Energy Studies Review Volume 15, No. 2, Fall 2007

ASYMMETRIC INFORMATION AND SECURITY OF SUPPLY: AN APPLICATION OF AGENCY THEORY TO ELECTRICITY MARKETS

FLORENCE HERMON, DELPHINE PERROT, & VIRGINIE PIGNON

ABSTRACT

The recent blackouts in Italy and California have raised doubts on the ability of electricity markets to promote efficient investment in generation. Those crises affect the security of supply, which can be viewed as a public good. Several incentive mechanisms have therefore been proposed to ensure security of supply and are currently contemplated by public authorities in many countries.

The aim of this paper is to analyse two of these incentive mechanisms that can be implemented by the regulator. We develop a principal-agent model with two types of generators, differentiated by their access to capital markets. We compare a capacity payment, which we model as a menu of incentive contracts with strategic reserves, which we model as a retention rule.

Keywords:
public goods, deregulation, electric utilities, market design

Florence Hermon, *EDF R&D, Economic and Technical Analysis of Energy Systems Department, 1 av. du Général De Gaulle -BP 408-92141 Clamart Cedex France, Email: florence.hermon@edf.fr*
Delphine Perrot, *EDF R&D, Economic and Technical Analysis of Energy Systems Department, 1 av. du Général De Gaulle -BP 408-92141 Clamart Cedex France, Email:delphine.perrot@edf.fr, and University Paris I Panthéon-Sorbonne LAEP - Public Economy LAboratory, 112 Bd de l'Hôpital 75013 Paris*
Virginie Pignon, *EDF R&D, Economic and Technical Analysis of Energy Systems Department, 1 av. du Général De Gaulle -BP 408-92141 Clamart Cedex France, Email: virginie.pignon@edf.fr and University Paris XI ADIS 54 bd Desgranges 92331 Sceaux*

1. INTRODUCTION

The 2001 California electricity crisis, as well as the power cuts in Spain, London and Italy, contributed in raising doubts on the efficiency conditions concerning the newly liberalized electric sector. Following many other network industries, like railways, telecommunications and airlines, competition has been introduced in the electric power sector since the mid 1980's. It has been a fundamental change in a sector traditionally characterized by horizontally and vertically integrated firms. Those firms benefited from a local monopoly on consumers and their costs were automatically covered through a change in regulated tariffs.

From an organizational point of view, competition enhanced the need to separate transmission and distribution, which are still considered as natural monopolies, from generation and supply in which competition could be introduced. Transmission system operators have therefore been created, mostly on a state basis in European countries, to manage the transmission network, to ensure coordination between network users in a non discriminatory way and to maintain the real time balance between generation and consumption of electric power on the system. These functions are essential not only for the effectiveness of competition but also because they guarantee a secure electric power supply and a reliable system. Electricity is non storable and an imbalance between generation and consumption may overload electric power lines with limited transmission capacity and end up triggering power cuts.

From a practical point of view, transmission system operators get information on the quantities that generators have planned to produce generally the day before delivery. These quantities may be the result of bilateral contracts, signed between generators and consumers or of organised electricity markets, where the most competitive supply bids are retained by the market operator through a merit order dispatch. Given their essential functions for the system and for the effectiveness of competition, transmission system operators are regulated by a regulatory authority using schemes that most often give them an incentive to minimize transmission costs.

One of the motivations for competition in the electric power sector was to encourage efficient investments, or at least to avoid the risk of over-investments costly to society. And indeed, in many countries, the first years of competition have shown a decrease in investment levels, noticeably in generation, without real infringements of the reliability of electric power supply. But this situation has changed with the continuous growth of electricity demand and the need for replacement of old generation facilities: for example, 20 to 30 GW should be renewed by 2020 in Germany; UCTE[1] (2003) statistics show a slight decrease in remaining generation capacity in 2004 and a noticeable fall after 2007. The lack of adequate investment in electricity generation units emerges now as one of the most significant problems that has not been properly addressed by the initial steps of market restructuring.

This paper deals with this security of supply issue using agency theory, taking into account asymmetric information between the different actors of the electricity market.

The lack of generation capacity is only one of the origins of a power cut since it does not allow meeting peaking demand in real time. Generation adequacy was particularly at stake in the June 2003 power cuts in Italy. But other problems may also trigger cuts. Insufficient investments in networks for instance, which raise the question of the incentive scheme that

[1] UCTE is the union of the European transmission system operators, except Great Britain, Ireland and Nordic countries.

should be designed for transmission and distribution system operators; it seems that this was the main reason for the recent power cuts in London and Spain. Coordination problems between transmission system operators may also endanger security of supply, especially for countries which heavily rely on imports – the coordination problems between the Swiss and Italian transmission operators largely contributed to the September 2003 power cuts in Italy. More recently, European countries have also witnessed that geopolitical considerations are also important for security of supply given the relative concentration of primary energy reserves in some countries. The specific difficulty with the lack of generation capacity issue is that generation adequacy depends on investment and generating decisions of agents which are in a competitive environment. As we will see later, the conflicting interests among the market participants in the electric power sector may create asymmetric information and moral hazards that could endanger security of supply.

2. LITERATURE

Why would the market lead to insufficient generation capacity? In the literature, at least two main reasons have up to now been explored.

The first one refers to market power. Because of the relatively low price elasticity of electric power demand, even a slight decrease in available generation capacity should result in a high increase in prices. In other terms, generators, whatever their size on the market, may benefit from a tight situation characterized by insufficient generation capacity. Knowing this, they may not be incited to invest much. That is, for example, one of the explanations given to the Californian electricity crisis in 2000 (Borenstein, 2002, Joskow, 2001).

