

Evaluation of power market designs on investment incentives and capacity adequacy

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Abstract: Electricity industry restructuring should not sacrifice supply security to pursue economic efficiency. Till now there is no academic consensus on which electricity market design provides the least distorting investment incentives. Alternative approaches that have been adopted around the world for ensuring the appropriate level of investment in electric generation capacity are discussed, and much attention is devoted on the evaluation of capacity payment systems. The finding is that on one hand, capacity payment systems have good effect on reducing spot market price volatility and increasing the volume of generating capacity at the costs of relatively high total electricity prices; on the other hand, however, they are not robust against either the abuse of market power in the energy market or being manipulated.

Key words: electricity industry restructuring; capacity adequacy; investment; evaluation; robustness

1 Introduction

During the last 20 years, the regulatory framework for the wholesale sector of the electricity industry has been replaced in many countries by forces of market competition in order to produce electricity efficiently and reliably. Currently there are more than a dozen existing liberalized electricity markets around the world. Due to the different characteristics of the existing power systems (e.g. generation mix, network topology, asset ownership structure, etc.) and asset ownership structure these markets vary in terms of the market organization, system operation, transmission charges, congestion management, and investment incentive mechanisms. Moreover, some of them are reported successful, such as the PJM (Pennsylvania–New Jersey–Maryland) market, the National Australia Electricity Market; some of them seem unsuccessful or even failed, such as the California market (defunct) and the Japanese Electric Power Market^[1].

Although extensive effort has been involved in market designing, there is a continuing debate over various aspects of electricity market design, such as policymaking on ensuring supply security^[2]. Until 2001, the wholesale market system in England and Wales provided for additional capacity payments to be made to all generators scheduled to supply during hours when supply was unusually tight (i.e. when the loss-of-load probability was relatively high). The wholesale markets created and managed by the Eastern Independent

System Operators in the U. S. during the late 1990s have continued their traditional policies of requiring the load serving entities to enter into contracts for capacity to meet their projected peak demand plus an administratively determined reserve margin. Argentina's competitive electricity market system also included capacity payments to stimulate investment in reserve generating capacity. In Chile, distribution utilities are required to enter into forward contracts to meet forecast demand plus a reserve margin. California's wholesale electricity market design did not impose capacity, reserve or forward contract obligations and the California electricity crisis of 2000 – 2001 is sometimes (erroneously) blamed on underinvestment in generating capacity^[3]. On the other hand, the wholesale market in England and Wales abandoned capacity payments when the New Electricity Trading Arrangements (NETA) were introduced and the Australian National Electricity Market has never had capacity payments or capacity obligations. In short, there is no scientific agreement about whether liberalized electricity markets can be expected to produce adequate capacity levels on a continuous basis.

However, it is important for the policymaker to know how the “market rules” designed directly or indirectly affect the quantity and mix of generation investment, that is, system reliability, before they are implemented. Numerous studies have analyzed the short-term efficiency of restructured electricity markets^[4–8]. If generators can exert market power by offering high

prices or withholding generating capacities, the spot price will exceed competitive levels and potentially offset any efficiency gains from liberalization. However, less attention has been paid to the long-run efficiency of restructuring; specifically there is much less quantitative discussion on generation investment.

It is well acknowledged that market liberalization has changed the investment framework: from central planning to decentralized decision-making. Under traditional regulatory regimes, investment decisions are taken, or at least approved, by government. The planning process aims in principle to meet forecast growth in the demand for electricity and on replacing plants that were no longer physically operable. The traditional approach to this was to build planning reserves based on the forecasted load, loss of load probability (LOLP) calculation and estimate of the value of lost load (VOLL), and allocate the costs of the extra capacity implicitly among consumers. In a liberalized market, generally there is no central planning for new generation capacity investments and no more guarantees are made for recovery of generation investment and return. On the other hand, generation companies do not have any obligation for ensuring sufficient supply of electricity. Investment decisions are made by market players who will bear the costs and risks of their decisions.

