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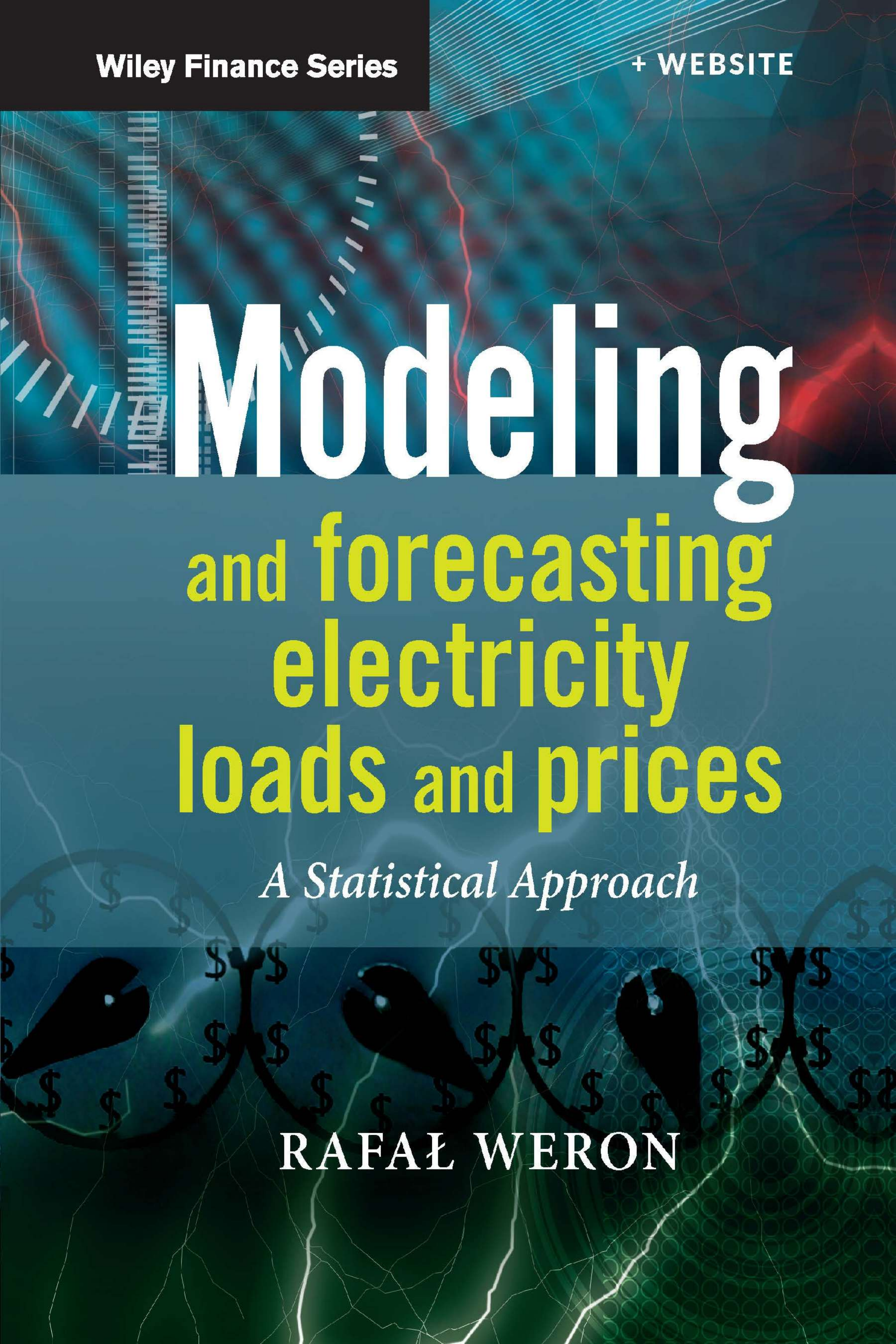

Modeling and forecasting electricity loads and prices

A Statistical Approach

RAFAŁ WERON

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Preface

Since the discovery of the light bulb, electricity has made a tremendous impact on the development of our society. Today, it is hard to imagine a life without it. To provide every factory and household with a sufficient supply of electric energy, electric companies were set up. They used to serve dedicated geographical areas from which consumers had to buy their electricity. Traditionally, centralized regulation of the electricity supply industry was considered necessary to ensure security of supply and efficient production. Efficiency was achieved through economics of scale. The power sector was characterized by a highly vertically integrated market structure with little competition. However, during the last two decades dramatic changes to the structure of the electricity business have taken place around the world.

