## English translation of the report:

# Strommarktdesign

### Preisbildungsmechanismus im Auktionsverfahren für Stromstundenkontrakte an der EEX

**Prof. Dr. Axel Ockenfels***
**Dr. Veronika Grimm**
**Dipl.-Vw. Gregor Zoettl**

**11 March 2008**

*Note: The present translation is a service provided by EEX in order to make the report accessible to a broader audience. Only the German text written by the authors is authentic, however.*

*Axel Ockenfels is professor of economics and director of the laboratory for economic research at University of Cologne (http_ockenfels.uni-koeln.de/ao). Dr. Veronika Grimm and Dipl.-Vw. Gregor Zoettl are researchers at University of Cologne.

# Electricity Market Design

## The Pricing Mechanism of the Day Ahead Electricity Spot Market Auction on the EEX

**Prof. Dr. Axel Ockenfels***
**Dr. Veronika Grimm**
**Dipl.-Vw. Gregor Zoettl**

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*Axel Ockenfels is professor of economics and director of the laboratory for economic research at University of Cologne (http_ockenfels.uni-koeln.de/ao). Dr. Veronika Grimm and Dipl.-Vw. Gregor Zoettl are researchers at University of Cologne.

## *Preamble by EEX AG*

In the summer of 2007, the Saxon exchange supervisory authority asked EEX to examine whether there are possibilities for improving the existing pricing mechanism of the day ahead electricity spot market auction on the EEX in order to enhance competitive pricing and to furthermore evaluate which alternative pricing mechanisms might be suited in order to meet this scope. According to article 24 of the German stock exchange act, exchange prices have to be established properly and they have to be in line with the real market situation in trading. Not least against the backdrop of the public debate regarding the quality of the prices established on EEX, the pricing mechanism has to be checked for possibilities for optimisation. Upon this request, the management board of EEX decided to have an external expertise prepared and carried out a restricted invitation to tender on the subject of “pricing mechanism of the day ahead electricity spot market auction on the EEX” in concert with the exchange supervisory authority. Prof. Dr. Ockenfels was awarded the contract.

This expertise serves the purpose of fulfilling the request for this investigation by the exchange supervisory authority and will be submitted to it. Furthermore, it will be presented and discussed on the exchange council. In addition to this, this expertise is intended to make a contribution to the further development of the market design in electricity trading and will be made accessible to the public by EEX.

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## 1 Introduction

In view of increasing electricity prices, pricing at the power exchange is in the spotlight. The reasons for high producer prices can be *fundamental factors* (high production costs, capacity shortages, high demand, environmental policy interventions, etc.), an unsatisfactory *market structure* with oligopolistic price mark-ups and, finally, the *market rules,* if these do not support pricing and competition optimally. In this expertise, we will examine the influence of the market rules. In this context, we will pay special attention to the pricing mechanism in the auction procedure for hourly contracts on the EEX day ahead spot market ("spot market auction"). Our examination is based on various assumptions regarding competition and cost structures, the measurement or evaluation of which did not constitute the subject of this expertise, however. As a supplement to this, we will compare the market design of EEX with market platforms from other European countries and with alternative concepts of market organisation and macrostructure of markets.

Because of possibilities for arbitrage the clearing price at the power exchange is of central importance for the prices on all other electricity markets, e.g. on derivatives markets, in OTC trading and in sales agreements with final customers. If, for example, buyers and sellers in electricity trading have the option of trading at the power exchange, the traders on both sides of the market must, at least, not be worse off in their expectations in bilateral agreements concluded off the exchange than in corresponding transactions at the power exchange. Neither a buyer nor a seller of electricity will accept a price off the power exchange if he or she is convinced that a better deal could be concluded on the exchange. As a result of this, the exchange price inevitably constitutes the point of reference even for trading off the exchange[1] from an economic perspective, so that problems in the market rules on pricing for the exchange can multiply in pricing on other markets.

Because of the lack of storability of electricity, power exchanges require comparatively complex rules and regulations and a careful consideration of numerous ancillary technical conditions in the generation and transmission of electricity. The central result of this expertise is that the spot market auction generally

[1] The price which is paid for power on a derivatives market or under long-term bilateral agreements can, of course, still deviate from the exchange price achieved at the time of the delivery – however, it cannot deviate systematically: Wrong expectations in the one or the other direction will be neutralised in as far as arbitrage transactions are possible. Deviations are only conceivable if e.g. sellers display behaviour that is systematically more risk-averse than that of buyers.

complies with these demanding requirements. According to the state of art in economics, the electricity price cannot be reduced systematically and sustainably by means of changes in the design of the spot market auction. At the same time, the spot market auction is embedded in a highly dynamic market architecture which is subject to constant change in the framework of European harmonisation and co-ordination efforts. We will comment on these changes and issue recommendations with regard to this.

Our evaluation is based on findings from economic research into market microstructures using primarily game theory methods. Throughout the expertise, we implicitly or explicitly assume that the players on the market do not respond to incentives irrationally and that “market equilibria“ have a special appeal. An equilibrium is a stable situation in as far as there is no incentive for any player on the market to change its behaviour or plans in equilibrium. This means that if a system is not in equilibrium, there is at least one player with such an incentive. Unexpected shocks - e.g. on account of energy-policy measures, changes in fuel prices or in the development of productivity – can lead to a situation in which volatile systems such as the electricity market become unbalanced. However, we can typically expect that deviations from the equilibrium are not systematic and that expectations are not systematically distorted. It is also for this reason that the incentive theory and equilibrium analysis as applied in this expertise constitute the basis of all modern economic analyses.

In chapter 2 we will provide an introductory overview of the environment in which the power exchange operates on EEX (market macrostructure) and of how the auction rules are designed (market microstructure). Chapter 3 presents the two fundamental forms of organisation for electricity markets (exchange and pool model) and discusses their advantages and disadvantages. Chapter 4 covers essential design aspects of the spot market auction. This e.g. includes an evaluation of the auction and bid formats as well as a discussion of the connection with interdependent markets. In chapter 5 we will introduce the rules and regulations of the spot market auctions in other European electricity markets and compare these with the spot market auction on the EEX. Chapter 6 contains a summary. As a supplement to this, we will provide an overview of the fundamental economic principles and rules of pricing in electricity wholesale markets in as far as such are relevant with regard to questions of market design.

## 2 Electricity Trading on the EEX

The liberalisation process for the German electricity market began with the enactment of the Law on the Fuel and Electricity Industries in the version of 24 April 1998, which transposed the EU Energy Directive 96/92/EC into national law. Said act opened the supply with electricity for competition. The free selection of the electricity supplier by the final consumer and the rules regarding access to the transmission system constitute central elements of the law.[2]

During the initial stage of liberalisation both long-term and short-term electricity trading was exclusively effected bilaterally (so-called “over-the-counter” or “OTC” transactions). Very soon, however, power exchanges also evolved as central electricity trading platforms. In the year 2001, the German power exchanges of LPX (Leipzig) and EEX (Frankfurt) merged to establish the new Leipzig-based EEX AG.

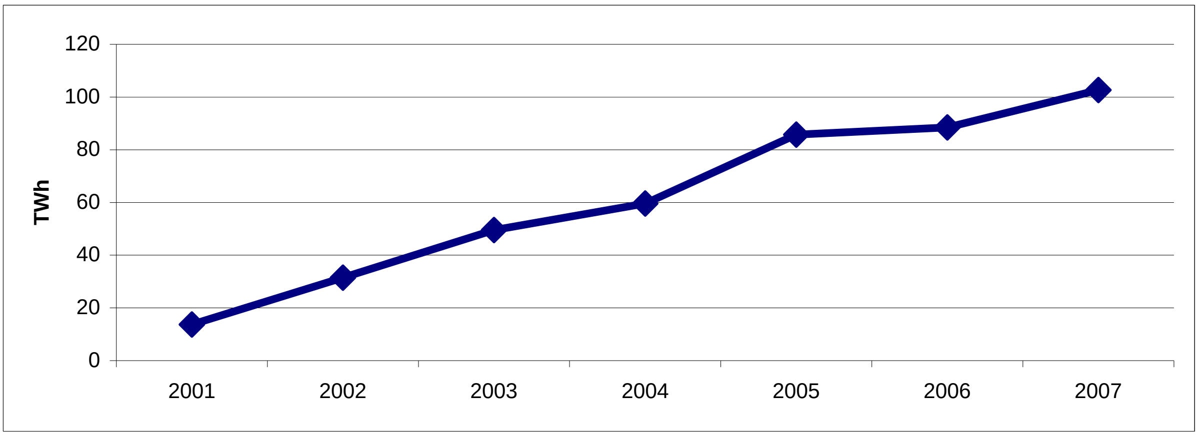


**Figure 2.1: Development of the DA trading volumes on EEX (source: EEX).[3]**

Currently, more than 100 TWh and approx. 15 percent of the electricity consumed within the market area of EEX are traded in the day-ahead auction for hourly electricity contracts of EEX, which is held on a daily basis, with a strong trend towards growth (figure 2.1 and 2.2) – also compared with other exchanges. The rest of the trading activities are still mainly carried out in bilateral, usually longer-term OTC transactions. In recent years the trading area of EEX has been expanded continuously. Whereas electricity could only be traded in Germany at the beginning,

[2] The law was revised regarding access to transmission systems in the year 2005; this revision went into effect on 1 June 2007.
[3] The figures for 2007 are extrapolated for an entire year.

the control area of APG (Austrian Power Grid) in Austria was integrated into the market area later on.

In December 2006, trading in electricity for the separate market area of Switzerland was launched on EEX. Separate bids, which are taken into account independently of each other but in accordance with the same auction rules, have to be submitted for the market areas of Germany/Austria and Switzerland. We will concentrate on the description of the electricity market within Germany herein below.

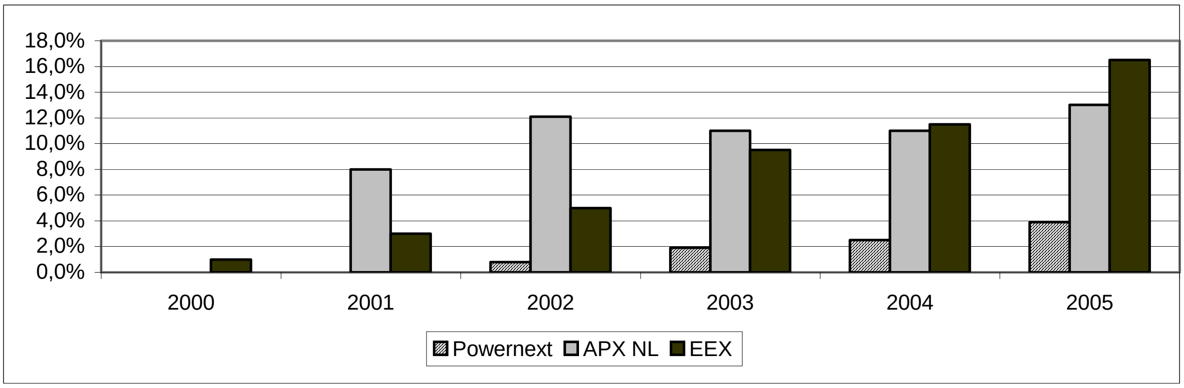


**Figure 2.2: Comparison of DA trading volumes (source: DG Competition 2007)**

EEX offers a system of interlinked, interdependent markets on which electricity can be traded with various time horizons. The day-ahead auction during which hourly electricity contracts and block contracts for the respective next day can be traded at 12:00 am of every weekday is at the centre of these markets. Contracts for Sunday and Monday are assigned in the auction on Friday.[4] In the auction, bid functions both for every individual hour and block bids comprising several contiguous hours can be submitted. With regard to block bids there is a number of standardized blocks (Base (0:00am to 12:00pm), Peak (8:00am to 8:00pm), Off-Peak 1 (0:00am to 8:00am), Off-Peak 2 (8:00pm to 12:00pm), EEXNight (0:00am to 6:00am), EEXMorning (6:00am to 10:00am), EEXHighNoon (10am to 2:00pm), EEXAfternoon (2:00pm to 6:00pm) and EEXEvening (6:00pm to 12:00pm). However, trading participants also have the

[4] In the future, central auctions are also to be held on the days of the weekend.

possibility of defining blocks for random contiguous hours.[5] The maximum admissible bid price is EUR 3,000 per MWh for all contracts.

All bids are aggregated into supply and demand functions in accordance with art. 24 of the trading conditions as outlined herein after. As a first step, all bids for all individual hours and for all blocks are converted into linearly interpolated sell or buy curves. In this context, the price bid for the individual hours is taken into account, while block bids are assumed to be unlimited initially. The market price of this first step is established on the basis of the intersection of the resulting supply and demand functions.

As a second step, the block bid which would incur the highest losses at the hourly prices of the first step – i.e. the block bid which displays the biggest gap to the market prices established in the first step - is then excluded (irreversibly). In cases where two bids have exactly the same gap, the bid with the lower volume is excluded. In accordance with this principle, individual blocks are excluded in further iterations until all blocks which have not been excluded yet can at least realise their total demand.

As a result, the algorithm described above usually generates a market clearing price for every hour of the following day. Every provider which supplies electricity during a given hour receives the respective price for that hour, buying electricity during that hour pays that same price. Since all trading participants trade at the same price this mechanism is also referred to as the “uniform price auction”. Side payments are not made: According to the algorithm, block bids are only executed if the price asked is lower than the total of the hourly prices (on the supply side) or if the willingness to pay is higher than the total of the prices offered (on the demand side). As we will see, block bids, which might be utilised at the hourly prices shown, might, hence, be rejected.

Moreover, a situation might arise in which a market clearing price cannot be established. This can e.g. be due to the reason that the demand exceeds the supply at the maximum permissible price or that block bids prevent market clearing. In case supply and demand cannot be matched, the Trading Conditions permit the EEX management to have a second submission of bids by the trading participants. In the event that a market clearing price cannot be established during this second auction either, the management board is entitled to delete all block bids which prevent market clearing. A proportionate assignment in which the insufficient supply is distributed to

[5] See art. 21 of the Conditions for Trading on EEX, which are available at http://eex.com/de/document/13393.

the demand proportionately or in which the insufficient demand is distributed to the supply proportionately can constitute the last resort in order to enforce market clearing (see art. 24 (5) and (6) of the Trading Conditions for further details).

In case the transmission capacity is not sufficient for the execution of the schedules established in the spot market auction, the markets can be divided into different price zones (art. 24(4)). However, this case has never occurred so far since the transmission system capacities within the trading area of EEX are sufficiently high, and most importantly the quantities traded on the EEX constitute only a small portion of the total daily load. Usually, EEX does not have any knowledge of contracts which have already been concluded before the start of trading on the exchange and, hence, these cannot be taken into account. Transmission system bottlenecks arising from all the schedule reports by the participants in the market (i.e. from the total of all quantities traded on the exchange and of all OTC quantities traded prior to or in parallel with exchange trading) are resolved by means of a re-dispatch on the part of the transmission system operators.

Before the central auction, the electricity providers have the possibility of trading blocks in continuous trading between 8:00am and 12:00am. In this process, three types of blocks can be traded: Peak (8:00am to 8:00pm), Off-Peak (8:00pm to 8:00am) and Base (00:00am to 12:00pm). Moreover, the possibility of trading for the next day on a bilateral basis through the platform of EEX even after the central auction from 3:00pm (which means after the generation of the first preliminary schedule) and up to 75 minutes before the physical delivery of the electricity was established on 25 September 2006. This trading phase is referred to as “intraday trading” and permits electricity trading “around the clock” until shortly before physical delivery. Furthermore, futures on the day-ahead price of the daily auction, gas (day-ahead and futures), CO2 emission allowances and further products are traded on EEX.

## 3 Macrostructure of Liberalised Markets

In recent years, all European countries have moved from regulated regional monopolies to liberalised electricity markets. In this context, the fact that bilateral trading alone cannot fulfil the requirements of the electricity market has become obvious. One reason for this is that the supply of electricity and the demand for electricity always have to be balanced even in case of high volatility so that speed constitutes an essential factor for efficiency and clearing of an electricity spot market.

Ultimately, only centralised, multi-lateral market organisations can provide the required transparency on prices and shortages at the speed which is required for an efficient allocation and co-ordination of generation, transmission and balancing electricity. Nonetheless, bilateral electricity trading is of major importance (see chapter 4.1) – especially on the derivatives markets where speed is of minor relevance at best. For this reason, both centralised, multilateral and decentralised, bilateral trading platforms typically co-exist on electricity markets (Stoft, 2002).

Two models for the organisation of the central trading platforms have emerged: the exchange model and the pool model. There is no uniform, definitive definition of these two market models. In practice, many markets display elements of both market models. In this chapter we will discuss the fundamental properties as well as the advantages and disadvantages of pool and exchange markets.

### *3.1 Exchange model*

By now, all liberalised electricity markets in Europe have largely been organised in accordance with the exchange model, while many countries outside Europe have opted for the pool model. Exchange models are characterised by a decentralised organisation of the market and decentralised decisions. Electricity trading usually takes place in a sequence of closely connected but separate markets and other allocation mechanisms for generation, transmission and balancing electricity. Electricity supplying companies dispatch their power plants independently and co-ordinate with the transmission system operator. In almost all countries a central auction in which the trading participants can largely trade hourly contracts on electricity for the following day is held one day before physical delivery.[6] Participation in the exchange is not mandatory, so that trading which "bypasses" the exchange is also possible. The description of electricity trading rules of the EEX contained in chapter 2 provides an example of what an exchange model can look like in practice.

The decentralised form of organisation under the exchange model ensures that market prices can drive decisions and that generating companies can optimise the use of power plants independently in all stages. Compared with the pool model, one further advantage is that market platforms can compete with each other. This quickly leads to adjustment pressure in case of a defective, inefficient or costly market design of the power exchange. On the other hand, the decentralised organisation can

[6] The rules for the market in Great Britain deviate considerably from the rules in other European countries, see section 5.4.

lead to problems in co-ordination and to inefficiencies in cases where the different markets are only synchronised to an insufficient degree and where the participants in the markets have wrong expectations regarding prices and shortages in linked markets.

For this reason, the co-ordination of the markets for generation, transmission and balancing energy constitutes a central challenge for exchange models. Since generation and transmission are complements from the supplier's perspective and since the generation for the spot market and for the market for balancing energy are substitutes, the decision regarding how much electricity is offered in the spot market auction and at which price e.g. depends on the prices and bottlenecks in transmission and in balancing energy. Errors in the evaluation of the availability of transmission capacities or of balancing energy prices lead to inefficient dispatch of the generating plants, increased electricity costs and, at worst, to a reduced reliability of the electricity supply.

After the liberalisation, transmission bottlenecks were not taken into account or only considered marginally in pricing at the spot market for the case of power exchanges. In practice, the neglect of potential transmission problems within the individual market areas has only constituted a minor problem so far. One reason for this is that, historically, most trading platforms and exchanges were only designed for national borders and that sufficient transmission capacity was usually available within these borders. On the other hand, transmission system bottlenecks which might arise can be ignored initially and overcome by means of a re-dispatch by the transmission system operator. The costs of such a re-dispatch are financed by grid usage charges. However, it is not unlikely that transmission system bottlenecks will play a more important role for the efficiency of the electricity supply in the future in view of increasing cross-border trades and the further increase in feeding-in of wind energy.

Exchange models can respond flexibly to such challenges. In Europe, interconnector capacity is usually acquired in special so-called "explicit auctions", which are independent of the actual electricity trading. On some exchanges (for example on NordPool; see chapter 5.1) bottlenecks are also taken into account "implicitly" in the framework of the so-called "market splitting" directly in pricing mechanism at the spot market auction. "Market coupling", in which the allocation of international transmission capacities is closely interlinked with the design of power exchanges, constitutes a third option within the power exchanges. This option will be explained in more detail in chapter 4.5.

### *3.2 Pool model*

The pool model which many countries outside Europe have decided to adopt is the alternative to the exchange model. The “prototype” of the pool model was implemented in the US regions of Pennsylvania, New Jersey and Maryland (abbreviated PJM). The PJM market design has been copied at least in part by many countries, including Canada, Australia, New Zealand and Russia.

Pool models have a centralised organisation. The entire electricity trading has to be transacted via the pool and long-term contracts are usually traded as purely financial products. In most cases, only the supply side bids actively into the pool, while the demand is estimated and bid into the pool in an aggregated manner. After that, all operational decisions regarding generation, transmission and balancing energy are optimised by computer algorithms both comprehensively and simultaneously.

The fact that electricity trading has to be effected via the pool necessitates bid formats which can reflect the cost structures of the electricity generators in detail (chapter 4.2). In most cases, this is implemented by means of bids comprising several parts. Such bids comprise an asking price for starting-up of the power plant, the generation of electricity as such as well as shutting down.

Mandatory trading under the pool model facilitates the co-ordination of generation and transmission. The use of the power plants and the use of the grid, in particular, are optimised at the same time by the so-called “locational marginal pricing” or “nodal pricing”. In this process, electricity prices are established for every feed-in and withdrawal point in such a way that these prices reflect the existing transmission bottlenecks and generation cost structures in the overall system in an economically accurate manner.[7] The simultaneous optimisation of the overall system implies that the dispatch of power plants is also organised centrally and in the framework of the daily and mandatory spot market. In this context, it is necessary to give additional payments (so-called “side payments”) to some providers in the event that their power plants are dispatched but the nodal prices associated to each power plant are not sufficient to satisfy all production cost including start up and shut down (chapter 4.2).

[7] In this context, we have to assume that all bids are submitted “truthfully“. The important issue of strategic behaviour in the pool model will be addressed later.

The markets for balancing energy are also integrated into the pool: The bids for the day ahead spot market are used to cover the demand for the following day as well as the demand for so-called "system services" (in Germany: balancing energy) at the same time. This means the pool model combines all those markets which are usually asynchronous in exchange-based markets into one single market. Provided the bids accurately reflect the cost structures, in principle at least, this model permits an efficient use of all resources.

