Electricity supply security: Cost efficiency of providing security and diversified consumer level

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August 2009

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Abstract

Security of supply in electricity is questioned in liberalised markets as it is often characterised as a public good. We examine if this can be modified allowing for creation of security markets, which can be justified by welfare gains. From a welfare perspective it is possible that security levels are too high and obtained with too high costs. An efficiency improvement might be to adjust the effort so that marginal cost for securing supply are at similar levels in generation capacity and in network maintenance. Secondarily, a consumer defined level of security might improve welfare. Finally, different willingness to pay among customers and construction of advanced markets might increase welfare further.

Keywords: security of supply, electricity markets, public goods

JEL: Q4; Q41; H4, L94

1. Introduction

Security of supply in electricity has received widespread attention in light of the liberalisation of electricity markets. The basic question is whether liberalised markets will secure that adequate capacity is available and whether tight efficiency regulation of electricity networks will result in deteriorating quality of network reliability. Maintaining security of supply in liberalised electricity markets has been seen as a critical test for the functioning of the markets. This has been especially relevant for the existing spot and futures markets, and less explicit for the quality aspect of electricity, which has only to a marginal extent been covered by markets. This paper describes the possible steps and some necessary conditions for establishing markets for security of supply services in a Danish and Nordic perspective. In a European perspective increased focus has been put on maintaining quality of supply in a liberalised and efficiency regulated market. CEER (2005) refer to 8 countries out of 19 European countries covered having specific quality elements included in the incentive regulation for distribution (network) companies. This is mainly based on concern for that quality would deteriorate in a liberalised and tighter efficiency regulated environment.

For the adequacy aspect of security concern has been raised that market prices are not sufficiently high to secure new generation capacity. In particular the peak power resources do not seem to be attractive without some capacity payments. Construction of such markets

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in an efficient way has been broadly discussed in literature including Hogan (2005) and Joskow and Tirole (2006), but the linkage with grid investment is less covered. In this paper we argue that investment in adequacy in generation and transmission capacities should be balanced with the costs of reducing interruptions in the distribution grids.

There are several possible benefits of having the security aspect covered by a market instead of by direct regulation. First step is to secure that a given level of security is satisfied at the least costs. A requirement for this is that marginal security costs in generation, transmission and distribution are at comparable levels. The argument is that consumers have identical cost of interruptions (Value Of Lost Load, VOLL) whether due to generation capacity constraints, capacity/ fault in transmission lines or faults in distribution equipment. Costs have to be equal across sectors operating in competitive markets and sectors that are directly regulated. If the regulator itself is demanding security of supply services from all three parts of the power sector the simplest form of a market would be implemented with suppliers and a single buyer. This would not result in the optimal level of security as the final demand for security would not be reflected; only the regulators estimation of average interruption costs. If it is possible to reduce the public good property of security of supply, a market might lead to a more correct level of security, but the largest benefits would be associated with possible differences in VOLL among customers. Some evidence suggests that there are large differences in interruption costs. de Nooij et al. (2007) find large differences between sectors, regions and in time for the Netherlands. They also refer to the issue of actually providing a level of supply security that is actually at two high levels especially concerning the adequacy part.

Secondly, the possibility of individualised security of supply exists. To the degree it is possible to exclude customers; this would imply that different degrees of security can be supplied to customers with different costs of lost load. Examples of this possibility exist, but it is not a widespread practise in the liberalised power markets of today. The linkage to the flexible demand element in the existing power markets is discussed. Flexible demand and interruptible load share the property of having to individually affect the load of customers. If mechanisms are in place to have individual customers adjust their load with a warning time the step to having individual interruption is also possible. Special emphasis is given to relating the possible markets to the actual interruptions in Denmark.

As a majority of interruptions (frequency) are related to distribution grid faults, the cost of reducing these faults relative to the cost of maintaining the capacity reserves that secures that almost no load has been lost due to capacity constraints is questioned. Would an integrated market for security services transfer resources from capacity reserves to distribution grid infrastructure? Finally is the equity question. Will we accept discrimination among residential customers regarding their supply security and the price they pay for a given level of security. In most countries it has not been allowed to discriminate among residential customers for their connection costs, network charges and the electricity price within a supply area. However as it is now, the security of supply is varying among the consumers without this being reflected in any difference in payments.