The effects of this change have dual characters. On the positive side, market liberalization may bring about significant savings due to a more efficient investment level and a more efficient investment composition. On the other side, there are also possibility for “degrading system reliability” resulting from inadequate levels of generation.

This paper investigates how these market designs impact generation investment and electricity spot prices by simulations and whether they are robust or not against either the abuse of market power in energy market or being manipulated. Specially, this paper examines capacity payment systems. Capacity payments and capacity requirements are conceptually equivalent. Capacity payments or capacity requirements have been justified on the grounds that capacity possesses the properties of a positive externality and therefore will be under-provided by the market. Capacity payment systems act directly to attract new generation capacity investment, thus increasing the total level of capacity, and indirectly reduce spot prices during peak loads, thus reducing the overall volatility of spot market prices.

In order to investigate long-term effects of restructuring on investment, recently there are only a few studies which have analyzed generation investment be-

havior in a restructured environment from both qualitative and quantitative perspectives.

Botterud and Korpas formulate the power generation investment problem for a decentralized and profit-maximising investor operating in a restructured competitive power system. They have examined how uncertainty influences the optimal timing of investments in new power generation capacity by real option approach and how a fixed or viable capacity payment would influence the investment decision, and discussed the system consequence of the resulting investment strategies^[9].

Rochlin and Huang demonstrate there is a complex interrelationship between reserve margin, contract over and price caps. Their simulation results indicate that in designing a resource adequacy requirement, the decisions on the reserve margin, the percentage of contract cover, and the level of price caps should not be made in isolation^[10].

Kahn asserts that capacity requirements are a very inefficient way of providing reliability; they tend to provide it at far too high a cost. And he also argues that the highest priority must go to establishing the essential condition of an ideally functioning energy market by real-time metering and pricing at least on an hourly basis to a sufficient fraction of the market^[11].

De Vries qualitatively reviews the advantages and disadvantages of various capacity mechanisms implemented in currently in-operating markets and proposed in literature. His analysis focuses specifically upon options for European markets, which typically are without mandatory power pools and have significant exchanges with neighboring markets^[12].

Owen argues that long term reserves should be viewed as price insurance and be treated as a private good and discusses the origins and shortcomings of capacity payments and capacity requirements and explains how long term supply contracts in the form of call options with premiums that depend on the contracts' strike prices can meet the need for ensuring supply adequacy and the financial health of the generation sector^[13].

The rest of this paper is organized as follows. The next section gives an explanation of the unique character of electricity market, that is, the reasons why it is different from other commodity markets. Further in section 3, the problem of generation capacity in electricity markets without special capacity mechanisms is discussed. After that, we review several alternative capacity mechanisms adopted in currently running markets and proposed in the literature. Then we focus on making an evaluation of capacity payment systems. The

final section is our concluding marks.

2 The reasons for capacity mechanisms

The determinant reason for capacity mechanisms in electricity markets is the unique characteristics of electricity supply and demand as the following:

1) Large variations in demand for electricity over the course of a year and uncertain load growth in the future;

2) Economical non-storability;

3) The capital-intensive nature and long lead time of new generation facilities;

4) The need to physically balance supply and demand at every point on the network continuously to meet physical constraints on voltage, frequency, and stability;

5) The inability to control power flows to most individual consumers;

6) Limited use of real time pricing by retail consumers;

7) The expected high reliability of power systems due to the importance of electricity to modern life.

There are several important implications from these attributes. First and foremost, a large amount of generating capacity that is available to meet peak demand plus the associated operating reserve requirements supplies relatively small amounts of energy during the year. Potential investors in new generating capacity must expect to cover their variable operating costs, their fixed operating and maintenance costs, and their capital costs from sales of energy and operating reserves over the life of generating capacity under consideration. The profitability of generating units that are likely to operate only for a relatively small number of hours in each year ("peaking capacity") is especially sensitive to the level of prices that are realized during the small number of high demand hours in which they provide energy or operating reserves. Relying on periodic price spike to signal the need for peaking capacity has some significant weakness. If without any capacity payment, some generation companies especially those providing peak capacities may not be able to recover investment costs from a competitive generation market. And the uncertain demand growth for electricity in the future, capital-intensive and long life time nature of new generation investments together cause investment risk to be high. Even when the expected average income of this potential generator is enough to recover its variable and capital costs with a reasonable profit margin, a risk-aversion firm would feel that the high volatility of the generator's income renders the investment very risky, and consequently the firm would turn down

the opportunity to invest. Strbac and Kirschen demonstrate that the uncertainty of the returns leads risk-averse investors to under-invest in peaking units^[14].

