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Energy price risk management

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Abstract

The price of electricity is far more volatile than that of other commodities normally noted for extreme volatility. Demand and supply are balanced on a knife-edge because electric power cannot be economically stored, end user demand is largely weather dependent, and the reliability of the grid is paramount. The possibility of extreme price movements increases the risk of trading in electricity markets. However, a number of standard financial tools cannot be readily applied to pricing and hedging electricity derivatives. In this paper we present arguments why this is the case.

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1. Introduction

Energy price risk management is still in its infancy compared to the more developed interest rate and foreign exchange markets [1–3]. However, we have to bear in mind that commodity markets are not anywhere near as straightforward as financial markets. They have to deal with the added complexity of physical substance [4], which cannot simply be manufactured, transported and delivered, at the press of a button.

An innate energy industry conservatism coupled with highly profitable years caused stagnation despite the two oil price shocks of the 1970s. But the world oil price collapse of 1986 and the beginning of electric utility deregulation and privatization throughout the world are continuing to drive change in energy commodity markets [1,5,6].

In the wake of the recent price run-ups and defaults, managers have been forced to review their credit and counterparty risk policies. Traditional credit analysis has emphasized the financial risk associated with the failure of a buyer to pay for the

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goods purchased. Although this can be a concern in the power market, recent events have highlighted the substantial and perhaps less predictable market risk resulting from the failure to deliver by a seller [7]. The defaults in late June 1998 threw the US buyers into a superheated Midwest market, desperate for replacement power. This resulted in soaring prices that reportedly topped out at $7500 in real-time trading – 300 times the average price of $25/MWh!

The possibility of extreme price movements increases the risk of trading in electricity markets. Unfortunately, a number of standard financial tools cannot be readily applied to pricing and hedging electricity derivatives. But before we explain why let us briefly describe today's electricity markets.

2. Electricity markets

The deregulation of the electricity industry is giving way to a global trend toward the commoditization of electric energy [8]. This trend has recently intensified in Europe and North America, where market forces have pushed legislators to begin removing artificial barriers that shielded electric utilities from competition. As a result, during the last decade, we have witnessed a major explosion in the number of nontraditional power suppliers and financial engineers marketing electricity and electricity derivatives in the wholesale power markets. Only in the early four year period 1993–1996, over 200 new marketers (qualified energy brokers) have appeared on the US electricity market [5]. Similarly, during the last six months more than 70 companies have obtained licenses to trade electricity on the just liberalized Polish wholesale power market.

Organizations which have been used to long-term fixed price contracts are now becoming increasingly exposed to price volatility and, of necessity, are seeking to hedge and speculatively trade to reduce their exposure to price risk. The scenario in today's energy market is similar in many ways to the emergence of derivatives trading in the capital markets. From the modest beginnings in the late 1970s, financial markets have seen a massive explosion in the use of derivative products. Starting with simple futures contracts and forward rate agreements through swaps and on to increasingly ingenious and complex contracts. The financial derivatives markets invented layer upon layer of new derivatives products using the basic building blocks to design tailor-made hedges for customers [9].

Most derivative markets begin with exchange traded futures. Global energy markets are no different. Heating oil futures appeared on the New York Mercantile Exchange (NYMEX) in November 1978 and futures on crude oil appeared there in March 1983. As in all other markets options followed quickly – on crude oil futures in 1986 and on heating oil a year later. Commercial banks began providing commodity price risk management products in 1986, when The Chase Manhattan Bank arranged the first oil swap [10]. Natural gas futures and OTC instruments began in 1990. And electricity futures contracts began trading on the world's most mature Scandinavian power market (Nord Pool – the Nordic Power Exchange) in 1995 followed next year by the US