The original monopolistic situation has been replaced by *deregulated*, *competitive markets*, where consumers, in principle, are free to choose their provider. To facilitate trading in these new markets, exchanges and pools for electric power have been organized. Everything from real-time and spot contracts to derivatives – such as (standardized, but not marked to market) forward, futures and option contracts – are traded. A power exchange, though, is not a necessity for a deregulated power market. In fact, in most countries the majority of deals – especially medium and long term – are made on a bilateral basis on the so-called over-the-counter (OTC) market. Nevertheless, it has been argued that the establishment of power exchanges has promoted competition and contributed to the high trading activity seen, for instance, in the Nordic market. Furthermore, the exchange serves as a source for updated, independent and good-quality market information.

In a competitive power market electricity can be bought and sold at market prices like any other commodity. As a consequence, the amount of risk borne by electric utilities, power producers and marketers has increased substantially. Successfully managing a company in today's markets takes a fair amount of statistical analysis and educated guesswork. These in turn involve developing dedicated statistical techniques and managing huge amounts of data for modeling, forecasting and pricing purposes.

Unlike the analyses of random samples of observations that are discussed in the context of most other statistics, the analysis of time series is based on the assumption that successive values in the data file represent consecutive measurements taken at equally spaced time intervals. While this assumption is violated for a vast majority of financial data sets, it is fulfilled for power market data. Electricity spot prices, loads, production figures, etc., are sampled 24 hours a day, 365 days a year. This gives us a unique opportunity to apply statistical methods in the way they were meant to be used.

When electricity sectors were regulated, utility monopolies used short-term load forecasts to ensure the reliability of supply and long-term demand forecasts as the basis for planning and investing in new capacity. That is no longer the case where competition has been or is being introduced. The costs of over- or under-contracting and then selling or buying power on the balancing market have increased so much that they can lead to financial distress of the utility. Minimization of volumetric risk has never been of such importance as it is today. As a result, load forecasting has gradually become the central and integral process in the planning and operation of electric utilities, energy suppliers, system operators and other market participants. Its position as one of the major fields of research in electrical engineering is not threatened as well since the financial penalties for forecast errors are so high that research is aimed at reducing them even by a fraction of a percent.

On the other hand, extreme price volatility, which can be even two orders of magnitude higher than for other commodities or financial instruments, has forced producers and wholesale consumers to hedge not only against volume risk but also against price movements. Price forecasts have become a fundamental input to an energy company's decision making and strategic development. As a result of the supply stack structure, load fluctuations translate into variations in electricity prices. However, an inverse relationship has been also observed. In some cases the issue of whether load drives power prices, or vice versa, is not easily answered. Clearly, as they become partially co-determined, load and price forecasting could be treated as one complex task.

It is exactly the aim of this book to present a common framework for modeling and forecasting these two crucial processes for every energy company. The statistical approach is chosen for this purpose as it allows for direct input of relevant statistical properties into the models. Furthermore, it is attractive because physical interpretation may be attached to the components of the models, allowing engineers and system operators to better understand the power market's behavior.

GUIDE TO THE CHAPTERS

The book is divided into four chapters. The first one introduces the structure of deregulated, competitive electricity markets with the power pools and power exchanges as the basic marketplaces for price discovery. Electricity contracts and the spot price setting mechanism are thoroughly described. The chapter ends with an up-to-date survey of market solutions implemented in different parts of the world, with a particular emphasis on European and North American structures.

Chapter 2 reviews the so-called *stylized facts* of selected power markets. In particular, the spiky nature of electricity prices, the different levels of seasonality inherent in load and price time series, the anti-persistent behavior of prices and the heavy-tailed distributions of returns. Well-known and novel methods, like the Average Wavelet Coefficient and the rolling-volatility technique, are utilized. The findings are illustrated mostly on data from two, not only geographically distinct regions: Scandinavia and California. The first region is well known for the world's oldest, successfully operating power exchange, Nord Pool, and for vast amounts of good-quality data. California, on the other hand, is 'famous' for the market crash of 2000, which led to the blackouts in the San Francisco area in January 2001 and the first bankruptcy of a power exchange in history.

Load forecasting has become increasingly important since the rise of competitive energy markets. Short-term load forecasting can help to estimate load flows and to make decisions that can prevent overloading and reduce occurrences of equipment failures. Short- and medium-term load forecasting, on the other hand, is important for modeling prices and valuation of spot and derivative contracts for delivery of electricity. Consequently, hourly and daily forecasts up to a few days ahead are of primary interest in everyday market operations. Chapter 3 reviews the relevant techniques, with particular emphasis on statistical methods. Various models with and without exogenous variables are illustrated and compared in two comprehensive case studies.