This paper is organised with a section presenting the public good property discussion for electricity supply security and the modifications required for creating a market for supply security. The next section examine the possible welfare gains from creating markets in different situations regarding interruption costs distribution and costs of supplying security. It argues that full markets are only necessary if there are large and unsystematic differences between costs of interruptions for different consumers. Following this a section suggest the possibility of gradually moving in the direction of markets first by improving the sources providing security of supply and later by involving consumers when this becomes possible by the individual excludability established with interruptible meters in each installation. The last sections include conclusions and comments.

2. Security of Supply and the Public Good Argument

This section discusses public good characteristics of security of supply and changes as a necessary precondition for construction of markets for this ancillary service.

Security of supply is in the literature regarded as a pure public good, and by others, not characterised as a public good. It is a necessary precondition that security of supply is not a pure public good to have a well functioning market without having to use regulation.

Electricity is not valued by consumers solely through its quantitative dimension, but rather through services that it provides. Most of such electricity dependent services are based on preplanning that assumes a stable supply of electricity to be available at request in real-time. Following, security of supply expresses the system's ability to ensure continuous supply of electricity at a stable frequency and voltage, and can be seen as the qualitative dimension of the electricity good.

The term 'Security of supply' refers to the likelihood that electricity will be supplied without interruptions. Thus, often the terms security and adequacy are distinguished so that (Oren, 2000):

- *security* is the ability of the system to withstand sudden disturbances, e.g., disconnection of a distribution line.
- *adequacy* is the ability of the system to supply the aggregate electric power and energy requirements of the consumers at all times, e.g., have enough power capacity, enough network capacity, and system functionality.

In recent years, the main argument for regulation of power market with focus on security of supply has mainly been the reading of security of supply as a public good. Several papers view security of electricity supply as a public good, e.g., Abbott (2001) "This means that security is non-rival in public good terms. Security of supply also appears to be nonexclusive in that it is difficult to exclude people from benefiting from that reduced risk associated with the construction of additional capacity." Counter wise, Rochlin (2004) states that "the market provision of an adequate reserve margin does not fail the rivalry or the exclusionary principles and does not qualify as a public good".

In order for us to evaluate these two contradicting statements, we start out by the economic definition of public goods. Public good are often defined as goods that are non-excludable as well as non-rival. This means, it is not possible to exclude consumers from consumption of the good, and at the same time, consumption of the good will not reduce the amount of good available for consumption by others (Mas-Colell, Whinston, and Green, 1995). Following, determination of social optimal equilibria in the case of public goods are found to be difficult when the number of participants is large, as the amount of people knowing each other is relatively small, i.e., the possibility of ones actual marginal benefit being detected is very small. This problem is referred to as "the free rider problem", which typically arise in markets for public goods. Hence, it can be used to explain why regulation is needed in markets for public goods.

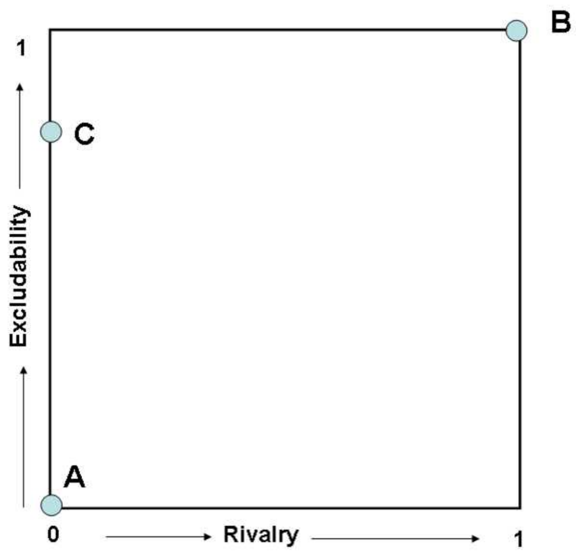

Figure 1: Classifying goods according to the degree of rivalry and excludability. A – Pure public good, B – Pure private good, and C – Non-rival good.