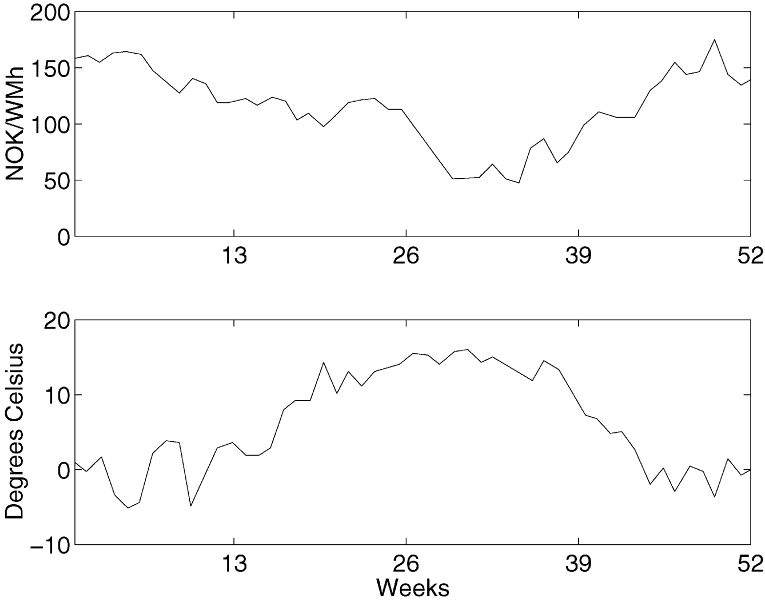

Fig. 1. Nord Pool spot system price (top) and mean temperatures in Oslo, Norway (bottom) for the whole 1998 year. Clearly lower temperatures cause higher power consumption (heating) and thus raise electricity prices.

(NYMEX) and Australian/New Zealand markets. First electricity options appeared on NYMEX in 1996. Last year Nord Pool introduced first exchange traded exotic options – asian (average) options on electricity futures. Gas and electricity are now accelerating the change process of liquid trading and cross-energy commodity arbitrage. In effect, a conservative industry is continuing to be transformed through financial engineering.

3. Arbitrage pricing

Demand and supply of electricity are balanced on a knife-edge because electric power cannot be economically stored, end user demand is largely weather dependent (see Fig. 1), and the reliability of the grid is paramount. Relatively small changes in load or generation can cause large changes in price and all in a matter of hours, if not minutes. In this respect there is no other market like it.

Because of storage problems, standard arbitrage type arguments cannot be used to price a number of electricity derivatives [3]. For example, when pricing a forward contract on crude oil, i.e., a contract for delivery of a specified amount of oil for a fixed price K at a specified location and time in the future, we use the formula

$$K = U(1 + rT) + C,$$

where U is the current price of crude oil, r is the risk-free interest rate, T is the time of maturity of the contract, and C is the so-called *cost of carry* (a sum of storage, insurance, spoilage, and obsolescence costs). The formula can be derived by analyzing the following strategy [3,11,12]:

- take a short position in the forward contract (i.e., agree to deliver oil for a fixed price K at maturity) and take a loan from a bank to finance buying crude oil worth U dollars,
- store the oil until maturity (for time T) incurring the cost of carry C,
- at maturity deliver the oil to the buyer of the forward contract for a fixed price K and return the loan (with interest) to the bank.

The forward price K should be such that from today's (the time we sign the contract) perspective no arbitrage is possible, i.e., we cannot make money without taking risk. Thus the forward price should equal today's price (U) plus interest (UrT) paid to the bank for lending the money plus the cost of carry (C). However, for contracts written on electricity the cost of carry is very large (or even infinite) compared to the value of the delivered commodity and for this reason arbitrage type arguments cannot be used to price electricity derivatives. So what can we do? Well, we can either use other methods (eg. weather correlations, consumption prediction) for pricing such derivatives or use derivatives written not on electricity itself but on other derivatives. The former method is used for pricing the first layer of derivatives – forwards and futures on electricity, whereas the latter for next layers – options on futures, swaptions, etc.

4. Volatility

In Fig. 2, the average daily prices of the California Power Exchange (CalPX) spot market and their returns are plotted for the period April 1st, 1998 – January 31st, 2000. Note that, unlike in the financial markets, electricity is traded every hour of the year – including nights, weekends and holidays. Average daily price is a simple reference index constructed by adding up all 24 hourly prices during a day and dividing the sum by 24. One hour is the smallest time interval when prices can change, because in spot electricity trading prices are set constant for delivery of power during a certain hour.

The price of electricity is far more volatile than that of other commodities normally noted for extreme volatility. Applying the classical notion of volatility – the standard deviation of returns (i.e., logarithmic price changes: $r_t = \log x_{t+1} - \log x_t$), we obtain that measured on a daily scale for a series roughly one year in length:

- treasury bills and notes have a volatility of less than 0.5%,
- stock indices have a moderate volatility of about 1–1.5%,
- commodities like crude oil or natural gas have higher volatilities (1.5–4%),
- very volatile stocks have volatilities rarely exceeding 4%,
- and electric energy has the highest volatility – up to 50%!