Second, given the particular attributes of electricity service, consumers will not tolerate extreme price volatility or reliability risks. Electricity is not like other products and has often been characterized as being imbued with the public interest. Because electricity is a necessity of modern life and is a product for which there are few if any substitutes (in the short run at least), policies have been instituted to ensure universal access and very high standards of reliability, such as "one day in ten years" criterion. Individual consumers and the economy as a whole cannot tolerate periods of either highly volatile prices and/or inadequate supplies. Imposing a market that presumes, and indeed, depends upon periods of price volatility and periodic high prices is therefore not in the public interest and unacceptable.

In short, capacity mechanisms should be designed to dampen the boom-and-bust cycles in generating capacity, improve the stability and predictability of system reliability, and minimize risks to consumers from volatile prices.

3 The problem of generation capacity in energy-only electricity markets

In energy-only electricity markets generators bid only energy prices and, in the absence of constraints, all bids below the market-clearing price in each hour get dispatched and paid the market-clearing price. The primary income source for recovery of capacity cost is the difference between the market clearing price and the generators' marginal costs. When ancillary services are procured separately by the system operator, generators can earn additional revenue by selling ancillary services, such as regulation and spinning reserve capacity, through short term ancillary service markets or long term contracts.

As the theoretical basis, work by Caramanis shows that under ideal conditions, electricity-only markets provided efficient outcomes in both the short and the long term^[15]. Generally, this school of thought asserts that underinvestment would be caused by obstacles to the proper functioning of the market mechanism, such as price restrictions or construction permits. The proper course of action, in this view, is to improve the investment climate by eliminating all extraneous sources of risk, such as regulatory risk and other obstacles to investment. This kind of free market ideologue believes that the capacity markets or capacity payments are not needed at all, and everything could be dealt with by

market forces in the energy-only market. In a perfectly competitive market where prices of electricity vary continuously to reflect the supply and demand status at each moment, payment to infra-marginal generators (above the system marginal cost) should cover their capacity costs. Economic theory tells us that in a long-term equilibrium, the optimal capacity stock is such that scarcity payments to the marginal generators, in case demand exceeds supply, will cover the capacity cost of these generators. This equilibrium is achieved through exits of generators whose costs cannot be recovered and entry of new generators whose cost structure will bring them operating profits that exceed their capacity costs^[13]. Therefore, theoretically allowing the prices of electricity to reflect short-term supply and demand status will create market signals for a proper capacity expansion. But the requirements for theoretical conclusion are strong: the usual general equilibrium assumptions of a complete set of spot and forward markets or perfect foresight, price-taking behavior by producers and consumers, risk neutrality or adequate risk-sharing contracts and convex production possibilities. Of course, these ideal conditions are never satisfied.

In practice, however, energy-only markets can only provide incentives for investment by subjecting consumers to price volatility, price levels, supply shortage and a level of risk to reliability that customers and policymakers would find unacceptable. For such a market to work, prices must be unconstrained in order to signal investors that it will be financially worthwhile to build new generating capacity. Therefore an energy-only market is characterized by boom-and-bust cycles and does not have a stable equilibrium at a reasonable reliability level.

Moreover, as a practical matter, due to the possible exertion of market power, in some emerging power markets price caps or bid limits have been necessarily imposed or proposed. Experience to date from operating competitive wholesale markets suggests that without a capacity mechanism, incentives for investment are in fact not adequate to achieve the objectives of electric industry restructuring, such as the case occurred in California electricity markets.

