Negative Prices in Electricity Markets

In this paper we describe how liberalisation has lead to the segmentation of trading opportunities for electricity with different periods to delivery. We clarify the price characteristics in each segment, including the extreme volatility in short-term prices and the phenomenon that electricity prices can become negative close to the time of delivery. With the Dutch market as an example, we show the implications for risk management and the valuation of derivatives. We argue that a distinct price model is required for risk management and derivative valuation in each market segment. Derivative valuation goes beyond the financial contract itself and can be very useful for taking strategic decisions on flexible generation assets.
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LIBERALISATION AND DEREGULATION in electricity markets have resulted in active trading between generators, suppliers, distributors, large end users and several intermediaries for hedging and speculation purposes. In sharp contrast to conventional markets trading has been clearly segmented, both geographically as well as in terms of delivery period. Geographical segmentation is the result of limited cross border transport opportunities and different regulations per country. Most noteworthy however is the segmentation that is due to the non-storability of the commodity: separate trading mechanisms and markets exist for electricity with different periods to delivery, ranging from long-term forward markets to (very short-term) imbalance markets. Each market segment is characterised by distinct price characteristics that provide a challenge for risk management, derivative valuation and asset optimisation. In this paper we clarify the properties of the market segments and focus on the extraordinary characteristics of very short-term prices. We highlight the implications for option valuation, which provides the means for valuing flexible generation assets.

> Each market segment is characterised by distinct price characteristics <

The interest in option valuation stems from the limited liquidity and large pricing differences between electricity options. Therefore, market prices do not provide the desired benchmark on which to base strategic decisions. For example, if a generation plant can be treated as an option on spot electricity prices, then we would ideally value this plant based on tradable options. The illiquid market and the lack of valuation benchmarks is partially due to the inapplicability of standard pricing models to price electricity options with short periods to delivery, especially when the short-term electricity prices become negative. This motivates the growing attention for option pricing models for electricity in general and our focus in this paper on the phenomenon of negative prices. Option premiums on short-term prices are much higher than can be expected from standard pricing models as Black-Scholes (1973) or Black (1976)[2]. We therefore analyse the requirements that a pricing model should fulfil for the shortest-term (quarter-hourly imbalance) prices. An appropriate price model would also improve strategic decisions on flexible real assets.

The Forward Market

The ongoing liberalisation of electricity markets has resulted in a relatively liquid trade of longer-term contracts between several market participants. Popular forward contracts are week-ahead, coming months, quarters and years. The major part of the trading is settled OTC where the parties come together, sometimes facilitated by brokers. Even though some exchanges are quite successful (e.g. Nord Pool, EEX), in those markets OTC trades still form a major portion of the total trading in forwards. OTC trading is facilitated with the adoption of master agreements, which increasingly follow the standards of the European Federation of Energy Traders (EFET). In addition, information providers such as Platt's and Heren provide some transparency by publishing forward prices.

Market participants mainly organise electricity trading on a country-by-country basis in the form of country desks, because national grids still have their own procedures and limited exchange capacities between them. Prices in the forward market are quite well comparable to those in other commodity markets. Volatility is limited and forward returns conform to the normality assumptions pretty well, as shown in Table 1: skewness and kurtosis do not deviate significantly from 0, so prices exhibit few outliers. Because of this price behaviour and because hedging with forwards is possible to some extent, the standard Black (1976) formula may be applied to value European-style call and put options on forwards.[3] Those instruments are traded on the Nord Pool exchange and OTC, and provide a means to manage longer-term risks. Apart from limited excess kurtosis and skewness, Table 1 also highlights a first indication of term-structure effects in forward prices: shorter-term forwards experience higher volatility than longer-term forwards. This effect is much stronger in electricity markets than most other markets and is due to the non-storability of the commodity, which prevents arbitrage between periods.

The Spot Market

Forward trading is mostly organised without the need to trade on an exchange. On the other hand, spot trading for day-ahead delivery is largely conducted on organised spot markets such as (in Europe) those from Nord Pool, EEX, APX, UKPX, COMEL and Powernext. The advantage of centralised markets is not only an increase of price transparency, but also a reduction in credit and counterparty risk. In the Netherlands for example, the APX takes full responsibility for counterparty risk, like a general clearing institute, and facilitates the exchange of power. On a daily basis potential buyers and sellers can hand in bids and offers for power on a specific hour for the day ahead. Based on the resulting supply and demand curves a market clearing price and a market clearing volume are determined for every single hour the next day. A transaction will be settled by the APX when a bid or ask (buy or sell) is hit. The most important function of the day-ahead market is giving market participants the opportunity to balance their own delivery or procurement on a short-term basis. Both before and after settlement on the exchange spot trading also takes place on OTC markets. However, the advantage of the exchange is that it looks after the financial settlement and guarantees the physical delivery. Therefore, the counterparty risk is fully reduced in contrast with bilateral agreements.