The second reason for the lack of generation capacity refers to public goods and external effects. Electric power is non storable which reinforces the central role of electric power networks in the security of supply. Network reliability entails the need to meet specific physical criteria in terms of network frequency and voltage and in case of unanticipated failures on generating and transmission equipment, generators have to respond very rapidly to maintain or restore these parameters to their normal values. Network collapses[2] entail that over a whole area some available generators can not run to satisfy load and consumers willing to pay a high price for electricity can not be served. Moreover, despite restructuring, the elasticity of demand is still limited; some consumers are even not aware of real time prices because they use meters which record their consumption over fixed periods of time only. Because of these characteristics, in order to avoid crude power cuts, generation capacity should at least be such that uncertain peak power demand could be met, taking into account the limited transmission capacity in the grid, the dynamic constraints on generation facilities that prevent from rapidly adjusting the amount of electric power generated[3], the interruptible load, and the risk of unavailability of generation units. In other words, it implies for some generators to have generation capacity that will be unused most of the time but has to be ready to run – for example, in case of a sudden increase in demand or unforeseeable incident on generation units. Such capacity will rarely generate, and when it generates it would require sufficiently high electricity prices to recover its total cost. These profitability conditions make it a very risky investment (Joskow and Tirole, 2004). Faced with such high prices and with the

[2] Network collapses may be due to an inappropriate action of a generator.
[3] Although these constraints vary according to the technology considered.

additional risk that these high prices are due to market power, politicians are often tempted to implement price caps. Those price caps limit the profitability to invest in generation capacity and reinforce the security of supply issue.

The generation capacity issue enhances the need for an incentive mechanism and several have already been proposed and implemented to improve the security of supply on the basis of market incentives[4].

One of the first mechanisms that has been implemented is capacity payments that have been introduced in England and Wales up to 2001, but also in Spain, in several Latin American countries and recently in the Italian electricity market[5]. In such systems, generators are given a payment based on the generation capacity that they declare available for the market, whether they effectively generate or not. Thus, the market operator or the transmission system operator, depending on the specific system considered, pays a price for the generation capacity that has been declared available. In the end, the capacity payments are recovered from customers as an uplift similarly to other charges such as transmission charges. This payment is an additional source of revenue for generators that should give them an incentive to maintain more capacity than they would otherwise. The concept of capacity payments is rooted in the theory of peak load pricing whose application in electric power was pioneered by Boiteux (Oren, 2004).

Another mechanism that is currently used is called strategic reserve. It consists in a system where the transmission system operator signs bilateral contracts with generators so that they keep some generation capacities available for the system. These strategic reserves should be used only when a shortage of electricity is anticipated. Compared to capacity payments, a strategic reserve is a more pragmatic approach that should be deployed as a back-up system only and creates elasticity at the end of the supply curve. But similarly to capacity payments, the cost of strategic reserves for the transmission system operator is then recovered from customers as an uplift. Strategic reserve is currently used in several countries like Sweden and the Netherlands (De Vries and Hakvoort, 2005). It should be noticed that the level of competition on the electricity market might have an impact on the price paid by the system operator for strategic reserves: the higher the number of potential suppliers, the more competitive the supply of strategic reserves, and the less they might be paid for strategic reserves.

Up to now, the literature on these incentive mechanisms has mainly focused on the following approaches. Some papers consist in proposals of new incentive mechanisms, such as reliability contracts (Battle, Perez-Arriaga, Rivier and Vazquez, 2003); but they often have not been demonstrated in a theoretical framework. In particular, their economic performances in a context of imperfect competition and imperfect information remain to be analysed. Another approach does not compare incentive mechanisms but analyses the economic incentive given by a specific mechanism regardless of the others (Creti and Fabra, 2007, Stoft, 2002). Eventually, some papers analyse the economic consequences of non-market and price distorsive mechanisms implemented because of the aforementioned specific physical characteristics of electricity and electric power networks (Joskow and Tirole, 2004).

As far as we know, this literature has not considered the aforementioned existence of asymmetric information between transmission system operators and generators, inherent in electricity markets, and which might greatly impact the efficiency of the incentive mechanism

[4] Refer to de Vries (2004) for an exhaustive presentation of these mechanisms.

[5] Capacity payments can take several forms. Here we choose to base our analysis on the English model.

that has been put in place. Transmission system operators are indeed responsible for the security of supply and have generally a central role in the implementation of the mechanisms which give an incentive to invest in generation capacity: they pay generators for and according to their available generation capacity in case of capacity payments and they set a reserve capacity and a remuneration for this reserve capacity in case of strategic reserves. But in order to satisfy this security criteria, they have to rely on investment and generation decisions taken by generators that are in competition as a result of liberalisation. In this context, even more than in the monopolistic one, generation costs, investment costs, investment plans, generation decisions are strategic pieces of information that generators might not want to reveal. Investment announcements for instance may be used so that potential new entrants in the market believe that there are no profit opportunities left. Likewise, generators facing difficulties to access capital markets might prefer not to reveal this information. More generally, vertical and horizontal unbundling which followed the creation of electricity markets has multiplied information asymmetries and contractual moral hazards among the market participants and between the market participants and the previously integrated transmission system operator (Joskow, 2002).