4 Alternative capacity mechanisms

As discussed above, energy prices in some restructured systems are not high enough to prompt adequate investment, so there are various capacity mechanisms implemented with currently running markets and proposed in the literature. De Vries contributes a detail discussion of different capacity mechanisms available to regulators to encourage investment in generation^[12].

4.1 Price-based capacity payments

Capacity payments have been widely implemented, such as in the UK (before the new trading arrangements (NETA)), Spain. Generators in such systems are given a per MW payment based on their availability (whether they get dispatched or not) or based on generated energy as an adder to the energy market clearing price. The capacity payments are collected from customers as a prorated uplift similarly to other uplift charges such as transmission charge. In some cases, capacity payments are indistinguishable from stranded investment compensation, which are viewed as an additional source of revenue for the generators that is needed in addition to the competitive energy revenues in order to guarantee their profitability.

The concept of capacity payment is rooted in the theory of peak load pricing whose application in the context of electric power was pioneered by Boiteux^[16]. According to this theory generation of electricity requires two factors of production, capacity and energy where the amount of energy that can be produced in any given time period is constrained by the available capacity.

The idea of capacity payments is that by reducing the fixed cost of generation, the long-run market equilibrium will shift towards a larger volume of generating capacity. Capacity payments are often made in compensation for an electricity price cap, which would otherwise probably lead to insufficient investment. Typically, capacity payments are extended to all generating units, for reasons of fairness, in order not to distort competition and to stimulate generating companies to delay the decommissioning of old units.

The effectiveness of capacity payments is doubtful because of two fundamental weaknesses: the absence of obligations on the part of generating companies in exchange for the payments and the indirect effect upon investment and hence reliability. Consequently, it is unclear what benefits consumers who in the end are the ones who finance the payments derive from them. The payments may not necessarily suppress the tendency towards investment cycles. While they reduce investment risk, they do not provide a clearer indication of the total demand for generating capacity than an energy-only market does. In addition, it is difficult to determine the optimal level of the payments. This argument also holds for the other price-based capacity mechanisms, a strategic reserve and operating reserves pricing: given the many uncertainties regarding the relation between market prices and investment behavior, it is more difficult to obtain a desired level of reliability through a financial incentive than by controlling the volume of gen-

erating capacity directly. The quantity-based capacity mechanisms (capacity requirements, reliability contracts and capacity subscriptions, discussed below) are more effective but also more complicated. Advantages of capacity payments are that they can be combined with a price cap, so they improve price stability, and that they are easy to implement.

4.2 Quantity-based capacity mechanisms

Another principle approach is quantity-based methods, in which either a market operator procures reserve capacity directly, as the case of Sweden, or sets up a capacity market as the case of the PJM market. There are several versions of capacity markets, but each has the following basic features: a target level of system generating reserves (commonly based on a probabilistic adequacy criterion of capacity deficits occurring only once every decade); the allocation of responsibility for meeting that target by creating an obligation (either on the part of load serving entities or the system operator itself) to acquire capacity or capacity credits; a system to assign credits to generators, based on their capacity and reliability, and perhaps to demand-side programs such as load controls that can substitute for capacity; a system that allows trading of credits so that those with credits beyond their needs can sell them to those who are short; a set of requirements defining how far ahead of time (days, months, or years) those responsible for obtaining capacity must contract for it; and a system of incentives to encourage availability of capacity when needed and for penalizing LSEs who have insufficient credits. Quantity-based systems include the installed capacity (ICAP) markets; available capacity (ACAP) markets, in which capacity is given credit on a day-by-day basis only if it is available on that day; and scarcity pricing of operating reserves, discussed earlier, in which the system operator states a maximum willingness to pay if it is short of spinning or non-spinning reserves. In the latter case, if the maximum willingness to pay is sufficiently high, then generators will receive enough extra revenues to pay for its capital costs from either the operating reserves or energy markets when reserves are short. High operating reserves prices spill over to the energy market during shortage periods because most generators can choose to sell in either market, and so there will be an opportunity cost to selling in the energy market.