Table 1. Return Properties of Electricity Contracts

	Volatility	Skewness	Excess Kurtosis
M1	32.9%	-0.36	-2.14
M2	20.3%	-0.83	1.00
M3	14.3%	-0.01	-0.12
Q1	15.7%	0.04	-0.02
Q2	8.6%	-0.18	2.64
Q3	8.7%	-0.25	1.05
Y1	7.4%	0.13	2.11

Forward statistics are based on weekly (5-daily) returns of German baseload contracts (volatility is annualised). Period: Jan 2002 – Mar 2003.
Source: Platts/Moneyline.

Being much closer to delivery than forward contracts, day-ahead spot price dynamics are inherently different from forward price dynamics. Since spot price changes are not normally distributed, the standard Black (1976) model is inappropriate for valuing (daily exercisable) options, caps, floors or collars. Distinguishing features of the prices are a strong level of mean-reversion, seasonality (across seasons and weekdays), extreme and possibly time-varying volatility (reaching daily levels of 1,000%), and occasional spikes. These characteristics have extensively been analysed by academics and practitioners alike and different modelling approaches have been proposed. A common approach is a mean-reverting model with stochastic jumps to account for occasional spikes. Since spikes are often very short-lived, the stochastic jump process (which assumes a long-lasting impact of spikes) does not work well for some electricity spot markets. A recent development is the application of regime-switches in which spikes are modelled as a separate price process. The advantage of a separate spike regime is that it better reflects the temporary nature of spikes. An additional advantage of this approach is that it allows (under certain conditions) for the derivation of closed-form formulas for European-style options on spot prices. Those formulas or simulation-based methods may be applied to value flexible end-user contracts with caps or floors, tradable daily exercisable options and generation assets with the flexibility to manage output on a day-to-day level. Outcomes of those approaches will generally be quite distinctive from standard option-formulas and yield much higher values especially for out-of-the-money call options. This may lead to price caps being sold too cheaply and flexibility in energy generation plants being valued too low.

> Prices in the forward market are quite well comparable to those in other commodity markets <

Simply modelling baseload or peakload prices is not sufficient for some options and the valuation of flexible generation: hourly prices should instead be modelled. Since spikes normally last for several hours in a row and revert back to normal levels more gradually, it is not so convenient to transfer spikes on an hourly level to a spike regime. Approaches that have been applied instead are state-of-the-art time-series models (Guthrie and Videbeck (2002), Cuaresma et al (2002)). The main challenge here is to accurately capture the interdependencies between prices on the same day and between similar hours on different days. In Table 2 we observe for example that the correlation between hours that are 7 hours apart is lower (0.21) than between a single hour on consecutive days (0.61). A similar complex interdependency exists in volatilities of prices (final column). Finally, some sort of jump behaviour (positive for peak-hours, negative for off-peak hours) may be required to capture the outliers. Monte Carlo simulations of hourly price models are used in risk management applications and form the basis for the val-

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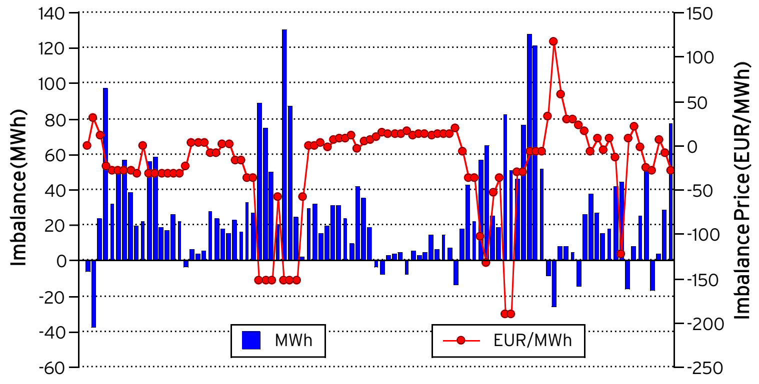
Table 2. Correlations Between Hourly Spot Prices

Time Lag	Correlation: Price	Correlation: Squared Price
1	0.78	0.63
2	0.63	0.48
3	0.51	0.37
4	0.44	0.34
5	0.34	0.23
6	0.27	0.20
7	0.21	0.16
24	0.61	0.60
48	0.36	0.31

Correlations between hourly spot prices and squared spot prices on the Amsterdam Power Exchange.

