gencos receive the corresponding profits. In my view, the authors make a very interesting usage of agent-based model as a bridge between game-theoretic and empirical analysis of the electricity market. On the one hand, as in the game-theoretical literature (see references within the paper), the situation is framed in terms of strategies and payoffs (mark-ups and profits respectively). On the other hand, the authors take advantage of the flexibility of the agent-based approach to describe precisely the industrial and business operations of gencos whereas the standard literature usually contents itself with the arbitrary choice of a functional form for the payoff function. The authors also aim at introducing some form of bounded rationality by letting gencos compute their strategies (mark-ups) using a genetic algorithm?[1]

(GA, hereafter) with a fixed number of iterations rather than a best response. One might however argue that GA is used here as a numerical approximation of best-response rather than as a model of actual behavior. As a matter of fact, it is not straightforward to me that the Nash equilibrium of the model could be computed exactly and that another algorithm could do better than the authors' GA in this respect. Another problem with the use of GA is that it turns the determination of pricing behavior, which is at the core of the model, into a kind of black-box . This impression is reinforced by the fact that the genetic-algorithm is re-ran every period (after the demand and wind supply have been announced) as if agents had no learning skills or memory whatsoever. It seems to me that what the authors shall in fact put forward as a model of strategic behavior is, for each genco, a mapping which associates a mark-up strategy to each demand and wind supply profiles. This mapping might be determined using a genetic algorithm, reinforcement learning or be given by a simple rule of thumb, the issue is anyway to make apparent the decision making process of gencos.

Nevertheless, when it comes to empirical relevance, the kind of agent-based model developed by the authors certainly outperforms existing game-theoretic models. Details of the calibration of the model are reported in a previous paper (Guerci and Sapio 2011, reference in the paper). The focus in the present paper is on the evaluation of the impacts on electricity price of an increase in installed wind capacity. The authors find out that as wind supply reaches its potential, electricity prices decrease but as congestion becomes more frequent (in lines that connect wind capacity zones), the price reduction effects of wind are partly offset by increased market power. The authors then point out that "the main policy implication of our results is that transmission investments in the southern zones would we worthwhile, since they would bring further electricity price reductions, to the benefit of consumers." I am not sure the model looks at the right time horizon or is comprehensive enough to make this kind of conclusion. Indeed, the results are obtained in a framework where wind- generated electricity is bought at a feed-in tariff. Feed-in tariffs first of all have a cost which is eventually bared by consumers and this cost is not represented in the model. More importantly, these tariffs shall to be in place during a

1. The description of the GA could also be made more precise.

transitory regime only. Wind-generated producers might become strategic as their market share grow, what would definitively modify the price formation mechanism. Given the uncertainty about the transformations of the electricity market induced by the growth of renewable energy sources, it might be that simple indicators like production costs remain more reliable indicators of final electricity prices. In my opinion a more actual question raised by the authors' analysis is: can additional investment in the grid be partial substitute for feed—in tariffs in the promotion of renewable energy sources ?

Reply to Comments

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In his interesting discussion, which we are grateful for, Antoine Mandel raises two important issues, concerning the way we represent learning by power generating companies, and the assumption of a stable and durable institutional setting for wind power support.

Concerning the first issue, the discussant wonders what behavioral interpretation can be adopted for the genetic algorithm. The discussant's impression is of a black-box tool for approximating Nash solutions.

Our starting premise is that gencos need high computational capacity. Indeed, our boundedly rational model focuses on the behavior of portfolio power-plants oligopolists facing complex decisions due to production and transmission constraints. This decision making process implies handling of a huge amount of information concerning network characteristics such as lines capacities that may vary daily, opponents' past strategies, fuel costs, power-plants planned outages, demand and wind supply forecast at a zonal level and so forth. Information retrieval and processing are costly both in monetary and time-consuming terms. Given the large number of interacting actors and engineering systems in the market, it is hardly the case that a globally optimal choice exists, and even if the optimum is there, even a sophisticated software may not be powerful enough to find it in a timely manner. Herbert Simon was the first to point this out: his real-world examples of procedural rationality involved the use of computers by business companies and inspired discussions of how companies solve these decision-making problems. As stated in the paper, we had the chance to talk with practitioners in more than one occasion (e.g. Italian gencos and the consulting company REF-E), and we learned that gencos and consultants do use sophisticated software to make decisions and forecasts. Further, it is worth mentioning that the existence of an optimum is not always granted even in explicitly optimizing models that represent a drastically simplified decision problem, as discussed e.g. in Hobbs *et al.* (2000) and Sapio *et al.* (2009) in the context of SFE models.

The implemented decision making process assumes that gencos handle information and make decision on an hourly basis. We can figure out that gencos learn only once the hourly mapping between the mark-up strategy and the hourly market configuration characterized by specific demand and wind supply forecasts, line capacities, gencos' planned outages, by repeatedly launching their software applications. This is the rationale why "the genetic-algorithm is re-ran every period (after the demand and wind supply have been announced [and we may say, after also other information is provided]) as if agents had no learning skills or memory whatsoever". This "extreme mapping" is a technical opportunity for a genco deliberating its optimal strategy, since they have all this information. The simulator embeds this mapping by handling all the mentioned information, having retrieved it by means of internet or institutional sources.

By the way, we agree with discussant's comment that we might have adopted a learning classifier system based on a condition-action mechanisms by restricting the way the conditioning is performed, for instance, considering only demand and wind supply forecasts and accepting gencos to be blind with respect to other factors. We might have probably obtained "to make [more] apparent the decision making process of gencos". But the way gencos operate in the market might be not so apparent to non-practitioners. Obviously, our learning algorithm based on genetic operators is just one possible way implementing a boundedly rational behavior. We could have sought to look for Nash solutions by exploring the parameter space in "extreme regions". This would have increased the computational burden, *i.e.* more rounds and a larger population of candidate solutions. Indeed, we have not performed yet such deep parameter selection based on goodness of fit. But our modeling strategy so far has been quite satisfactory in replicating the observed price dynamics, as showed in Guerci and Fontini (2011) and Guerci and Sapio (2011).

A second issue raised by the discussant is a fascinating one, as it poses a challenge not only for our future research, but for agent-based modeling in general. To be true, the institutional frame wherein the electricity market dynamics unfolds is itself a function, at least in the long term, of the diffusion of renewables and, more generally, of new technology. Wind power investments one day will not need the kind of subsidies we now observe, and gencos will revise their strategies accordingly. Similarly, predictions about the impact of gas-fired power plants on electricity prices made in the Sixties may not have foreseen the emergence of a deregulation movement enabled by the introduction of small-scale combined-cycle gas turbines. Analyzing how support measures are revised is response to market outcomes can be demanding, since it involves modeling the political process behind the design of green policies. As suggested by the discussant, investments in the grid and feed-in tariffs can be seen as substitutes, therefore in the case of wind power, what needs to be modeled is the policy-makers' way to solve the trade-off between grid investments and wind power subsidies. Exercise of this kind would create interesting links between agent-based modeling and the broader approach of coevolution between institutions and technologies (see Nelson 1994 and Von Tunzelmann 2004 for aggregate history-based theorizing, Künneke 2008 for sector-specific analyses).

References

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