### *3.3 Evaluation*

Electricity trading with a centralised organisation under the pool model largely emulates the originally vertically integrated and strictly regulated market architectures of the pre-liberalisation era and permits an excellent co-ordination of the various sub-sections of the electricity market. The fact that comprehensive simultaneous optimisation of generation, transmission and balancing energy was allegedly urgently required in order to take the numerous interdependencies and technical restrictions within the electricity market into account was frequently cited as an argument supporting pool models. This was said to be the only way in which electricity supply at minimum costs could be ensured.

However, pool models are also struggling with problems. One of these is the focus of the optimisation algorithms on *short-term* cost minimisation, which leads to a situation in which investment incentives can be distorted. Since pool models guarantee the settlement of dispatch-relevant costs, such as e.g. start-up costs, by means of side payments at all times, such cost components are not internalised sufficiently in investment decisions (Stoft, 2002).

Moreover, the demand side has few incentives and possibilities to make a contribution in pool models or to respond to prices which can lead to significant impairments of efficiency (Ockenfels, 2007a). Finally, mandatory trading at an electricity pool suppresses the competition among different market platforms. This, in turn, implies that in the case of a defective or deficient design of the procedures and rules at the pool, the market participants do not have alternatives, while there is no high adjustment pressure for the market platform.

Moreover, the fact that the optimisation algorithms used in the pool model do not generate the necessary incentives for the disclosure of the actual cost parameters is important. The optimisation procedure resembles those procedures which were used before the liberalisation of the markets. However, after liberalisation, the difference is that all relevant parameters are provided by profit-maximising providers which have private information on their costs at their disposal respectively and can use this information advantage strategically. The optimisation algorithms, on the other hand, operate on the basis of the assumption that all relevant parameters are submitted truthfully.

The problem of distorting incentive effects in case of asymmetric information in electricity trading cannot be resolved satisfactorily by means of the selection of a suitable algorithm simply on account of the high degree of complexity of the optimisation problem (Wilson, 2001, Stoft, 2002).[8] For this reason, the Standard Market Design (SMD), which was recently developed by the US Federal Energy Regulatory Commission (FERC), comprises a number of interventions in order to restrict strategic behaviour and exercising of market power, such as price caps (currently USD 1,000/ MWh) or close monitoring of the bidding behaviour of major market participants and disciplinary action against these in case of "obvious" exploitation of market power.

Finally, even the most comprehensive optimisation algorithms are inherently incomplete simply on account of soft- and hardware restrictions and, typically, they cannot take all relevant parameters into account or respond dynamically to forecast errors (Wilson, 2001). This means that, ultimately, the hypothesis that the algorithms for the simultaneous optimisation of the overall network can generate a reliable cost minimisation is a fiction. Pool models are based on the pre-condition of close monitoring of the market, its institutions and of the market participants. This not only implies high costs (of monitoring and market supervision) but also that the regulator (with poorer information) has to take decisions which the market takes in a system with a decentralised organisation. This is also a reason why there appears to be an overall trend towards more market architectures with a decentralised organisation (Wilson, 2001).

The advocates of exchange models emphasise that decentralised markets can also provide the right incentives for cost-minimal dispatch. One important precondition for this is that individual market participants succeed in making accurate predictions regarding the results of the allocation procedures in the different interlinked markets.

[8] The winners of the 2007 Nobel Prize in economics were awarded the prize for their works describing the fundamental difficulties in centralised systems for the allocation of scarce resources with asymmetric information. Theoretically, the problem can ultimately be resolved with so-called Vickrey-Clark-Groves mechanisms which, however, also comprise a number of other problems, which we will partly outline in chapter 4.4, in addition to their complexity.

This is a high requirement; however, if we consider that the markets are cleared every day, it does not appear implausible that expectations adjust in such a way that, ultimately, they are generally fulfilled. In addition to this, interdependent markets can also be closely co-ordinated and synchronised in the decisive points under the exchange model so that co-ordination problems are minimised (chapter 4.5). Other advantages of the exchange system are that, compared with the pool model, it is easier to achieve an active participation of the demand side in electricity trading and that the market participants can usually avoid institutions which do not work well and that, hence, errors in the design of the market cause less damage and can be identified and remedied faster.

Summarising, we can note that pool models are advantageous if competition is strong or regulation is effective, if the demand cannot play a big role in pricing and if the deficits in the centralised system optimisation which necessarily arise in practice are minimised. Exchange models with a decentralised organisation entail advantages if the co-ordination of interdependent markets is comparatively unimportant (for example because transmission bottlenecks are rare) or if a close co-ordination is already achieved by means of a suitable market architecture (for example by implicit mechanisms and market coupling).[9]

For Europe, there is no reason to pursue a change of the system towards pool models in the member states unless an efficient co-ordination of the individual electricity and transmission capacity markets is increasingly achieved in the European exchange-based systems. Decisive steps in this direction are currently being taken in all European markets. Exchange-oriented models can use market incentives by coupling national markets without having to relinquish the co-ordination of central decisions. (A change of the system for Germany alone is out of the question since the markets in the neighbouring countries have all implemented exchange models without any exceptions and since international convergence and harmonisation would be difficult to impossible in the case of diverging market macrostructures.)

[9] The scientific literature does not provide a general recommendation for the one or the other model; see Bower and Bunn (2000), Bower and Bunn (2001), Newberry (2003, 2004), Fabra and Toro (2003) and Hogan (1995).

# 4 Design of the electricity spot market auction

On the European energy market, a large part of the energy is traded in long-term contracts, while only a comparatively small part is traded day-ahead in the spot market auctions. Nonetheless, it is sensible to concentrate the economic analysis on pricing on the spot market. This is due to the fact that the prices in all upstream electricity markets reflect the expected spot market prices and since the spot prices, hence, determine the costs of electricity even in the long run (see chapter 1 and Appendix).

In chapter 4.1 we will deal with the rules of the day ahead electricity spot market auction. We will analyse the uniform price mechanism employed by EEX and discus alternative mechanisms in the framework of auction models. Initially, we will generalise from complexities which can occur on account of complementary cost elements. These will then constitute the focus of chapter 4.2, in which various possibilities of designing bid formats will be discussed. The role of price and bid limits at the power exchange and its impacts on electricity trading will be discussed in chapter 4.3. In chapter 4.4 we will consider proposals regarding the so-called “obligations to offer” and explain why this is not compatible with liberalised electricity trading in the exchange system. The linkage of the markets for electricity, balancing energy and transmission capacities which operate independently in the exchange system will be covered in chapter 4.5. In chapter 4.6 we will concisely describe the challenges for electricity markets to provide efficient investment incentives too. In conclusion, we will deal with some aspects of transparency in the spot market auctions from the perspective of market design in chapter 4.7.

## *4.1 Pricing rules*

Most electricity spot auctions operate in the form of a sealed bid auction.[10] In sealed bid auctions there is only one round of bidding; this means that the participants in the auction do not get any feedback on other bidders’ bidding behaviour in the auction to which they could respond. In open bid auctions, however, bidding is effected over various rounds. Open bid auctions entail the advantage that they can facilitate the bidding strategies of the participants in the auction (in particular in case of a complex evaluation of the commodities to be auctioned) and pricing by means of the disclosure of preliminary price information. Disadvantages of open bid auctions are,

[10] In various countries, there is also continuous exchange trading before and after the day-ahead auction, e.g. also on EEX. However, we will concentrate on the central auction for hourly contracts here.

on the one hand, the increased risk of collusion on account of the possibility of dynamic-reciprocal punishment and reward and of implicit co-ordinating collusion over individual rounds (Klemperer 2004). On the other hand, open bid auctions require synchronous bidding; all bidders have to co-ordinate at a given point in time over a certain period of time, which increases the transactions costs. Since spot market auctions are held regularly, however, and are typically embedded in continuous trading in addition, the flow of information *within* an auction is of only small significance for the reduction of complexity and pricing. At the same time, the disadvantage of a potentially increased risk of collusion as well as of increased transaction costs in auctions which are repeated daily tends to be reinforced (Rothkopf, 1999).

In sealed bid electricity auctions, bidders submit a bid curve, that is, they specify which quantity they are ready to offer at which prices for every hour of the following day. On the basis of the individual bid functions an aggregated bid function is calculated for every hour by sorting the bids according to the height of the price. The quantity traded is then established on the basis of the intersection of the supply aggregated in this way with the aggregated demand for the corresponding hour. The rules for pricing can vary depending on the auction format.

The predominant majority of the electricity spot markets, including the EEX spot market auction, is organised as a uniform price auction in which all units traded are bought or sold at the (uniform) market clearing price, which is established on the basis of the intersection of supply and demand. Great Britain forms an exception since it opted for a pay-as-bid auction. Moreover, the Vickrey auction is also discussed occasionally. The advantages and disadvantages of all three formats will be discussed below.

#### 4.1.1 Uniform price auction

The uniform price auction is the prevailing pricing rule for electricity spot market auctions. Its advantages include the comparatively transparent and simple pricing for bidders and demanders, which, moreover, does not require time-synchronous bidding and, hence, keeps transactions costs for bidders and demanders low. Furthermore, all market participants pay/ receive the same price for an identical product; for this reason, no market participant can be accused of having “paid too much” or “received too little” compared with other traders. Finally, the uniform price auction leads to full productive efficiency in competitive markets which cannot be expected for the pay-as-bid auction on account of its increased strategic complexity (chapter 4.1.3).

If, however, the electricity market is not sufficiently competitive, uniform price auctions can open up scope for withholding capacities with the aim of higher prices. This is due to the reason that the price asked for the second or any further unit of electricity can influence the price for the “previous” (inframarginal) units (Ausubel and Cramton, 2002).[11] Exercising of market power by means of withholding capacities can increase the costs of electricity and impair productive efficiency.[12]

There are two forms of capacity withholding – economic and physical withholding. In the case of physical withholding, the suppliers ask prices which are above the marginal costs.[13] In the case of physical capacity withholding, available power plants are not offered into the market right from the outset. Both forms of withholding can lead to a situation in which power plants are not used even though the respective marginal costs are below the market price.

In the case of inelastic demand, economic withholding does not necessarily imply that the dispatch is inefficient. If the suppliers do not differ in their size and cost structure, they will ask uniform marginal cost mark-ups, ensuring that the sequence of the use of the power plants is determined on the basis of the height of the marginal costs. In the more realistic case of different sizes and cost structures, oligopolistic

[11] Theoretically, withholding of quantities is a potential problem on all markets with non-atomistic competition: The economic standard model of non-atomistic competition (the so-called “Cournot model”) forecasts withholding of quantities for every number of competitors unless there is an *infinite* number of competitors. A number of studies also demonstrates that reductions of quantities can occur with regard to the uniform price auction. For example, a reduction of the demand and/ or of the supply was observed in electronic spectrum auctions in Germany (Grimm et al., 2003), in Austria (Klemperer, 2004) and in the USA (Cramton, 1995) as well as on the English (Wolfram, 1998) and on the Californian power market (Borenstein et al., 2002). Moreover, experimental evidence in the laboratory (Kagel and Levin, 2001, Engelmann and Grimm, 2004) and in the field (List and Lucking-Reiley, 2000) also discloses these mechanisms.

[12] Under certain circumstances collusive bidding strategies can also be exercised in auctions. For example, we can assume that the bidders (implicitly or explicitly) agree on a division of the demand which is assumed to be inelastic and generally known at a high price and that every bidder asks a small price for smaller quantities than the quantity agreed on in uniform price auctions. If a bidder then abandons this agreement and extends the quantity offered, said bidder and all others would then receive the low price. This stabilises collusion. However, in practice a co-ordination with regard to such collusive strategies is difficult or impossible to establish in a highly volatile and asymmetric environment like the power market. Supply and demand are uncertain, generators differ in their power plants and cost structures, while dealers differ in their trading aims and transactions on the derivatives markets and other arbitrage transactions in the interdependent markets frequently undermine collusion incentives.

[13] See Appendix regarding the definition of marginal costs and the existence of marginal costs in power generation.

competition will, however, lead to different marginal cost mark-ups and, hence, to an inefficient dispatch.

Physical withholding, however, necessarily leads to an inefficient use of power plants, which is illustrated by the following example taken from Ockenfels (2007a).

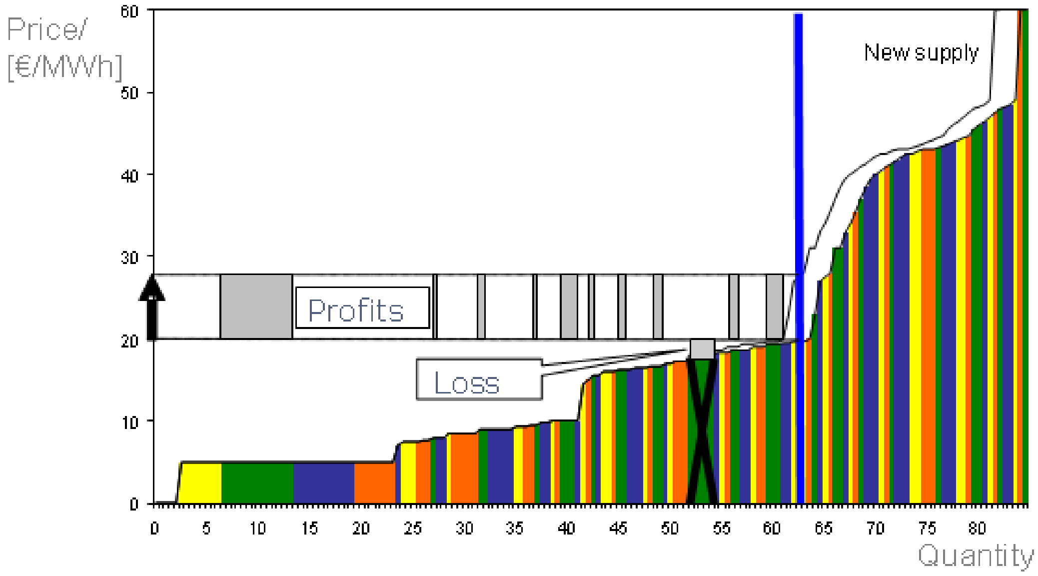


**Figure 4.1: Example of additional losses and additional profits in the case of withholding**

Figure 4.1 shows a stylisation of the marginal cost structure of the electricity generation of a “typical” market with relatively steep marginal costs close to the capacity limit (see Appendix). Every bar represents one power plant. The width of a bar indicates the capacity of the corresponding power plant, while the height indicates the marginal costs. Bars of the same colour are owned by the same supplier. Figure 4.1 does not display any specific market and the colours do not indicate any specific suppliers.

In the example, the market clearing price without capacity withholding (all power plants are offered into the market with their marginal costs) amounts to EUR 20 per MWh and it is obviously consistent with marginal cost pricing: EUR 20 per MWh are the (additional) costs of one further unit. At this price, the green supplier with the power plant marked with a black cross can also produce electricity profitably since the additional costs of electricity production for this power plant are lower than EUR 20 per MWh. If, however, the supplier withholds the electricity production from this power plant, the aggregated bid curve to the right of the power plant shifts left as illustrated in the chart. Because the green supplier takes the profitable power plant from the market, said party initially incurs a loss. At the same time, however, the price for the “inframarginal” power plants, i.e. those power plants which remain in the market and produce electricity, increases. Since the green supplier has a large number of other power plants on the market, withholding is profitable in the example – the additional profits exceed the loss caused by withholding. As a result, the demanders pay prices which are above the minimum marginal costs of production. Moreover, electricity is produced inefficiently since the power plant withheld could have produced electricity more cheaply than e.g. the price-fixing power plant.[14]

Withholding of quantities occurs on all markets (not only on electricity markets) which are not perfectly competitive. This means that perfect competition in which all suppliers always offer at their marginal costs is an unattainable fiction; in every real electricity market with less than an infinite number of suppliers there are occasionally incentives for exercising market power and for withholding capacities (see e.g. Cramton, 2004, Müsgens and Ockenfels, 2006, Ockenfels, 2007a, b). These incentives vary systematically with factors which are documented well in the literature on auctions.

In non-perfect competition, every supplier faces a fundamental inconsistency of goals between quantity and price: A higher price has to be "bought" with a smaller quantity. The extent of the inconsistency of aims depends on the reactions of the other market participants who discipline the pricing scope to an essential degree. In the case of capacity withholding, competitors can "close the gap" and fulfil the demand so that, perhaps, the price hardly changes. This is the case, in particular, if the capacity is not used to a high degree and if the supply elasticity is relatively high because of this (the supply is relatively level). At increasing electricity prices, the demand tends to demand less and, hence, also has a moderating effect on the price pressure.

The incentive to offer above the marginal costs declines with the size of the market and increases with the size of the supplier, in particular, with the inframarginal quantity on the market since the additional profit is proportionate to the inframarginal quantity if capacities are withheld. Vice versa, the rule applies that the incentive for capacity withholding becomes smaller with a small inframarginal quantity. A supplier which e.g. only offers one power plant into the market does not have any incentive to withhold capacity.

[14] Typically, the market-clearing quantity which is too low on account of the price mark-ups constitutes the more difficult source for the inefficiency of exercising market power. However, this is not too much of a problem on power markets in the short term if the demand is relatively inelastic and since, hence, quantity responses to price changes hardly have to be expected. However, the demand responds more elastically to price changes in the long run, so that marginal cost mark-ups can also lead to inefficient quantities in this case.

The “size” of the supplier which is relevant for these considerations is based on the electricity generation *which is not hedged in derivatives transactions*. This is due to the fact that a change of the price on the power exchange cannot increase the profit for electricity which has already been sold on derivatives markets. A supplier which has hedged 99.9 percent or more of its generation in derivatives transactions does not have any incentive to withhold capacity. In this case, asking prices to the amount of the marginal costs ensure that the derivatives transactions are executed in a profit-maximising manner (if the respective marginal costs are higher than the electricity price, the derivatives transactions are covered from the purchase of electricity on the exchange). Likewise, the rule applies that a supplier which has hedged a share of 90 percent of its capacity by means of derivatives transactions offers into exchange trading as if he only owned the remaining 10 percent of the capacity.[15]

Derivatives transactions not only reduce the incentives for withholding capacities on the spot markets, they also create incentives to commit to comparatively high generation quantities on the derivatives markets already – similar to what is proposed in the standard oligopoly theory under the so-called Stackelberg model (Allaz and Vila, 1993). As a result, liquid derivatives markets lead to – in some cases considerably – lower prices in case of strategic behaviour (Bolle, 1993, Bushnell, 2006). The positive effect of derivatives market transactions should primarily arise in exchange trading since transparency and observability constitute the preconditions (Hughes and Kao, 1997). Moreover, the demand elasticity on day-ahead markets is lower than on derivatives markets so that higher prices can be expected if market power is exercised without derivatives markets. Theoretical considerations of this kind are supported by empirical field research (Bushnell et all., forthcoming, Wolak, 2000), experience gathered from the crisis in California (for example Bornstein et al., 2002) as well as evidence from controlled laboratory experiments (Brandts et al., forthcoming), which suggest that derivatives markets can reduce prices significantly and increase efficiency (Kittsteiner and Ockenfels, 2006). This means that – contrary to what is occasionally supposed – a electricity market with a high share of derivatives transactions and a restricted trading volume on the spot market which is connected with it is *less* prone to exercising of market power (see also chapter 5). In

[15] The large (German) suppliers typically sell the predominant share of their production through derivatives markets. The biggest generating company in Germany, RWE, for example specifies that it has already sold more than 95 percent of the annual production for the delivery year 2007 in its quarterly report regarding the situation as of the 1st quarter of 2007.

addition to this, there is, of course, also the welfare-increasing effect of derivatives transactions through risk hedging.

### 4.1.2 Pay-as-bid auction

The political sector and the public frequently propound proposals as to how the pricing mechanism on the power exchange would have to be changed in order to lower expenditure on electricity. The fact that all providers receive the same price, which is established on the basis of the costs of the "most expensive" power plant (see Appendix) in the spot market auctions, in particular, leads to requests for changes. A typical idea, which is communicated in various forms, is that the suppliers should not be paid more than they ask. The appertaining auction is called "pay-as-bid" auction. In the pay-as-bid auction, the traded total quantity is established by means of the intersection of the aggregated supply and demand function as in the uniform price auction. However, the suppliers receive the price which they ask for the respective unit for every unit.

The concept in this case is that the expenditure on electricity could be lowered to a considerable extent by means of a change of the pricing rule since the power plants to the left of the most expensive power plant do not necessarily receive the price of the most expensive producing power plant (as would be the case in the uniform price auction) in the pay-as-bid auction. A similar assumption is that capacity withholding is no longer worthwhile in a pay-as-bid auction since the bid for one unit of electricity cannot influence the price for the other units of electricity. According to this hypothesis, deviations from marginal cost bids are less profitable. However, both of these assumptions are incorrect as is illustrated in the following figure.

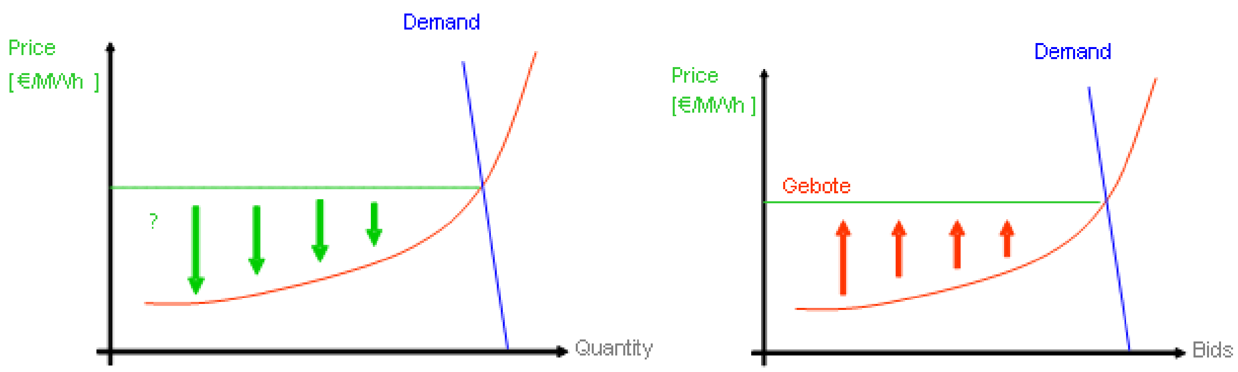


**Figure 4.2: Pay-as-bid auction**

The red line shows the aggregated supply function in a uniform price auction; the market clearing price is established by means of the intersection of demand and supply. As can be seen, all suppliers except the most expensive supplier receive a price above the respective asking price in the uniform price auction. The green arrows illustrate the assumption that the expenditure on electricity would reduce in a pay-as-bid auction since all suppliers now only receive the respective asking price. The right part of the figure illustrates that this is not the case. Why should a power plant with marginal costs to the amount of EUR 10 per MWh put up with a price to the amount of EUR 10 per MWh in the pay-as-bid auction if it could still be accepted with an asking price to the amount of the much higher market clearing price to the amount of perhaps as much as EUR 50 per MWh? In other words – a supplier which can sell its electricity for the market clearing price will, at least, not ask less than the market clearing price. There is, hence, no incentive to offer “true” marginal costs in the pay-as-bid auction.