The motivation for installed capacity requirements, sometimes also called capacity obligations, is similar to that for capacity payments. The resulting capacity markets provide generators with the opportunity to collect extra revenue for their unused reserve generation capacity and provide incentives for the building of

adequate reserves.

4.3 Strategic reserve

A strategic reserve consists of a set of generating units that are kept available for emergencies by an independent agent, typically the system operator^[17]. The question is under what conditions this reserve is deployed. If the market is to perform its regular task and invest in generation capacity, it should be able to rely upon periodical price spikes to finance its investment in peaking units. This means that the reserve should only be deployed at a high price, namely a price equal to the value of lost load. This raises two issues. First, it may be politically unsustainable to allow prices to rise so high for any length of time if they can be lowered by deploying the strategic reserve. After all, the reserve will be something of a public facility. The second issue is that the incentive to withhold capacity by market parties will not be eliminated until the deployment price of the strategic reserve is reached. Nevertheless, if the reserve is to be deployed at any lower price, it will reduce the incentive to invest. This scenario would create a need for a larger reserve.

4.4 Reliability contracts

A disadvantage of capacity requirements is that they do not provide an incentive to maximize the availability of reserve capacity. An improvement in this respect is provided by reliability contracts, a system of call options that the system operator purchases from the generation companies^[18]. When the options are called, the producers are required to pay the system operator the difference between the market price and the strike price. Operating power plants are a perfect hedge for the generators: their net income is equal to the strike price. Generation companies that have sold options that are not covered by available generation capacity when the options are called, lose on those options. This provides generation companies with an incentive to sell an option volume that is equal to the available volume of the generation capacity that they control. A second advantage is that the generation companies receive an incentive to maximize the availability of their generation units during periods of scarcity. Overall generation adequacy is determined by the system operator, by the volume of options that the operator purchases.

4.5 Capacity subscriptions

Where the previous two systems still contain an element of central coordination, a system of capacity subscriptions leaves all variables to the market^[19]. In fact, this system may be considered more market-oriented than a traditional, unregulated electricity market, because it allows consumers to choose their level of

generation adequacy. In this system, each customer needs to purchase an electronic fuse, which can limit his/her electricity use. The fuses are activated by the system operator during periods of scarcity. Customers can choose the size of their fuses. The fuses are sold by generation companies and need to be covered by available generation capacity. Thus, the market for fuses indicates the total demand for generation capacity and provides generation companies with fixed revenues to cover their investments. This system turns the security of supply into a private good; consumers can choose their own level of generation capacity that they want to have reliably available. The drawback of this system, compared with the previous options, is that it is more elaborate, as it requires the installation of an electronic fuse at each customer site.

5 Evaluation of capacity payment systems

This section makes an evaluation of the capacity payment systems from two perspectives. The main goal of a capacity mechanism is to ensure an adequate level of generation capacity. Therefore the first perspective is from the effectiveness in stabilizing generation investment at a desired level. On the other side, a proper capacity mechanism should not provide market players either incentives of exerting market power in the electricity market or chances of being manipulated, that is, the second perspective is the robustness analysis against the abuse of market power in the electricity market and robustness against being manipulated.

The supply of adequate capacity can be determined either through prices (capacity payments) or through quantities (capacity requirements). The following discussion focuses on capacity payment mechanism.

5.1 The effect of capacity payments on generation investment

The effect of capacity payments on generation investment and the spot market prices based on a quantitative simulation model are investigated. Cai^[20] and Cai and Tezuka^[21] give a detail description of the simulation model. The model and the data of this study are also available on demand. Here only the simulation results are described^①.

The mean generation capacity levels for varying payment levels are graphed in Fig. 1. One finding is that, higher capacity payments produce higher capacity levels. Payment level III (\$ 40/kW-year) brings about much more capacity investments than level I (\$ 20/kW-year) and level II (\$ 30/kW-year). If not take the beginning several years into account, the reserve margins under payment level III are ranging from

10 % ~ 25 % , while under the case of level I, several years are short of generation capacities. Another finding is that no matter what the payment level is, the long-term performance of the market demonstrates boom-and-bust character. Capacity mechanisms are originally designed to dampen the boom-and-bust cycles, but the effects are not so obvious. The reason is the generators (investors) make investment decisions basing not only on capacity subsidies but also on the profitability from the wholesale market, which is affected by the capacity subsidies as discussed afterward.