Taking into account this asymmetric information, this paper analyses and compares capacity payment and strategic reserves - two alternative incentive mechanisms at the disposal of the transmission system operator. We develop a simple principal-agent model with two types of generators, differentiated by their relative ease to access capital markets and thus to finance their investments. Capacity payments are modelled as a menu of incentive contracts, whereas strategic reserves are modelled as a retention rule. The next section presents the framework of the model. The fourth and fifth ones compare the two incentive mechanisms under perfect and imperfect information. Finally, the last section compares the relative efficiency of the two alternative mechanisms.

3. THE FRAMEWORK

We consider the relationship which takes place in electricity markets between a regulator and the generators. We assume, for a technical reason, that the regulator and the transmission system operator share the same objective function[6]. As a consequence they are considered as a unique entity, which we call the regulator in the following part of the paper.

The aim of the regulator is to ensure the security and reliability of the electric system at minimum cost. In order to do that, it contracts with generators to incite them to invest in generation capacity. We focus in this paper on two incentive mechanisms. First we study the capacity payment given by the regulator to the generators that have declared available generation capacity. Considering two types of generators, the capacity payment can be modelled as a menu of incentive contracts. With capacity payments indeed, in England and Wales, but also in Spain and in Italy, generators get paid in exchange for installed generation capacity, whether this capacity is effectively used to produce energy or not. The more generation capacity one has, that is to say the more the generator previously invested, the more capacity payments it receives. Capacity payments vary therefore according to the investment effort of generators (which depends on the relative ease of the generator to access

[6] An interesting extension of this model would be to take into account the conflict of interest or the potential collusion in a three levels model: principal, supervisor and agent.

capital markets) and the system operator proposes a certain price for a certain generation capacity. The generator chooses its investment effort, and thus its quantity of new capacity installed accordingly.

Secondly, we consider strategic reserves where the regulator contracts bilaterally with some generators to provide available capacity when needed. Unlike the menu of incentive contracts, the strategic reserves allow the regulator to break the contract when the generator fails to fulfil it. In other terms, the transmission system operator bilaterally contracts a certain amount of generation capacity that must be available and ready to run in periods of energy scarcity, and pays a certain price for it. In case the generator is finally not able to supply energy on the basis of the aforementioned contracted capacity while the system is short of energy, then the regulator has the right to break the contract and looks for another generator.

The sequence of events is described as follows:

- The regulator has to design an incentive contract for the generators. Here, the regulator may choose the type of contract he wants to implement. Either the contract takes the form of a menu of incentive contracts (à la Laffont and Tirole 1993) in that it ensures that each generator will be paid a certain price according to the observed level of available generating capacity, or alternatively, the contract takes the form of a retention rule (à la Banks and Sundaram 1998) where generators contractually commit to maintain strategic reserves for the system in exchange of payment.
- Secondly, the generator accepts or rejects the proposed contract.
- Thirdly, the contract is carried out and the regulator observes the resulting provision of generation capacity.
- Finally, on the basis of its previous observations, the regulator decides whether to renew or not its contractual relationships with the incumbent generator.

3.1 The Actors

The actors of the model are the regulator on one hand, and the generator on the other hand.

The Regulator

The regulator's utility function depends positively on the reserves of generation capacity, RC, which is a positive function of the investment effort, e, provided by the generator. However, the regulator's utility function is negatively impacted by the capacity payment, p, that it has to pay to the generator to compensate him for its investment's effort. Since the regulator is incited to reduce its costs, this effect is negative.

The regulator's utility function for each period t is given by:

(1) $$U_t = RC(e_t) - p_t$$

$$\text{with } \frac{\partial RC}{\partial e} > 0 \qquad \text{and} \qquad \frac{\partial^2 RC}{\partial^2 e} < 0.$$

The Generator

The generator's utility function for each period t is given by the following equation:

(2) $$V_t = p_t - \theta_t v(e_t)$$

where $v(e)$ represents its disutility to provide investment effort. This disutility depends positively on the difficulties faced by the generator to access capital markets, which are represented by the parameter θ. We assume that $v'(e) \geq 0$ and $v''(e) > 0$, pointing out that the generator's marginal disutility is an increasing function of e.

We assume two types of generators, characterized by their access to capital markets: the generator can face high difficulties to access capital market, $\theta = \overline{\theta}$, which means that its marginal cost to invest in generation capacity is high, or low difficulties, $\theta = \underline{\theta}$, which means that its marginal cost to invest in generation capacity is low. For the remaining part of the paper, we refer to the high cost generator's type as the inefficient generator's type, and to the low cost type as the efficient one. Then, $\theta \in \{\overline{\theta}, \underline{\theta}\}$, with $\overline{\theta} > \underline{\theta} > 0$.

We assume that the set of efficient generators is a non-empty set.

4. The two alternative incentive mechanisms: the perfect information framework

Under perfect information, the regulator exactly knows the generator's type. Moreover, another feature of the perfect information framework is that the generator's effort level is observable and also verifiable. Verifiable means that an external control agency, the competition authority or council for instance, can implement punishment on a generator which does not provide an optimal effort level[7]. In other terms, we consider that the external control agency can impose a sanction, $\beta > 0$, sufficiently high to prevent generators from deviating.