The first conclusion to derive from this is that markets for public goods typically need regulation in order to reach the efficient level of output. That is, if the security of electricity supply is seen as a public good, then we need to have regulation in order for us to reach the social optimal level of security of electricity supply. But before we decide on, whether or not, we are dealing with a public good, we spend a little more time analysing the two requirements non-rival and non-excludable.

Figure 1 illustrates the two dimensions of public good characteristics with three types of goods. Point A is a pure public good where its value to individuals is not reduced by others consuming the same good and at the same time it is impossible to exclude anyone form consuming the good. If it is possible to exclude consumers individually we arrive at point C a non-rival type of good. Finally a normal pure private good is represented by point B in Figure 1.

Abbott (2001) states that security of electricity supply is *non-exclusive* because, once a unit of capacity is added to the system all consumers benefit from the increased reliability that it provides. Stoft (2002), finds it non-exclusive because of demand side flaws. He argues that since there are no real-time metering and, at the same time, lack of technology required to disconnect consumers individually in case of an inadequate supply, security of electricity supply is non-exclusive. Counter wise, Rochlin (2004) finds that it is exclusive because, even though, it is not possible to exclude consumers ex ante, it is possible to use ex post payment. That is, the mechanism to collect charges for using reserves.

According to Stoft (2002), security of electricity supply is also *non-rival* because, once produced it is unaffected by the amount of consumers that obtains a benefit. This corresponds to Abbott (2001) who means that security is non-rival because "any expansion in capacity designed to meet growth in demand not only reduces the risk of black-outs for those being supplied from the new plant but also reduces everyone else's risk at no extra cost". Counter wise, Rochlin (2004) finds that this is not the case since using reserves decreases the reserve margin and hence, reduces the level of reliability. And when the reserve margin is sufficiently low, the use of one unit more leads to load shedding.

The conclusions regarding non-rivalry and non-exclusion are, therefore, not straightforward. Hence, if we should treat security of supply as private instead of public good, we need a controversial shift from an 'obligation to serve' to 'obligation to serve at a price'. And following, we need to see a quality differentiation where security of supply is not externalized from the market via, e.g., back-up systems.

This lack of technology to meet these requirements are partly mentioned by Stoft (2002) with lack of real-time metering and real-time billing, which causes a lack of demand elasticity in the market, and inability to disconnect individual consumers. But recent technological developments (Illustrated in Figure 2 with the vertical arrow) have enabled individual billing and disconnection excluding free riders, wherefore, we find that security of electricity supply does not fail the exclusionary principle, and hence, does not qualify as a pure public good. With respect to non-rivalry we find all three statements credible, and not contrary.

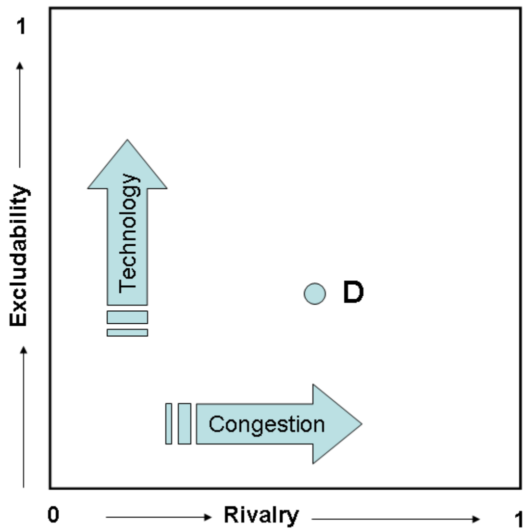

Figure 2: Classifying congestible public goods according to the degree of rivalry and excludability (Point D).