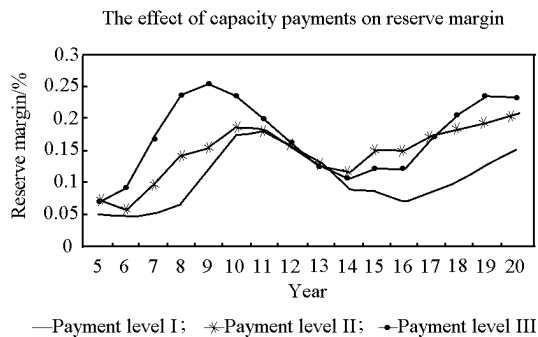


Fig. 1 The effect of different capacity payment levels

On the other hand, as expected, higher capacity payment levels reduce peak prices as shown in Fig. 2.

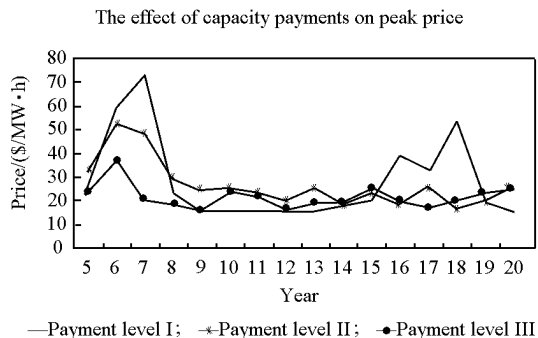


Fig. 2 The effect of capacity payments on peak price

Since peak and near-pick prices are reduced by higher capacity payment levels, higher payments also result in

① Because the model randomly samples markup rate of bidding prices and estimation error, in "Monte Carlo" simulations, it is typical to repeat the random draws many thousands or more times. One particular simulation does not represent a prediction of the market's development over the next years; rather it is one sample path which, when repeated a number of times, allows for a statistically precise estimate of the average long-run performance of a particular payment system and set of assumptions. But in practice, only 64 times for each payment level have been done.

a reduction in overall spot market volatility and mean spot market price. The standard deviation and mean of the spot market price for year 5th – 20th are plotted in Fig. 3. These reductions in mean price and volatility do not come without costs. A per MW·h capacity charge can be calculated by dividing total capacity payments for a given year by the total number of MW·h that were consumed in that year. When this charge is added to the mean price, a total price for electricity can be computed. This total price covers both energy and capacity payment costs. As shown in Fig. 4, this total price of electricity increases with increasing capacity payment levels. This result can be interpreted from the perspective of financial science. Capacity payments conceptually equate a call option on electricity; the increase in total electricity price associated with capacity payment is analogous to the price of the option. This option protects consumers from upward price movements and is exercised when excess capacity, originating from capacity payments, is utilized during peak load periods. Average spot market price and per MW·h capacity payments are plotted in Fig. 4 for each of the capacity payment levels.