4.1 Optimal incentive contract: the perfect information case

As the set of efficient generators is a non-empty set, under perfect information the regulator designs a contract only for the efficient generator's type, $\left(\underline{p}^*, \underline{e}^*\right)$. The regulator has to grant a level of capacity payment according to the amount of generation capacity provided by the efficient generator. Let's assume that δ is the discount factor, which is common to all players and periods, with $\delta \in \left]0,1\right[$. The number of contracts fulfilled by a generator, in an intertemporal perspective, is given by τ. The contractual game is repeated at each period because for a given generator, the generator's type (easy or difficult access to capital markets) may change from one period to the other. Therefore, the regulator's intertemporal utility function, U^i under perfect information can be written as:

$$U^i = \sum_{\tau=0}^{\infty} \delta^{\tau} \left[RC\left(\underline{e_t}\right) - \underline{p_t}\right]$$

with

$$\underline{e} = \underline{e_1} = \underline{e_2} = ... = \underline{e_t} \qquad \text{and} \qquad \underline{p} = \underline{p_1} = \underline{p_2} = ... = \underline{p_t}$$ [8]

[7] See Laffont and Tirole (1993) for further explanations about the implementation of an external control agency in the case of verifiable information.

[8] This can be done due to the assumption that the same contract is repeated each period.

which gives

(3) $$U^i = \frac{1}{1-\delta}\left[RC(\underline{e}) - \underline{p}\right]$$

Similarly, the intertemporal utility of a generator which draws the efficient type each period can be written as:

$$V^i = \frac{1}{1-\delta}\left[\underline{p} - \underline{\theta} v(\underline{e})\right]$$

To determine the optimal incentive contract, the regulator maximizes its intertemporal utility function (3) under the intertemporal participation constraint $\frac{1}{1-\delta}\left[\underline{p} - \underline{\theta} v(\underline{e})\right] > 0$. The participation constraint means that in order to incite the generator to accept the contract, the generator's utility function has to be at least equal to its reservation utility, which we normalize to zero.

The results of the regulator's maximization program gives the optimal incentive contracts, $\left(\underline{p}^*, \underline{e}^*\right)$, which is defined in proposition 1.

***Proposition 1**: The optimal incentive contracts designed for an efficient generator's type by the regulator under perfect information* $\left(\underline{p}^*, \underline{e}^*\right)$ *is characterized by:*

$$\underline{p}^* = \underline{\theta} v\left(\underline{e}^*\right) \text{ and } \underline{e}^* \text{ such that } RC'\left(\underline{e}^*\right) = \underline{\theta} v'\left(\underline{e}^*\right)$$

The amount of generation capacity provided by an efficient generator's type, $RC\left(\underline{e}^*\right)$*, corresponds to a first best equilibrium.*

Proposition 1 shows that the optimal effort level to invest in generation capacity is such that the marginal utility of investment effort for the regulator is just equal to the marginal disutility of investment effort suffered by the efficient generator's type. The optimal amount of capacity payment is such that it compensates exactly the disutility of investment effort suffered by the efficient generator's type, which can not therefore get any rent or any utility surplus.

We next turn to the study of another incentive mechanism, the retention rule.

4.2 Optimal retention rule: the perfect information case

Unlike the menu of incentive contracts, the use of a retention rule does not allow anymore the regulator to discriminate between the two generator's types, by offering two different contracts according to each generator's type.

The use of a retention rule consists for the regulator in designing a sole contract $\left(RC^*, p^*\right)$at the first stage of the game and to observe the amount of generation capacity provided by the generator, $RC(e)$, at the end of the contractual game. The difficulty for the regulator is to set the contractual threshold value for the generation capacity, $RC^* = RC\left(e^*\right)$ such that:

if $RC(e) < RC^*$, then the generator that used to supply strategic reserves is no more eligible for the new contract and another generator is selected if $RC(e) \geq RC^*$, then the same generator is selected for the following contracts.

Under perfect information, the regulator observes perfectly each generator's type. Let us assume that there is a non-empty set of efficient generators among the available generators on the electricity market. Observing each generator's type, we assume that the regulator chooses an efficient one and designs the retention rule according to this type. The regulator can therefore choose to set the retention rule at the efficient generator's level.

To determine the optimal contract under perfect information, (RC^*, p^*), the regulator has to maximize its utility function (1) with respect to the participation constraint of the efficient generator. The results are given in the following proposition.

***Proposition 2**: The optimal contract designed under perfect information, (RC^*, p^*), is characterized by the values of RC^* and p^* defined in proposition 1. Thus, the amount of generation capacity resulting from the retention rule corresponds also to a first best equilibrium: $RC^* = RC(\underline{e^*})$.*

The results of proposition 1 and proposition 2 show that the two incentive mechanisms are similar in the perfect information framework.

5. THE ADVERSE SELECTION PHENOMENON

We suppose now that the generator's type is private information. This asymmetric information between the regulator and each generator's type emphasizes an adverse selection phenomenon faced by the regulator when it designs the incentive contract. More precisely, a regulator which offers a contract to an "a priori" efficient generator's type, may observe at the end of the contract that the generation capacity is lower than the optimal level obtained with an efficient type. In such cases, the problem faced by the regulator is that it can not determine if the generation capacity level is low because of the inefficient type of the generator or because the generator was an efficient one mimicking an inefficient one in order to obtain an informational rent. This uncertainty concerning the reasons of the low level of generation capacity prevents the regulator from using its sanction power (β) or to rely on the competition council to punish the generator that is cheating on its type.

Let's assume that the regulator knows a priori the distribution of the values of θ characterized by: $\Pr(\theta = \underline{\theta}) = \alpha$, and $\Pr(\theta = \overline{\theta}) = 1 - \alpha$.

5.1 The efficiency of a menu of incentive contracts

Under asymmetric information, the menu of incentive contracts designed under perfect information is no longer optimal as it leads to a low investment effort level, whatever the generator's type[9].