Figure 1. Imbalance Results

Quarter-hourly imbalance and imbalance prices (average of supply and extraction price) on 9 March 2003 for the Dutch power market.



Source: Tennet

uation and optimal management of assets that may be operated on an hourly level.

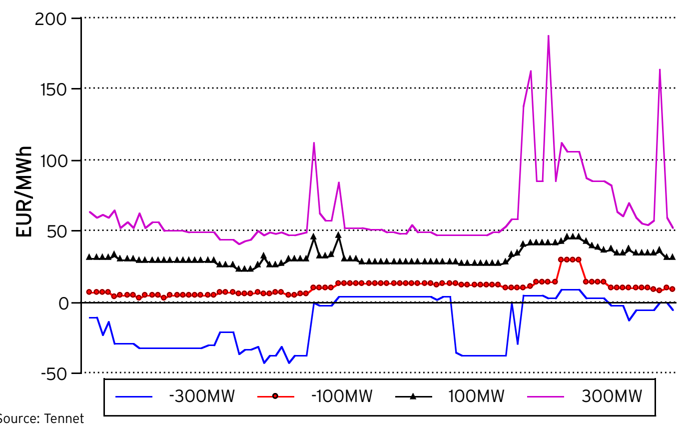
The Imbalance Market

In order to keep an electricity network functioning, the balance of power (supply equals demand) must be maintained at all times. In the Netherlands for example 34 market participants have the so-called 'programme responsibility', which includes the requirement to supply a daily schedule of expected supply and demand on a quarter-hourly basis. Just before the electricity is generated and consumed, the network operator TenneT settles any discrepancies between forecasted and actual supply and demand (see Figure 1 for the discrepancies on 9th March 2003). Apart from its own emergency capacity that it may use, the network operator organises an imbalance market on a daily basis to 'smooth' the discrepancies. On this market variable capacity may be offered to TenneT: participants can bid on both increasing or decreasing their supply or demand (Figure 2). A quarter of an hour before delivery, TenneT determines the required capacity. This results in 96 imbalance prices for each of the 96 daily quarters of an hour. Market participants with a negative imbalance pay according to the imbalance market results and participants with a positive imbalance earn according to the imbalance market results. Given the technical problems of an immediate shutdown or start-up of a facility the imbalance market is much more volatile than the spot market, which on its turn is much more volatile than the forward market. Price modelling and option valuation on imbalance markets is still largely unexplored; that's why we explore this topic in more detail.

> Price modelling & options valuation on imbalance markets is still largely unexplored <

Figure 2. Imbalance Bid Curves

Quarter-hourly bid curves on 9 March 2003 for the Dutch power market. Each line (-300, -100, 100, 300 MW) represents the price for which power generators are willing to supply power up to the specific volume.



Source: Tennet

Negative Imbalance Prices

In this paragraph we explore a unique phenomenon in electricity markets: negative prices. Negative prices mean that the destruction of the commodity has more value than its creation: electricity is a waste product and is dumped on the market. How does this situation arise and why can electricity be seen as a waste product? As discussed before, there must always be a balance between supply and demand on a power network. Primarily during the night power supply can be higher than demand. This nightly imbalance is caused, for instance, by the installation of combined-cycle facilities and the so-called must-run character of non-flexible generators. Combined-cycle installations are basically installed for the generation of heat (steam) whereby electricity is a co-product. Reducing the must-run output is hardly possible from a technical perspective or it involves high shutdown costs.

Negative prices are acceptable to power suppliers because the opportunity costs of a shutdown period are sometimes much higher. Generally, prices will be negative in only a short period of time and mainly during the night. However, Figure 1 shows that negative prices can sometimes last for long periods of time and can attain extreme levels. The graph contains the imbalance market results in the Netherlands on March 9th 2003; it shows that the market is very volatile and prices can jump from -190 €/MWh up to +120 €/MWh within two hours. When negative prices last for a longer period (corresponding to a positive imbalance), shutting down generation capacity will pay off and imbalance prices will automatically increase.