Finally, Chapter 4 discusses price modeling and forecasting. Six different approaches are surveyed and two – statistical and quantitative – are further studied. This choice is backed by the methods' adequacy to model and forecast electricity prices in two pertinent contexts (and time horizons): short-term forecasting and medium-term or monthly modeling. The former context refers to the situation of bidding for spot electricity in an auction-type market, where players who are able to forecast spot prices can adjust their own production schedules accordingly and hence maximize their profits. The latter is relevant for balance sheet calculations, risk management and derivatives pricing. As in the previous chapter, the theoretical considerations and techniques are illustrated and evaluated using real-world data.

In fact, there are 16 case studies in the whole book, making it a self-contained tutorial to electricity load and price modeling and forecasting. The text is comprehensible for graduate students in electrical engineering, econometrics and finance wanting to get a grip on advanced statistical tools applied in this hot area. Market players looking for new solutions and practical advice will surely find the book attractive as well. All readers will benefit from the Matlab toolbox on the accompanying CD, which not only demonstrates the presented topics but also allows the user to play around with the techniques. The toolbox and its manual will be kept up-to-date on the website (http://www.im.pwr.wroc.pl/∼rweron/MFE.html) and readers are welcome to download updates from there. Needless to say, all readers are very welcome to contact me with any feedback.

Rafał Weron
Wrocław, September 2006

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A book like this would not have been possible without the help of many friends, colleagues and students. Various parts of the text have benefited from numerous discussions, also via e-mail and Skype. The software on the attached CD would have been much less advanced and complete if it wasn't for the invaluable programming skills of a number of individuals. I refrain from listing all their names here for fear that this section might otherwise exceed the others in length.

1 Complex Electricity Markets

1.1 LIBERALIZATION

Over the past two decades a number of countries have decided to take the path of market liberalization. Despite slight differences, the motivation for liberalization of the power sectors world wide has shared common ideological and political reasons. In particular, a strong belief that the success of liberalization in other industries can be duplicated in the power sector and a 'need' for splitting (or *unbundling*) the vertically integrated monopoly structures that traditionally have managed generation, transport and distribution. The introduction of competition has been justified by the perceived benefits of introducing market forces in an industry previously viewed as a natural monopoly with substantial vertical economies. The breach of the natural monopoly character has been possible, in turn, due to changes in generation technologies and improvements in transmission. Therefore the motivation behind electricity liberalization is, in the long run, to promote efficiency gains, to stimulate technical innovation and to lead to efficient investment.

Power market liberalization was pioneered by Chile. The reform, which began in 1982, was based on the idea of separate generation and distribution companies where power was paid for according to a formula based on the cost, a dispatch system with marginal cost pricing and a system of trading power between generators to meet customer contracts. Large-scale privatization began in 1986 and led to the (partial) vertical disintegration of the sector and the formation of a wholesale power trading mechanism.[1]

The Chilean reform was followed by the reorganization of the British electricity sector in 1990. The wholesale market only included England and Wales until 2005, thereafter Scotland as well. The Nordic market opened in 1992, initially in Norway, later in Sweden, Finland and Denmark. In Australia, markets in Victoria and New South Wales began operating in 1994; followed by opening of the Australian National Electricity Market (NEM) in 1998. New Zealand reformed the power sector in the same period, officially launching the market in 1996. In North America, a number of northeastern markets (New England, New York, Pennsylvania–New Jersey–Maryland – PJM) began operating in the late 1990s. California followed in 1998, and Texas and Alberta (Canada) three years later. The number of liberalized electricity markets is steadily growing world wide, but the trend is most visible in Europe.

Some of the pioneers in electricity market reform have been successfully operating for over a decade. Others have undergone substantial changes in design to improve the performance. Yet a few reforms have failed miserably. The California market crash of 2000/2001, the spectacular bankruptcy of Enron that followed, and the widespread blackouts in North America and Europe in 2003 are sometimes used to argue that electricity market liberalization is a flawed concept.

[1] It should be noted that the Chilean reform conformed with the economic doctrine of the military dictatorship. In the case of the power market, though, it had the long-lasting positive effect of stability. The 2004 revision of the law has not changed the status quo. See Jamasb *et al*. (2005) for a comprehensive review of the electricity sector reforms in Latin America; Pollitt (2005) concentrates solely on the Chilean market.