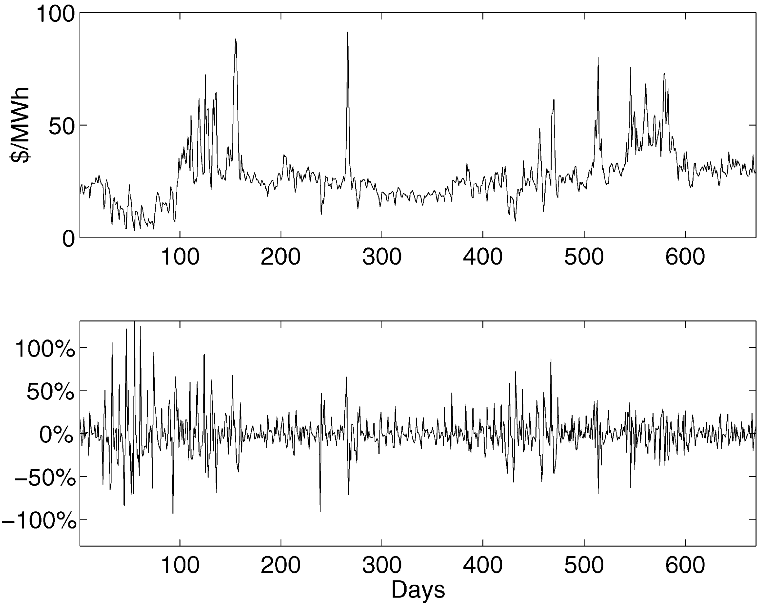

Fig. 2. Average daily spot prices (top) and their returns (bottom) for the California Power Exchange since the opening of the exchange (April 1st, 1998) till January 31st, 2000.

However, when measured on different time scales, electricity price volatility does not behave like that for most financial instruments and commodities. For the data illustrated in Fig. 2 daily volatility is about 23%, whereas monthly (30 days) volatility is about 33%. This is much less than predicted by Brownian motion (the distance travelled by a particle is proportional to the square root of time) for which we would obtain $23\% \times \sqrt{30} \approx 125\%$. Thus Black–Scholes-type formulas [10–12] should in general overestimate premiums of long-term options written on electricity!

Another feature of electricity price volatility is its seasonal character. The daily and weekly seasonality of volatility can be illustrated [13,14] by the intra–weekly plot of mean absolute hourly price changes, see Fig. 3. The statistical week is divided into 168 hours from Monday 0:00–1:00 to Sunday 23:00–24:00. Each bar represents the mean absolute change in prices for every hour from the same weekdays counted for energy prices from CalPX. The sampling period starts with the opening of the exchange (April 1st, 1998) and lasts until January 25th, 2000, so that we analyze 95 full weeks.

The patterns of volatility are clearly correlated to the on-peak/off-peak specification of the market. The lowest volatility is observed on the weekends and during night (off-peak) hours. However, unlike for the global interbank FX (currency) market [14], the volatility during weekends is of the same order of magnitude as that for working days. High volatility is observed during on-peak working day hours, with a maximum for hour 15:00–16:00. Saturday has a similar volatility pattern, but on Sunday the maximum is postponed till 17:00–18:00.

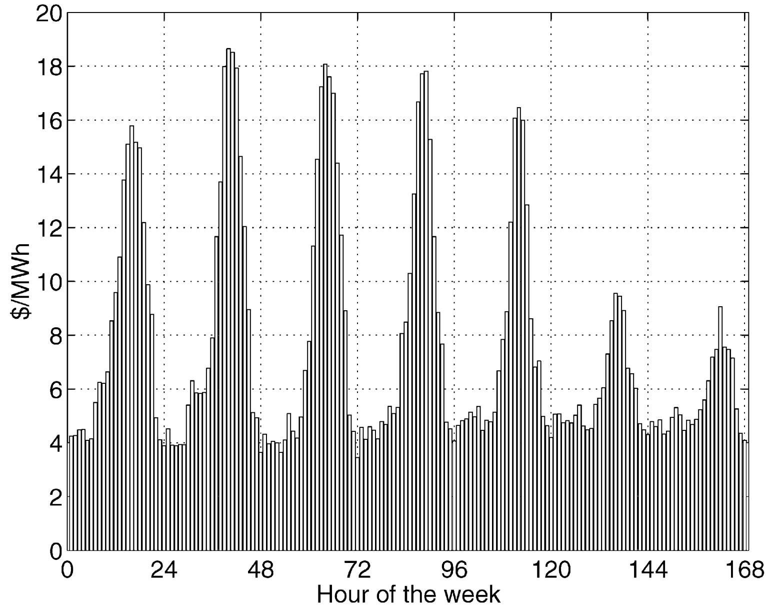

Fig. 3. Intra-weekly plot of mean absolute hourly price changes for the CalPX spot market. The statistical week is divided into 168 hours from Monday 0:00–1:00 to Sunday 23:00–24:00.