The regulator has therefore to design a new menu of incentive contracts, which takes into account the participation constraint of the inefficient generator's type. The constraint means that even if the inefficient generator's type during the first period remains inefficient during the following ones, it has to be incited to fulfil the contract designed for its type:

[9] See Laffont and Tirole (1993) for a formal demonstration of this result.

$$\sum_{\tau=0}^{\infty} \delta^{\tau} \left[\left(\overline{p} - \overline{\theta} v\left(\overline{e}\right) \right) \right] \geq 0 \tag{4}$$

Besides, the regulator has to consider the incentive compatibility constraint of the efficient generator when designing its contract. This second constraint means that an efficient generator is incited to choose the contract designed for its type if its intertemporal utility is greater in that case than if it mimics an inefficient generator's type:

$$\underline{p} - \underline{\theta} v\left(\underline{e}\right) + \frac{1}{1-\delta}\left[\alpha\left(\underline{p} - \underline{\theta} v\left(\underline{e}\right)\right) + \left(1-\alpha\right)\left(\overline{p} - \overline{\theta} v\left(\overline{e}\right)\right)\right] \geq$$

$$\overline{p} - \underline{\theta} v\left(\overline{e}\right) + \frac{1}{1-\delta}\left[\alpha\left(\underline{p} - \underline{\theta} v\left(\underline{e}\right)\right) + \left(1-\alpha\right)\left(\overline{p} - \overline{\theta} v\left(\overline{e}\right)\right)\right]$$

$$\Leftrightarrow \underline{V} = \overline{V} + \psi\left(\overline{e}\right) \tag{5}$$

Where $\psi\left(\overline{e}\right)$ represents the informational rent that the regulator has to give to the efficient generator in order to incite him to reveal its type by choosing the right contract (i.e. the contract designed for an efficient generator), $\psi\left(\overline{e}\right) = \left(\overline{\theta} - \underline{\theta}\right) v\left(\overline{e}\right) \geq 0$.

Maximizing its expected intertemporal utility function:

$$E\left(U\right) = \frac{1}{1-\delta}\left[\alpha\left(RC\left(\underline{e}\right) - \underline{p}\right) + \left(1-\alpha\right)\left(RC\left(\overline{e}\right) - \overline{p}\right)\right]$$

under the two previous constraints, the regulator designs the new menu of contracts, $\left(\underline{p}, \underline{e}\right)$, $\left(\overline{p}, \overline{e}\right)$.

The results are given in the following proposition.

***Proposition** 3: The maximization program of the regulator under the constraints (4) and (5) gives the optimal menu of incentive contracts under asymmetric information* $\left\{\left(\underline{p}, \underline{e}\right), \left(\overline{p}, \overline{e}\right)\right\}$. *This menu of incentive contracts is characterized by:*

- *a contract designed for the efficient generation type,* $\left(\underline{p}, \underline{e}\right)$, *defined by:* $\underline{e}$ *such as* $RC'\left(\underline{e}\right) = \underline{\theta} v'\left(\underline{e}\right)$ *and* $\underline{p} = \underline{\theta} v\left(\underline{e}\right) + \psi\left(\overline{e}\right)$
- *a contract designed for the inefficient generator,* $\left(\overline{p}, \overline{e}\right)$ *defined by:* $\overline{e}$ *such as* $RC'\left(\overline{e}\right) = v'\left(\overline{e}\right)\left[\overline{\theta} + \frac{\alpha}{1-\alpha}\left(\overline{\theta} - \underline{\theta}\right)\right]$ *and* $\overline{p} = \overline{\theta} v\left(\overline{e}\right)$.

These results are derived directly from the first order conditions.

Following the standard results obtained in proposition 3, the contract designed for the efficient generator type is such that the generator provides the optimal investment effort level, $\underline{e} = \underline{e}^{*}$, but the capacity payment is higher than the one obtained under perfect information. This surplus of capacity payment is needed in order to incite the efficient generator to provide an efficient investment effort level. Concerning the inefficient generator, its contract is characterized by an optimal capacity payment, $\overline{p} = \overline{p}^{*}$, but its effort level is lower than the one which would have resulted from the optimal contract under perfect information, if the regulator faces only inefficient generators $\left(\alpha = 0\right)$. A lower effort level than under perfect information is required in order to decrease the informational rent granted to the efficient generator.

5.2 Optimal retention rule under asymmetric information

We have previously shown that under asymmetric information the competition council is no more able to impose a sanction in case of a cheating generator.

As the regulator can not distinguish anymore between the two types of generators and has no longer the possibility to offer a menu of incentive contracts, it has to design a contract and the associated retention rule that incite both generator's types to provide the threshold value of investment effort, $(\hat{p}, \hat{e})$..

5.2.1 Determining the incentive constraint

The use of a retention rule implies a new incentive constraint, compared to the capacity payment. The regulator has to take into account this new constraint when it determines the contract offered to both generator's types. A generator, whatever its type, is incited to provide the threshold value of investment effort if, and only if, its expected and discounted utility function in that case is superior or equal to the one obtained when the generator does not provide the contractual effort level.

The expected and discounted utility function of an efficient generator which provides the threshold value of investment effort, and seeks therefore to be retained for another contract, is given by:

$$E\left(V_{\underline{\theta}}\right)^{T} = \hat{p} - \underline{\theta} v(\hat{e}) + \sum_{\tau=1}^{\infty} \delta^{\tau} \left[\hat{p} - E(\theta) v(\hat{e})\right] \quad (6)$$

where the superscript T means that the generator agrees to provide the threshold value of investment effort. The first term of the right member of (6) corresponds to the utility derived by the generator from fulfilling the first time contracting period, whereas the second term represents the sum of the generator's expected and discounted utilities during all the following contracts it chooses to fulfil. The uncertainty for the generator during the following contracts comes from its incapability to forecast its type in the future, or more precisely, to anticipate the difficulties to have access to capital markets that it will face during the following contractual periods. Those difficulties come from the cost of capital for an operator, which depends on the return on equity for the shareholders and on the interest rate requested on debt, which depends itself on the confidence of bankers.