These failures, however, cannot be attributed solely to market liberalization. The California crisis was due to a coincidence of several factors, one of which was a flawed market design (see Section 1.4.2). Likewise, power market liberalization paved the way for the Enron bankruptcy and the 2003 blackouts, but was not the root cause of these events.

On the other hand, liberalization is praised by others for the positive impact it has had on the economy. The mentioned benefits include a clear trend of falling electricity prices and a more efficient use of assets in the electricity sector. Both 'benefits' are, however, questionable. Net electricity prices have generally decreased, but the new taxes imposed on the prices have in many cases reversed the effect. In particular, the trend of falling prices is not that apparent, if it exists at all, for small or medium size industrial customers and especially for household consumers.[2] We have to remember, though, that prices paid by some consumer groups do not necessarily reflect the costs of producing and transporting electricity. In regulated power markets industrial customers often subsidize retail consumers.

The vertically integrated utilities, that traditionally operated in the power sector, have had the tendency to create substantial overcapacity. Market liberalization has generally reduced this overcapacity. In addition it has also been shown to provide gains from higher efficiency in the operation of generation, transmission and distribution services. But since liberalization is expected to bring economic benefits in the long run, in the short term certain groups (like the previously subsidized household consumers) may not realize immediate benefits or may even experience losses.

Another controversial issue is the ability of liberalized power markets to provide sufficient incentives for investment in new generation (or transmission) capacity. In the new environment, investment decisions are no longer centrally planned but are the outcome of competitive forces. Consequently, capital-intensive technologies with long construction times are generally avoided, even if their marginal costs are low. Instead generation plants that can be built in short time horizons (like the gas-fueled plants) are preferred. But even then, the expectation of lower prices can cause private investors to postpone expenditures on new generation capacity or the expansion of transmission network. This puts policy makers under pressure to intervene. Consequently, there is an ongoing debate whether to establish capacity payments (as in a number of Latin American countries and Spain), organize capacity markets (as in the northeastern United States) or to have 'energy only' markets (as in Australia and New Zealand).

The basic idea of *capacity payments* (originally introduced in Chile in 1982) is to award to each generator a daily payment which is a measure of the contribution of the generator to the reliability of the power system, i.e. its availability. International evidence suggests, however, that capacity payments create poor incentives to alleviate the capacity problem and may even worsen it. For instance, generators may try to increase capacity payments by making fewer capacity resources available thereby increasing, rather than decreasing, the probability of shortage.

Quantity-based capacity payment systems (as opposed to the price-based capacity payments discussed above) generally have taken the form of *installed capacity* (ICAP) *markets*. The main purpose underlying the introduction of these markets has been to ensure that adequate capacity is committed on a daily or seasonal basis to meet system load and reserve requirements. The distributors that sell electricity to end-user consumers must satisfy their capacity obligations, which equal their expected peak monthly loads plus a reserve margin. They can accomplish this,

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[2] See `http://www.iea.org`, `http://www.eurelectric.org` and `http://www.europa.eu.int/comm/eurostat/` for relevant statistical data and comparisons.

either by internal or bilateral transactions, or through the capacity market in which generators sell a recall right that empowers the system operator to recall them in the event of shortages. As the markets matured, market coordinators realized a need to encourage generator reliability and remove a potential source of market power. Consequently, *unforced capacity* (UCAP) credits were developed, which are calculated by taking the ICAP and adjusting it on the basis of the reliability of the generator.

In the *'energy only' markets*[3] the wholesale electricity price provides compensation for both variable and fixed costs. The 'price' we have to pay for this are the price spikes, i.e. abrupt and generally unanticipated large changes in the spot price that in extreme cases can lead to bankruptcies of energy companies not prepared to take such risks (see Case Study 2.2.1). Price spikes should send signals to investors that new generation capacity is needed. However, if the spikes are rare and not very extreme they may not provide sufficient motivation. In such a case regulatory incentives (e.g. capacity payments) to prompt timely and adequate investment may be necessary. A related social issue is whether consumers are willing to accept price spikes at all. If not, protective price caps are necessary, which again require regulatory incentives for investment in new capacity.

Clearly electricity market liberalization is a challenging and ongoing process. It requires not only strong and sustained political commitment, but continuous development as well. Only then will it bring the expected benefits to the economy and the society. What complicates the situation is the fact that there is not one single best market model. In every case specific decisions have to be made that take into account the economic and technical characteristics of a given power system. However, no matter what are the actual regulations regarding unbundling, third-party access (TPA)[4] or cost-reflective pricing, there is one common feature of all successful markets: a formal price quotation mechanism. We will look more closely at this mechanism in the following sections.