5. Autocorrelation of returns

Seasonality of a time series of returns r_t can be demonstrated by plotting the autocorrelation function [15]

$$\mathbf{acf}(r,k) = \frac{\sum_{t=k+1}^{N}(r_t - \bar{r})(r_{t-k} - \bar{r})}{\sum_{t=1}^{N}(r_t - \bar{r})^2},$$

where N is the sample length and

$$\bar{r} = \frac{1}{N}\sum_{t=1}^{N} r_t$$

for different time lags k as in Fig. 4. For electricity spot price returns there is a strong 7-day dependence which, when we think about it, is not that surprising. However, what is surprising is the fact that this dependence structure lasts almost forever (or as long as the analyzed data set)! For most financial data, autocorrelation of returns dies out (or more precisely, falls into the confidence interval of Gaussian random walk) after 10–20 days and long-term autocorrelations are found only for squared returns or absolute value of returns [11,13,14,16,17].

This 7-day cyclic correlation can be removed by differentiation, i.e., by constructing the data series $z_t = r_{t+7} - r_t$. The lagged autocorrelation of z_t is shown in Fig. 5. We can observe two evident outliers: for lag $= 1$ day and for lag $= 7$ days. Both have negative

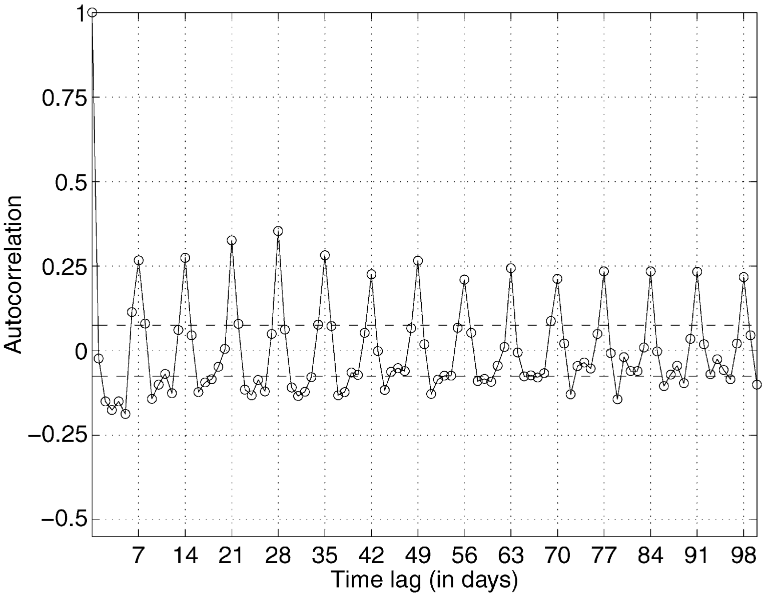

Fig. 4. Lagged autocorrelation function for CalPX spot price returns (see Fig. 2). Dashed horizontal lines represent the 95% confidence interval of a Gaussian random walk.

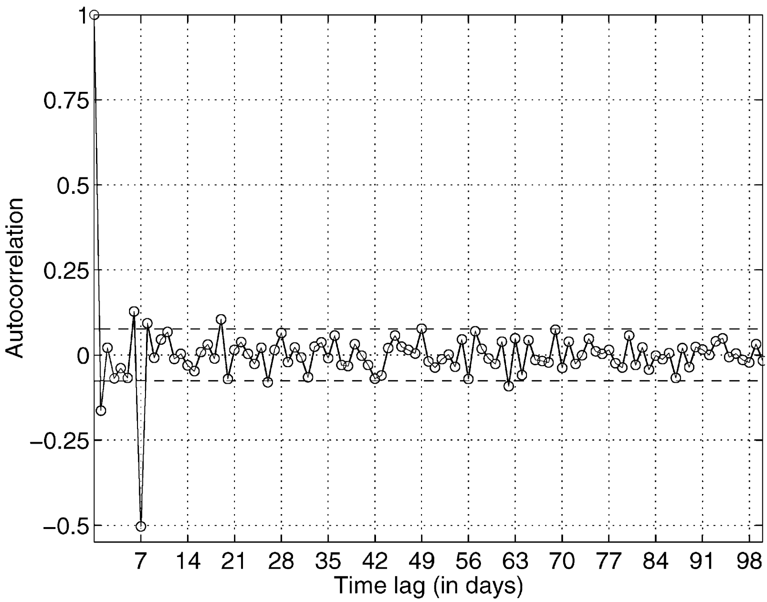

Fig. 5. Lagged autocorrelation function for CalPX spot price returns after differentiation by 7 days. A strong mean-reverting property is revealed.

correlations. This implies a strong mean-reverting property [12] of the returns as was already suggested by the results of Section 3.

6. Final remarks

As we have shown the price of electricity is far more volatile than that of other commodities normally noted for extreme volatility. However, the term structure of volatility distinguishes electricity from most financial assets and forces us to use Black–Scholes-type models with great care and a doze of skepticism. On the other hand, the mean-reverting property puts electricity in the same box as interest rates and suggests that the search for models of electricity price dynamics should be started with examining and calibrating certain interest rate models [18,19].

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