If we turn to the definition of congestible public goods, we find goods for which congestion reduces the benefits to existing consumers when more consumers are accommodated. That is, the marginal cost of accommodating an additional consumer is not zero after the point of congestion is reached. This is illustrated in Figure 3, where the marginal cost of allowing additional users to consume the congestible public good fall to zero after the good is made available to any one user but then rise above zero after N* users are accommodated per hour. Examples of congestible public goods are roads, bridges, and public parks. In the terms of non-rivalry and non-exclusion, congestible public goods are non-rival in consumption only up to a certain point (N*). After the number of consumers exceeds a certain amount, the good becomes at least partially rival in consumption (Figure 2 horizontal arrow). These types of goods are often represented in form of services flowing from shared facilities, here, e.g., reserve power to cover failures. In theory, these goods can be distributed through markets either by government or by firms through the sale of admissions, memberships, or other use-related fees which may or may not receive public subsidies (Hyman, 1993).

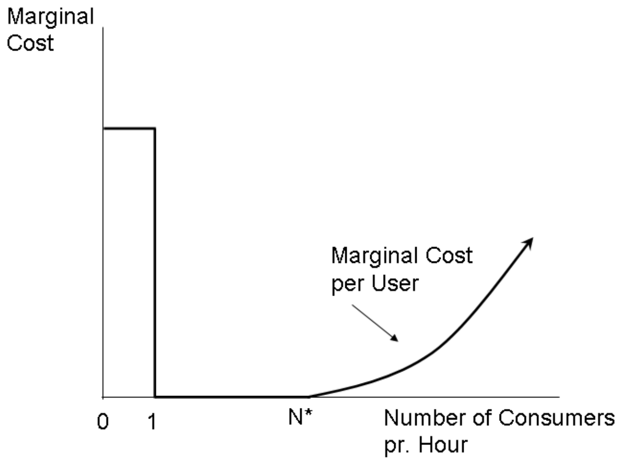

Figure 3: The marginal cost for a congestible public good. (Source: Hyman, 1993)

Placing the congestible public good in Figure 1 gives a point in the middle of the figure, as illustrated in Figure 2. This point corresponds to a good where there is some degree of rivalry and price exclusion is possible through tolls.

Returning to the question on the need for regulation of the quality of electricity supply, i.e., security of supply, we face a conclusion with ambiguity. Following, we need to discuss to which extent it is possible to use market mechanisms in a market for security of supply, and hence, to which extend we need to regulate under the given barriers as well technological as administrative.

3. Welfare Gains from Construction of Markets for Security of Supply

Security of supply is one aspect of quality services associated with electricity supply. This aspect is not priced directly in the price paid for the electricity, neither in the wholesale markets nor in retail sale. Indirectly the price for final consumers includes costs associated with maintaining security of supply. The average costs of securing supply are borne by final consumers, for example as charges to the system operator, but it is not directly linked to their individual demand for security of supply[1]. Here we investigate the consequences if markets for this kind of service are constructed and what will be the possible gains?

Cost minimisation in securing a given level of security of supply

First, it could be expected that a market with competition in the supply of electricity security would reduce the cost associated with reaching the level of security. Without a market it is not secured that all the possible technologies to increase security of supply are made available to the regulator, and in particular not in the correct volume. If the regulator has all the information available it is, however, possible to reduce the error relative to the market considerably.

[1] Interruptible contracts also exists in the Nordic market and these contracts price the reduced security of supply that these mainly large industrial factories are willing to take.