1.2 THE MARKETPLACE

1.2.1 Power Pools and Power Exchanges

Liberalization of the power sector has created a need for organized markets at the wholesale level. Two main kinds of market for electricity have emerged: *power pools* and *power exchanges*. The differences between them can be explained by using two criteria: initiative and participation. Power pools and power exchanges share many characteristics and distinguishing between them is not always trivial. In particular, the oldest and one of the most mature power exchanges in the world is called *Nord Pool*.

Two types of power pools can be identified: technical and economic. *Technical pools* or *generation pools* have always existed. Vertically integrated utilities used a pool system to optimize generation with respect to cost minimization and optimal technical dispatch. In such a system the power plants were ranked on merit order, based on costs of production. Hence, generation costs and network constraints were the determining factor for dispatch. Trading activities were limited to transactions between utilities from different areas. International trade activity was limited, due to a low level of interconnection capacity.

[3] Also called 'one price only' markets (IEA 2005a).

[4] TPA regulations define and govern the access to the transmission and distribution network. In the European Union the vast majority of countries have opted for regulated TPA, under which prices for access are published by the system operator and are not subject to negotiation.

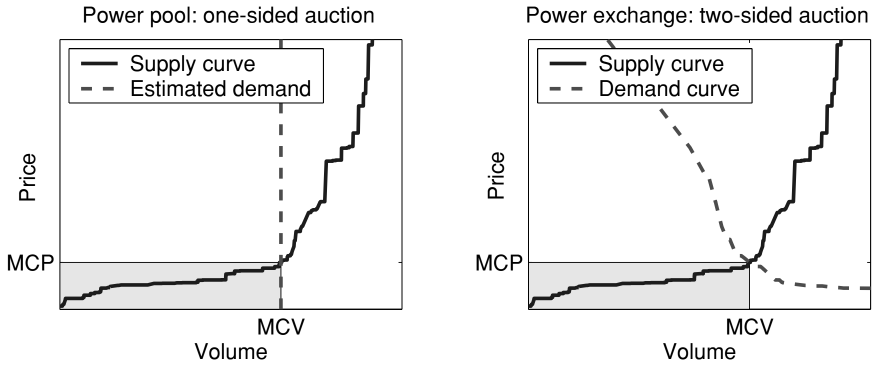

Figure 1.1 Power pool vs. power exchange price formation mechanism. *Left panel:* In a power pool the *market clearing price* (MCP) is established through a one-sided auction as the intersection of the supply curve (constructed from aggregated supply bids) and the estimated demand (which automatically defines the *market clearing volume*, MCV). *Right panel:* In a power exchange the MCP is established through a two-sided auction as the intersection of the supply curve (constructed from aggregated supply bids) and the demand curve (constructed from aggregated demand bids)

Economic pools or simply *power pools* have been established to facilitate competition between generators. They have mainly been created as a public initiative by governments willing to introduce competition in generation. This system has been used world wide, for instance, in England and Wales (before the introduction of the New Electricity Trading Arrangements – NETA, see Section 1.3.1), Spain, Alberta and PJM (Pennsylvania–New Jersey–Maryland).

Participation in an economic pool is mandatory, i.e. no trade is allowed outside the pool. Moreover, since trading has to account for numerous technical limitations, like plant availability and unit commitment, the participants can only be generators. They bid based on the prices at which they are willing to run their power plants. The *market clearing price* (MCP) is established through a one-sided auction as the intersection of the supply curve (constructed from aggregated supply bids) and the estimated demand (which automatically defines the *market clearing volume*, MCV), see the left panel in Figure 1.1. Because of the technical aspects involved, these bids can be very complex. Hence, the price determination mechanism involves a computationally demanding constrained optimization leading to a low level of transparency.

On the other hand, a *power exchange* (PX) is commonly launched on a private initiative, for instance, by a combination of generators, distributors and traders. Most of the recently developed European markets (including the Netherlands, Germany, Poland, France, Austria) are based on this model; see Table 1.1 with the timeline of organized day-ahead electricity markets. Participants include generators, distribution companies, traders and large consumers. Participation in the exchange is voluntary. However, there are some exceptions. For instance, the California Power Exchange (CalPX) was mandatory during the first years of operation in order for it to develop liquidity. Nord Pool, is a voluntary exchange at the national level but is mandatory for cross-border trade. The Amsterdam Power Exchange (APX) is mandatory for players who obtain interconnector capacity on the daily auction.

The genuine role of a power exchange is to match the supply and demand of electricity to determine a publicly announced market clearing price (MCP). Generally, the MCP is not