The same also applies to similar ideas, such as e.g. the request to tax the difference between the market clearing price and the asking price. No rational supplier would ask its marginal costs to the amount of EUR 10 per MWh at a market clearing price to the amount of EUR 50 per MWh if it has to pay taxes on the amount of the difference but receives the same price without having to pay tax for an offer to the amount of EUR 50 per MWh.

From the game theory perspective, pay-as-bid rules lead to a game which could be called “Guess the market clearing price!”. Such bidding behaviour leads to a comparatively high degree of uncertainty regarding the market result and to inefficiency. If all companies submit bids close to the estimated market clearing price regardless of the costs of their power plants, power plants of one supplier producing relatively expensively might be given priority over the electricity of another supplier producing cheaply in case of errors in the forecast.

The concept that purchasing costs of electricity could be saved systematically by changing the pricing rule mistakenly ignores the suppliers’ strategic response to change market rules. A reduction of the price to below the (additional) costs of the last unit of electricity produced cannot be achieved (see Appendix).

### 4.1.3 Comparison of uniform price auction and pay as bid auction

Both the uniform price rule and the pay-as-bid rule generated incentives to raise asking prices to above marginal costs in case of competition problems. Which pricing rule should then be preferred? A number of arguments support the uniform price auction or, at least, do not militate against this form of auction:

The auction theory demonstrates that, generally speaking, the two formats cannot be ranked clearly as regards productive efficiency and the expenditure on electricity. Ultimately, the question of which auction minimises the costs of electricity depends on the distribution of the suppliers' cost structures. Accordingly, empirical field research does not arrive at a clear ranking either. Even though field studies on auctions in government bonds seem to find a small advantage in the uniform price auction and experimental analyses also seem to corroborate this at least for certain preference constellations, there is also conflicting evidence (e.g. Engelmann and Grimm, 2004).

Typically, the pay-as-bid auction leads to inefficiency if the competitors' costs and the market clearing price are uncertain: Though a higher asking price increases profits in the event of production under these circumstances, it also reduces the likelihood of production in this case. This means it is conceivable that suppliers which cannot evaluate the competitive situation and the market-clearing price accurately do not produce electricity even though they could produce more cheaply than their competitors. This applies, in particular, because of the fact that the bids in pay-as-bid auctions approximate the expected market clearing price relatively closely so that even minor errors in forecasts imply a productive inefficiency which, in turn, will be felt in higher prices in the long run. The risk of inefficiency even persists if there are no competition problems because even in this case the pay-as-bid auction forces the suppliers to deviate form marginal cost bids so that the efficiency depends on the quality of the information on the competitors' behaviour and options in this case. In addition to this, the high strategic complexity of the pay-as-bid auction can ultimately lead to non-rational behaviour, which adds further complexity to forecasts (as has been shown in highly controlled experimental studies).

In the uniform price auction the preparation of bidding focuses on the respective own marginal costs. This means an efficient use of the power plants can be expected in perfect competition since the respective own marginal costs are known (in as far as such exist; see chapter 4.2). Even though perfect competition cannot be reached on electricity markets, it can be shown both theoretically and empirically that uniform price markets with increasing competition converge towards full efficiency relatively quickly, i.e. already with a relatively small number of suppliers (see Cramton and Stoft, 2006 and the literature cited there).

Since the pay-as-bid auction primarily rewards good estimates, “large” suppliers have an advantage since they can typically generate better information on market developments and structures. Large suppliers, hence, have an advantage in the pay as bid auction. In the uniform pricing auction, however, “small” suppliers – or those which only offer small, non-hedged quantities in the spot market auction – can benefit from the information and market power which other suppliers command. This is due to the fact that the suppliers exercising market power “make room for other suppliers” by withholding capacity. Since the price in the uniform price auction is the same for everyone and since it is, hence, a “public good” for all suppliers, even the suppliers exercising market power benefit comparatively little from this since they lose contribution margins by withholding capacities while the other suppliers can benefit from price increases without any restrictions. By means of this the uniform price auction promotes market entry in the event of competition problems and, hence, has superior, self-correcting competition incentives.

Moreover, the rule applies that pay-as-bid auctions cannot simply be applied to two-sided electricity markets in which both the demander and the supplier bid into the market. Whereas the market clearing price simply applies to all participants in the uniform price auction, two-sided closed pay-as-bid markets have to specify how the gap between asking prices and prices offered is dealt with.[16]

In conclusion, it has to be remarked that pay-as-bid auctions cannot comply with another central task of the power exchange. They do not generate a clear reference price with regard to which market participants can conclude derivatives transactions and with the help of which they can hedge risks. This results in increased uncertainty, intransparency and co-ordination problems between interdependent markets and in increased strategic complexity.

In summarising we can state that the rule applies that the uniform price auction as applied by EEX rightly constitutes the dominating pricing mechanism in almost all liberalised markets. Nonetheless, the uniform price auction comes in for criticism. However, the reasons for such, usually, do not have any economic foundation. One item of criticism is that the price cannot fall to below the (additional) costs of the most

[16] An open bid auction was implemented in Great Britain, so that this problem has receded into the background. The difficulties associated with this will be discussed in chapter 5.4.

expensive unit produced. However, this is the case in all markets organised on the basis of competition (without restriction of arbitrage transactions): pricing based on marginal costs permits the right signals to be issued for short-term (dispatch) and long-term (investments) efficiency.

A related point of criticism is why a power plant with an asking price to the amount of its marginal costs of EUR 10 per MWh also has to enjoy a market clearing price to the amount of EUR 50 per MWh. As regards the short term, the answer is that arbitrage transactions prevent different prices. For the long term, a deviation of variable costs and revenue is essential for the working order of markets in addition. Fixed costs do not play any role in the suppliers' individual asking prices. If the suppliers were only paid the actual *additional* costs incurred, they could not cover their fixed costs and no one would invest (see Appendix for detailed explanations).

The assumption on which the criticism is based is that too much money is paid for electricity systematically in a uniform price auction. However, this concern is unfounded. If the electricity market is in an efficient equilibrium, the market clearing price will just cover variable *and* fixed costs on average in the long run – independently of the individual marginal costs, which are bid into the market in the short run. Even though the electricity market is typically not in equilibrium in the short term since unexpected price fluctuations in fuel or allowances, policy decisions, etc. in connection with long adjustment and extension times can lead to comparatively high or low prices. In this case, however, the uniform price auction generates the right incentives in order to be able to return to an efficient equilibrium with full cost coverage.

If, for example, gas prices unexpectedly increase from an equilibrium situation, this will lead to price increases and, hence, to "windfall profits" in coal-fired and nuclear power plants and water works. If they fall, this can lead to corresponding declines in production and "windfall losses" in these power plants so that incentives for investments are reduced. Changes in the relative fuel prices, prices for allowances and other factors driving the marginal costs, hence, entail price signals in marginal cost pricing which are indispensable both for the short-term cost-efficient electricity production and for long-term intelligent investment incentives according to the undisputed economic school of thinking.

#### 4.1.4 Vickrey auction

A third auction format which is occasionally also discussed for electricity markets is the so-called “Vickrey auction”. Unlike the uniform price and pay-as-bid auction, this auction can ensure that cost *efficiency* can be achieved at all times also in case of oligopolistic market power and technical restrictions on principle. On the other hand, it is, however, only suited for pool models, entails significant disadvantages regarding pricing and is, moreover, very complex.

If we generalise from the strategic behaviour on the demand side (which is assumed to be completely inelastic here), from the possibility of trading electricity outside the power exchange, a comparatively simple version of the Vickrey mechanism can be considered: As in the case of the two auction formats already presented, the suppliers submit an asking price for every (additional) unit and, as before, the highest bids are accepted until the demand has been satisfied. However, the electricity price for a given unit is neither the market clearing price as in the uniform price auction nor the price bid as in the pay-as-bid auction. Said price is rather established for every unit by means of the “opportunity costs” which are incurred by the supplier’s participation in the auction.

If, for example, a supplier produces *k* units according to the result of the auction, it will receive the amount of the *k*th lowest lost price bid of the *other* suppliers for its first unit, the amount of the (*k* - 1)th lowest lost price bid of the *other* bidders for its second unit, etc. and, finally, the smallest losing price bid of the *other* bidders for its kth unit. Why are these opportunity costs? E.g. if the supplier dispenses with the production of its last (*k*th) unit, the supplier with the smallest losing price bid for this unit will be accepted so that the marginal costs of said party will materialise.

This unconventional pricing is based on the following intuition: Every winner of an auction receives the asking price of the supplier which would generate the additional unit of electricity without the auction winner’s bid for an additional unit of electricity produced. Since the price achieved by the auction winners does not depend on their own bid in this case but always on the losing bid of *another* supplier, the price for their own electricity generation cannot be influenced by strategic capacity withholding. As a result, profit maximisation leads to a situation in which the supplier wishes to generate an additional quantity in particular at those times at which its marginal costs are below the price which is exogenous for said party. Consequently, all suppliers will bid at marginal costs and cost efficiency has been achieved.

Since all suppliers now offer marginal costs, the revenue achieved by an electricity producer for every unit now corresponds to the marginal costs which this unit would have cost if the electricity producer had not taken part in the auction. In this sense, the revenue for one unit of electricity as it were reflects the savings in electricity costs which the winner of the auction achieves through its participation. On account of its pricing rule the Vickrey auction internalises the incentive to minimise the costs of electricity production (though not necessarily the expenditure for electricity) on the part of the suppliers.

But even if the Vickrey auction can theoretically ensure efficiency at all times, it is still not suited for use in practice on electricity markets. This applies in particular to exchange models because suppliers can only be paid different prices in the case of arbitrage and, hence, the “law of one price” is effectively forestalled in down-stream and up-stream markets. This is neither possible nor desirable on exchange markets (see Appendix). But even if this succeeded, the Vickrey auction still has to obtain its efficiency maximising property with unfavourable price effects: Even though electricity is a completely homogeneous commodity, the Vickrey auction can lead to drastically different revenues for suppliers in an equilibrium, even if they produce electricity at the same marginal costs. This can be illustrated with the help of an example. We assume that 2 units of electricity are demanded and bidder *X* can produce at marginal costs of 10 for the first unit and 50 for the second unit, while bidder *Y* has marginal costs of 10 and 11. In the Vickrey auction, both parties bid at marginal costs and are accepted for one unit each. But, even though both suppliers have exactly the same costs for the quantity produced, bidder *X* receives EUR 11, while bidder *Y* receives EUR 50 according to the Vickrey pricing rule.

Moreover, the Vickrey rule implies that bidders producing a lot of electricity receive a higher price than bidders with a lower electricity production. This is due to the reason that higher marginal costs are incurred for “later units” and that higher prices have to be paid because of this. The economic intuition behind this is that bigger bidders have more market power and, hence, need to receive a higher compensation for not engaging in strategic bidding via marginal costs.[17] While the dispatch is always

[17] Theoretically, Vickrey auctions can be considered if there are complementarities in the costs (chapter 4.2). However, additional problems with Vickrey auctions arise in these cases. One of the problems is that the expenditure for power incurred can be very high in the event of material competition. Moreover, there are frequently strong incentives for collusion (Milgrom, 2004).

efficient, the Vickrey auction can lead to comparatively high expenses for electricity, in particular, in the case of the existence of market power.

Overall, the Vickrey auction does not constitute an alternative for exchange models and, moreover, it is not a plausible alternative for pool models on account of its high complexity and potentially unfavourable effects on electricity prices. That is why it is not used in practice on electricity markets. However, the analysis of the Vickrey auction demonstrates that there is no “perfect” electricity market auction since there is an inconsistency of goals between efficiency and prices in the case of market power. On principle, Vickrey mechanisms can ensure complete production efficiency; however, they can only do this at the expense of pricing which is, ultimately, not acceptable. At the same time, the rule applies that no other market mechanism can completely eliminate strategic behaviour and efficiency losses in the case of competition problems. A suitable architecture of the electricity market, however, significantly curbs the negative impact of low competition in the short and long term.

### *4.2 Bid formats and complementarities*

The uniform price auction and many of the considerations so far are based on the assumption that there is a price which clears the market. In the event of sufficiently strong competition this price can ensure efficiency in production and investments. In practice, however, there are technical restrictions (so-called “non-convexities” or “complementarities”) in electricity production, which can play a significant role in pricing and which can call the existence of a uniform market clearing price for a given hour of the following day into question entirely. Complementarities arise e.g. on account of start-up and shut-down costs of power plants, ramping rates (start-up and shut-down speeds), minimum and maximum production quantities (for example in pumped hydro storage) as well as the minimum load of a power plant. They lead to a situation in which an extension of the generation of electricity can lead to a disproportionately low increase in production costs (where a power plant which is already in operation produces the electricity) or to a disproportionately high increase in production costs (namely where a new power plant has to be started up for the production of the additional unit). In order to achieve full production efficiency such technical particularities have to be taken into account, which has consequences for the design of the auction and, in particular, the bid format. If e.g. the bids cannot reflect the individual cost components accurately, the costs cannot be taken into account accurately in pricing. This would result in inefficiency.

To illustrate this point we will e.g. assume that all suppliers can offer electricity at variable costs of production to the amount of EUR 20 per MWh up to the respective capacity limit of 200 MW. However, this is only the case if they start up the respective power plant, which generates another KEUR 6 in start-up costs.[18] The demand needs electricity for two hours. At a price of EUR 35 per MWh, a supplier generates exactly zero profits with full capacity utilisation, because the supplier achieves a surplus over the variable start-up costs to the amount of EUR per MW for each of the two hours so that he can also just cover the start-up costs over these two hours (200 MW x EUR 15 per MWh x 2h = KEUR 6). This example illustrates two core problems which can arise on account of complementarities in the cost structure:

First of all, a market clearing price might not exist: Let us assume that the demand for electricity is inelastic and amounts to 1,100 MW for each of the two hours. At a price of less than EUR 35 per MWh the supply is zero in the example, whereas every supplier offers 200 MW at a price of EUR 35 per MWh or more. Since the supply, hence, has to be zero or a multiple of 200MW, there is no price at which the supply is equal to the demand. The reason for this is that whenever a supplier produces, it wishes to produce at the full capacity because of the start-up costs (which are then "sunk costs"), which is, however, not compatible with the demand. The non-existence of market-clearing prices can result in strategic uncertainty for the market participants also in case of strong competition. However, it does not imply that there is no competitive equilibrium in exchange models. On the contrary, there are equilibriums at which the prices might not clear the markets but at which the equilibrium prices at least approximate market clearing prices.[19]

Secondly, an auction design which only permits suppliers to bid separately for every hour of the following day leads to financial risks and efficiency problems in cases of uncertainty. In the example above, a supplier would be ready to offer its capacity in the first hour at a price of EUR 35 per MW provided it can ensure that it is *also accepted for the second hour* at least at the same price. If it cannot ensure this, however, it either has to run the risk of incurring losses, which is the case if the price falls to below EUR 35 per MWh during the second hour or if he only secures the

[18] If applicable, start-up costs can also depend on the extent of the capacity started up (MW). Our example simplifies with regard to this; however, see Stoft (2002), who develops more complex examples with regard to this.

[19] For example, the market might be cleared in such an equilibrium with the exception of one supplier which only sells a part of its capacity even though it would like to sell the entire capacity (see for example Stoft, 2002).

contract for one hour (in the latter case, the use of the power plant would only be profitable as of a price of EUR 50 per MWh). Or the supplier has to refrain from offering at all in view of this bidding risk even though it might incur costs for power which are lower than the evolving market prices over two hours.

Essentially, there are two approaches as to how such complementarities can be taken into account in the costs: The first approach is typically implemented in exchange models and uses block bids in so-called combinatorial auctions. The second approach is found in pool models and uses multi-part bids which are used in combination with non-linear prices. Both approaches will be presented herein below.

### 4.2.1 Combinatorial auctions

Combinatorial auctions are auctions in which bidders can bid on combinations of objects (so-called “blocks”) instead of on individual objects only. In the example above, the bidders can e.g. condition their price offer in such a way that the bids are accepted for at least two consecutive hours in a combinatorial auction. In this way the suppliers’ financial risks can be reduced and cost efficiency of electricity production can be increased: In this specific case, the suppliers would demand (at least) EUR 50 per MWh for a 200-MW delivery during the first *or* second hour and EUR 35 per MWh for both hours together. The corresponding asking prices for a 100-MW delivery would amount to EUR 80 per MWh or EUR 50 per MWh respectively. The cost-minimal fulfilment of a demand to the amount of 1,100 MW implies that five suppliers offer 200 MW each and one supplier offers 100 MW in every hour and that all power plants operate for two hours.

If bids are possible for *every possible* combination, a combinatorial auction can, theoretically, achieve a perfectly efficient result at all times. However, the example already indicates that, potentially, a very large number of bids can be submitted since, on principle, random conditioning to quantities and times is possible and since, e.g. mutually exclusive bids can be submitted. If, for example, all combinations of the hours of the following day were to be permitted in the spot market auction, this would already result in more than 16 million different hour combinations, which would have to be considered on principle. Such combinatorial auctions would pose difficult challenges for bidders and market platforms (see Ausubel and Milgrom, 2005, Cramton, Shoham and Steinberg, 2006 on the theory and practice of combinatorial auctions).

The specification of a restricted number of possible block bids constitutes a reasonable possibility of reducing complexity.[20] These block bids should reflect existing complementarities as best as possible and e.g. only permit contiguous time blocks. In the event of the bidders having better information on existing synergies, it might also be recommendable to have the bidders have a say in the selection of possible combinations in the framework of the bidding procedure (Park and Rothkopf, 2005).

In fact, combinatorial bidding on a selection of pre-defined blocks was permitted in practice over a long period. In this process, block bids combining several consecutive hours could be submitted. However, many exchanges, including EEX, have now moved to a situation in which the bidders can decide for themselves which hours they want to combine into blocks. (In individual cases, the bidding flexibility is extended by means of further, innovative bid formats to which we will come back in the comparison with other European electricity markets in chapter 5.1.)

Usually, the permitted size of block bids is restricted. On EEX, block bids for at maximum 250 MWh per h can be submitted; on other exchanges the quantity is frequently lower (Meeus, 2006). These block bids are then taken into account in pricing and allocation determination jointly with the bids on individual hours. In this process, the algorithms used on the power exchanges including EEX iteratively look for a “good” allocation (see chapter 2 and Meus et al., 2005); however, they cannot always guarantee an “optimum” auction result – not even with the free selection of the block bids.

The use of “second-best” search algorithms instead of “optimum” allocation algorithms has various causes. Firstly, the determination of the optimum allocation in combinatorial problems is generally a notoriously difficult problem, a so-called “NP-complete” problem, which cannot be solved at all or at least not within a reasonable amount of time if there is a large number of bidders and potential combinations (see de Vries and Vohra, 2003). For this reason, the time restrictions (the results of the auction have to be announced after a short period of time in order to go ahead with rostering for the use of the power plants) alone do not permit extensive optimisation. Secondly, complete efficiency does not only require random conditional bid formats, including mutually exclusive bids, but also so-called non-linear prices, which, in turn, increase the complexity of pricing and bidding significantly and also reduce the

[20] See Pekec and Rothkopf (2005), Milgrom (2004) and Kittsteiner and Ockenfels (2006).

transparency of the procedure. And, thirdly, the inefficiency which might result from "second-best" search algorithms as used in power exchanges, is very low (see below).

### 4.2.2 Linear prices

On power exchanges, typically *"linear prices"* are used. That is, for every individual hour of a day a unique market clearing price is established, all units for this hour are traded at that price. In the case of complementarities, this restriction can lead to inefficiencies even if block bids are permitted on a large scale. In this context, the phenomenon of "paradoxically rejected blocks", in particular, has to be mentioned. Initially, common algorithms for the determination of the allocation and of market prices, as on EEX, determine the market clearing price on the basis of the hourly bids. Block bids are only considered if the corresponding asking price is lower than the total of the market clearing prices for the desired hours (or if the price offered is higher than the total of the hourly price for block bids on the demand side). Since the additional consideration of a block bid leads to a change in the market clearing prices for the hours concerned, however, block bids can be rejected if their asking price could be fulfilled at the given market prices – however, not at the prices which would result if the bid were taken into account.[21]

From the perspective of efficiency, it might be desirable to accept such a block bid nonetheless under certain circumstances and to offset the difference between the total of the hourly payments and the asking price by means of a side payment, which would, however, constitute a break with linear prices. With side payments there is a comparatively high risk of being rejected with block bids in the auction. The problem tends to be the more difficult the bigger the blocks are for which bids are submitted.[22]

Theoretically, the rule applies that perfect efficiency can only be guaranteed with non-linear prices. Non-linear prices are typically applied in pool models with a number of degrees of freedom existing in this context. Usually, the suppliers in pool models are asked to submit bids comprising several parts which can reflect start-up costs and

[21] Art. 24 (14) of the EEX trading rules points out the possibility that block bids might not be executed even though they would be profitable at a given market solution.

