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The impact of the introduction of nuclear power on electricity prices in a power exchange-based liberalised market

Eric Guerci [a], Fulvio Fontini [b,*]

[a] GREDEG (UMR 6227), University of Nice Sophia-Antipolis, 250 rue Albert Einstein, 06560 Valbonne, France
[b] Department of Economics and Management, University of Padova, Via del Santo 33, 35123 Padova, Italy

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ABSTRACT

In this paper, we evaluate the impact of the introduction of electricity produced by Nuclear Power (NP) plants on the electricity price formed in a liberalized, power-exchange based market. In order to do so, we build a realistic large-scale agent-based model that replicates the features of a real market (the Italian one). Firstly, we validate the computational model using exact historical data about supply, demand and network characteristics. A statistical analysis confirms that the simulator well replicates the observed prices. Then, a future scenario is simulated, based on plausible market evolutions and energy carriers' price dynamics. The future electricity prices are evaluated with and without NP plants. Different NP plants' ownerships are considered to take into account how agents' competition is affected by the introduction of such a large base-load generator. It is shown that NP reduces the prices and volatility, but the size (and the sign) of the impact depends on the pattern of the expected demand load and the ownership structure of the NP plants.

1. Introduction

Worldwide, there seems to be a twofold attitude towards nuclear power (NP) production. On one hand, the increasing cost of hydrocarbons, the security of supply concerns and environmental pressures related to global warming are encouraging new investment in NP plants for electricity production in several countries, such as Russia, Finland, India, China and the United Kingdom (UK).[1] On the other hand, increasing safety concerns, exacerbated by the accident at the Fukushima Daiichi Nuclear Power Plant in Japan, have delayed or halted NP development plans in those countries that were planning to extend the operating licences of existing NP plants or build new ones, such as Germany and Switzerland, or reintroduce NP plants where they were previously phased out, such as Italy. Regardless of the different trends that can be observed in several countries, from an economic point of view the issue of compatibility of NP with liberalised markets remains an open point to be analysed. In particular, an intriguing and challenging research question refers to the evaluation of the impact that the introduction of NP may have in a liberalised electricity market in which electricity is traded in a centralised power exchange.[2] Indeed, increasing the share of NP production in the production mix should lower the price of electricity, taking into account the NP's marginal cost component. The rationale for this is that the wholesale electricity price is determined by the supply cost of the marginal technology, namely, the technology that is providing the last Wh in a given period of time. An increase in the base load determined by NP production would displace the supply curves of some more expensive hydrocarbon-fired turbine (HT) plants, thus lowering the marginal cost. The common counterargument to this is that, if the amortisation and fixed-cost component of NP production are to be restored through some specific component of the electricity tariff, the end price for consumers may increase. However, both arguments should be contextualised in the specific market structures and physical settings of a given real-power system. The proper way to evaluate the possible impact of NP introduction in a liberalised market is to assess hour by hour which plant is likely to be displaced, i.e.,

* Corresponding author.
E-mail address: fulvio.fontini@unipd.it (F. Fontini).

[1] At the end of 2011, there were 63 plants already under construction and 143 planned in 28 countries. Source IAEA (2010).

[2] In the literature, it is common to distinguish between a 'power exchange' and a 'power pool', on the basis of whether there is a single price or a nodal one (Stoft, 2002) or whether the participation to the market is voluntary or compulsory, respectively (Boisseleau, 2004). In what follows, we will refer to a power exchange in a broad sense, namely, a centralised market for exchanging electricity at a wholesale level with a single equilibrium price. Moreover, we will assume that all plants, including NPs, will participate in the exchange, regardless of whether such participation is compulsory or not.

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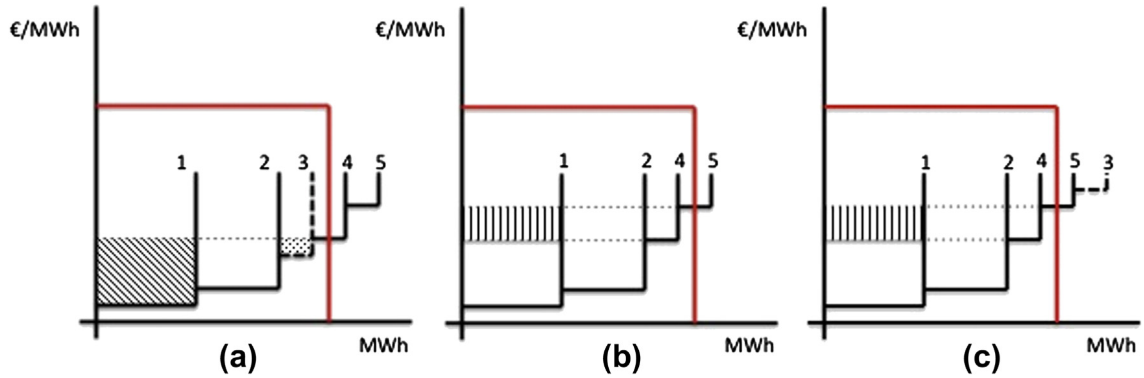