Establishing the social optimal common level of security of supply

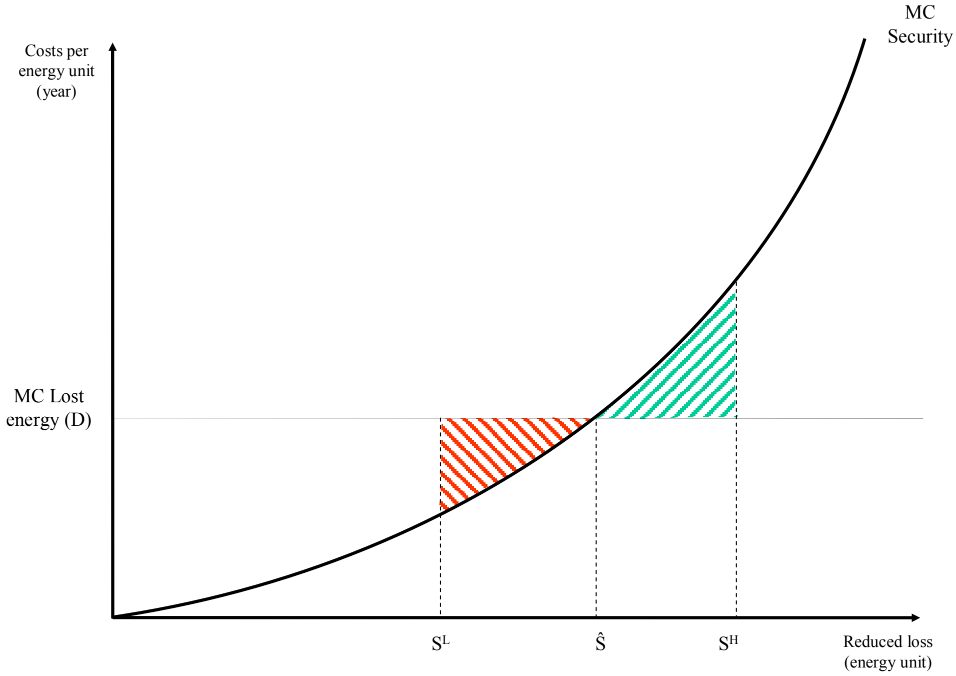

Figure 4 Possible welfare loss with an in-optimal level for security of supply

For the elements of costs also involving consumers and their costs of supply interruptions we start by examining one common level of security of supply.

For simplification it is assumed that:

- Cost of interruption per energy unit is independent of duration and timing of the interruption
- All consumers are identical with respect to cost of interruption
- Marginal cost of limiting the expected loss of energy per year is increasing with reduction in expected loss

In Figure 4, there is a possible welfare loss if the arbitrarily chosen level of security is too low (S^L) or too high (S^H) relative to the level $\hat{S}$ where consumer's real cost of interruption are equal to marginal costs of supplying additional security. If security is a pure public good, it is likely that consumers will express an opinion favouring high levels of security as that is not seen as affecting their costs. If authorities and regulators are adjusting to these opinions, it is possible that we are having too high levels of security and thereby are experiencing a welfare loss. The opposite situation can arise if individuals are asked to actually pay additional for security and they understate their willingness to pay to enjoy the free ride on this service.

Possible loss due to not serving different levels of security to different consumers

In the next case (Figure 5), we now relax the assumption of consumers having the same costs of interruptions. In some studies, for example de Nooij et al. 2007, it has been found that industry is experiencing lower costs of being interrupted than do service sectors and private households. For households it is even plausible that there are quite large differences, for example, dependent on whether their heating is based on electricity supply or even more basic if they are actually at home during the hours when interruptions occur.