[22] In fact, restrictions regarding the size of the block bids are sometimes justified on the basis of the fact that this would make the problem of the "paradoxically rejected blocks" less visible and that this would expose the respective market platform to less criticism. From the perspective of economic efficiency, this argument is not very valid. For this reason, the restriction of the size of the block bids on EEX, which is not very restrictive compared with others, has to be welcomed.

other cost elements in addition to the variable costs of production. Reference prices at which most contracts are traded are then calculated on an hourly basis in line with a global optimisation calculation.

Some suppliers, however, also receive side payments in addition in order to fulfil their asking price if the total of the hourly reference prices or of the nodal prices is not sufficient in order to be able take a block bid into account.[23]

In the numerical example above, a pool model would e.g. pay out grants for electricity production to the power plant operators which cannot cover their start-up costs in the optimum (subject to the assumption that their respective costs were disclosed truthfully). On principle, side payments can implement an optimum mode of operation of the power plants by means of this even in the case of complementarities.

While non-linear prices have largely been discussed with regard to pool markets so far, there have been a number of proposals as to how non-linear prices could be implemented on exchanges recently (O'Neill et al., 2006). However, the introduction of non-linear prices on exchanges is controversial. While an inefficient allocation necessarily also leads to inefficient provision on pool markets (since the entire quantity is traded on the pool), this is not necessarily the case in optional power exchanges under an exchange model. The reason for this is that a large part of trading takes place on the bilateral market, so that a high degree of flexibility in optimising the rostering for power plants is already secured in addition to exchange trading. If for example there were a high likelihood that block bids might not be considered to the full extent and adequately on the exchange, bidders could also trade and hedge their blocks off the exchange.

In fact, the relevant literature contains numerous arguments against the introduction of non-linear prices at power exchanges.[24] On the one hand, reform costs would have to be expected in the event of a change in the pricing rule. On the other hand, it would be costly and expensive to introduce the participants to the far more complex rules. Moreover, the high complexity could deter potential participants so that it would be uncertain whether the potential higher profits from trading would attract a larger number of participants than those deterred by the complicated rules.

Further problems would have to be expected in the decision regarding a concrete pricing rule. This is due to the fact that if we eliminate the corresponding ancillary conditions (requiring the linear prices) from the optimisation problem, the problem

[23] Some observers define pool models on the basis of the possibility of individual side payments.
[24] A summary is provided in Meeus (2006), chapter 8.

does not have a clear solution and the question of which solution is best is inherently unclear. This would mean that decisions which would “arbitrarily” prefer some market participants at the expense of others would have to be taken upon the introduction of non-linear prices.

Moreover, the mechanisms which combine the linear hourly prices with side payments would create new challenges for the market participants’ risk management. While they can usually hedge against the price risk regarding the hourly prices, there is no such financial instrument regarding the side payments.

Ultimately, the question of how inefficient linear prices at power exchanges *actually* are is relevant for an evaluation of the different approaches since the theory only says that linear prices *cannot always guarantee complete* efficiency in the event of complementarities. Is it worthwhile obtaining residual efficiency potentials through a significant increase of the complexity of the rules and regulations? Stoft (2002) argues that complementarities only cause a loss of efficiency in the order of magnitude of 0.01 percent or less at power exchanges with linear marginal cost pricing as also carried out on EEX. Complementary cost elements such as start-up costs are largely already covered by marginal cost pricing. Moreover, he theoretically shows that equilibriums can lead to efficient or “almost” efficient allocations even with the restriction to linear prices. Moreover, Meus et al. (2005) do not find any significant improvements in efficiency on account of the introduction of non-linear prices in their simulation studies. For this reason, there is little evidence suggesting that the benefit on account of the introduction of non-linear prices could exceed its costs overall. The possibility of block bids in the spot market auction, which is provided for on EEX and in other exchange models, constitutes an adequate and reasonable approach in view of the complexities connected with the first-best mechanism and in view of the potentially high degree of achievement of efficiency.

### *4.3 Price and bid caps*

In most day-ahead spot market auctions, there is a bid cap and a price floor: The possible bids have a lower and an upper limit. There can be various reasons for this. On pool markets on which the entire available capacity has to be traded a bid cap has the effect of a price cap; the market price cannot increase to above the maximum bid permitted.

The positive effect of price caps has been analysed comprehensively in the economic literature. Price caps can reduce incentives to withhold capacity economically or physically. This can be a legitimate concern, in particular, on electricity markets since prices induced by market power can become very high in the event of a low elasticity of demand and of capacity bottlenecks (Borenstein, 2002, Ockenfels, 2007a, b).

In perfect competition, prices should be determined by the demand side's willingness to pay in the event of capacity bottlenecks in order to avoid short-term outage ("value of lost load", VoLL) and can exceed the costs of electricity generation by far in these cases (see Appendix). In fact, a price cap should never be set below VoLL prices in perfect competition since this would otherwise impair efficiency. The estimates of such scarcity prices vary very much and e.g. range between KUSD 2 to 50 per MWh (Bushnell, 2005), KUSD 10 per MWh (Hobbs et al., 2001) and KUSD 3 to 30 per MWh (Cramton and Stoft, 2007).

The determination of the amount of price caps for non-perfect competition is difficult. On principle, low price caps entail the risk of a negative influence on the production and investment incentives. If they are below the maximum (additional) costs of electricity production, they entail an immediate partial stop of production. However, price caps to the amount of average costs can also lead to drastic problems. This is due to the fact that marginal costs and prices are often below the average costs, so that full cost coverage and competition would be incompatible at price caps to the amount of average costs (see Appendix and chapter 4.6). Ultimately, positive effects can only be achieved if the price limit is "neither set too low nor too high".[25]

Regardless of the discussion regarding the right height of price caps, they cannot be implemented without difficulties in exchange models and they cannot be implemented at all in day-ahead spot market auctions. Bid caps on energy exchanges, such as those implemented by EEX to the amount of EUR 3,000 per MWh, are not price caps. This is due to the reason that market participants can also trade off the exchange at all times if the price which can be achieved on the market (whether because of market power or because of scarcity) is above the bid cap. If the bid cap has been selected too low, a price at which supply and demand correspond cannot always be found. In this case, either rationing is necessary or re-negotiations have to be held with the market participants (see chapter 2 for the procedures on EEX). However, the risk is that price limits which are too narrow entirely deter suppliers from trading on the exchange; they will then trade bilaterally off the exchange with

[25] An analysis of price caps in incomplete competition is provided in Grimm and Zoettl (2007b). This also shows that price caps can even increase investment incentives in incomplete competition provided they are set properly.

corresponding negative consequences for transparency, efficiency and speed (chapter 3).

A sufficiently high bid cap can have certain effects, nonetheless. For example, the suppliers might be deterred from hitting the bid cap since they are afraid of market interventions by the political sector or the regulator otherwise. Moreover, a bid cap can also protect the suppliers which submit bids without limits against extremely high price fluctuations to a certain degree. Finally, bid caps can help to avoid errors in the submission of bids – such as e.g. that bids with one digit too many are submitted. Under consideration of the price dynamics on EEX so far, a bid cap to the amount of EUR 3,000 per MWh appears to be sensible for the fulfilment of such functions. Moreover, it is consistent with the bid caps on other European exchange markets (chapter 5) and on the lower limit of the price caps for electricity markets proposed recently (Cramton and Stoft, 2007). However, because of the price effects which are only limited, the risk of a drain of exchange participants as well as the high marginal cost volatility in electricity markets, bid caps regularly have to be checked with regard to the question of whether their amount has to be adjusted. (So far, the EEX auction price has never reached the bid cap.)

The lowest possible bid price is at the other end of the price range. Usually, and as is also the case on EEX, this lowest price is EUR zero (see chapter 5 for an international comparison). For the case of the day ahead electricity spot market auction on the EEX, this lower price limit does not comply with the cost structures of electricity generation, however. Notice that marginal costs can become negative in certain hours, since power plants with very high costs of starting-up and shutting-down and low variable costs of production can produce at negative marginal cost. This is the case, in particular, if shutting down the power plant during the next hour is more expensive than having it operate. If the suppliers are not permitted to express negative marginal costs through their bids, the cost efficiency of electricity generation might suffer or clearing of the market can be made more difficult. For this reason, the possibility of negative price bids and prices has to be welcomed from an economic perspective.

Negative prices would not be necessary if there were unrestricted flexibility in conditional bids (also over many days) and “first-best” optimisation algorithms in pricing beyond the day ahead electricity spot market, since no supplier would be ready to accept *overall* negative prices for a electricity generation block if all complementary cost components are included accurately (see Appendix). As we have explained in chapter 4.-2, “block bids” cannot be permitted without certain restrictions and “second-best” search algorithms can only be realised in pricing on account of the high complexity. In this situation, negative price bids can assist the suppliers in conveying their cost situation more precisely, which reduces the risk of losses for the suppliers and increases the efficiency of generation.[26]

### *4.4 Obligation to offer*

In the discussion regarding the electricity market an “obligation to offer” which is to be included in the market rules in order to curb market power is sometimes called for. The term obligation to offer is not defined clearly. Frequently, this is defined as binding power generators over to offer at least those capacities which are not yet tied up in long-term agreements (or agreements regarding balancing power) in the spot market auction. The results presented so far permit an evaluation of the consequences of such proposals: An obligation to offer is incompatible with an exchange-based design of the electricity market.

As is shown in the analysis in chapter 4.1, an obligation to offer cannot systematically reduce prices within the existing micro- and macrostructure of the market since, ultimately, it does not make any difference for the demand prices whether companies withhold their capacity physically (i.e. do not offer an available power plant in the spot market auction) or economically (i.e. ask prices above the marginal costs) there. This is shown in a simplified manner in figure 5.3: From the perspective of the demand it does not matter whether the supply curve (or a part thereof) shifts left because of physical withholding or whether it moves up because of economic withholding; the resulting price effects are equivalent.[27]

[26] Negative prices are already provided for on the markets for balancing energy, namely for negative balancing power in the case of which the production is reduced or the demand is increased “artificially” in return for payments of money.
[27] Economic and physical withholding can have different effects on efficiency and the measurement of market power.

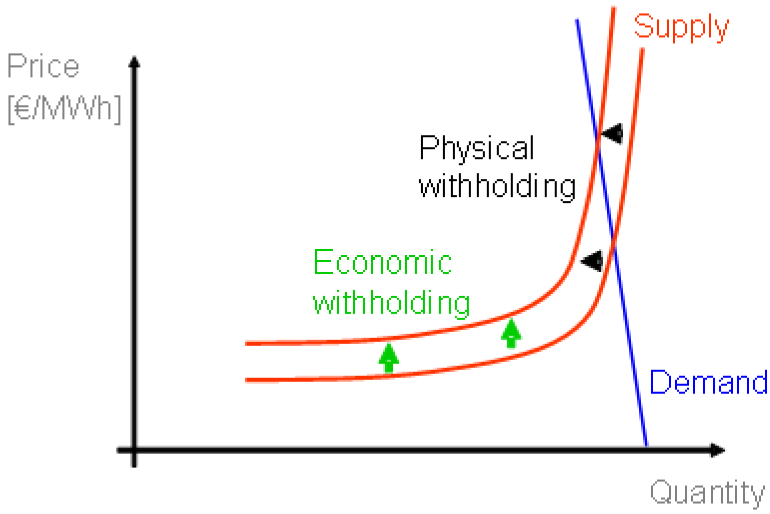


**Figure 4.3: Physical and economic withholding**

Hence, an obligation to offer could not resolve possible problems regarding market power within the current system unless the price at which the power plants have to be offered is also regulated in addition to the obligation to bid. Ultimately, this would mean that the regulation would have to take the decision regarding production away from the generators to a comprehensive degree and de facto abolish the market.

A further-reaching proposal is to combine the obligation to offer with a price cap on the exchange. However, the line of reasoning in chapter 4.3 proves that this measure cannot lead to disciplining of market power either. If a bid cap on the exchange systematically restricts trading, it leads to a migration of the market participants into OTC transactions. The exchange would lose one of its central functions, i.e. the determination of a daily reference price to which all derivatives transactions refer and with which the market participants can hedge their risks. This would result in inefficiencies. The aim of regulation, however, would not be reached since electricity would then be traded bilaterally – without a price cap.

A response to this could be the requirement that *all* trading *has to be* effected on the exchange. If, however, such an obligation to offer all the generation capacities in Germany in the spot market auction existed, this would tend to aggravate the issue of market power since derivatives markets reduce the incentive to exercise market power (chapter 4.1). Moreover, a pool model cannot mitigate the issue of market power as we have explained in chapter 3.

In summarising, we can conclude from the analysis in chapter 4 so far that interventions into pricing or the flexibility of bidding in the spot market auction constitute instruments which are not very suitable for disciplining market power and improving cost efficiency. The further development of the co-ordination of interdependent markets as described in the following chapter, on the other hand, promotes competition and is particularly promising for this reason.

### *4.5 Connection of interdependent markets*

The connection of interdependent markets constitutes an important challenge in the power exchange model. Before the electricity reaches the final consumer it not only has to be produced but also transmitted to the consumer. For this reason, electricity and transmission are complementary goods for the electricity supplier – one of the components is no good without the other one. There are various options for the sale of electricity: Forward or futures markets, the day-ahead market, the intraday market and the markets for balancing energy, which, in turn, are each substitutes from the supplier's perspective. A lack of co-ordination between the individual markets increases the strategic complexity, places high demands on the market participants' capacity to make forecasts and can, hence, obstruct the efficient provision of electricity and drive up prices. Therefore, the co-ordination has to be supported actively through the architecture of the market.

A sequence of interdependent markets permits adjustments to the respective current status of information. For example, the advantage of the intraday market is that trading after the daily auction is still possible once further information on the availabilities of power plants and wind speeds is available. Forward markets are needed in order to hedge the market participants' risks and to keep the incentive for exercising market power low. However, sequential market dynamics can impair cost efficiency namely where no market can operate optimally without accurate information on the respective other market result.

Within the market area of most European power exchanges scarcity situations arise only rarely. For this reason, the market for transmission capacities is usually not integrated into exchange trading; typically, bottlenecks can be neglected during generation and are only resolved *after* the auction by means of a re-dispatch if required. In some regions with more frequent transmission bottlenecks, however, these are taken into account *simultaneously* with the evaluation of the bids in the spot market auction. This applies in particular in Scandinavia (NordPool) in the framework of the so-called "market splitting" (see below and chapter 5.1).

For historic and political reasons, the boundaries of the European market areas usually extend along the national borders.[28] In order to be able to trade electricity between individual market areas where transmission bottlenecks occur comparatively frequently, border-crossing transmission capacity currently usually has to be acquired in special auctions *prior to* clearing during the spot market auction (Waver, 2007). The sequence of the markets places high strategic requirements on the market participants since the suppliers have to acquire international transmission rights in advance as it were “as a precaution” in case of uncertainty regarding generation prices. Perfect co-ordination and efficiency would imply that the prices would have to be the same in all areas without congestion, exclusively inflows of electricity should be observed for regions with higher clearing prices. However, a failure of co-ordination manifests itself in the observation that transmission capacities actually are occasionally free even though the prices in two regions differ or that power flows “in the wrong direction”. For example, transmission capacities are auctioned off on the Dutch-German border before the generation markets are cleared. Since the bids in the auction for transmission capacity depend on the uncertain result of the generation market, inefficiencies arise in the use of the transmission capacity, as has e.g. been found in the Energy Sector Inquiry (2007).

The sequence of European exchange trading (the spot market auctions are held at different times between 10:00 and 12:00am) permits the suppliers to offer quantities which have not been sold on other markets in case of co-ordination problems. However, they cannot respond optimally to the price differences between the regions since these can only be observed once the bids have been submitted. The following sections deal with the principal options of how the individual trading platforms can be better co-ordinated.

*Market coupling.* While most European power exchanges were organised as national markets over a long period of time, markets have increasingly been interconnected in the more recent past. In some European regions, e.g. the Benelux countries and France, this has already taken place and in other countries, such as Germany, this is planned with the exchanges in Belgium, the Netherlands and France as well as with NordPool for the near future.

[28] Scandinavia has been the only exception over a long time. Today, individual national trading areas increasingly merge into bigger market regions, even though the national trading platforms are usually preserved.

If two markets are coupled, the bidders and suppliers only bid on one exchange respectively; however, their bids are taken into account in all coupled markets in this case. The involved exchanges exchange so-called import and export curves specifying at which prices electricity is to flow into the market area or from the market area before pricing. The market clearing price is then calculated simultaneously for all coupled markets on the basis of all bids using an iterative procedure. The prices for the different regions only differ if the international transmission capacity is not sufficient in order to implement identical prices. This procedure reduces the strategic uncertainty of the suppliers. In coupled markets, the transmission capacity is used to the full extent whenever this increases efficiency. (If the balancing energy market is included, inefficiencies in the reservation of scarce interconnectors can also be used for balancing energy.) If awarding of transmission rights is connected to actual physical transmission, this also helps to prevent companies from “blocking” transmission capacity in order to keep the price in one of the regions artificially high.[29] Moreover, the rule applies that coupling of the markets reduces the potential for national market power since minor additional transmission capacities used efficiently between market areas could already significantly reinforce the competition (Borenstein and Bushnell, 1999). The efforts by EEX to support and foster market coupling are, hence, suitable for increasing the efficiency of the provision of electricity and to curb market power.

*Markt splitting* moves one step beyond market coupling, which is already implemented in part or initiated in part in Europe, since a centralised auction house is required for the market areas taking part. While only information on the aggregated flows is exchanged between the market areas taking part in market coupling (the import and export curves), all the information on feed-in and withdrawal points is available for the central auction house in market splitting through the bids and the reported long-terms agreements.[30] Generally, this enables an efficient division of the market area into zones with different prices. Theoretically, the price zones can change during every hour depending on the bids. In case of an endogenous determination of the regions (i.e. if additional available information is used), market

[29] See Joskow and Tirole (2000) with regard to the strategic incentives of withholding of capacities in this context. In so-called “open market coupling” pure transmission capacities (even without the appertaining power) are also sold on the day-ahead market on the exchanges in addition, so that the problem of strategic withholding of transmission capacities arises.

[30] On principle, the rules of EEX also provide for market splitting, which however, cannot take the capacities already traded into account automatically and which cannot identify actual scarcities for this reason.

splitting is more efficient than market coupling. If arbitrarily small regions with different prices are permitted, in the limit a so called system of “nodal pricing” could be implemented also in the context of a power exchange, which theoretically guarantees complete efficiency in the use of transmission capacities. This will be discussed in more detail below. However, even in the case of endogenous determination of a restricted number of bigger regions with different prices, a market splitting system can achieve additional gains in efficiency.

The question of how much better market splitting is compared with market coupling, e.g. depends on how much the regions determined endogenously would deviate from the regions specified in market coupling. At the moment, we can assume that the scarcities will actually mainly arise on the borders between the trading areas of the national exchanges, which is why the two systems should not be very different from one another at least with trouble-free communication. This also applies to Scandinavia, where the different regions for market splitting are not determined endogenously but have been firmly specified for a long time. This is due to the fact that the potential bottlenecks in Scandinavia result from the generation structure: concentration of generation in the north versus concentration of consumption in the south. However, in the case of increasing transmission problems also within countries, market splitting would constitute a natural option for the further development of market coupling.

*Nodal pricing* goes yet another step further than market splitting. Also in this case regions between which prices can deviate are not specified – as in the ideal form of market splitting. The regions with different prices are rather established endogenously under consideration of all bids and the feed-in or withdrawal points associated with these. Even if there is only one single bottleneck, the prices on every single feed-in and withdrawal location are different since the electricity between two nodes in the network flows along every possible route in line with the physical laws. As a result of this, price differentiation is the mandatory consequence of a comprehensive optimisation of generation and transmission on all nodes of the system. The prices not only reflect the generation costs for every power plant but also the transmission capacity used. The system is based on the assumption that the auctioneer is aware of all physical flows to be expected. For this reason, it appears to be suitable for centralised pool markets, which also use this system in part.

Theoretically, nodal prices could also be implemented in exchange trading, i.e. in the framework of market splitting with randomly small regions with different prices. However, the implementation into practice is not free from problems. Nodal pricing is extremely complex and, at best, it can be achieved with an extremely high and demanding calculation effort. At the same time, intuition regarding the price effects of the electricity supply, transmission capacity, expansion and closure of power plants, etc. cannot be applied on account of the interdependence of all nodes in the network; small changes in the network can entail major distribution and allocation effects. Moreover, the impact which nodal pricing has on manipulation incentives and exercising of market power has been investigated relatively little.[31] Finally, many advantages of the exchange model, such as platform competition and uniform reference prices, would have to be relinquished. This seems to set natural limits for the further development from market coupling to market coupling and to nodal pricing.

### *4.6 Investment incentives and capacity markets*

*Long-term efficiency* constitutes one of the most important arguments in favour of the liberalisation of the electricity market, in addition to the hope for productivity increases and lower prices. The market is to generate the right price signals for smart investment decisions and an efficient capacity and risk allocation.

So far, the interaction between the “short-term competition” in the spot market auction with long-term capacity planning has been studied comparatively little. This also has to do with the fact that far-reaching experience with investment cycles on electricity markets has not yet been gathered since competitive electricity markets have not existed for a sufficiently long period of time.

Empirical evidence suggests that the investment incentives on liberalised electricity markets are not free from problems. Joskow (2006) writes that a “failure of organized wholesale electricity markets to provide adequate incentives to stimulate investment in new generating capacity to balance supply and demand efficiently” has been recognised as a fact by now – at least in the USA. There are examples of markets on which prices and demand increase, on which, however, the investments do not keep step so that bottlenecks are already forecast. UCTE (2007) (also) considers capacity bottlenecks to be possible for Germany as of 2015.

[31] See, however, Joskow and Tirole (2000), Borenstein et al. (2000) and Harvey and Hogan (2000).