Negative prices cause sizeable operational problems, for example in energy risk management systems. Not all systems can handle a negative deal in their VaR-calculations, cash-flow projections or invoice procedures. An even larger challenge is the appropriate modelling of negative prices for optimisation and realistic valuation of the most flexible generation assets.

Modelling Negative Prices

Since options on imbalance prices are barely traded, modelling imbalance prices is mainly for risk management, and for optimal management and valuation of the most flexible generation units. A flexible unit will be generating power when the facility is 'in-the-money', meaning that the spark spread (equal to commodity price minus variable cost of fuel) is positive. Many energy risk management systems use the so-called delta hedging strategy [4] in order to forecast the optional production capacity in advance. This strategy is based on the same assumptions as other standard option formulas. These models assume that electricity and fuel prices evolve according to a gradual process ('Brownian Motion') with no extreme changes, mean reversion or negative prices: it assumes prices are lognormally distributed.

To understand how negative prices can be dealt with, it is important to understand why negative prices lead to modelling problems. The problems all stem from the fact that standard price models are based on price returns (or in fact logreturns). A return becomes in fact infinite when prices approach zero and is not defined at all for negative prices.[5] Incorporating negative prices can basically be achieved with two approaches: an indirect (structural) approach and a direct approach. The structural approach does not model prices directly, but models them as the outcome of a price formation process. This process may include for example the imbalance (Figure 1) and the imbalance bid curves (Figure 2), from which imbalance prices result. A structural approach offers valuable insights in the formation of prices and is appealing to industry professionals, who 'recognise' in it the functioning of the market. However, for risk management systems they easily become too complex, because they need to contain several stochastic variables (such as imbalance and imbalance bid curves), which provide challenging modelling and implementation tasks by themselves.

A direct price modelling approach is not straightforward either, but at least reduces the problem to one variable: the price. We propose to allow for negative prices by setting a lower bound on the actual price and re-scaling prices with respect to this lower bound. An important advantage of this approach is that the lower bound can be based on economic rationales and market experience. It also allows for the extreme positive outliers, while limiting the negative outliers in prices. Moreover, this approach permits the usage of relatively standard time-series models on the re-scaled price returns. Imbalance prices exhibit sudden jumps and similar complex interrelations as those in hourly spot prices: within days and across days in both price levels and price volatility. For a realistic model it is necessary to include both types of interrelations. We suggest that a combination of the periodic autoregressive model in Guthrie and Videbeck (2002) and specifications that model each time period separately (Cuaresma et al., 2002) can achieve this goal.

Conclusions

Options are helpful products for managing unexpected price and volume fluctuations. Given the high volatility of short-term electricity prices it could be expected that electricity options are very popular. However, currently bilateral options are traded in the OTC market only on a small scale, and the exchange trade of options is even lower. The few options that are traded are mainly on forward contracts, such as for example an option on the forward 2004. But also options on day-ahead spot prices (daily exercisable options) are traded occasionally. A major explanation for the low trading volume is the difficulty to value those contracts. When current methods of option valuation are improved, the trading of options could be stimulated. Before trading in short-term options really takes off, option valuation techniques are already required: to manage and value flexible generation assets. In order to determine whether an investment is worthwhile or not a power generator can be considered as an option on power production. This method of real option valuation becomes more and more familiar. However for a proper valuation of the most flexible generation assets,

> Imbalance prices exhibit similar complex interrelations as those in hourly spot prices <

it is important that standard option pricing models will be adjusted to price spikes as well as negative prices.

The study of negative commodity prices has made clear that negative prices have a special impact on option pricing models. Standard models as Black-Scholes (1973) and Black (1976) are not applicable to options with negative underlying value. New models can be very helpful for financial options as well as for strategic decisions (real options) like the management of flexible generation assets ■

Footnotes

1. The authors thank Kasper Walet (Maycroft Consultancy) and Gerard van Baar (Deloitte & Touche) for helpful comments.

2. Black's (1976) model is similar to the famous Black-Scholes (1973) model, but applicable to options on forwards and futures.

3. If returns are skewed or exhibit clear kurtosis the extended Black formula with separate terms for skewness and kurtosis (Jarrow and Rudd, 1982) yields more reliable results.

4. Without the possession of the option in reality the increase or decrease of an option value can be optimally simulated by holding an amount of the underlying asset equal to the option delta.

5. For example, what is the return if prices increase from -10 to +10?

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