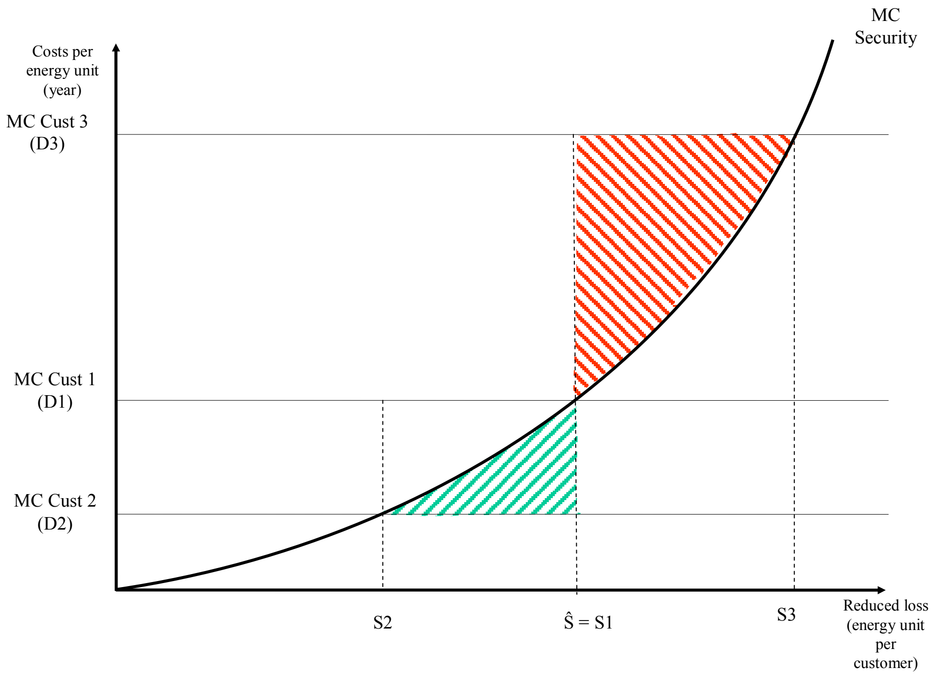

Figure 5 Different interruption costs for consumers

The demand part of the market for security of supply is particularly important for possible welfare losses if the costs of lost energy are different among the consumers. In Figure 5, without a market, Customer 2 will be supplied too high security, and Customer 3 too low security. Only Customer 1 is experiencing a level of security that corresponds to her interruption costs. The welfare loss will, therefore, be the sum of their individual losses.

The figure illustrate that difference in interruption costs is a major argument for creating markets for security of supply, providing different levels of interruption probability to different consumers. A market with consumers directly participating implies having different levels for security of supply for different consumers. Still, this seems fine in the case where there is no difference in supply costs for different consumers as assumed in the case in Figure 4 and Figure 5.

A problematic issue in this simple representation is the difference in costs of establishing security of supply to the individual customers. For the network security (failures) different levels of interruption probability can be supplied even without the existence of a market.

This is for example induced by the incentives in network regulation of electricity distribution. Network regulation justified by the natural monopoly characteristics of electricity distribution networks is widespread. In the last decade this regulation has become more complex and in many cases includes elements of quality regulation. Ajodhia et. al. (2006a,b) documents the effects of including quality in network regulation in some European countries. They find that the quality has increased in Italy by introducing a redistribution scheme between distribution companies based on quality performance. The objective has been to increase quality by benchmarking because the quality was perceived as low. If this is based on aggregate measures of performance the regulated distribution/network companies will be induced to reduce interruptions for customers for which quality improvement is relatively cheap. In this way there is introduced an incentive to provide customers with different quality levels (supply security).

4. Gradually Improving the Way Security of Supply is Established and Reducing the Costs

We have argued that the discussion of public good properties is important for electricity security of supply. Additionally the possible welfare gains from changing the provision and the supply of security are strongly dependent on the level of willingness to pay and the differences among consumers. Based on this we here argue that there are several natural steps that can be taken moving towards solutions resulting in cost reductions and welfare gains. It is not necessary or optimal to take all steps to improve the situation and even the technical and economical implementation is not feasible for all steps yet.

Each step towards a more advanced response to security of supply preferences is strongly dependent on the above discussion of the public good characteristics. In this section we use the pure public good as point of departure for a possible increase of market functionality on allocating resources to security of supply and setting the level of security in a cost efficient way.

First Step: Cost minimization

Cost minimisation in securing a given level of security of supply is the main objective in this step. The first step can be implemented in the case where the public good argument still holds (Point A in Figure 1). In this case the level of security has to be set arbitrarily at a socially acceptable target, which is not derived from consumers individual marginal benefits at different levels of security of supply. Given the level of security of supply, the cost of supplying this has to be minimised. That is, we have to find the most cost efficient way to ensure the level of security of supply. This implies that marginal cost of supplying security for customers must be identical for possible suppliers of this service.