In liberalised electricity markets a lack of investment can be connected to the fact that the reliability of the electricity supply is a public good (no one can be excluded from it) so that the benefit from investments cannot be internalised efficiently. Moreover, providers cannot benefit from a prevailing extreme scarcity in the event of a blackout on account of a lack of generation since, typically, a market price does not exist and is not paid during blackout; during the spot market auction, there is an excess supply and an excess demand in the spot market auction – at least if all further efforts at clearing the market fail (chapter 2). Finally, it is also conceivable that price or bidding limits or other interventions in the market as a result of (justified) price peaks imply investment impediments (Ockenfels, 2007b and Grimm and Zoettl, 2007b).

Moreover, the rule applies that even perfect competition cannot guarantee a “sufficient” generation capacity. Figure A.5 in the Appendix illustrates that capacity bottlenecks are absolutely necessary in perfect competition in order to create the required investment incentives. However, this also means that, at an “adequate” capacity level which safely avoids bottlenecks and blackouts, electricity prices are too low to invest in “adequate” capacity. In the case of non-perfect competition, regulation and/ or exercising of market power has to ensure the required investment incentives (e.g. Grimm and Zoettl, 2007a). Neither of the two cases guarantees that the capacity decisions will lead to a reliable electricity supply. This applies, in particular, in the case of a demand which cannot protect itself against involuntary blackouts on account of generation bottlenecks (Ockenfels, 2007a, Cramton and Stoft, 2007).

As an answer to this challenge, some economists propose the establishment of capacity markets as a complement to electricity trading on the power exchange. Capacity markets can be designed as derivatives markets for physical capacity in which the demanders or regulators purchase capacity or buy such at auction in proportion to the expected demand in the future so that the expected system peak load is (more than) covered. A capacity market avoids bottlenecks, curbs market power potentials and price volatilities and leads to robust investment incentives (Joskow, 2006, Cramton and Stoft, 2006, 2007, Ockenfels, 2007a). If the prices generated on EEX are sufficient for efficient investments, the capacity market becomes superfluous quite simply on account of prices to the amount of zero. Hence, a capacity market might be a smart solution in order to enrich the market architecture of the exchange model with a long-term perspective.

### *4.7 Transparency and fairness*

Frequently, the aim of fair and transparent electricity trading is quoted in the political discussion. An expertise by White&Case and NERA (2007) regarding possibilities for the improvement of transparency on the electricity wholesale market provided opinions on this from various perspectives. One essential result of the expertise is that transparency deficits were not identified in the field of the “exchange” information for the spot market auction on the EEX and that, however, the transparency regarding “non-exchange information” on grid load, transmission, transfer points, generation, balancing energy, etc. would have to be improved. In this expertise we would like to supplement the debate regarding transparency with regard to the spot market auction with a few points from the perspective of market design.

From the market participants’ perspective the spot market auction is connected with a number of interdependent markets. Anti-competitive intransparency regarding the “non-exchange” information on behaviour and options in non-exchange interactions referred to herein above is only a transparency question from a secondary perspective in this case; it is rather a question of the suitable market architecture instead. Closely synchronised markets such as those currently pursued with the increasing market coupling lead to the disclosure of many relevant pieces of information in the form of market prices and at the time relevant for the trading participants. At the same time, market coupling leads to a reduction of the value of information advantages since the strategic complexity and uncertainty in the preparation of offers in interdependent markets is reduced. Hence, market coupling leads to more transparency and fairness in the spot market auction automatically as it were. This means market coupling then automatically leads to more transparency and fairness in the spot market auction.

The design of the spot market auction as a uniform price auction supports transparency and fairness at the spot market. The auction leads to a clear reference price which is accessible for every one and which can be used by all market participants in all upstream markets for orientation and strategic planning to the same degree. No supplier can gain price advantages by exercising market power or by means of advantages in information; on the contrary, strategic withholding of capacity leads to a situation in which the supplier exercising market power benefits comparatively little since said party cannot offer all of its capacities into the market – a phenomenon which is sometimes referred to as the “curse of market power” in the literature. For this reason, “big” suppliers cannot exclude “small” suppliers from the price effects resulting from strategic behaviour or information advantages. Moreover, the rules of the uniform price auction are simple, its strategic complexity is low, in particular, for “small” suppliers (which orientate themselves exclusively on their marginal costs) and the bid formats used on EEX are easy to manage. This is another reason why there are neither transparency deficits nor unfair initial conditions which would have to be attributed to the design of the spot market auction on the EEX. With regard to other auction formats, in particular the pay-as-bid auction, however, there would be problems (chapter 4.1).

One possible objection regarding the bid formats would be that “major” suppliers suffer less from a non-optimal consideration of block bids than small suppliers since the former are better able to optimise the internal use of their power plants because of the bigger capacities and are, hence, better able to minimise the start-up costs. Another potential objection is that the algorithms partly reject block bids even though they can produce electricity more cost-efficiently than at the market-clearing price (chapter 4.2). Both consequences appear to be unfair. However, a complete and entirely efficient consideration of block bids in the spot market auction is impossible due to the high complexity of the resulting problem (chapter 4.2). Moreover, the exchange model allows taking into account complementarities by trading for example in upstream electricity markets, such that in practice the remaining problems should be rather small.

Finally, the interaction between repeated interaction in the daily spot market auction and transparency regarding capacities and the behaviour of the market participants is important from the perspective of bidding theory. In particular in the event of a low and fixed number of traders and of low uncertainty regarding demand and supply behaviour further strategic incentives could emerge, which have not been discussed further in the analysis in chapter 4.1. For example, a situation appears conceivable in which the supply is influenced by dynamic strategies in which conditioning on the strategic options or the competitors’ behaviour in the past is effected. On principle, game theory models of repeated oligopolistic interaction permit both more strongly competitive and more strongly co-operative behaviour on the part of the suppliers. For this reason, it appears conceivable that the repeated interaction has an additional impact on market results. However, the theoretical and empirical literature disregards this influence in large parts (even though there are exceptions, e.g. Le Coq, 2004), because clear forecasts are inherently difficult, the issue is reduced or disappears entirely in case of uncertainties (such as those typical on the electricity markets) and because simpler models have proved to be useful and empirically valid in many situations.[32]

However, from the perspective of market design we can, at least, note that the availability of information on the options and behaviour of the competitors in an auction usually tends to have a *negative impact* on the competition in the case of competition problems. After all, information on the availability of power plants and bidding behaviour make it easier for the suppliers to calculate the possible price effect of unilateral withholding of capacities more accurately, to condition their own strategy to the other suppliers' behaviour more precisely and, if applicable to stabilise implied or explicit multilateral collusive agreements, since deviations from agreements are easier to detect and punish. For example, there have been speculations that the increased transparency on account of the changes in the market rules for the balancing energy market, which have been implemented recently, have initially led to increased prices since the additional information has provided the suppliers with important information for optimising the asking prices.

For this reason, the auction literature (Klemperer, 2004) as well as the empirical (Symeonides, 2003), experimental (Huck et al., 2000) and theoretical (Abreu et al., 1985) literature on market power almost uniformly warn against the hypothesis that increased transparency necessarily reduces competition problems (see also Ivalid et al., 2003). On the contrary, it is occasionally recommended that the flow of information between competitors and auction participants be restricted to a minimum (Rothkopf, 1999, Cramton, 2004). This applies, in particular, with regard to electricity spot market auctions where it should be difficult to stabilise collusive dynamic strategies without any additional information on individual bidding options and on bidding behaviour on account of their inherent price and demand volatility.

Withholding of information does not imply that the market cannot be supervised in this case. Strategically usable information could be made accessible to a market monitoring group or regulating unit in an up-to-date manner without any competitive risks (Towmey et al., 2006). Moreover, information which permits an insight into the less transparent transactions concluded off the exchange could also be inquired and

[32] See e.g. Sannikov and Skrzpacz (2007), who show that collusion is not possible even in case of repeated interaction in homogeneous products and "noisy" information received continuously, or Rothkopf (1999) and Fabra (2003) - specifically on power markets.

collected and could, hence, help to build trust. This information could partly also be published with a delay in time. The request for increased transparency and supervision, which is sometimes put forward, is, hence, not inconsistent with the demand for a restricted flow of information only before and during the electricity market auction.[33]

## 5 A comparison of European power exchanges

A liberalisation process similar to the one of the German electricity market has taken place in most European countries. Figure 5.1 shows the development of the wholesale prices at power exchanges in selected European countries, which we will analyse in more detail below.[34] This includes NordPool (Scandinavia), APX Power NL (Netherlands), Powernext (France), APX Power UK (Great Britain) and Omel/ OMIE (Spain).

[33] Frequently, there is less of a lack of data and transparency but a lack of the required expertise in order to interpret the available data properly, in particular, on power markets. For this reason, professional power market monitoring the central tasks of which comprise the identification and independent evaluation of problems in trading behaviour, the structure of power generation and the architecture of the power markets is sometimes called for (Ockenfels, 2007a, Wolak, 2004, Towmey, et al. 2006). Such problems can emerge, in particular, in long-term capacity developments (chapter 4.6), which determine the future developments of the prices and the security of supply to a decisive degree.

[34] Not least in the framework of the European harmonisation efforts all exchanges are in a highly dynamic process of institutional change, which is only documented in a decentralised manner and with varying degrees of accuracy. We have endeavoured to compile the current status on the basis of the different websites of the exchanges and of other sources. We regret that we might not have been able to do this in fine detail in full.

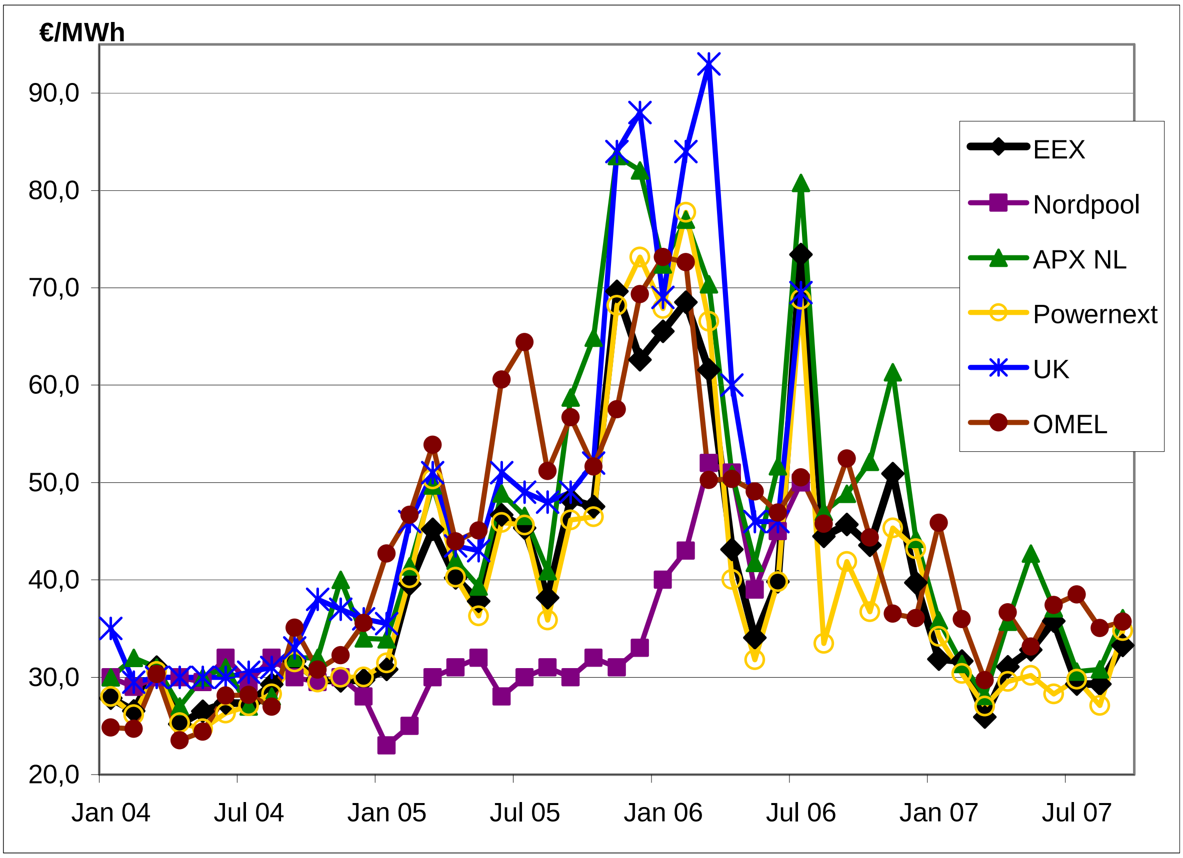


**Figure 5.1.: Exchange prices in Europe (monthly averages; source: EEX, APX, Powernext, Omel, DG Energy and Transport)**

During the period presented the EEX prices are generally at or below the average range of all observed prices (cf. Energy Sector Inquiry 2007). Price differences can be due to different competition structures, different cost structures[35] or different market designs in the individual countries.

Table 5.1 provides an overview of central competition parameters and institutional characteristics of the European power exchanges described in this chapter. The last two lines convey an impression of the size of the individual exchanges in their respective market areas according to DG Competition (2007b):[36] "Volume DA" reflects the quantities traded on the day-ahead market on the exchange with reference to the total consumption in the market area. The total day-ahead quantities

[35] For example, in Great Britain gas-fired power stations are usually price setting while the prices in Scandinavia are not that dependent on price fluctuations on the gas market and the development of the prices for emission allowances (from 2005) because of a high share of hydroelectric power and low effects of emission trading.
[36] These are average values for the period of time from June 2004 until May 2005. The quantities traded on the most important OTC platforms quantify the extent of trading off the exchanges.

traded in the market area, i.e. including all transactions concluded bilaterally, are specified in brackets behind these figures. The liquidity of the day-ahead markets in Scandinavia and Spain, which is relatively high, compared with EEX, and the relatively low liquidity in Great Britain is (also) explained by the respective market design as will be shown in the following sub-sections. Likewise, “Volume Derivatives” specifies all forward and futures transactions concluded on the exchange and bilaterally. The fact that spot market auctions have a liquidity which is low compared with the total turnover and that the exchanges play a comparatively important role in day-ahead trading, while a considerable part of the futures transactions is traded bilaterally (chapter 3, 4.1 and 4.2), is consistent with the theory and, at least, not detrimental for the efficiency of the electricity markets. Lines 5 to 7 show the number of market participants officially registered and active at the exchanges, which partly display considerable variation.[37] The other lines in table 5.1 summarise the respective institutional framework conditions in exchange pricing in the different countries. The table demonstrates that, apart from many common features, there are also significant differences in the organisation of the market.

[37] See DG Competition (2007b). According to the definition all those market participants are considered active which have traded at least 0.5 percent of the total volume of the exchange during the period of time from January 2005 until May 2005. In this context, the first number refers to bids regarding hour 3 and the second number refers to bids regarding hour 12. If only one number is specified, a differentiation according to hours could not be made on account of a lack of data. No differentiation according to hours could be made for the NordPool market area – the values specified, however, refer to the different areas in the following order: Sweden, western Denmark, Finland, and eastern Denmark.

| | | EEX | Nord Pool | APX NL | Power-next | APX UK | Omel |
|---|---|---|---|---|---|---|---|
| **Allgemein:** | | | | | | | |
| Market area | | DE, A, CH | NOR, SE, FIN, DK | NL | F | UK | E |
| Bid floor | | 0 | 0 €/MWh | 0,01 €/MWh | 0,01 €/MWh | - | n.a |
| Bid cap | | 3000€/MWh | 2000 €/MWh | 3000€/MWh | 3000€/MWh | - | n.a. |
| Trading days per week | | 5 | 7 | 7 | 7 | 7 | n.a. |
| Trading participants (Spot) | licensed | 153 | 124 | 50 | 66 | 57 | 670 |
| | act. sellers | 35-26 | 24,19,14,7 | 23-24 | 27-28 | 18-19 | 15-13 |
| | act. buyers | 31-36 | 7,16,9,7 | 24-22 | 29-32 | 15-19 | 6-7 |
| **Day-ahead trading** | | | | | | | |
| **Continuous trading** | hours | - | - | - | - | yes (1/2 h) | - |
| | blocks | yes | - | - | yes | yes | - |
| | from - to | 8 - 12 | - | - | 7:30-11:30 | rolling 2 Days | - |
| | | | | | | | |
| **Auction** | hours | Ja | Ja | Ja | Ja | - | yes |
| | multi-part | blocks | blocks | blocks | blocks | - | yes |
| | gate closure | 12 | 12 | 11 | 11 | - | 10 |
| **Intraday trading** | | | | | | | |
| Hours | | yes | yes | yes (1/4 h) | yes | yes (1/2 h) | yes |
| Multi-part | | blocks | blocks | blocks | blocks | blocks | yes |
| Trading model | | continuous | continuous | continuous | continuous | continuous | auction |
| Trading hours | | 24/7, DA as of 3:00pm | 24/7, DA as of 2:00pm | 7:30am-6:00pm, DA as of 12:00pm | 7:30am-11:00pm, DA as of 11:30am | 24/7, as of 2 days before delivery | 6x, Interval of 105 minutes |
| Before physical delivery | | 75 min | 60 min | 120 min | 60 min | 60 min | 135 min |
| **Congestion management** | | | | | | | |
| within market area | | Redispatch | Splitting/ Redispatch | Redispatch | Redispatch | Redispatch | Redispatch |
| between market areas | | only explicit | only explicit | coupling: NL/B/F | coupling: NL/B/F | only explicit | only explicit |
| between market areas (planned) | | coupling: Nordpool and NL/B/F | coupling: NL/B/F and DE | coupling: Nordpool and DE | coupling: Nordpool and DE | coupling: NL/B/F | splitting with P approx. as of 2008, coupling with F |
| | | | | | | | |
| **Further products** | | S-Futures, CO2, Gas | S-Futures, other S-Futures, CO2 | CO2, Gas Endex: S-Futures | S-Futures, CO2, Gas, Weather | S-Forwards, CO2 | - |
| **Quantities (in % of concumption):** | | | | | | | |
| Vol. DA exchange (total) % | | 13,2 (18,6) | 42,8 (n.a.) | 11,9 (17,8) | 3,4 (4,9) | 2,2 (n.a.) | 84,0 (84,0) |
| Vol. Derivatives exchange (total) % | | 74 (639) | 196 (523) | 39 (548) | 6 (85) | n.a. (146) | 0 (n.a.) |

**Table 5.1: Overview of the power exchanges**

If we look at the situation internationally, two competing market models have been established in the design of liberalised electricity markets: the pool model and the power exchange model (chapter 3). On the liberalised electricity markets of Europe, however, the power exchange model has been fully implemented by now. With the exception of Great Britain, uniform price auctions are used everywhere within the exchange model. In pre-trading and post-trading there are, however, significant differences. Even though block bids are also taken into account on all markets, this is partly done in different bid formats. The synchronisation of generation and transmission markets is controlled by different institutions in parallel with the respective relevance in the different market areas. The respective rules and regulations for electricity trading are described below and, in as far as this is relevant, they are compared with the rules on EEX, which have already been introduced in chapter 2.

## *5.1 NordPool*

The northern European power exchange NordPool comprises the market regions of Norway, Sweden, Finland and Denmark. At NordPool electricity trading is offered on seven days per week over 24 hours each, i.e. around the clock. In this process, various markets interlock as we will describe below.

On the “Elspot” day-ahead market the market participants can submit a bid function, which can comprise up to 62 price steps in addition to the upper and lower limits for bids specified by NordPool (EUR 0 and 2,000 per MWh), for every hour of the following day. After the central auction, which takes place at 12:00am, there is an intraday market (called “Elbas”) on NordPool. Since 10 January 2007, the market area has been extended to include Germany, in addition to Sweden, Finland and eastern Denmark. Intraday trading commences at 2:00pm on the preceding day and ends one hour prior to physical delivery. Prior to the central spot market auction single hours can be traded in continuous trading via the platform of the exchange. In parallel, both hours and blocks can be traded via a phone platform in addition.

Block bids are possible in the day-ahead auction. Blocks can consist of any contiguous hours; however, they have to comprise at least one hour. Whereas the hourly bids can be accepted independently of each other as well as partly in each case, a block bid can only be executed in its entirety.[38] In addition to this, NordPool offers two comparatively innovative bid formats. Initially, the bidders have the possibility of placing each one of their block bids in a hierarchy of mother and daughter block bids and a third block bid dependent on acceptance of both the first and the second bid. A daughter block bid or the third block bid can only be accepted if the higher-ranking block in the hierarchy is accepted. This conditioning option

[38] If a market participant wishes to prevent a situation in which only a part of bid for a certain hour is taken into account, said participant can submit the bid as a block bid.

enables a more precise consideration of complementarities in the costs than would be possible with standard block bids. For example, the mother block bid can allocate the start-up costs to the first hour of use, so that the daughter block bid and the third block bid dependent on acceptance of both the first and the second block bid do not have to include this in their pricing any more. This makes it easier for the bids to reflect the dynamics of the costs actually incurred, which tends to facilitate bidding and promote cost efficiency.[39]

Secondly, the so-called “flexible hourly bid” is also helpful. This is a sell bid with a reservation price and a fixed quantity which is allocated to the hour with the highest market clearing price where the market clearing price is higher than the reservation price. This bid format is advantageous for both bidders and the exchange. It facilitates the solution of intertemporal optimisation problems for the bidders since price forecasts are no longer necessary for certain applications. On the one hand, this applies to large industrial electricity consumers on the demand side which are ready to suspend their production for a restricted period of time in the event of very high market prices in order to be able to sell electricity from their existing contracts on the market. On the supply side, power plants which can only produce a restricted quantity of electricity during a given period of time, such as pumped storage hydro power stations, benefit from this. For the exchange this bid format is interesting since it reliably relieves peak hours.

Both bid formats could also be considered for the German spot market auction. However, it appears likely that the flexible hourly bids will be used significantly more frequently in Scandinavia than in Germany because of the higher share of hydroelectric power stations there. On the other hand, the integration of bid formats which can potentially promote efficiency appears to cause low costs at most so that their introduction should be considered.