When an efficient generator chooses to deviate from the contract, it provides no effort level during the first contractual period and it is not retained for the following ones. So, its utility function in that case is given by:

$$E\left(V_{\underline{\theta}}\right)^{NT} = \hat{p} \quad (7)$$

where the superscript NT means that the generator does not agree to provide the threshold value of investment effort. As it is not retained for a following contract in that case, it receives its reserve utility (that we have normalized to zero) during all the following contracting periods.

The utility function of an inefficient generator, depending on its choice to fulfil or not the threshold value of investment effort, is, respectively, given by:

(8) $$E\left(V_{\bar{\theta}}\right)^{T} = \hat{p} - \bar{\theta}v(\hat{e}) + \sum_{\tau=1}^{\infty}\delta^{\tau}\left[\hat{p} - E(\theta)v(\hat{e})\right]$$

and

(9) $$E\left(V_{\bar{\theta}}\right)^{NT} = \hat{p}$$

Each type of generators is incited to fulfil the threshold value of investment effort if its intertemporal utility is higher in that case than in the other. Formally, the participation constraint for each generator's type can be written as:

For the efficient type:

(10) $$E\left(V_{\underline{\theta}}\right)^{T} \geq E\left(V_{\underline{\theta}}\right)^{NT}$$

For the inefficient type:

(11) $$E\left(V_{\bar{\theta}}\right)^{T} \geq E\left(V_{\bar{\theta}}\right)^{NT}$$

Comparing (6) with (8) shows that if the participation constraint of the inefficient type is met, the participation constraint of the efficient type is also met. Thus, the regulator can determine the contract by taking into account only the participation constraint of the inefficient generator's type (8).

Re-writing (11) with its expressions in (8) and (9) gives the new expression of the incentive constraint associated to the inefficient generator:

(12) $$\sum_{\tau=1}^{\infty}\delta^{\tau}\left[\hat{p} - E(\theta)v(\hat{e})\right] \geq \bar{\theta}v(\hat{e})$$

5.2.2 The contract and the associated retention rule

The regulator has to determine the contract $(\hat{p},\hat{e})$ and then to set the threshold value of generation capacity above which the incumbent generator will be retained for another contractual period. Even if the performance of the next period is independent of the performance of the previous one, the regulator has to retain the generator for another period in order to incite it to provide the threshold value during the first period.

Thus, the regulator maximizes its intertemporal discounted utility function subject to the incentive constraint of the inefficient generator's type (12).

The results of the regulator's maximization program are given in the following proposition.

***Proposition 4**: The contract designed by the regulator when it uses a retention rule,* $(\hat{p},\hat{e})$, *is characterized by :*

- *a threshold investment effort,* $\hat{e}$, *such that :* $RC'(\hat{e}) = v'(\hat{e})\left[E(\theta) + \bar{\theta}\left(\frac{1-\delta}{\delta}\right)\right]$
- *a payment for strategic reserves,* $\hat{p}$, *defined by :* $\hat{p} = v(\hat{e})\left[E(\theta) + \bar{\theta}\left(\frac{1-\delta}{\delta}\right)\right]$

The associated retention rule, $RC(\hat{e})$, *implies that :*

- *if* $RC(e) < RC(\hat{e})$, *then the incumbent generator is no more eligible for the capacity payment and another generator is selected*
- *if* $RC(e) \geq RC(\hat{e})$, *then the incumbent generator is selected for an additional contractual period.*

These results come directly from the first order conditions.

It follows from proposition 4 that $0 < \hat{e} < \underline{e}^*$. As a consequence, the equilibrium amount of generation capacity is characterized by: $0 < RC(\hat{e}) < RC(\underline{e}^*)$. In return, the regulator has to allocate a capacity payment, $\hat{p}$, such that $\hat{p} < \underline{p}^*$.

The two alternative incentive mechanisms are efficient under asymmetric information. Indeed, each of them allows raising the amount of strategic reserves from a third best equilibrium to a second best equilibrium. Nevertheless, the cost of the incentive effect for the regulator implies that none of those mechanisms is able to restore a first best equilibrium.

We turn next to the efficiency comparison of the two alternative incentive mechanisms.

6. MENU OF INCENTIVE CONTRACTS *VERSUS* RETENTION RULE

Using the results stated in propositions 3 and 4, we assess the relative efficiency of strategic reserves and capacity payment. Thus, we compare $RC(\underline{e})$, $RC(\overline{e})$, $RC(\hat{e})$ on the one hand, and $\underline{p}$, $\overline{p}$, and $\hat{p}$ on the other hand. The results of these comparisons between the level of generation capacity according to each incentive mechanism and between the level of capacity payment that has to be given in return are summarized in the following proposition.