Using the definition of security of supply with respect to adequacy and security we find the following elements of the problem:

System adequacy:

- Costs of securing adequate power capacity
- Costs of securing adequate transmission capacity
- Costs of securing adequate distribution capacity

Security (probabilities for failures):

- Back-up short term – marginal cost of reducing probability
- Frequency etc. – marginal cost of reducing probability
- Transmission and distribution faults – marginal cost of reducing probability

All the system elements contributing to the probability of loss of load should have marginal costs for reducing the probability at similar levels. This can be achieved without creating new markets. A basic assumption behind the above arguments is that failures and interruptions are independent, what will not always be the case but is assumed to hold for the majority of interruptions.

In this step, there is an option of allowing the State or the supplier of security to supply different levels of security to individual customers based on difference in costs of supplying, and not under consideration of the consumers marginal benefits. This is relevant for networks and is already induced by the quality regulation included in many countries for regulation of electricity network monopolies. The reason for differentiating the level of security of supply is given by the network structure of the system and not the difference in consumer behaviour.

For adequacy consumer resources can be mobilised by increasing demand response to compete with generation and network capacity as sources of security. This will reduce both the costs of supplying a given level of supply security and will increase the average efficiency of electricity generation, which constitute the primary benefit of demand response. Increasing demand response involves overcoming both regulatory and technical barriers which is becoming cheaper and is included in the smart meters. But first and foremost final customers must be charged the price that signals a capacity constraint, at least the hourly prices signalling the generation capacity constraints. In the Nordic market the demand response options and problems have among others been covered in Andersen et. al. (2006) focusing on Denmark. Increased demand response in the short run reduces the costs of supplying a given level of security, but is not an action of the consumer expressing the marginal willingness to pay for security of supply, but only the marginal willingness to pay for electricity.

Second Step: Maximizing consumer benefits

Like the first step, the second step represents the case where the public good argument still holds. But in this step the level of security has to be set accordingly to the consumer marginal benefits estimated or expressed.

Adjusting the level of security of supply to average interruption costs for consumers (value of lost load) does not necessarily involve the construction of a market. The costs for consumers (households as well as business) have been estimated from several studies in a large number of countries. This can be used for setting a less arbitrarily target for security of supply. Estimates are in general not based on expressed willingness to pay as this will not be as accurate as what would be established, if a well functioning market could be constructed due to the free rider problem still being present when we have a public good. The aim of this step is to reduce the welfare losses related to an inefficient level of security of supply, i.e., a level that diverge from the average consumer marginal willingness to pay as was illustrated in Figure 4. We find that authorities setting the level of security at high and increasing levels in some countries should question whether we are actually supplying a security level that is too high. Too high a level imply a welfare loss that consumers are also burdened by through their too high network charges and even more likely too high public service obligation charges from system operators responsible for adequate capacity and reserves.

Third Step: Individual levels for security of supply

The welfare gain of moving to this step is found when there are large differences among consumers cost of lost load or their willingness to pay for security as illustrated in Figure 5,

In this third step we need to be able to distinguish between the individual consumers, i.e. relaxing the public good characteristics. In order for the individual consumer to express their own marginal willingness to pay, it must also be possible to exclude customers from security of supply, in order for them to have an incentive to reveal their true willingness to pay for this service. Hence, interruptible supply to customers and metering equipment is needed. This means that we are relaxing the assumption of non-excludability (Point C in Figure 1).

This step is different from a construction with compensation payments identical for different customers which is normally the model chosen in the European compensation payment schemes for long interruptions. Such a scheme is an option in a regulatory instrument belonging to the described second step where regulators provide network companies with incentives to adjust their marginal effort for security against the compensation payments for interruptions they have to provide. Associating individual customer's costs of lost load with customer specific compensation payments, or payments for specific levels of security of supply will be consistent with this third step.

If the objective is to reduce the possible welfare losses associated with differences in marginal benefits between different consumers as described in Figure 5, this step will require some kind of a market that involve consumers. The market need not necessarily be a separate market, but could be an integration of the security costs in ordinary power markets. This requires that individual consumers are charged, and chose their level of demand based on different prices.