NordPool is the only European power exchange on which market splitting is carried out. In this process, the market is divided into individual partial regions whose borders are located within Norway and on the border-crossing points between the

[39] This means that in the numerical example from chapter 4.2 the supplier can submit a mother block bid to the amount of EUR 50 per MWh for the first hour during which the start-up costs are actually incurred and a daughter block bid to the amount of the variable costs of production of EUR 20 per MWh for the second hour. By establishing these conditions the supplier can protect itself against losses caused by declines in prices or a non-use during the second hour and the market operator can implement an efficient allocation.

individual countries. If there are no transmission bottlenecks between two regions for the balanced allocation in the spot market auction, the market price for both regions is the same. If, on the contrary, transmission bottlenecks arise between two regions, the prices of the respective regions concerned cannot be fully adjusted. Market splitting takes all of the transactions concluded so far (frequently also bilateral contracts), which have to be reported in advance for this reason, into account. Moreover, transmission capacity within the territory of application of market splitting can only be “blocked” provided there is an electricity trading contract which needs this capacity for transmission. If transmission capacity on the borders of the countries concerned is still available after the central day-ahead auction, it can be used for quantities traded in intra-day trading. All in all, these rules ensure that capacities only remain unused if there is really no one wishing to use this capacity. Within the remaining regions (Sweden, Finland and Denmark) transmission system bottlenecks are resolved by means of a re-dispatch.

External transmission system capacities (between the NordPool regions and neighbouring countries) are awarded in explicit auctions. Such auctions for the allocation of international transmission capacities have been common on numerous European borders for some years, even though they make co-ordination more difficult compared with implicit mechanisms. Usually, the transmission system operators of the neighbouring countries share the revenue. In the auction transmission rights for a certain period of time are acquired and the respective electricity trading contracts then have to be synchronised accordingly.

Coupling of NordPool with the markets in Germany (EEX) and Holland (APX) is planned for the near future.[40] The allocation of the international transmission capacities between the countries concerned will probably be integrated into day-ahead exchange trading in the framework of market coupling.

Since sufficient transmission capacities are usually available or have usually been available within Germany, market splitting is not carried out here. However, in the medium or long run, there are reasons for thinking about a market-oriented system of bottleneck management within Germany. For example the trend towards the reinforced construction of power plants (including off-shore wind capacities) in the north and the concentration of consumption in the south can soon lead to increased

[40] Cf. the Memorandum of Understanding of 2 November 2006 (regarding market coupling between Denmark and Germany) and the letters of intent regarding market coupling within the framework of the NordNed connection between the Netherlands and Norway. See e.g. www.nordpoolspot.com.

transmission bottlenecks. In this case, the optimisation of the use of transmission capacities at the time of electricity trading has to be preferred over a solution by means of re-dispatching. One reason for this is that the costs for the re-dispatch are socialised by the transmission system operator directly through the grid charges and that this sets inefficient incentives regarding the allocation of demand, electricity generation and transmission capacity.

One result of the market splitting in Scandinavia is the high liquidity of the exchange since international transmission capacity can only be acquired on a day-ahead basis on the exchange in connection with a power contract. This liquidity effect can also be expected in cases where several exchanges are coupled as has been suggested for EEX in the framework of market coupling with various exchanges. If the allocation of the transmission capacity on the borders of the trading areas is integrated into exchange trading, market coupling achieves the same effects as market splitting: In this case, the exchanges constitute the mandatory trading platform for international day-ahead transactions.

### *5.2 APX Power NL*

Recently, the auction has been held at 11:00am (instead of at 10:30am as before) on the Dutch APX (Amsterdam Power Exchange). This enables market coupling with Belgium (BeLPeX) and France (Powernext). Both hourly and block bids between EUR 0.01 and 3,000 per MWh can be placed in the central auction (the interval of the possible bids has also been changed on account of market coupling). Blocks can consist of any contiguous hours; however, they have to consist of at least one hour. Blocks can only be accepted in their entirety as regards both the volume specified and the period of time specified. Before the central auction (11:00am) electricity for the following day (DA trading) cannot be traded on APX in Holland.

On 14 September 2006, an “intra-day and strips” market was launched on APX. Here, continuous trading is possible after the auction from 12:00am until 6:00pm of the preceding day and from 7:30am until 6:00pm of the delivery day. On the APX strips market, a number of standardised block contracts (2h blocks, Base: 00am-12pm, Peak: 7am to 11pm, Super Peak: 8:00am to8:00pm, Off-peak: 11pm to 7am) can be traded continuously in addition to random single bids with a duration of 15 min. Trading is only possible until 2 hours prior to physical delivery.

Transmission bottlenecks do not play any explicit role on APX. They are only taken into account after schedule reporting by means of a re-dispatch by the Dutch transmission system operator.

External bottlenecks (except on the borders to transmission to Belgium and France) are allocated in explicit auctions. The bottlenecks to Belgium and France are allocated in the framework of market coupling with BelPeX and Powernext, which is described in chapter 4.3.

All in all, the rules of APX are similar to those for the German market. However, unlike the situation in Germany, there is no continuous trading prior to the spot market auction. There is, however, the possibility of trading blocks even after the auction in intraday trading. Intraday trading ends a little earlier (2 hours prior to physical delivery, in Germany 75 minutes prior to physical delivery); moreover, trading is suspended at night.

### *5.3 Powernext*

On the French exchange Powernext day-ahead continuous trading is offered with 11 standardised blocks between 7:30am and 11:00am and a central auction is held at 11:00am. Individual hours, 11 standardised blocks or blocks which are defined individually but comprise at least two hours are tradeable products. The standardised blocks comprise the following time intervals: 0:00am to 4:00am, 4:00am to 8:00am, 8:00am to 12:00am,12:00am to 4:00pm, 4:00pm to 8:00pm, 8:00pm to 12:00pm, 0:00am to 12:00pm, 8:00am to 8:00pm, 0:00am to 6:00am, 0:00am to 8:00am, 8:00am to 4:00pm.

Moreover, an intraday market on which trading is possible after the auction from 11:30 am to 11:00pm of the preceding day and from 7:30am to 11:00pm of the delivery day and until 60 minutes prior to the physical delivery has been available since July 11, 2007. In this case, the products are also individual hours, 11 standardised blocks and blocks defined individually but comprising at least two hours. Moreover, futures, gas and CO2 emission allowances are traded on the French Powernext. The organisation of the French market also resembles that of the German market. The central difference between these two countries is that France has already implemented market coupling with neighbouring countries while this is still in the planning stage in Germany.

Market coupling between APX, BeLPeX and Powernext in the day-ahead market was launched on November 22, 2006. The exchanges involved have harmonised the relevant rules for that purpose. This concerns primarily the timing for the day-ahead auctions which are now held at the same time, i.e. 11:00am. However, this also comprises technical details such as upper and lower limits on bids (EUR 0.01 to 3,000 per MWh). The timing of market coupling is illustrated in figure 5.2. The advantages of market coupling have already been discussed in chapter 4.5 and they have also been covered in the framework of the evaluation of market splitting in chapters 4.5 and 5.1.

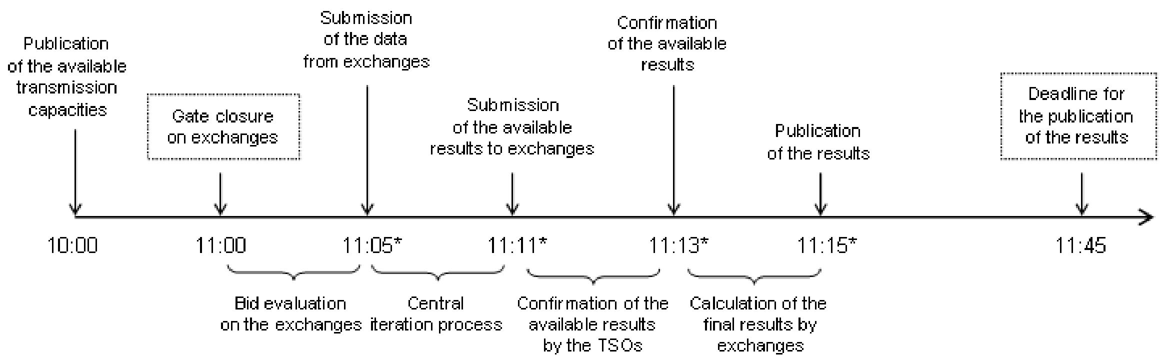


**Figure 5.2: Typical time sequence for market coupling (source: APX)[41]**

According to the prevailing opinion, market coupling of these three regions is a success.[42] The utilisation of the international transmission capacities has increased considerably. Table 5.2 shows that there is no shortage in 58 percent of the cases. At these times, there is a joint market on which all market participants of the three countries concerned compete completely.

| | (NL&B&F) | (NL&B/F) | (NL/B&F) | (NL/B/F) |
|---|---|---|---|---|
| Frequency | **58%** | **28%** | **12%** | **2%** |
| | | | | |

**Table 5.2: Results of market coupling, average values for November 2006 to August 2007 (source: APX)**

The experience with market coupling between France, Belgium and the Netherlands primarily demonstrates that all market rules do not have to be harmonised by any means in order to achieve a coupling of the central day ahead spot market auctions leading to a more efficient use of the transmission capacity. Whenever the suppliers

[41] Times marked (*) designate only one typical sequence.
[42] There are concrete plans for extending this market coupling to Germany and Luxembourg. Cf. the Memorandum of Understanding of 6 June 2007 by and between the regulatory authorities, the transmission system operators, the power exchanges and market participants concerned from the 5 countries of Belgium, France, Germany, Luxembourg and the Netherlands with regard to this.

have to expect that transmission bottlenecks are not found in coupled markets (i.e. if there is only one market area), they are not only facing domestic competition but also foreign competition on the exchange. Since the price of the day-ahead auction is a reference price to which derivatives transactions of the exchanges also refer, international coupling of the day-ahead auctions also has an impact on the pricing level of the remaining electricity trading markets including all derivatives transactions. For this reason, market coupling has the potential enabling it to significantly curb prices.

### *5.4 APX Power UK*

Great Britain was one of the first countries with a liberalised energy market. The so-called UK Pool was introduced as early as in 1992. However, the centralised pool model was replaced by NETA (New Electricity Trading Arrangements) in 2001. Finally, BETTA (British Electricity Trading and Transmission Arrangements) went into effect in 2005.

As a result, Great Britain today has a market with a strongly decentralised organisation in which market participants can trade electricity in a sequence of overlapping markets. The suppliers themselves are in charge of the use of the power plants and the co-ordination with the transmission system operator.

On the only power exchange, APX Power UK,[43] electricity is traded on two different markets in parallel. Half hours and smaller blocks bids are traded on the so-called “Spot Market” on APX UK, whereas bigger blocks are traded on the “Prompt Market”.

On the Spot Market, trading is offered exclusively in continuous trading around the clock. As of seven days before the physical delivery of electricity the 6 different 4-hour blocks 11:00pm to 3:00am, 3:00am to 7:00am, 7:00am to 11:00am, 11:00am to 3:00pm, 3:00pm to 7:00pm and 7:00pm to 11:00pm can be traded. As of two days before physical delivery 2-hour blocks (11:00pm to 1:00 am, etc.) and individual half hours can be traded. Continuous trading of all products on the Spot Market takes place until 60 minutes before physical delivery.

On the Prompt Market, the following blocks are traded as of seven days before the physical delivery of electricity: Overnight (11:00pm to 7:00am), Block 3+4 (7:00am to 3:00pm), Peak (7:00 to 7:00pm), Off-Peak (7:00pm to 7:00am), Extended Peak (7:00am to 11:00am) and Base (0:00am to 12:00pm). Moreover, blocks are also

[43] It is owned by APX Group just like the Dutch power exchange APX Power NL. During the transition stage there were several trading centres operating in parallel.

traded explicitly for the weekends and base and peak contracts are also traded explicitly for a whole week. Price fixing on the prompt market takes place twice every day at 12:00 am and at 6:00pm.

Transmission capacities abroad and potential bottlenecks within the market area are not taken into account during the sale on the exchange.

Moreover, UK Forward contracts (i.e. long-term contracts with physical delivery) as well as emission allowances are traded on APX.

While the market structure resembles the German structure to a considerable degree in Great Britain, the market micro-design differs in some central aspects. The most important aspect is the lack of a central spot market clearing auction for day-ahead trading in the form in which such is found at all other electricity markets discussed within the present report. As a consequence, there is no clear reference market price for electricity for market clearing in Great Britain. This reduces the transparency of electricity trading and increases the likelihood of inefficiencies, since arbitrage transactions result to be more difficult.

At the same time, the British design illustrates a central aspect of the analysis of the pricing rules in chapter 4.1. The pay-as-bid rule is applied in exchange trading in Great Britain. As it were, per definition, pay-as-bid mechanisms make the determination of a clear reference price for arbitrage transactions and electricity trading more difficult and, hence, reduce transparency. This probably also contributes to a central problem on APX UK: the insufficient liquidity which amounts to only approx. 3 percent of the load. The low degree of acceptance of the power exchange is self-reinforcing and leads to a situation in which liquidity steadily decreases.

### *5.5 OMEL*

The Spanish market is also organised as a sequence of overlapping markets. The companies can conclude long-term bilateral transactions or trade on the day-ahead and on the intraday market of the power exchanges OMEL/ OMIE (Operador del Mercado de Electricidad/ Operador del Mercado Iberico, Espana). Similarly to the electricity markets described so far, a central spot market auction for market clearing is also held here (at 10:00am) and intraday trading also takes place. This means the general design of this electricity market resembles the markets analysed so far.

However, there are a number of special control elements which differentiate the Spanish market from other exchange-based market designs. For example, participation in trading on OMEL/ OMIE is generally voluntary; however, the suppliers receive special payments, so called capacity payments, which make trading on this platform more attractive than pure bilateral trading, such as e.g. in the framework of OTC transactions, spot trading on the exchange. This is the reason why the spot market of the Spanish exchange accounts for by far most trading compared with other trading platforms (table 5.1).

Another special feature on the Spanish market which is incompatible with competitive pricing is that the difference between the consumer price and the exchange price (minus the transactions costs) is paid to the suppliers during the “transition stage” which still continues after liberalisation. These payments are referred to as “Competition Transition Costs” (see Fabra and Crampes, 2005 for more details).

On the day-ahead market, the market participants can submit bids for individual hours and blocks for the following day just like at the other power exchanges. Moreover, further specifications of the bids are permissible. It is, in particular, possible to specify indivisibilities and minimum returns, load gradients and planned maintenance times. Such multi-part bids permit a more precise specification of the complementarities described in chapter 4.2 and other special characteristics in electricity generation than is possible with block bids such as those available on the remaining market platforms. At the same time, however, the rule applies that more complex bid formats are required to a special degree in Spain because of the high liquidity since complementarities cannot be taken into account by means of transactions concluded off the exchange to the same degree to which this is e.g. possible in Germany. Moreover, the side payments which are connected with multi-part bids are easier to enforce if the market participants are connected with the exchange as it were through the capacity payments. However, it is unlikely that the underlying algorithms for the calculation of the allocation and side payments can create efficiency (chapters 3 and 4.2).

Subsequent to the central day ahead auction, intraday trading takes place. Different from the other electricity markets where intraday markets are organized with continuous trading only, intraday trading in Spain is organised in six consecutive clearing auctions. The products traded are the same as those traded on the day-ahead spot market. Intraday trading is possible until 135 minutes before physical delivery. Such a sequence of clearing auctions can, however, create room for co-ordination failure and forecast errors which do not have to be expected in continuous trading (chapter 4.5, Milgrom, 2004).

Possible congestion of the transmission system is not taken into account at the day ahead electricity Spot market in Spain, but is resolved after the spot market by re-dispatch. Moreover, the transmission capacities to the neighbouring countries Portugal and France are not taken into account in trading on the spot markets so far. For some time, however, there have been detailed plans for a complete integration of the electricity markets on the Iberian Peninsula within the framework of market splitting. This is to be effected under the auspices of the Iberian market operator OMI in the framework of the MIBEL project. In this process, the market activities would be divided among the two countries: In this case, the entire spot trading would take place on the Spanish exchange OMEL/ OMIE exclusively, while all long-term trading transactions would be concluded exclusively on the Portuguese exchange OMIP. The market integration of the spot markets in particular and the questions connected with this regarding the management of bottleneck capacities have, however, proved to be difficult. Portugal favours the re-dispatch, while Spain favours market splitting on the basis of the NordPool model.

One further particularity of the Spanish market can be found in the fact that the consumer prices are fixed. In practice, the regulated consumer price is occasionally interpreted as a price cap on the exchange price. However, the question of what happens when procurement prices on the exchange increase to above the consumer price has not been resolved.

All in all, the Spanish market combines a number of deviations from pricing at marginal costs and non-competitive elements in paying the generating companies as well as a number of special provisions and side and additional payments. This results in trading which is very likely to be comparatively inefficient, which, ultimately, has to lead to relatively high electricity wholesale prices. The high concentration of trading on the Spanish spot market (because of the capacity payments), in particular, connected with the restriction of the consumer prices reminds us of the situation in California before the collapse of the market in 2001. At the time, many observers and analysts criticised the insufficient trading on the derivatives market which not only protects various sides of the market against price risks but can also reduce incentives to exercise market power. Moreover, in view of increasing wholesale prices and capacity bottlenecks, the restriction of consumer prices in California led to a situation in which numerous utilities became insolvent so that the state had to help out and buy electricity on the wholesale market (see e.g. Borenstein, 2002 for the details). It does not appear unlikely that the Spanish wholesale market might also be prone to such risks because of its insufficient institutional design.

## 6 Conclusion and Executive Summary

*Market macro-structure.* No liberalised electricity market can manage without a multilateral trading platform. However, the design of such trading platform differs between electricity markets. All European electricity markets are based on the so-called power exchange model which is characterised by voluntary exchange trading and a decentralised market organisation and decisions. The advantages of the power exchange model include that the resulting market clearing prices generally allow for an efficient dispatch of power plants and send accurate investments signals. Furthermore demand side bidding can be integrated without any problems and competition among the trading platforms provides alternatives and adjustment pressure in the case of deficient or inefficient market design. The so-called pool model which is frequently implemented in other countries outside Europe, which implies mandatory participation of all suppliers, provides an alternative form of organisation. The advantages of such a central organisation include, in particular the close co-ordination and synchronisation of generation, transmission and balancing energy.

In a perfect, completely competitive world both macro-structures tend to achieve comparable results regarding efficiency and market prices. In practice, however, decentralised exchange models have advantages if the co-ordination of interdependent markets is comparatively insignificant (e.g. because transmission bottlenecks are rare) or if close co-ordination is already achieved by means of a suitable market architecture (e.g. because of implicit mechanisms and market coupling). On the other hand, pool models are advantageous if competition is strong or can be regulated effectively, if demand side bidding does not play a big role and if the deficits of a centralised system optimisation, which always occur in practice, can be kept small.

With regard to Germany, it appears difficult to evaluate whether a pool model would have done better in the past since it remains unclear in how far it would have been possible to regulate the market participants' behaviour effectively in the overall system. With regard to the future, a move towards the pool model is out of the question for Germany since all neighbouring electricity markets have implemented exchange models and a switch to the other system by a single country only would imply dis-integration from the European electricity market. A change of the entire European system might be conceivable theoretically; however, this would entail high risks and uncertainties at least during the transition stage. The resulting benefit, on the other hand, would be low, since increasing co-ordination of the national markets and the synchronisation of the different subsequent electricity markets, makes centralized coordination by a pool model less important.

*Market microstructure.* The pricing mechanism of the day ahead electricity spot market auction on the EEX is consistent with the recommendations suggested by the modern economic research on the design of electricity markets and auction theory. The uniform price auction used by EEX, in particular, has a number of well-documented advantages compared with other pricing mechanisms discussed. These advantages include a high transparency, a clear reference price, the same prices for all market participants, no relative advantages due to asymmetric information or market power and finally self-enforcing competitive incentives. In the case of sufficiently competitive behaviour the uniform price auctions leads to complete efficiency (efficient dispatch of power plants in the short term and efficient investment incentives in the long term) and to the lowest possible prices on the electricity market. For the case of market power, no other pricing procedure systematically leads to lower expenditure on electricity or to higher production efficiency.

Because of its advantageous properties the uniform price auction is the dominating pricing rule on all liberalised electricity markets. In Europe, Great Britain was the only country which decided against the uniform price auction – at best with mixed success. The lack of a reference market clearing price and the missing liquidity on the electricity market exchange, which is probably a consequence of the former, the incentives for strategic bidding even on non-concentrated electricity markets and the self-reinforcing incentives for exercising market power tend to have a negative impact on the efficiency of the market. Other market areas, such as California, have decided against the pay-as-bid auction after theoretical discussions and evaluation of practical experience.

Changing only small details of the existing spot market design has to be evaluated carefully since even minor changes of those rules can trigger big changes of the participants' incentives. We recommend to EEX to retain the current pricing rule for the day ahead spot market electricity auction without any restrictions. We warn, in particular, against direct interventions in pricing as well as against indirect interventions, e.g. through a restriction of the bidding flexibility. In decentralised markets, which allow for any kind of arbitrage transactions, changing the rules of the spot market auction will not lead to a market clearing price below the costs of the last (most expensive) unit of electricity produced. That is, price caps based on total average costs, obligations to offer or similar interventions and restrictions at the spot market will not lead to a systematic and sustainable reduction of total expenditures for electricity, as fundamental economic principles show. This is true for power exchange-oriented electricity markets both with and without market power. However, this does not imply that market institutions and market rules are irrelevant. But while direct intervention at the electricity spot market would do more harm than good, the exercise of market power can much better be restricted systematically by means of the co-ordinated connection of the spot market auction of previously hardly connected electricity markets (see below).