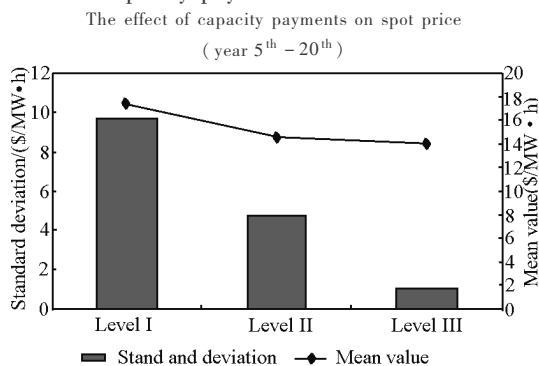


Fig. 3 The effect of capacity payments on the spot prices

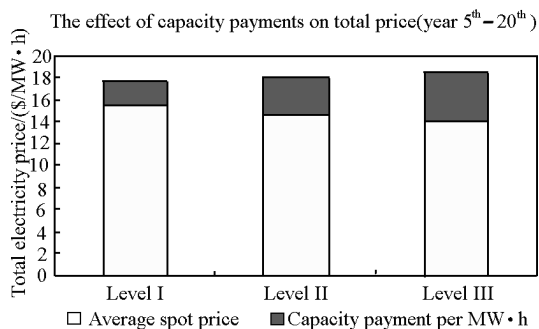


Fig. 4 The effect of capacity payments on average total price

5.2 Robustness analysis

In the following, the robustness of capacity mechanism is qualitatively discussed from two aspects: one is the capacity mechanism should be robust against the

abuse of market power in the electricity spot market; the other is the capacity mechanism should be robust against being manipulated.

5.2.1 Robustness against the abuse of market power in the electricity market

A capacity mechanism should also stimulate generation companies to maximize their output during periods of scarcity, and not to withhold capacity when it is needed most. Capacity mechanisms that focus on creating sufficient generating resources should be effective in reducing periods of scarcity to the economic efficient minimum. To keep the inevitable periods of scarcity from lasting longer and costing consumers more than necessary, there should be an incentive to maximize generator output. This issue is significant because capacity withholding adds to the probability of service interruptions and may create large income transfers from consumers to producers.

However, one disadvantage of payment systems for installed capacity is that they do not reduce the incentive to withhold capacity during shortages. The payments are made for generator's potential to provide power, not for their actual contribution to maximizing reliability. To mitigate this incentive, capacity payments are usually accompanied by an electricity price cap. But this would also reduce incentives for demands to exhibit price-elastic behavior. More fundamentally, the reduction in generator revenues due to the price cap would need to be known in order to calculate the correct level of capacity payments. It is precisely the problem of electricity markets that it is difficult to determine the expected revenues from price spikes. If generating companies are not able to estimate them due to a lack of information, it is highly questionable that the policymaker would have better information and be more successful.

5.2.2 Robust against being manipulated

It should be taken care that a change in the market design should not introduce new opportunities for the abuse of market power. For example, payments for available capacity may cause unavailable capacity to be declared available; the owners could prevent the capacity from being called upon by bidding very high in the energy market. Therefore, another criterion therefore is to avoid opportunities for manipulation, in particular price gouging through capacity withholding.

The experience in some markets, such as the PJM system and the compulsory British Electricity Pool, teaches us that the creation of a new market for generation capacity may offer new opportunities for the abuse of market power. That is, the predictability of calculated capacity payments can lead to manipulating of the

payments in concentrated markets^[22]. But a priori evaluation of the robustness of a capacity mechanism against being manipulated is difficult. And up to now, it is well acknowledged that the dynamic capacity payments in the former England and Wales Pool has been manipulated, which resulted in overpayments to the generating companies.

To summarize, capacity payments can reduce the peak prices and higher capacity payments can be expected to produce higher generation capacity level. But capacity payment systems are not robust against either the abuse of market power in the energy market or being manipulated.

6 Conclusion

Electricity industry restructuring should not sacrifice supply security to pursue economic efficiency. One of the key issues is the ability of a liberalized electricity industry to deliver appropriate investment incentives and maintain generation adequacy in the long-term. Experience accumulated to date is insufficient to assess the long-term benefits from liberalizing the electricity industry and there is no best market design. “Second-best” and “robust” market designs should be the practical goal for the policymaker.

This paper initiates a review, discussion and evaluation on some issues related to ensuring adequate generation capacity investments in electric power markets. With a simulation model, we quantitatively demonstrate that the design of a restructured electricity market with capacity payment systems can significantly impact long-term investment behavior and electricity spot prices. The results show that capacity payments act to reduce market volatility and increase the volume of generating capacity at the expense of increasing total electricity prices but they are not robust against the abuse of market power in energy market and easily being manipulated.

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