***Proposition 5**: The comparison between* $RC(\underline{e})$, $RC(\overline{e})$, $RC(\hat{e})$ *and* $\underline{p}$, $\overline{p}$, *and* $\hat{p}$ *shows that:*

- *The amount of generation capacity obtained with the use of a retention rule is always lower than the amount obtained with the incentive contract designed for the efficient generator:*

(13) $$RC(\underline{e}) > RC(\hat{e})$$

However, the amount obtained with the use of a retention rule is higher than the amount obtained with the incentive contract designed for the inefficient generator under the following condition:

(14) $$RC(\hat{e}) > RC(\overline{e}) \quad \text{iff} \quad (\overline{\theta} - \underline{\theta})\left(\alpha + \frac{\alpha}{1-\alpha}\right) > \overline{\theta}\left(\frac{1-\delta}{\delta}\right)$$

- *Comparing the level of capacity payment obtained under the two alternative mechanisms gives the following results:*

When condition (14) is fulfilled, then the capacity payment of the retention rule is higher than the capacity payment of the incentive contract designed for the inefficient type:

(15) $$\hat{p} > \overline{p} \;\; \text{if} \;\; \hat{e} > \overline{e}$$

The capacity payment of the incentive contract designed for the efficient type is higher than the capacity payment of the retention rule under the following condition:

(16) $$\underline{p} > \hat{p} \text{ if } \delta > \frac{v(\hat{e})}{v(\underline{e})}$$

Proof. See Appendix.

When the condition (14) is not fulfilled, the gap between the two types' cost to access capital market $(\overline{\theta} - \underline{\theta})$ times a factor of the types distribution $\left(\alpha + \frac{\alpha}{1-\alpha}\right)$ is lower than the disutility suffered during the first period by the inefficient generator when it decides to provide the threshold value of the retention rule $RC(\hat{e})$. In that case, the regulator has no interest in choosing the retention rule as $\hat{e} < \overline{e} < \underline{e}$. Conversely, when the condition (14) is fulfilled, then $\overline{e} < \hat{e} < \underline{e}$.

Concerning the level of capacity payments, $\overline{p} < \hat{p} < \underline{p}$ if (14) holds and if δ is sufficiently high (i.e. $\delta > \frac{v(\hat{e})}{v(\underline{e})}$).

It follows from proposition 5 that the retention rule is an interesting choice for the regulator as long as $\overline{e} < \hat{e} < \underline{e}$ and $\overline{p} < \hat{p} < \underline{p}$. These results depend on the model parameters, and are more likely to hold when the probability for a generator to be efficient is high $(\alpha \to 1)$, and/or the gap between the two types' cost to access capital market $(\overline{\theta} - \underline{\theta})$ is high and/or the discount factor is high $(\delta \to 1)$.

The results show that the regulator may have an interest in choosing the retention rule, depending on the parameters' level. One of the advantages of the retention rule is to give the same amount of generation capacity and the same level of capacity payment whatever the type of the generator. On the contrary, the efficiency of a menu of incentive contracts depends on the type of generator. This uncertainty may endanger security of supply, which may incite the regulator to rely on strategic reserves rather than on a menu of incentive contracts to ensure security of supply.

The comparison between the two mechanisms depends on the relative levels of exogenous parameters.

The retention rule is all the more interesting as the discount factor, δ, is high, i.e. generators highly weight the future in their utility function. In a capitalistic market like the electric power market, investments are indeed amortized on a rather long period. Their profitability will be all the more secured as the incentive mechanism incorporates this long term view. In real markets, we can see that the short-termism of capacity mechanisms has been highly criticized. Consequently, regulators tend to extend capacity contracts' duration[10].

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[10] This has been one of the most debated issue about the regulatory reforms of the U.S. capacity markets (see Joskow, 2007).

Concerning the gap between the two types' cost to access capital market $\left(\overline{\theta}-\underline{\theta}\right)$, the wider the gap, the greater the uncertainty for a regulator using a menu of contracts. In the worst case, black-outs may happen. Given their high political costs, we expect that a risk averse regulator would prefer a retention rule to ensure security of supply.

When the probability to have an efficient generator, α , increases, the cost associated to the incentive constraint with a retention rule decreases. More precisely, the disutility of an inefficient generator which decides to provide the threshold value of capacity during the first period is all the more compensated in the subsequent periods as α increases. In that case, the regulator will also prefer to use a retention rule.

7. CONCLUSION

In the coming years, we expect the renewal of most European electricity generation capacity; in Germany for instance, letting aside the moratorium on nuclear facilities, 20 to 30 GW should be renewed by 2020. In this context, and knowing the high political cost of power cuts, the current academic proposals of incentive mechanisms to guarantee the security of supply may be appealing to public authorities. Their relative properties in a competitive market should nevertheless be assessed in a unified framework, particularly because generators may be unequally efficient in their investment process and might not be willing to reveal this information in the new competitive framework.

Considering a principal - agent framework, this paper compares two of these incentive mechanisms: capacity payments, currently used in Spain, Italy, and modelled as a menu of incentive contracts, and strategic reserves, used in Sweden and modelled as a retention rule. We assess the level of security of supply and the level of price paid for this security in both cases.

In particular, our model shows that, when the discount factor, the probability to select an efficient generator and the gap between the costs to access capital market are high, the generation capacity with strategic reserves lies between the generation capacities resulting from the menu of incentive contracts. Besides, the price paid with strategic reserves also lies between the prices resulting from the menu of incentive contracts. In other words, the choice between the two incentive mechanisms depends on market conditions.

Even if the results of this comparison are not clear cut, an interesting conclusion is that the menu of incentive contract creates some uncertainty concerning the amount of generation capacity obtained. Given the very high political risks of black-outs, we may therefore conclude that a risk adverse regulator will likely choose a retention rule and favour a "no-risk" situation, even if the economic performances of capacity payments may be better in specific circumstances. It seems besides to be confirmed by a recent event: while the capacity payments have been removed in the UK electricity market in 2001, the regulator has allowed the system operator to buy forward contracts in order to ensure a sufficient amount of energy.