In addition to the preservation of the current spot market design we recommend a revision as to the question of in how far the bid formats can be made more flexible beyond the existing rule in a manner which is beneficial to the market participants. For example “conditional” and “flexible” bids, such as those used at NordPool, as well as negative price bids can reduce the strategic complexity for the market participants and better comply with the complementarities in the generation of electricity. If these and other proposals regarding a further flexibilisation of the bid formats are supported by the market participants, both residual short-term and long-term efficiency potentials in electricity generation can be utilised and prices could be curbed by tendency. This applies all the more since trading and liquidity at the power exchanges will probably increase after having introduced market coupling. Then bidding flexibility plays an even more important role in order to achieve cost efficiency. Competitive or strategic disadvantages are not to be expected at least for the proposals specified above.

*Market coupling.* Because of the unanimous choice of the power exchange model in the European Countries, those electricity markets are largely identical in their macro-structure. Moreover, there are far-reaching similarities in the microstructure as regards the pricing rule, bid formats and timing as well as the connection of trading activities within the exchanges. The most notable exceptions include Spain (distorting and inefficient incentive elements), Great Britain (deviating pricing rule) and NordPool (more flexible bid formats). Apart from the exceptions referred to above, the institutional design of the German power exchange resembles the rules and regulations of the other trading platforms in all central elements. The biggest difference and the highest dynamics are found in the degree of international co-ordination and cross-border integration of the different electricity markets. EEX is also making efforts to implement market coupling with NordPool as well as the Netherlands, Belgium and France. Unlike the changes in the market macro- or microstructure, these co-ordination efforts are particularly suited to placing the electricity markets on a more solid foundation in many respects. Market coupling permits the efficient co-ordination of generation, transmission and balancing energy, which can, otherwise (by means of "explicit" mechanisms), only be achieved inefficiently. Efficient congestion management also leads to bigger relevant markets giving rise to increased competition. Those two implications of market coupling have the potential to significantly reduce costs and prices and to significantly increase competition. At the same time, market coupling leads to more transparency and fairness, since the relevant information on shortages and relative prices in the different, interdependent markets, can directly be taken into account by all market participants at a synchronized market. For this reason, we expressly recommend that, in view of the very encouraging results so far, coupling of the spot market auctions be developed further as an instrument for the co-ordination of partial markets, the restriction of market power and increasing transparency in line with the competition.

In further steps, coupling of intraday trading and of the markets for balancing energy as well as developments towards market splitting and nodal pricing, in addition to this, appear to be very promising. The limits of these additional developments will be set by the high and complex requirements for market participants and platform operators, which increase quickly with a more pronounced coupling of the markets.

The example of market coupling shows that the architecture of the market requires active design efforts not least because of the technical and economic particularities of the electricity market. Market coupling permits the optimisation of all trading activities in the short run. The consensus among energy economists, in particular in the USA, increasingly appears to be that the introduction of a (suitable) capacity market will facilitate the optimisation of the trading activities in the long run. As a complement to exchange spot trading, a capacity market can lower investment risks, reduce price volatilities and promote market entry. Since, however, this discussion has not yet arrived in Europe and since it does not concern the core of this expertise, we would like to leave it at this suggestion here.

## Appendix: Fundamental economic principles for electricity pricing

While the market clearing prices at power exchanges are established through the interaction of fundamental, strategic and institutional factors, there is a number of observations which are generally valid for electricity wholesale markets organised on the basis of competition. Those are largely independent of the respective details of the market structure and market rules. These fundamental principles are described in this chapter in as far as they are relevant for the analysis of the market rules and for the challenges put to market design.[44]

> **Observation 1.** *In electricity wholesale markets, the supply is determined by the marginal costs of generation to a decisive degree. These costs increase considerably, in particular, on the capacity limits.*

In the operational decision as to as of which price electricity is offered the *marginal costs* of production play the central role on all markets organised on the basis of competition. By definition, marginal costs are those costs which are incurred when a supplier produces *an additional* output unit. A supplier which cannot achieve a price at least equal to the amount of the marginal costs will, hence, not offer any additional output units. This rule applies both in markets without any market power and in oligopolistic competition, even though in the latter case prices which are above the marginal costs can also be asked.

The marginal costs of electricity production include, in particular, the fuel costs and other *variable* costs of production. In addition to this, the opportunity costs, which arise if the production resources are not used in the manner with the highest possible value, are also part of the marginal costs. In electricity markets, opportunities arise in a number of interdependent markets. Electricity which is sold on balancing energy markets or on neighbouring exchanges obviously cannot be sold in the spot market auction, so that the price of balancing energy and/ or prices on other markets can play a role for the clearing price in the spot market auction. Emissions trading provides another example of opportunities. Tradeable certificates have a market value to the amount of the price of the certificate. The "consumption" of certificates in the production of electricity prevents the possibility of selling the certificates in

[44] See Stoft (2002) or Ockenfels (2007a) for partly supplementary presentations.

emissions trading; for this reason, it causes (marginal) costs. As a result of this, certificate prices are relevant for the electricity price.[45]

The most important particularities of the electricity market include the fact that electricity cannot be stored (efficiently and in large quantities). For this reason, the generation and consumption of electricity have to be balanced at all times since, otherwise, frequency fluctuations in the grid with the consequence of blackouts might arise. As a result of this, the generation of electricity has to be able to respond flexibly to short-term fluctuations in the demand and in the production capacity. Therefore, production is characterised by a mixture of heterogeneous types of power plants with different costs structures reflecting this flexibility. Base-load power plants (for example nuclear power plants) usually operate for most of the time of the year and are characterised by high fixed costs and low marginal costs, while peak-load power plants (for example gas turbines) are only used as needed and have comparatively low fixed costs but, typically, high marginal costs.

For this reason, the supply on electricity markets is characterised by an extraordinarily heterogeneous cost structure. In the base-load range, the supply curve on the electricity market is typically flat, while it is steeper closer to the capacity limit. Figure A.1 shows a stylised overview of what the supply in the electricity market looks like.[46] At higher prices, the suppliers are prepared to offer additional electricity. While base load only generates low additional costs, peak load has to ask considerably higher prices in order to be able to cover the additional costs. The supply curve, in particular, typically becomes very steep and inelastic on the limit of the generation capacity. This is due to the fact that, in the short term, it is not possible to supply more than the available capacity can provide.

[45] The relevance of opportunities in the decision regarding the supply can also be illustrated with the help of the example of a hydroelectric power plant, which is supplied from a small reservoir. If it produces power for today's power wholesale, the generation capacity for the market for tomorrow (the opportunity) is lower. If the supplier expects higher prices tomorrow, it will, as a result, not produce any power today. This rule applies even if the price for today is above the supplier's variable costs of production today. The supplier will rather at least ask a price corresponding to its opportunity costs, which, in turn, depend on the future prices.

[46] See e.g. DG Competition (2007a) for a quantitative estimate of the course of the marginal costs of German power generation which confirms the quantitative course in the chart.

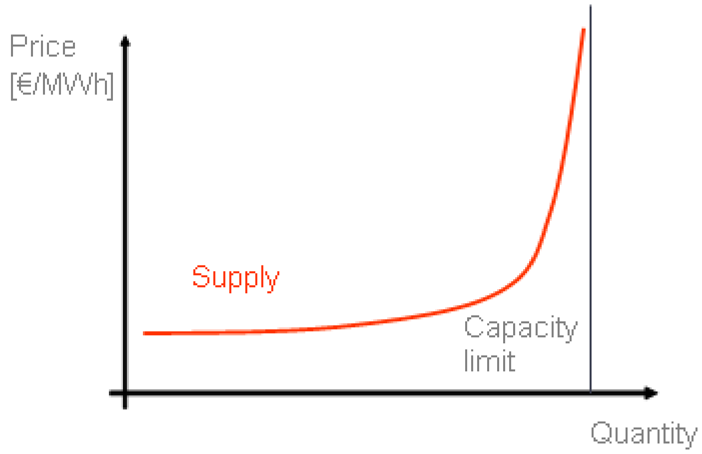


**Figure A.1: Supply function on the electricity market**

Occasionally, marginal costs cannot be defined clearly. In electricity production this is the case, in particular, if there are so-called “complementarities” or “non-convexities”, which are e.g. caused by start-up costs. Start-up costs are incurred upon every re-start of a power plant. On the one hand, these are costs for heating-up the power plant and for network synchronisation and, on the other hand, the temperature fluctuations which arise increase wear and, hence, the maintenance costs. Under certain circumstances these costs can amount to a multiple of the variable operating expenses.

For example, if the generation of another unit of electricity requires the start-up of a new power plant, the start-up costs are, obviously, relevant with regard to the marginal costs. The allocation of the start-up costs to the additional units produced is, however, not definite, so that both the term “marginal costs” and the bidding strategies and the bid formats become more complex. In this case, the costs are no longer exclusively dependent on the quantity produced, but have to be defined depending on “generation blocks”, which also specify the mode of operation of the power plants. Theoretically, the increased complexity can lead to the non-existence of market clearing prices, risks of losses on the side of the suppliers and to inefficiency in the use of the power plants. Chapter 4.2 described examples of this and showed consequences for market design and for the bid formats.

If electricity could be stored free of charge or comparatively cost-effectively, it would be exclusively generated with the production technology which has the lowest average costs and could then be called off from the warehouse as needed. In this case, the supply curve would have an (almost) horizontal shape like those curves we typically find in many other competitive industries. This would help to avoid many of the complexities of electricity trading and in market design which are discussed in this expertise. This e.g. includes the complex coupling of interdependent markets (chapter 4.5), the consideration of start-up costs and their complementarities in the cost structure (chapter 4.2), the direct inclusion of the market for balancing energy into the day ahead spot market auction (chapter 4.5) and the potentially increased incentives to exercise market power close to the capacity limits (chapter 4.1).

> **Observation 2.** *The price is established on the basis of offsetting of supply and demand; the price is highly volatile and subject to many stochastic influences on electricity markets.*

As on other markets, the equilibrium price on the electricity market is established by means of the equilibrium of (offered) supply and (offered) demand. In this context, the market rules can have an impact on what the offered supply and demand functions look like; this is also the subject of chapters 4.1 and 4.2.[47]

While the supply is primarily dominated by marginal costs, exchange prices initially typically only play a limited role in residential demand. Since, after all, the residential demand does not see the exchange prices and pays an average price for electricity regardless of the time of the consumption, it does not respond to price fluctuations on the power exchange. The typical private demander saves the same amount of money regardless of whether he or she reduces his/ her consumption by one unit on Sunday morning at 4:00 am or on Monday morning at 8:00am, even though the prices and the costs of production can differ considerably at those times.

However, demand responses can also arise in other groups. Industrial consumers can, e.g., conclude contracts providing for a reduction or suspension of the electricity supply whenever certain price limits are reached. Moreover, suppliers of electricity might also submit demand bids at the spot market auction, in order to re-buy electricity which has already been sold via long-term contracts. This is profitable in case the supplier’s own marginal costs of generation are above the market clearing price. As a result of this, the demand for electricity is not completely inelastic in exchange-based markets (see Ehlers and Erdmann, 2007 with regard to EEX). On

[47] The supply decrease in price and the demand cannot increase in price so that the price can balance the (offered) supply and the (offered) demand – regardless of the market design and the market structures – for as long as there is an intersection of the curves.

the other hand, the supply can be largely excluded from active trading in so-called pool energy markets (chapter 3).

In any case, supply and demand are matched at the power exchange. In this process, a market clearing price which is highly volatile over time and characteristic of all electricity markets emerges. Figure A.2 shows the prices which have evolved on the Leipzig-based energy exchange EEX on a day selected randomly, i.e. October 1, 2007, during the preceding month as well as during the 12 preceding months. Prices fluctuate considerably during a day, over the weeks but also in the course of the year. Prices which reach a multiple of their level in the early morning by noon are just as much routine on the electricity market as major fluctuations during the week and over months and years.


**Figure A.2: Price volatility (and volumes traded) on the power exchange on October 1, 2007, during the preceding month and during the 12 preceding months (source: EEX)**

Figure A.3 illustrates that price volatility is an equilibrium phenomenon on electricity markets. Prices of zero (or, provided this is permitted under the market design, prices of even less than zero) and prices of more than EUR 1,000 per MWh do not constitute compulsory evidence of a lack of efficiency of the market design or of the competition. They can, rather, also be a consequence of the complexities which are specific for the electricity market and which, ultimately, arise on account of the lack of storability of electricity.

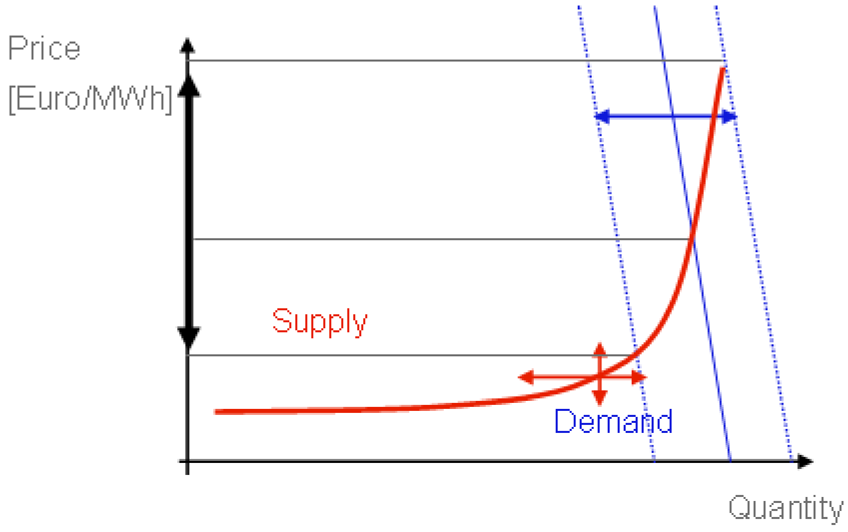


**Figure A.3: Price volatility as an equilibrium phenomenon**

In addition to the partly low elasticities of supply and demand, the reasons for the price volatility also include the fact that the demand is highly variable in the course of the day, the week and the year, e.g. because of weather influences and the effects of the economic situation (the demand function in figure A.3 shifts left or right). In addition to this, the supply also fluctuates in the short run, e.g. on account of power plant overhauls, stochastic power plant failures, volatile injection of wind power and other weather impacts, and in the long run, e.g. on account of capacity changes (the supply function in figure A.3 shifts left or right). Finally, the marginal costs of electricity production are highly volatile since the costs of certificates and the fuel costs, in turn, are very volatile (the supply function moves up or down).

The price and cost volatility creates new challenges for the design of electricity markets in the field of co-ordination, information and response achievements, which are addressed implicitly or explicitly in almost all chapters of the expertise.

**Observation 3.** *There can be only one price for electricity.*

In free competition (without the prevention of arbitrage transactions), there can be only one price for electricity since electricity is a perfectly homogeneous good (“law of one price”). A situation in which electricity is traded at different prices cannot be an equilibrium situation since arbitragers benefit from price differences until these have disappeared (similarly to the situation on financial market exchanges).[48] Together with the observation below regarding the lowest possible electricity price this observation has direct implications for the optimality of various pricing rules of power exchanges (chapter 4.1).[49]

**Observation 4.** *The price cannot fall below the additional costs of the most expensive unit produced.*

No supplier is ready to sell a unit of electricity at a price which is lower than the additional costs of this unit. This rule obviously also applies to the supplier of the most expensive unit produced. In conjunction with observation 3 we can conclude that, in free competition, the price for all units must at least be as high as the additional costs for the most expensive unit produced – regardless of market design and market structure.

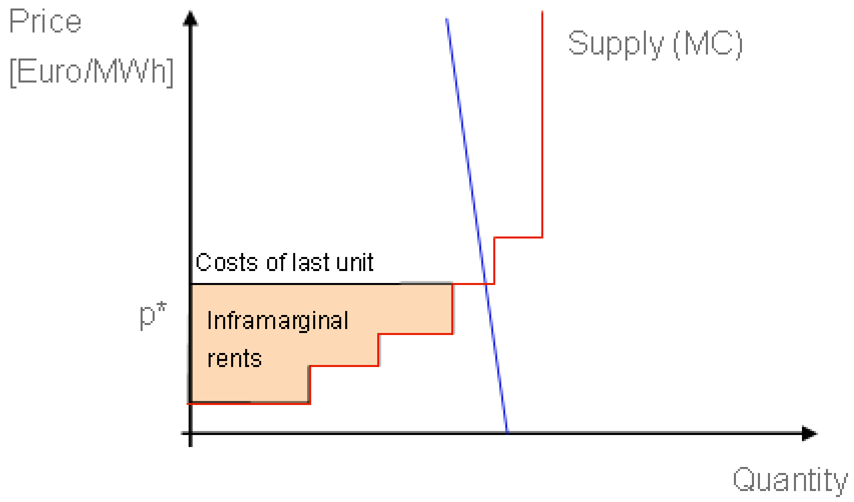


**Figure A.4: The marginal cost price equals the costs of the last unit**

Figure A.4 illustrates observation 4. It assumes a competitive market so that the supply corresponds to the respective marginal costs (MC). An equilibrium of supply and demand is reached at a price which corresponds to the additional costs of the most expensive unit produced, which are identical with the marginal costs in this

48 Of course, price differences can arise in different regions and at different times, e.g. on account of transmission bottlenecks. From an economic perspective, power in Italy and power in Germany or power on a Sunday morning and power on a Monday morning are different commodities.

49 On account of the obligation of transacting all power trading through one market platform arbitrage transactions can be prevented and different supplier prices can be enforced because of this in pool models (chapter 4).

case. All units produced to the left of the intersection receive a price which is above the respective marginal costs. Because of this, “inframarginal rents” are generated which can be used to cover fixed costs, which, in turn, are not relevant for marginal costs and are, hence, not relevant for the bids in the spot market auction, regardless of whether or not the fixed costs have already been depreciated.

> **Observation 5.** *From time to time, the price has to be higher than the additional costs of the most expensive unit produced as well as higher than the average costs of production.*

But how can fixed cost be covered if they are not relevant for the bid prices of the generating companies in the spot market auction? Sometimes, it is explicitly or implicitly assumed that the price on the electricity market is always established on the basis of the additional costs for the most expensive (“last”) unit produced – provided market power does not play an important role. This, however, would be wrong. If this were the case, the necessary consequence would be market failure; no supplier would be ready to invest in capacities for the production of the last unit because the additional costs of the last unit are lower than the average costs of the last unit since the fixed cost components have to be ignored in the calculation of the *additional* costs. In the long run, no supplier would want to produce the “last” unit needed.

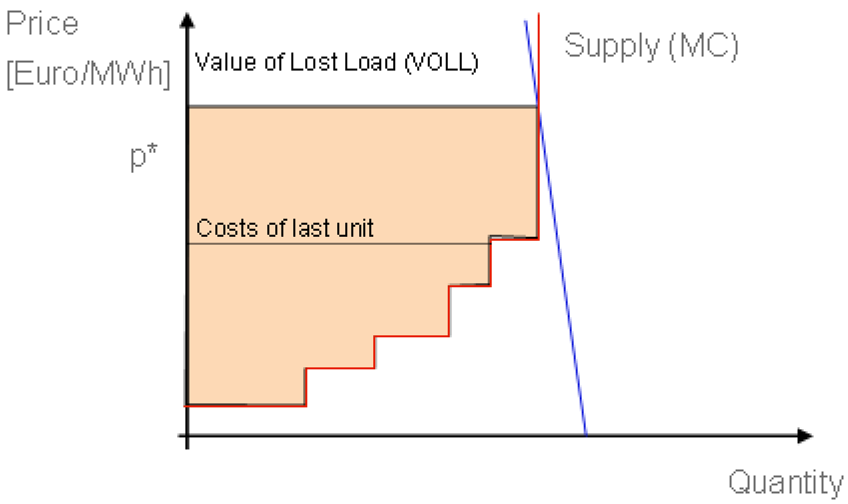


**Figure A.5: Total cost price is higher than the costs of the last unit**

For as long as there is no shortage in capacity, an electricity market cannot provide sufficient price signals for investments in new capacity. Figure A.5 shows what happens if capacity becomes scarce. In the example, the capacity has been fully utilised; additional capacities are not available. In this case, the market clearing price is higher than the costs for the last unit and is determined by the demand. This has to be the case, since an excess demand would exist if the price amounted to the costs of the last unit. The price determined by the demand is also referred to as the “scarcity price”. It rations the scarce capacity in such a way that demand and supply can be balanced on the power exchange. This means the scarcity price reflects the so-called “Value of Lost Load”. This is the amount of money at which the “marginal consumer” would be prepared to relinquish the electricity in the short run. Figure A.5 illustrates that in such scarcity situations the price exceeds the additional costs of the last unit so that incentives for investing into generation capacities covering the peak loads can arise. In a long-term equilibrium, the peak-load plants have to be able to cover their full costs completely with the help of the scarcity prices.

Scarcity prices, which can be much higher than the costs of the last unit, also occur in perfect competition, without market power and with market entry. In Figure A.5 we can assume that all suppliers bid at their marginal costs because the marginal costs are undetermined at the capacity limit so that prices above the costs of the last unit are consistent with marginal cost pricing.

Temporarily high prices do not imply that suppliers also generate high profits in the long run. In the event of efficient competition and excess capacities the prices are lower than the level which permits investment costs to be covered. In this case, however, prices necessarily also have to exceed the variable costs and the average costs at times in order to set investment incentives sooner or later.[50]

The existence and amount of scarcity prices and their implications for market design are covered in chapters 4.3 and 4.6.

[50] A price mechanism with “demand controlled scarcity prices“ on the capacity limits is also found on other markets on which the products traded are not “storable” or only storable to a limited degree from the customers’ perspective. For as long as there are no capacity scarcities, the marginal costs for airline tickets, hotel rooms, rental cars and tickets to musicals are very low and substantially lower than full costs. In these fields prices also fluctuate significantly. For example, on Friday afternoons, before holidays and during trade fairs, prices for airline tickets increase steeply. At these times, prices are not only driven by the additional costs of production of the last unit but also by the demanders’ willingness to pay. This dynamic pricing in which prices fluctuate below and above average costs enables the suppliers to cover their full costs.

**Observation 6.** *The transport of electricity is dependent on transmission systems.*

The implications which this trivial observation has for the design of power exchanges are described in chapter 4.5.