Fig. 1. Power exchange market equilibrium (a) with physical withholding (b) and economical withholding (c) of capacity.

become ultra-marginal by the supply of NP. This can be done by trying to replicate, in the most realistic way, the specific market setting where the NP plant is assumed to be introduced, taking into account both its actual and perspective characteristics (grid constraints, physical location of all other plants, load shape and size, etc.). This is the aim of our work. In order to evaluate the impact of the possible introduction of NP production in a liberalised pool-based market, we analyse the behaviour of a real market through an agent-based simulation,[3] which is able to provide a rich understanding of the dynamics of player interaction, as well as viable forecasts of future dynamics. We frame the study in the context of the liberalised Italian market for several reasons. First of all, it is one of the most liquid power exchanges in Europe (ACER/CEER, 2012). Transmission constraints play an important role in the Italian market, which is split into price zones. This, coupled with the observation that the structure of the power supply is largely dominated by gas-fired power plants, ease the identification in each zone and hour of the power plant that is most likely to be displaced by the introduction of NP. Moreover, the Italian ISO makes available (with a time lag) a large set of data regarding the effective hourly market bids submitted, as well as the characteristics of all active plants for a sufficiently long time series. This allows disaggregating the analysis at an extremely detailed level. Finally, there is presently no NP production in Italy. There were plans to introduce it, but those plans were halted by a referendum following the accident at the Fukushima Daiichi Nuclear Power Plant. Regardless of the effective future introduction of NP in Italy, the information available on the proposed NP plan, its actual absence in the market and the level of disaggregation of the available data allow us to realistically simulate, to a large degree, the impact of NP introduction for different possible scenarios of NP ownership. Indeed, when assessing the possible consequences of some market interactions, it is insufficient to evaluate the market structure. It is also important to take into account the behaviour of those who participate in the market. It is commonly assumed that NP plants cannot be used strategically, reducing the market supply in order to set the price. As mentioned before, the introduction of a large base-load shifts the supply curve to the right, crowding out other plants that have higher marginal costs and reducing the equilibrium price. Let us call this the "base-load effect". The introduction of such a large base-load generator, however, increases the possibility of rent-seeking by its owner, if it can operate strategically on the equilibrium price of the market, i.e., the system marginal price (smp) withholding some capacity from the market. Consider Fig. 1.

In (a), we have reported five hypothetical supply bids made by plants fired under different technologies (labelled as 1–5 in the figure), and ordered on the basis of these bids. Let the bids correspond to the marginal cost of production for each technology. Given the load (in red), the second highest expensive is the marginal supply (the technology whose marginal cost determines the equilibrium price). The most expensive in such a market configuration is not dispatched. The lowest supply bid is the NP plant. The dashed area in (a) is the NP plant's rent (difference between the equilibrium price – system marginal price – and the production cost for a given amount of energy produced). Assume that the owner of the NP plant owns another non-NP plant, e.g., the supply curve (labelled 3) described by the dotted line in Fig. 1(a). Such an owner can be tempted to behave strategically, withholding the capacity of the non-NP plant; even if it would lose the marginal rent of the non-NP plant (dotted in Fig. 1(a)), it would gain the increase on the marginal rent of the NP plant due to the increase in the equilibrium system marginal price (vertically dashed area in Fig. 1(b)). This may lead to a net positive gain, as depicted in Fig. 1(b). Notice that it is not necessary to physically withhold capacity at the power exchange. There can be an economic withholding, namely, bidding at a price higher than the marginal cost in order to induce the market maker to alter the cost merit order, as described in Fig. 1(c).[4] The possibility of operating strategically with HT power plants owning NP plants can be termed "strategic interaction effect". Studying the extent that the latter can impact on the base-load effect is the aim of this paper.

In order to perform our task, we simulate the actual effective behaviour of the Italian power market. We create an agent-based interaction model that replicates the wholesale day-ahead Italian market and calibrate it over a sufficiently long time series. Then, we describe the structure of the power system at the time the NP plants may become active, according to a plausible scenario for technologies and grid structure. We repeat the simulation under the foreseen scenario to calculate the future hourly electrical prices for some representative days of the year, with and without NP plants. For the former case, we will investigate if and how the structure of competition across agents will be altered by the introduction of such a large base-load generator, if it is assigned to a single market operator.

[3] The agent-based literature on electricity markets is quite vast. For an extensive survey on the topic see Guerci and Sapio (2011, 2012).

[4] In principle there are two types of withholding, physical withholding (in which a serviceable power plant is deliberately rendered unavailable) and economic withholding (in which high bids are submitted in an expectation that the plant will not be called upon to run). We assume a market in which all economic withholding is permitted. Situations of physical withholding are not modelled, but the importance of such tactics is arguably moot in a context where economic withholding is unconstrained. The real Italian market allows economic withholding and forbids physical withholding (whenever the plants' unavailability is not due to cases of force majeur and is aimed at influencing the price).