An interesting extension of this paper would be to compare also a third capacity mechanism widely used in the US, the capacity market.

APPENDIX

We first compare the amounts of generation capacity obtained under each incentive mechanism. $\underline{e}, \hat{e}, \overline{e}$ are respectively defined by

$$\begin{Bmatrix} RC'(\underline{e}) = \underline{\theta} v'(\underline{e}) \\ RC'(\hat{e}) = v'(\hat{e})\left[E(\theta) + \overline{\theta}\left(\frac{1-\delta}{\delta}\right)\right] \\ RC'(\overline{e}) = v'(\overline{e})\left[\overline{\theta} + \frac{\alpha}{1-\alpha}\left(\overline{\theta} - \underline{\theta}\right)\right] \end{Bmatrix} \Leftrightarrow \begin{Bmatrix} F(\underline{e}) = \underline{\theta} \\ F(\hat{e}) = E(\theta) + \overline{\theta}\left(\frac{1-\delta}{\delta}\right) \\ F(\overline{e}) = \overline{\theta} + \frac{\alpha}{1-\alpha}\left(\overline{\theta} - \underline{\theta}\right) \end{Bmatrix}$$

with $F : e \to \dfrac{RC'(e)}{v'(e)}$

F is a decreasing function since $F'(e) < 0$. Thus, comparing $F(\underline{e})$, $F(\hat{e})$ and $F(\overline{e})$ gives:

- $F(\overline{e}) - F(\underline{e}) = \left(1 + \dfrac{\alpha}{1-\alpha}\right)(\overline{\theta} - \underline{\theta}) > 0$ thus $\underline{e} > \overline{e}$ $\forall \alpha \in]0,1[,\ \delta \in]0,1[,\ \underline{\theta} > 0,\ \overline{\theta} > \underline{\theta}$.

- $F(\hat{e}) < F(\overline{e})$ iff $E(\theta) + \overline{\theta}\left(\dfrac{1-\delta}{\delta}\right) < \overline{\theta} + \dfrac{\alpha}{1-\alpha}(\overline{\theta} - \underline{\theta})$

  $\Leftrightarrow \dfrac{\alpha}{1-\alpha}(\overline{\theta} - \underline{\theta}) > \overline{\theta}\left(\dfrac{1-\delta}{\delta}\right)$.

  Thus $\hat{e} > \overline{e}$ iff $\dfrac{\alpha}{1-\alpha}(\overline{\theta} - \underline{\theta}) > \overline{\theta}\left(\dfrac{1-\delta}{\delta}\right)$.

- $F(\hat{e}) > F(\underline{e})$ iff $E(\theta) + \overline{\theta}\left(\dfrac{1-\delta}{\delta}\right) > \underline{\theta}$

  $\Leftrightarrow \dfrac{\underline{\theta}}{\overline{\theta}} < 1 + \left(\dfrac{1-\delta}{\delta(1-\alpha)}\right)$ which is always true since $\overline{\theta} > \underline{\theta}$.

  Thus $\hat{e} < \underline{e},\ \forall \alpha \in]0,1[,\ \underline{\theta} > 0,\ \overline{\theta} > \underline{\theta}$.

Secondly, we compare the levels of capacity payment under each incentive mechanism. $\underline{p}, \hat{p}, \overline{p}$ are respectively defined by:

(1)
$$\underline{p} = \underline{\theta} v(\underline{e}) + \psi(\overline{e})$$
$$\hat{p} = v(\hat{e})\left[E(\theta) + \overline{\theta}\left(\frac{1-\delta}{\delta}\right)\right]$$
$$\overline{p} = \overline{\theta} v(\overline{e}).$$

(2) $\underline{p} - \overline{p} = \underline{\theta}\left(v(\underline{e}) - v(\overline{e})\right) > 0$ since v is an increasing function and $\underline{e} > \overline{e}$.

Thus, $\underline{p} > \overline{p}$, $\forall \alpha \in \left]0,1\right[$, $\delta \in \left]0,1\right[$, $\underline{\theta} > 0$, $\overline{\theta} > \underline{\theta}$.

(3) $\hat{p} > \overline{p}$ iff $v(\hat{e})\left[E(\theta) + \overline{\theta}\left(\frac{1-\delta}{\delta}\right)\right] > \overline{\theta} v(\overline{e})$.

It can be easily proved that $\hat{e} > \overline{e} \Rightarrow \hat{p} > \overline{p}$.

(4) $\underline{p} > \hat{p}$ iff $\underline{\theta} v(\underline{e}) + \psi(\overline{e}) > v(\hat{e})\left[E(\theta) + \overline{\theta}\left(\frac{1-\delta}{\delta}\right)\right]$. It can be proved that

$$\delta > \frac{v(\hat{e})}{v(\underline{e})} \Rightarrow \frac{\underline{\theta}}{\overline{\theta}} < \frac{\alpha v(\hat{e}) + v(\overline{e}) - \frac{v(\hat{e})}{\delta}}{\alpha v(\hat{e}) + v(\overline{e}) - v(\underline{e})}$$ which is equivalent to $\underline{p} > \hat{p}$.

ACKNOWLEDGEMENTS:

We are grateful to the participants of the Seminar of Economic Research at EDF R&D and to the participants of the EPCS and IAEE 2005 Conferences. We particularly would like to thanks Pr. W. Zantman (University Toulouse I) and Alexandre Klein (EDF R&D) for their helpful comments. The opinions and any errors in this paper are those of the authors and should not be ascribed to their employer

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