**Observation 7.** *Electricity markets can promote an increased market power potential.*

Since the demand on the power exchange can be comparatively inelastic and since the supply also becomes inelastic on the capacity limits, an increased potential for market power can evolve if the capacity reserves become scarce. Moreover, the price and cost dynamics on electricity markets complicate measurements of market power – at least, they become considerably more difficult than in other industries (Twomey et al., 2006, Ockenfels, 2007b, Stoft, 2002). For example, it is difficult to differentiate between “justified” scarcity prices and market power-induced oligopolistic price mark-ups in the event of capacity scarcity since the prices cannot approximate the costs in any case. The consequences for the institutional design of power exchanges supporting competition are discussed in chapters 4.3 and 4.6 and they are also mentioned in other chapters.

## Literature

Abreu, D., D. Pearce and E. Stachetti (1985). “Optimal Cartel Equilibria with Imperfect Monitoring.” *Journal of Economic Theory*, 39, 251-269.

Allaz, B. and J.-L. Vila (1993). "Cournot Competition, Forward Markets and Efficiency." *Journal of Economic Theory*, 59, 1-16.

Anandaligam, G., Day, R. and S. Raghavan (2005). "The Landscape of Electronic Market Design." *Management Science*, 51, 316-327.

Ariely, D., Ockenfels, A., and A.E. Roth (2005). "An Experimental Analysis of Ending Rules in Internet Auctions." *RAND Journal of Economics*, 36, 790-809.

Ausubel, L.M. and Cramton, P. (2002). "Demand Reduction and Inefficiency in Multi-Unit Auctions.", Working Paper, University of Maryland.

Ausubel, L.M. and P. Milgrom (2006). "The Lovely But Lonely Vickrey Auction." Chapter 1 in Peter Cramton, Yoav Shoham, and Richard Steinberg (ed..), Combinatorial Auctions, forthcoming, MIT Press.

Bartholomew, M. (2004). "The UK electricity market – from pool to exchange." in: Roggenkamp M. and Boisseleau F. (Hrsg.). "The regulation of power exchanges in Europe." *Energy & Law 2 Series*, 311.

Bolle, F. (1992). "Supply Function Equilibria and the Danger of Tacit Collusion: The Case of Spot Markets for Electricity." *Energy Economics*, 14, 94-102.

Bolle, F. (1993). "Who Profits from Futures Markets?" Ifo studies, 3-4, 239-256.

Borenstein, S. (2002). "The Trouble with Electricity Markets: Understanding California’s Restructuring Disaster." *Journal of Economic Perspectives*, 16(1), 191-211.

Borenstein, S., (2005). "The Long Run Efficiency of Real-Time Electricity Pricing." *The Energy Journal*, 26(3), 93-116.

Borenstein, S., J. Bushnell, and S. Stoft (2000). “The competitive effects of transmission capacity in a deregulated electricity industry.” RAND Journal of Economics, 31(2), 294-325.

Borenstein, S., Bushnell, J. and Wolak, F. (2002). "Measuring Market Inefficiencies in California's Wholesale Electricity Industry." *American Economic Review*, 92(5), 1376-1405.

Bower J., and Bunn D. (2000). "Experimental analysis of the efficiency of uniform price versus discriminatory auctions in the England and Wales electricity market." *Journal of Economic Dynamics and Control*, 25, 561-592.

Bower J. and Bunn D. (2001). "Model-based comparison of pool and bilateral markets for electricity." *The Energy Journal*, 21(3).

Brandts, J., Pezanis-Christou, P. and Schram, A. (forthcoming). "Competition with Forward Contracts: A Laboratory Analysis Motivated by Electricity Market Design." *Economic Journal*.

Brunekreeft, G., S. Twelemann (2005). "Regulation, Competition and Investment in the German Electricity Market: RegTP or REGTP." *The Energy Journal*, 26 (Sonderausgabe), 99-126.

Bushnell, J. (2006). "Oligopoly Equilibria in Electricity Contract Markets." Working paper.

Bushnell, J., E. Mansur, and C. Saravia (forthcoming). "Vertical Arrangements, Market Structure and Competition: An Analysis of Restructured U.S. Electricity Markets." *American Economic Review.*

Cramton, P. (2003). "Electricity Market Design: The Good, the Bad, and the Ugly", Proceedings of the Hawaii International Conference on System Sciences.

Cramton, P. (2004). "Competitive Bidding Behavior in Uniform-Price Auction Markets." Proceedings of the Hawaii International Conference on System Sciences.

Cramton, P., and S. Stoft (2005). "A Capacity Market that Makes Sense." *Electricity Journal*, 18, 43-54.

Cramton, P., and S. Stoft (2005). "Forward Reliability Markets: Less Risk, Less Market Power, More Efficiency." *Utilities Policy*, forthcoming, 2008.

Cramton, P., Hung-po Chao and Robert Wilson (2005). "Review of the Proposed Reserve Markets in New England." *mimeo*.

Cramton, P. (2006). "New England's Forward Capacity Auction." *mimeo*.

Cramton, P. and Stoft, S. (2006). "The Convergence of Market Designs for Adequate Generating Capacity." Working paper.

Cramton P., Shoham Y. and Steinberg R. (ed.) (2006). "Combinatorial Auctions." MIT Press.

Cramton, P. and S., Stoft (2007). "Forward Reliability Markets: Less Risk, Less Market Power, More Efficiency." Working paper.

Cramton, P. (1995). “Money Out of Thin Air: The Nationwide Narrowband PCS Auction.” *Journal of Economics and Management Strategy* 4. 267-343.

Crampes C. and Fabra N. (2005). "The Spanish Electricity Industry: Analysis and Prospects." *The Energy Journal,* Special Issue on European Electricity Liberalisation, 127-154.

de Vries, S. and R. Vohra. "Combinatorial Auctions: A Survey", *INFORMS Journal on Computing*, 15, 284-309.

DG Competition (2007a). "Structure and Performance of Six European Wholesale Electricity Markets in 2003, 2004 and 2005." DG Comp 26th February 2007, Prepared by London Economics in association with Global Energy Decisions.

DG Competition (2007b). "Energy Sector Inquiry by the European Commission." (2007). Available at: http://ec.europa.eu/comm/competition/antitrust/others/sector_inquiries/energy/#final

DG TREN (2004). "Analysis of cross-border congestion management methods for the EU internal electricity market. Study by Fontier economics and Consentec." Final report, available at: http://europa.eu.int/comm/energy.

DG TREN (2006). "Quarterly Review of European Electricity and Gas Prices",8, September 2006.

EEX (2007). "Conditions for Trading on EEX." Document release 13A, Leipzig 1 Sept. 2007.

Ehlers, N. and Erdmann, G. (2007). "Kraftwerk aus, Gewinne rauf? Wird der Preis in Leipzig manipuliert?" *Energiewirtschaftliche Tagesfragen*, 57(5), 42-45.

Ehrenmann A. and Neuhoff K. (2003). "A comparison of electricity market designs in networks." CMI-Working Paper 31, CMI, MIT Electricity project. http://www.econ.cam.ac.uk/electricity.

Ehrenmann A. and Y. Smeers (2005). "Inefficiencies in European congestion management proposals." *Utilities policies*, 13(2), 135-152.

Ehrenmann A. and Smeers Y. (2006). "Critical Assessment of Congestion Management Solutions: Efficiency and Market Power." Paper presented at the workshop Institutional setting for the IEM: The Role and Status of Power Exchanges, Florence School of Regulation, 23 pages.

Elmaghraby W. and Oren S. (1999). "The efficiency of multi-unit electricity auctions." *The Energy Journal*, 20(4), 89–116.

Elmaghraby W. J., O'Neill R., Rothkopf M. and Stewart W. (2004). "Pricing and Efficiency in Lumpy Energy Markets." *The Electricity Journal*, 17(5), 54-64.

Elmaghraby W. (2005). "Multi-unit auctions with complementarities: Issues of efficiency in electricity auctions." *European Journal of Operational Research*, 166(2), 430-448.

Engelmann, D. and V. Grimm (2004). "Bidding Behavior in Multi-Unit Auctions - An Experimental Investigation and some Theoretical Insights." http://home.cerge-ei.cz/engelmann/WorkingPapers/DerExGEB.pdf.

European Commission EC (2005). "Fourth benchmarking report, Annual Report on the Implementation of the Gas and Electricity Internal Market" *Communication from the Commission*, COM (2004) 863, available at http://europa.eu.int/comm/energy.

Fabra, N. (2003). "Tacit Collusion in Repeated Auctions: Uniform Versus Discriminatory." *mimeo*.

Fabra, N. and C. Crampes (2005). "The Spanish Electricity Industry: Plus ça change…." Cambridge Working Papers in Economics, number 0502.

Fabra, N. and J. Toro (2003). "The Fall in British Electricity Prices: Market Rules, Market Structure, or Both?" EconWPA 0309001.

Fabra, N., von der Fehr N-H. and Harbord D. (2002). "Modeling Electricity Auctions." *The Electricity Journal*, 72-81.

Fabra N., von der Fehr N-H. and Harbord D. (2004). "Designing electricity auctions." CSEM WP 122, University of California Energy Institute.

Flatabø, N., Doorman G., Grande O. S., Randen H., and Wangensteen I. (2003). "Experience With the Nord Pool Design and Implementation." *IEEE Transactions on power systems*, 18(2).

Gatzen, C., Ockenfels, A., and Peek, M. (2005). "Sind die Gesetze des Wettbewerbs auf dem Strommarkt außer Kraft gesetzt? – Analyse der Strompreisentwicklung auf dem Großhandelsmarkt in Deutschland." *Energiewirtschaftliche Tagesfragen*, 50(11), et spezial, 4-11.

Gilbert, R. Neuhoff, K. Newbery, D. (2004). "Allocating transmission to mitigate market power in electricity networks." *RAND Journal of Economics*, 35(4), 691-709.

Grimm, V., F. Riedel, and E. Wolfstetter (2003). “Low Price Equilibrium in Multi–Unit Auctions: The GSM Spectrum Auction in Germany.” *International Journal of Industrial Organization*, 21, 1557-1569.

Grimm, V. and G. Zoettl (2007a). “Strategic Capacity Choice under Uncertainty: The Impact of Market Structure on Investment and Welfare.” Working Paper, University of Cologne.

Grimm, V. and G. Zoettl (2007b). “Production under Uncertainty: A Characterization of Welfare Enhancing and Optimal Price Caps.” Working Paper, University of Cologne.

Guilo, F. and Rahman D. (2001). "Bidding in an Electricity Pay-As-Bid Auction." Working paper No. 2001 W5, Nuffield College, Oxford.

Harvey, S.M. and W.W. Hogan (2000). “Nodal and zonal congestion management and the exercise of market power.” Working paper.

Hogan W. (1995). "To Pool or Not to Pool: A Distracting Debate." *Public Utility Fortnightly*. Jan 1. http://www.pur.com/pubs/310.cfm.

Hogan, W. (2005a). "Electricity Restructuring: Public Purposes, Markets, and Institutional Design." *mimeo*.

Hogan, W. (2005b). "Electricity Market Restructuring: Successful Market Design." *mimeo*.

Hogan, W. (2005c). "On an 'Energy Only' Electricity Market for Resource Adequacy." *mimeo*.

Hogan, W. (2007). "Acting in Time: Regulating Wholesale Electricity Markets." *mimeo*.

Huck, S., H.-T. Normann and J. Oechssler (2000). “Does information about competitors’ actions increase or decrease competition in experimental oligopoly markets?” *International Journal of Industrial Organization*, 18, 39-57.

Hughes, J.S., and J.L. Kao (1997). “Strategic Forward Contracting and Observability.” *International Journal of Industrial Organization*, 16, 121-133.

Hunt, Sally (2002). "Making Competition Work in Electricity." Wiley.

Ivaldi M., B. Jullien, P. Rey, P. Seabright, and J. Tirole (2003). “The Economics of Tacit Collusion - Final Report for DG Competition.” European Commission.

Jamasb, T. and M. Pollitt (2005). "Electricity Market Reform in the European Union: Review of Progress towards Liberalization and Integration." *Energy Journal*.

Joskow, P. L. (2006). "Competitive Electricity Markets and Investment in New Generating Capacity." Working paper, MIT.

Joskow, P. and Tirole, J. (2000). “Transmission rights and market power on electric power networks.” RAND Journal of Economics, 31(3), 450-487.

Joskow, P. and Tirole, J. (forthcoming). "Reliability and competitive electricity markets." *RAND Journal of Economics*.

Kagel, J. H. and D. Levin (2001). “Behavior in Multi-unit Demand Auctions: Experiments with Uniform Price and Dynamic Auctions.” *Econometrica* 69 (2), 413-454.

Kahn, A. E., Cramton P., Porter R. H. and Tabors R. D. (2001). "Pricing in the California Power Exchange Electricity Market: Should California Switch from Uniform Pricing to Pay-as-Bid Pricing?" Blue Ribbon Panel Report, California Power Exchange.

Kahn, A.(2001), "Uniform Pricing or Pay-as-Bid Pricing: A Dilemma for California and Beyond." *Electricity Journal*, 70-79.

Kahn, Alfred E., Peter Cramton, Robert H. Porter, and Richard D. Tabors (2002). "The Adequacy of Prospective Returns on Generation Investments under Price Control Mechanisms." *The Electricity Journal*, 15(2), 37-46.

Kittsteiner, T. and Ockenfels, A. (2006). "Market Design: A Selective Review." *Zeitschrift für Betriebswirtschaft*, Special Issue, 121-143.

Klemperer, P. and Meyer, M. A. (1989). "Supply Function Equilibria in Oligopoly under Uncertainty." *Econometrica*, 57, 1243-1278.

Klemperer, P. (2004). "Auctions: Theory and Practice." Princeton University Press.

Le Coq, C. (2004). "Long-Term Supply Contracts and Collusion in the Electricity Market." Working Paper, Stockholm School of Economics.

List, J. A. and D. Lucking-Reiley (2000). "Demand Reduction in Multi-Unit Auctions: Evidence from a Sportscard Field Experiment." *American Economic Review* 90(4), 961-972.

Littlechild S. C. (2001). "Electricity: Regulatory developments around the world." Available at: www.econ.cam.ac.uk/electricity/publications/index.htm.

Madlener R. and Kaufmann M. (2002). "Power exchanges spot market trading in Europe: theoretical considerations and empirical evidence." Available at: http://www.oscogen.ethz.ch.

Meeus, L. (2006). "Power Exchange Auction Trading Platform Design." Doctoral Dissertation, KUL.

Meus, L., K. Verhaegen and R. Belmans (2005). "Pricing in Electricity Energy Auctions with Block Orders." Working paper.

Milgrom, P. (2004). "Putting Auction Theory to Work." Cambridge University Press.

Müsgens, F. (2006). "Quantifying Market Power in the German Wholesale Electricity Market Using a Dynamic Multi-Regional Dispatch Model." *Journal of Industrial Economics*, 54 (4), 471.

Müsgens, F. and Ockenfels, A. (2006). "Marktdesign in der Energiewirtschaft." In: Franz, W., Hesse, H., Ramser, H. J., Stadler, M. (ed.): Umwelt und Energie, Wirtschaftswissenschaftliches Seminar Ottobeuren, Mohr Siebeck, Tübingen.

Neuhoff K. and Newbery D. (2006). "Integrating energy markets: does sequencing matter?" *Utilities Policies* , forthcoming, preprint available at http://www.econ.cam.ac.uk/faculty/neuhoff.

Neumann, S., Sioshansi, F., Vojdani, A. and Yee, G. (2006). "How to get more response from demand response." *The Electricity Journal*, 19(8), 24-31.

Newbery, D. (2003). "The effect of NETA on wholesale electricity prices." Working Paper 59854, Department of Applied Economics, Cambridge, UK.

Newbery, D. (2004). "Electricity Liberalisation in Britain: the quest for a satisfactory wholesale market design."

Newbery D. (2005). "Refining Market Design." Paper presented at the Conference Implementing the Internal Market of Electricity: Proposals and Time-Tables in Brüssel. Available at: http://www.sessa.eu.com.

Newbery, D. (2006a). "Market Design." *mimeo*.

Newbery, D. (2006b). "Electricity pricing, the ETS, and market power in the gas market." Presentation at Max Planck Institute Bonn.

Ockenfels, A., and Roth, A. E. (2002): "The Timing of Bids in Internet Auctions: Market Design, Bidder Behavior, and Artificial Agents." *Artificial Intelligence Magazine*, 23 (3), 79-87.

Ockenfels, A. and Roth, A. E. (2006): "Late and Multiple Bidding in Second Price Internet Auctions: Theory and Evidence Concerning Different Rules for Ending an Auction." *Games and Economic Behavior*, 55, 297–320.

Ockenfels, Axel (2007a). "Strombörse und Marktmacht." Study for the Ministry of Science, Economic Affairs and Transport of the State of Schleswig Holstein. *Energiewirtschaftliche Tagesfragen*, 57(5), 44-58.

Ockenfels, Axel (2007b). "Marktmachtmessung im deutschen Strommarkt in Theorie und Praxis: Kritische Anmerkungen zur London Economics-Studie." Study prepared on behalf of RWE AG. *Energiewirtschaftliche Tagesfragen*, 57(9), 12-29.

O'Neill, R.P., P.M. Sotkiewicz, B.F. Hobbs, M.H. Rothkopf and W.R. Stewart, Jr (2005). "Efficient Market-Clearing Prices in Markets with Nonconvexities". *European J. Operational Research*. 164.1, 269 - 285.

Park S. and Rothkopf M. H. (2005). "Auctions with bidder-determined allowable combinations." *European Journal of Operational Research*, 161(2), 399-415.

Peek, M. (2005). "Strompreisentwicklung am deutschen Großhandelsmarkt – Der Einfluss von Fundamentalfaktoren." *Zeitschrift für Energie, Markt, Wettbewerb [Magazine for Energy, Market and Competition] – emw*, 5, 31-37

Pekec, A. and Rothkopf M. H. (2004). "Noncomputational Approaches to Mitigating Computational Problems in Combinatorial Auctions." In: Cramton P., Shoham Y., Steinberg R. (Hrsg.) Combinatorial Auctions, M.I.T. Press.

Pérez-Arriaga I. J. and Olmos L. (2003). "A plausible congestion management scheme for the internal electricity market of the European Union." Working Paper IIT, Ref. Number: IIT-03-037A, 2004, available at: http://www.iit.upco.es.

Peterson S. and Augustine C. (2003). "Regulatory Failure in the California Electricity Crisis." *The Electricity Journal*, 16(7), 56-64.

Rothkopf, M. (1999). "Daily Repetition - A Neglected Factor in the Analysis of Electricity Auctions." *Electricity Journal*, 12, Number 3, 60-70.

Roques, F., Newbery, D. M. and Nuttall, W. J. (2006). "Generation Adequacy and Investment Incentives in Britain: from the Pool to NETA." *mimeo*.

Sannikov, Y. and Andrzej Skrzypacz (2007) "Impossibility of Collusion under Imperfect Monitoring with Flexible Production", American Economic Review 97(5), 1794-1823.

Schwarz, H.-G. and Lang, C. (2006). "The Rise in German Wholesale Electricity Prices: Fundamental Factors, Excerise of Market Power, or both?" IWE Working Paper Nr. 02 2006.

Sheffrin, A. (2002). "Predicting Market Power Using the Residual Supply Index." *mimeo*.

Sioshansi, F. P. (2006). "Electricity Market Reform: What have we learned? What have we gained?" *The Electricity Journal*, 19(9), 70-83.

Sioshansi, F. P., and Pfaffenberger, W. (2006). "Electricity Market Reform: An International Perspective." Elsevier.

Stoft, S. (2002). "Power System Economics." IEEE Press.

Symeonides, G., (2003). "In which industries is collusion more likely? Evidence from the UK." *Journal of Industrial Economics*, 51, 45-74.

Twomey, P., Green, R. Neuhoff, K. and Newberry, D. (2006). "A Review of the Monitoring of Market Power." Cambridge Working Papers in Economics CWPE 0504.

UCTE (2007). UCTE System Adequacy Forecast. Report.

van Damme, E. (2005). "Liberalizing the Dutch Electricity Market 1998-2004." *The Energy Journal*, 26, Sonderausgabe.

Ventosa M., Baillo A., Ramos A. and Rivier M. (2005). "Electricity market modelling trends." *Energy Policy*, 33, 897–913.

von der Fehr, N., Amundsen, E. and Bergman, L. (2004). "The Nordic Market: Signs of Stress?" SESSA Conference *Refining Market Design*, Cambridge, 13-15.

Verband der Industriellen Energie- und Kraftwirtschaft [German Association of the Energy and Power Supply Industry] (2006), "Gibt es strategisches Verhalten auf dem Strom-Spotmarkt?", *VIK Releases*, 6, 128-131.

Wawer, T. (2007). "Konzepte für ein nationales Engpassmanagement im Deutschen Übertragungsnetz." *Zeitschrift für Energiewirtschaft*, 31(2), 109-116.

White & Case and NERA (2007). "Verbesserung der Transparenz auf dem Stromgroßhandelsmarkt aus ökonomischer sowie energie- und kapitalmarktrechtlicher Sicht." Expertise prepared on behalf of Saxon State Ministry of Economic Affairs and Labour.

Wilson R. (2001). "Architecture of Power Markets." *Econometrica*, 70(4), 1299-1340.

Wolak F. (2000). "An Empirical Analysis of the Impact of Hedge Contracts on Bidding Behavior in a Competitive Electricity Market." Working Paper, Stanford University.

Wolak, Frank (2004). "Lessons from International Experience with Electricity Market Monitoring." University of California Energy Institute, Working paper CSEM WP 134.

Wolfram, C. D. (1998). "Strategic Bidding in a multiunit auction: an empirical analysis of bids to supply electricity in England and Wales." *RAND Journal of Economics*, 29(4), 703-725.

Zachmann, G. (2005). "Convergence of Wholesale Electricity Prices in Europe? -A Time Series Analysis of Hourly Spot Prices." 7th IAEE European Energy Conference Bergen, August 28–30th, 2005.