Fourth Step: Adjusting to differences in costs with respect to timing and duration

Like the third step, this fourth step represents a case where the public good is relaxed. This step involves customers even more than in the third step, as this step targets the possibility of responding to different costs of interruptions depending on the duration and the timing of interruption. Such flexibility requires a more sophisticated market, were it is quite unrealistic that customers could monitor price movements so closely, but automatic equipment following general set price parameters could make individual demand respond to price signals. That is, a reaction to system disturbances at once they occur.

The supply side of security would adjust to such a market setting by adjusting their effort depending on the time of the day and the season and the duration of the interruption for each customer (customer group). If long interruptions imply high costs for some customers effort to re-establish their supply will be prioritised relative to other customers. If winter time interruption is critical for some individual consumers (consumer groups) the manpower and equipment to re-establish their consumption will be allocated to these customers in winter time and much less in summer time.

How much can be achieved without relaxing the characteristics of a public good?

Only the first and second steps are possible without relaxing the public good characteristics. If the real market from the third step with participation of consumers is to be established it must be possible to exclude customers from security of supply to give them an incentive to reveal their willingness to pay for this service. Hence, interruptible supply to customers and smart metering equipment is needed. Already today metering is mandatory for business in Denmark and interruptible contracts exist, but at bilateral and low level and much less used than in for example Norway. Experience has shown that the critical move is to actually have the customers charged by the hourly prices from wholesale markets.

5. Final comments and conclusions

Security of electricity supply has often been considered a public good. We find this property is changing from a pure public good towards being excludable for individual customers. This happens as excludability becomes technically feasible and with reasonable transaction costs by the spreading of smart meters. Also elements of congestible public goods become more relevant if we consider reducing adequacy requirements. Before constructing sophisticated separate markets there is however much to achieve from improving the functionality of existing power markets rather than just creating new isolated markets for security of supply. The more markets that are created the less volume in each market, the higher transaction costs and the more risk for exemption of market power. Therefore, improvements in the spot and regulating power markets should be emphasised if possible.

Supply interruptions are to a large extent caused by numerous events in the distribution grids and are rarely caused by non-adequate capacity at least in the power systems of Europe and especially the Nordic area. We find that there are basically no effort made to balance the costs that generation adequacy implies with the cost of reducing the lost electricity due to interruptions in the distribution grid. A first efficiency improvement might be to adjust the effort so that marginal cost for securing supply are at similar levels in generation capacity and in network maintenance and equipment quality. This step does not require customer interaction or market construction.

Demand response is one of the most obvious ways of improving how we establish adequate resources and this is also facilitated by metering combined with appropriate tariff schemes. With increased price response in the existing market, the load duration curve would flatten and the profitability of new power (or transmission) capacity would increase. This adequacy part of security of supply is thus influenced by the existing markets to a large extent, whereas, the problems caused by faults in transmission and distribution equipment is less directly influenced by the existing power markets.

Secondarily, a consumer defined level of security might improve welfare even if supply security will be reduced. We should in the electricity system consider that there is a balance between the cost we impose on consumers and the willingness to pay that characterize consumers. More effort should be used to determine willingness to pay for security or value of lost loads for different customer categories and at different timing of interruption. A more dynamic security effort, for example by operating dynamic reserve requirements would reduce costs at times where consumers have low willingness to pay.

Finally, different willingness to pay among customers and construction of simple or more advanced markets might increase welfare further. However, we would question if it is possible to create well functioning new markets for security of supply, and is it really better than improving the functioning of existing markets. Technological developments will make it possible to create markets in the future, but it is probably advisable to increase effectiveness of existing markets as at least part of the possible welfare losses can be reduced by including different forms of demand response in existing markets.

Acknowledgement

This paper is based on the work carried out in the Danish research project "Integrating supply security into the market" We greatly acknowledge the support of EFP-2006 and the discussions with participants in this project. Furthermore the paper benefitted from comments from colleagues. The two authors are the sole responsible for the conclusions drawn in this paper.

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